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Costs of Harvesting Beetle-Milled Lodgepole Pine in Eastern Oregon

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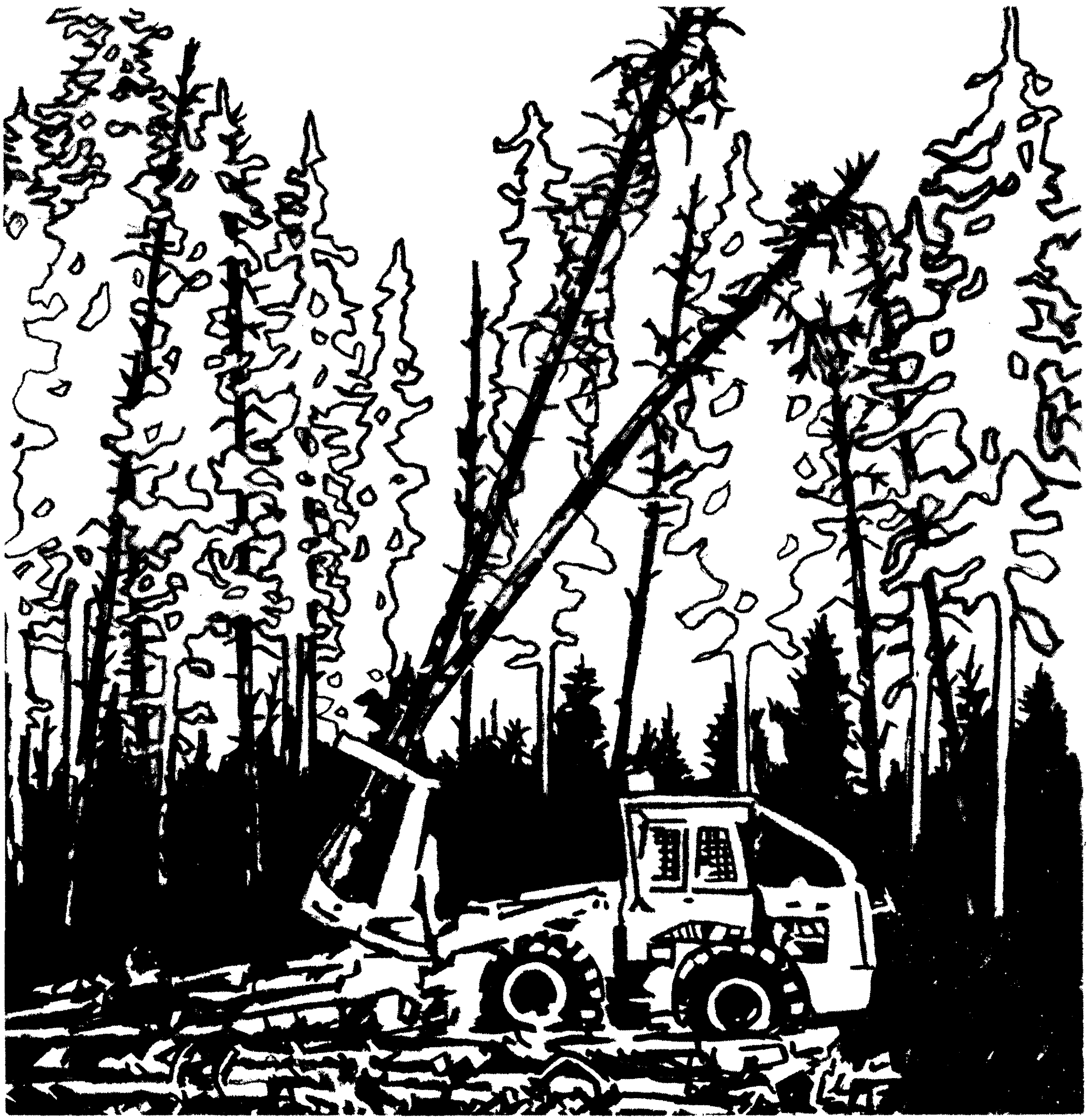

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Abstract

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The cost of harvesting and recovering roundwood logs and whole-tree chips from small diameter lodgepole pine *(Pinus contorta)* infested by mountain pine beetle (*Dendroc-**tonus*** sp.) was studied in the Blue Mountains of eastern Oregon in 1979. Mechanized harvest operations were conducted on six study sites totaling 134 acres. The average cost of producing chips was $31.30 per ton, wet, delivered 50 miles from harvest sites. The average cost of logs was $50.28 per ton, wet, delivered the same distance. A gross energy balance indicates that energy required by harvesting was about 3.4 percent of the gross energy content of the delivered products.

Keywords: Logging enterprise costs, lodgepole pine (dead), wood utilization, energy, insect damage (-forest products, mountain pine beetle.

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Introduction

The need for fiber and energy has directed attention to unused forest resources. Accessible, unused forest materials include extensive areas of standing dead timber killed by catastrophic insect epidemics. Extensive stands of dead timber are concentrated in regions of the western United States that produce softwood timber.

One such region is the Blue Mountains of eastern Oregon, where extensive stands of dead lodgepole pine ***(Pinus*** contorta Dougl. ex Loud.) are the result of an outbreak of mountain pine beetle *(Dendroctonus* spp.) in the 1960's and 1970's (fig. 1). The slow rate of decay prolongs the period of fire hazard associated with dry, dead timber, and the fire hazard increases as standing dead timber collapses and concentrates fuel near the ground. In northeastern Oregon in 1975, there were 1'million acres of lodgepole pine standing dead or threatened with beetle infestation. They contained an estimated 960 million cubic feet of wood.

Dead lodgepole timber, although small in size, can produce both energy and fiber. Trees tend to be concentrated in dense, even-aged stands that become susceptible to beetle kill after they reach 100 years of age. Clearcut harvesting offers a solution to the threat of fire, and the location of lodgepole pine on moderate slopes makes it suitable for mechanized harvesting.

Figure 1.—Dead lodgepole timber stand on harvest study unit 11H.

Purpose of Study

This study was undertaken to determine the potential of standing dead lodgepole timber for fuel and other products and to develop a basis for estimating the cost of mechanically harvesting standing dead lodgepole pine. In 1978, Currier and others had emphasized the need for information on harvest costs to promote the utilization of dead timber.[1]

In addition, the study was intended to:

1. Establish a methodology that could be used to evaluate the economic feasibility of harvesting residues in other forest types;
2. Identify opportunities to further reduce cosfs of harvesting or to increase value of products by modifying harvesting systems; and
3. Provide information about the ecological effects of mechanized harvesting on nutrient balance and soil compaction. (This information will be documented in a separate report.)

Cooperators

The study was planned and conducted by the Forest Service, U.S. Department of Agriculture, under contract to the Department of Energy. Research and administrative groups within the Forest Service involved in the study included the Pacific Northwest Forest and Range Experiment Station, the Forest Products Laboratory, the Pacific Northwest Region, and the Umatilla National Forest. Also involved were Oregon State University, Eastern Oregon State College, and Chrisstad Enterprises, Inc., an independent logging firm experienced in producing chips from standing lodgepole pine.

The beetle-infested lodgepole timber on the Umatilla National Forest was harvested by Chrisstad Enterprises, Inc., from July to September 1979, under a contract with the Forest Service. Different combinations of log-making and chip-producing methods were tried. The use of machines, labor, and fuel and the amounts of logs and chips produced were monitored by a research team from Eastern Oregon State College. The analysis of the costs of harvesting and delivering products from dead lodgepole pine is based on the cost of harvest operations, the cost of stumpage, and overhead costs chargeable to the harvest operations. Production costs represent actual costs incurred by the independent logging firm that harvested the dead lodgepole pine.

The Study Site

The study was conducted on six separate harvest units which represented about half the harvesting activity of a salvage sale on the Ukiah District of the Umatilla National Forest in the Blue Mountains of northeastern Oregon. The units are identified by numbers assigned in the timber sale contract (4, 46, 42, 26, 5H, and 11H), listed in chronological order of harvest. The units ranged in size from 15 to 32 acres and contained beetle-infested lodgepole pine that ranged in average d.b.h. from 6.3 to 10.0 inches. Estimated volume of standing (live and dead) timber varied from 1,100 to 2,500 cubic feet per acre. Average tree height varied from 40 feet for trees 4 inches in diameter to 80 feet for trees 11 inches or more in diameter. There was little correlation between volume of timber per acre and average diameter because of variations in stand density. Lodgepole stands were generally even-aged, approximately 80 to 110 years old at the time of the initial beetle infestation from 1972 to 1975. Stand characteristics determined by preliminary sampling, are summarized in table 1.

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[1] Currier, Raymond A.; Dykstra, Dennis P.; McMahon, Robert O; and Corder, Stanley E. Potential energy uses for diseased and beetle-killed timber and forest residues in the Blue Mountain Area. Report RLP/2227/T33-1. Prepared for the U.S. Department of Energy. 1978: 58p.

Table 1—Size and volume of standing lodgepole pine timber on 6 harvest units, Umatilla National Forest, 1979

Harvest unit	Size	Average d.b.h.	Estimated total volume	Volume per acre	
	Acres	Inches	Thousand board feet	Thousand board feet	Cubic feet 1/
4	19	8.0	170	8.9	1,800
46	18	6.3	225	12.5	2,500
42	15	7.8	120	8.0	1,600
26	32	9.6	315	9.8	2,000
5H	31	10.0	170	5.5	1,100
11H	19	10.0	160	8.4	1,700

1/Assumes 200 cubic feet of solid wood per thousand board feet of timber. Bark provides an estimated 2 to 3 percent additional volume for fuelwood.

The relatively uniform appearance of dead lodgepole tends to hide physical differences' in the timber. Study trees varied in size and number of drying checks. Although average diameter did not vary greatly, size ranged from 3 inches d.b.h. to more than 20 inches in a single stand. Drying checks within a stand ranged from a single, straight radial check to severe, multiple spiral checks. Furthermore, beetle-caused mortality typically does not occur in a single season but tends to accumulate over several seasons, resulting in a range of times since mortality and a variety of defects within a given stand.

Logs and Chips Produced

In all, 197 van loads of chips and 6,249 trimmed house logs and sawlogs were recovered from the six harvest units. Table 2 shows that total wet weight of chips was 4,171 tons, or an average of approximately 31 tons per acre. Total wet weight of logs was 1,385 tons or an average of about 10 tons per acre. Moisture content of logs and chips was determined separately for each harvest unit. Average moisture content was about 17 percent for all logs and about 24 percent for all chips. This contrasts with a general moisture content of 50 percent for material from live lodgepole stands.

Total weight of chips and roundwood was estimated to average 32 tons (ovendry basis) per acre.

Table 2—Logs and chips produced from dead lodgepole pine on 6 study units, Umatilla National Forest, 1979

Harvest unit	Acres	Logs: Number	Logs: Scaled volume	Logs: Weight		Chips: Weight			Chips and logs
			Thousand board feet	Tons wet	Tons ovendry	Tons wet	Tons ovendry	Bone-dry units 1/	Dry tons per acre
4	19	714	46.0	2/ 154.8	3/ 115.0	4/ 802.2	5/ 570.1	6/ 475.1	36.06
46	18	0	0	— 0	0	707.3	557	464.2	30.94
42	15	0	0	0	0	1088.2	809	674.2	53.93
26	32	1,192	130.9	286.7	259.8	973.9	762.4	635.3	31.94
5H	31	2,360	159.1	481.6	397.8	408	33.1	278.4	23.61
11H	19	1,983	151.5	462.0	378.8	191.1	145.5	121.2	27.59
Total or average	134	6,249	487.5	1,385.1	1,151.4	4,170.7	3,178.1	2,648.4	32.30

1/1 bone-dry unit = 2,4000 pounds or 1.2 ovendry tons.
2/Determined by average moisture content of logs for that harvest unit and dry weight.
3/Estimated from scaled volume at 2.5 tons ovendry per thousand board feet.
4/Determined from load weight at chip purchaser's plant.
5/Calculated from sampled moisture content of each load.
6/Basis of payment, equivalent to 1.2 tons, ovendry weight.

Harvest System and Equipment

The contract logger used modern mechanized harvesting equipment that included feller bunchers (fig. 2), grapple skidders, and chipping equipment. The operator had had several years of experience as an independent logger in the Blue Mountains, including 3 years of harvesting dead lodgepole timber. Prior to the study, he had engaged primarily in producing whole-tree chips (chips from entire trees, including bark).

For this study, the operator acquired a mobile log trimmer and a log loader to allow mechanized production of trimmed roundwood logs. Thus equipped, he had an efficient mechanized system to produce house logs and sawlogs from the larger diameter material, as well'as chips from the smaller or lower quality logs. He could have produced posts or fuelwood, but did not because local demand was limited. The study, therefore, focused on a conventional mechanized harvesting system designed to sort out the material most suitable for house logs and sawlogs and to chip the rest.

Figure 2.—Feller buncher harvesting beetle-infested lodgepole timber.

Modifications of Equipment Needed to Produce Logs and Chips

Production decisions were made entirely by the logging operator and crew, based on their perception of markets and product value. Initially, logs and chips were produced simultaneously on the same landing (fig. 3). But the mix of trees available on most units proved unsuited for simultaneous production of logs and chips. Trees large enough for logs often contained deep checks or other defects that made them unsuitable for logs. Production was slowed while trees were sorted according to defect. The simultaneous production of logs and chips on the same landing continued only on unit **4.** On all other units the chipper and log trimmer worked separately. On two units **(46** and **42)** only chips were produced. On units where both logs and chips were produced, the log trimmer was brought in first to sort and trim logs, and the chipper was brought in later to chip the remaining material. On these units, a preliminary examination was made to mark trees for either logs or chips.

Figure 3.—Log trimmer (left), grapple skidder (center), and mobile chipper (right) at a landing site.

Equipment Used

The basic equipment used to harvest all units included rubber-tired feller bunchers and rubber-tired grapple skidders. Feller bunchers sheared individual stems above the ground, accumulating as many as five before laying them on the ground in loads or "turns" for the grapple skidders. Grapple skidders brought the stems to landings in turns of 8 to 15 trees containing 35 to 80 cubic feet of wood. A mobile chipper, a mobile log trimmer, and a log loader were used to process timber into chips and/or logs at the landings. Feller bunchers, grapple skidders, mobile chippers, and log trimmers are referred to as major equipment in this report. A log loader and additional support equipment are referred to as auxiliary equipment.

Auxiliary equipment for the harvest operation included a log loader, a tracked bulldozer, a water tank truck for fire protection, a fuel tank truck for fuel transport and storage, a low-boy trailer, a truck tractor, a road grader, and a fully equipped maintenance truck for field repairs, plus miscellaneous equipment, tools, and pickup trucks.

Products were hauled and delivered by contract haulers, usually at a negotiated price per load, per mile. Loads of chips averaged 22 tons and were hauled 40 to 60 miles to a fiberboard plant. Loads of logs averaged 23 tons and were hauled from 40 to 100 miles to manufacturers of log homes or lumber.

Time Requirements

The operating time for each major equipment item was recorded for each study unit. The auxiliary equipment items listed previously were operated intermittently and were not monitored as closely.

The working schedule was usually from 6:00 a.m. to about 2:30 p.m., Monday through Friday. Scheduled hours of machine use account for the time equipment was on the site during regular working hours (about 8.5 hours per day, 42 hours per week) and are summarized in tables 3 to 8.

Major Equipment Time

Scheduled machine hours for major equipment were the total of productive time, delay time, idle time, and moving time.

Productive time was considered time during which equipment was engaged in productive harvesting activity. Delay time was counted when the crew was present but equipment was not operating. Idle time occurred when the crew was not present and equipment was idle because repair parts were lacking or occasionally because of extreme fire hazard.

A significant amount of time was spent moving equipment from one harvest unit to another. Harvesting each unit took 9 to 22 days, then equipment was moved to another unit. Moving equipment and setting it up on another site took up to half a day. Consequently, some of the scheduled machine hours were used for moving.

The average approximate time required to move equipment from one harvest unit to another, including delays and "start-up" time, were:

	Hours
Feller buncher	2
Grapple skidder	**2**
Mobile chipper	4
Log trimmer	4
Log loader	4

Variations in the equipment assigned to each harvest unit and the idle time charged to each unit are revealed in tables 3-8. The variations were caused by differences in stand characteristics and decisions by the logging operator. A substantial proportion of the idle time charged to harvest units 4 and 5H may have been the result of inexperience in coordinating log and chip production.

Table 3—Summary of time required for equipment, labor, and administration on harvest unit 4

Equipment	Productive time 1/	Moving time 2/	Hours fueled 3/	Delay time 4/	Crew hours 5/	Idle time 6/	Scheduled hours 7/	Administrative time 8/
				Hours				
Feller bunchers	48.4	4.0	52.4	9.5	61.9	61.6	123.5	
Skidders	61.3	4.0	65.3	8.6	73.9	99.8	173.7	
Chipper	34.5	4.0	38.5	18.0	56.5	48.5	105.0	
Log trimer	18.2	4.0	22.2	14.5	36.7	51.3	88.0	
Log loader 9/	9.1	--	--	--	--	--	88.0	
Auxiliary equipment E/	--	--	--	--	--	--	54.8	
Supervisor's time								109.5

1/Productive time = crew present and equipment operating.
2/Moving time = crew present and equipment self-propelled or hauled.
3/Hours fueled = productive time + moving time.
4/Delay time = crew present and equipment not operating.
5/Crew hours = productive time + moving time + delay time.
6/Idle time = crew not present and equipment not operating.
7/Scheduled hours = productive time + moving time + delay time + idle time.
8/Administrative time = total time spent on unit by supervisor.
9/Log loader productive time = one-half log trimmer productive time; log loader scheduled hours = log trimer scheduled hours.
10/Auxiliary equipment scheduled hours = one-half administrative time.

Table 4—Summary of time required for equipment, labor, and administration on harvest unit 46

Equipment	Productive time 1/	Moving time 2/	Hours fueled 3/	Delay time 4/	Crew hours 5/	Idle time 6/	Scheduled hours 7/	Administrative time 8/
				Hours				
Feller bunchers	68.7	2.0	70.7	8.8	79.5	7.5	87.0	
Skidders	39.4	2.0	41.4	8.5	49.5	10.6	60.5	
Chipper	32.6	4.0	36.6	14.3	50.9	11.6	62.5	
Auxiliary equipment 9/	--	--	--	--	--	--	53.0	
Supervisor's time								106.0

1/Productive time = crew present and equipment operating.
2/Moving time = crew present and equipment self-propelled or hauled.
3/Hours fueled = productive time + moving time.
4/Delay time = crew present and equipment not operating.
5/Crew hours = productive time + moving time + delay time.
6/Idle time = crew not present and equipment not operating.
7/Scheduled hours = productive time + moving time + delay time + idle time.
8/Administrative time = total time spent on unit by supervisor.
9/Auxiliary equipment scheduled hours = one-half administrative time.

Table 5—Summary of time required for equipment, labor, and administration on harvest unit 42

Equipment	Productive time 1/	Moving time 2/	Hours fueled 3/	Delay time 4/	Crew hours 5/	Idle time 6/	Scheduled hours 7/	Administrative time 8/
				Hours				
Feller bunchers	89.3	6.0	95.2	13.0	108.3	11.7	120.0	
Skidders	65.4	4.0	69.4	10.7	80.1	15.9	96.0	
Chipper	40.9	4.0	44.9	16.8	61.7	21.3	83.0	
Auxiliary equipment 9/	--	--	--	--	--	--	49.5	
Supervisor's time								99.0

1/Productive time = crew present and equipment operating.
2/Moving time = crew present and equipment self-propelled or hauled.
3/Hours fueled = productive time + moving time.
?/Delay time = crew present and equipment not operating.
5/Crew hours = productive time + moving time + delay time.
6/Idle time = crew not present and equipment not operating.
7/Scheduled hours = productive time + moving time + delay time + idle time.
8/Administrative time = total time spent on unit by supervisor.
9/Auxiliary equipment scheduled hours = one-half administrative time.

Table 6—Summary of time required for equipment, labor, and administration on harvest unit 26

Equipment	Productive time 1/	Moving time 2/	Hours fueled 3/	Delay time 4/	Crew hours 5/	Idle time 6/	Scheduled hours 7/	Administrative time 8/
				Hours				
Feller bunchers	134.1	6.0	140.1	16.5	156.6	9.4	176.0	
Skidders	123.0	4.0	127.0	20.7	147.7	18.6	166.3	
Chipper	'47.9	4.0	51.9	14.4	66.3	7.2	73.5	
Log trimer	67.8	4.0	71.8	14.0	85.8	13.2	99.0	
Log loader 9/	33.9	--	--	--	--	--	99.0	
Auxiliary equipment 10/	--	--	--	--	--	--	55.3	
Supervisor's time								110.5

1/Productive time = crew present and equipment operating.
2/Moving time = crew present and equipment self-propelled or hauled.
3/Hours fueled = productive time + moving time.
?/Delay time = crew present and equipment not operating.
5/Crew hours = productive time + moving time + delay time.
6/Idle time = crew not present and equipment not operating.
7/Scheduled hours = productive time + moving time + delay time + idle time.
8/Administrative time = total time spent on unit by supervisor.
9/Log loader productive time = one-half log trimmer productive time; log loader scheduled hours = log trimer scheduled hours.
10/Auxiliary equipment scheduled hours = one-half administrative time.

Table 7—Summary of time required for equipment, labor, and administration on harvest unit 5H

Equipment	Productive time 1/	Moving time 2/	Hours fueled 3/	Delay time 4/	Crew hours 5/	Idle time 6/	Scheduled hours 7/	Administrative time 8/
				Hours				
Feller bunchers	56.5	4.0	60.5	13.0	73.5	49.5	123.0	
Skidders	79.4	4.0	83.4	9.7	93.1	82.9	176.0	
Chipper	53.9	4.0	57.9	13.0	70.9	90.1	161.0	
Log trimer	51.0	4.0	55.0	7.2	62.2	77.8	140.0	
Log loader 9/	25.5	--	--	--	--	--	140.0	
Auxiliary equipment 10/	--						134.0	
Supervisor's time								268.0

1/Productive time = crew present and equipment operating.
2/Moving time = crew present and equipment self-propelled or hauled.
3/Hours fueled = productive time + moving time.
4/Delay time = crew present and equipment not operating.
5/Crew hours = productive time + moving time + delay time.
6/Idle time = crew not present and equipment not operating.
7/Scheduled hours = productive time + moving time + delay time + idle time.
8/Administrative time = total time spent on unit by supervisor.
9/Log loader productive time = one-half log trimmer productive time; log loader scheduled hours = log trimer scheduled hours.
10/Auxiliary equipment scheduled hours = one-half administrative time.

Table 8—Summary of time required for equipment, labor, and administration on harvest unit 11H

Equipment	Productive time 1/	Moving time 2/	Hours fueled 3/	Delay time 4/	Crew hours 5/	Idle time 6/	Scheduled hours 7/	Administrative time 8/
				Hours				
Feller bunchers	74.1	4.0	78.1	9.4	87.5	0	82.5	
Skidders	53.9	2.0	55.9	10.6	66.5	15.5	82.0	
Chipper	21.0	4.0	25.0	4.5	29.5	0	29.5	
Log trimer	47.9	4.0	51.9	16.1	68.0	15.5	83.5	
Log loader 9/	24.0	--	--	--	--	--	83.5	
Auxiliary equipment 10/	--	--	--	--	--	--	57.8	
Supervisor's time								115.5

1/Productive time = crew present and equipment operating.
2/Moving time = crew present and equipment self-propelled or hauled.
3/Hours fueled = productive time + moving time.
4/Delay time = crew present and equipment not operating.
5/Crew hours = productive time + moving time + delay time.
6/Idle time = crew not present and equipment not operating.
7/Scheduled hours = productive time + moving time + delay time + idle time.
8/Administrative time = total time spent on unit by supervisor.
9/Log loader productive time = one-half log trimmer productive time; log loader scheduled hours = log trimmer scheduled hours.
10/Auxiliary equipment scheduled hours = one-half administrative time.

Auxiliary Equipment Time

The time required to operate auxiliary equipment was short compared to that needed for major equipment. The log loader, for example, was operated only intermittently to sort and load logs.

The tracked dozer was used to clear spur roads, create landings, clean up after harvest, and occasionally to move logs or push stalled vehicles. The road grader was used occasionally to maintain roads. The truck tractor was used to move chipvans at the landings, especially to position the vans at the chipper. The truck tractor was used also to haul equipment on the low-boy trailer and to haul the chipper from one harvest site to another. The pickup trucks and maintenance truck were used to transport parts, supplies, and personnel. The watertank fire truck was used occasionally for dust abatement.

Time required of auxiliary equipment was not monitored continuously; scheduled time requirements were assumed to be one-half the total scheduled time of major equipment on each study unit (tables 3-8). Productive machine hours (actual use) for each piece of auxiliary equipment are estimated as follows:

Equipment	Hours of use
Tracked dozer	3 per landing site (clear landing) 3 per harvest unit (site clean-up, other duties)
Maintenance truck	1.5 per scheduled day
Road grader	3 per harvest unit
Truck tractor	0.5 per loaded chipvan 2 moving dozer per unit 2 moving chipper per unit
Fire truck	3 per landing site
Fuel tank truck	1 per scheduled day
Pickup truck (2 trucks)	2 per scheduled day (each truck)
Chain saws	1 per harvest unit

The number of landings, scheduled days of work, truckloads of logs and vanloads of chips required were as follows:

Harvest unit	Landings	Days	Vanloads	Truckloads: Saw logs	Truckloads: House logs
4	1	9	37	6	—
46	2	13	34	—	—
42	2	12	49	—	—
26	2	14	47	7	7
5H	2	22	21	14	14
11H	3	14	9	9	9

Labor and Supervision Time

Labor requirements varied with the types of equipment used. In general, one operator was required for each feller buncher, skidder, mobile chipper, log trimmer, and log loader. Crew members operated auxiliary equipment as required. The crew member who operated the chipper often operated the truck tractor used to reposition chipvans on landings. The log trimmer crew member operated the tracked dozer occasionally to maintain landings and spur roads. Operators of the feller buncher and skidder occasionally used chain saws to remove large snags. Additional duties of the crew included post-harvest cleanup of the site, occasional road maintenance, and dust abatement on the landings with the watertank fire truck.

Two maintenance people were regularly assigned to provide back-up maintenance of harvesting equipment. One was regularly assigned to the maintenance shop facility. The other was assigned to both shop and the field.

The foreman in charge of harvesting operations provided general supervision and occasionally performed such services as transporting spare parts and fuel or maintaining equipment. He also operated equipment for brief periods. The logging contractor occasionally assisted the foreman in supervising operations but usually performed administrative duties.

The logging contractor, the foreman, and the maintenance personnel were responsible for harvest activities on both study and nonstudy units during the study period. Because activity on the study units represented about half the total activity, only half the time of the above personnel was charged to study units.

costs

Harvest Costs

All cost estimates derived in this study are specific to the harvest operation studied in the Blue Mountain area in 1979. Extrapolation of results to other harvest operations or different times should be limited. The production times, do, however, illustrate the factors that must be considered in any cost analysis, and the techniques used here to estimate costs are applicable to any harvesting situation.

Total harvest cost is an aggregate of direct and indirect costs identified during harvest of the study units and includes the following breakdown:

Equipment —

1. Capital recovery or rental (ownership costs)
2. Maintenance (parts, supplies, and repairs)
3. Labor (wages and fringe benefits)
4. Fuel and lubricants
5. Insurance and local taxes

Operating overhead —

1. Administrative, supervisory, and maintenance
2. Stumpage, road maintenance, and environmental protection fees
3. Contracted transportation

Capital Costs

Investments in equipment and facilities are estimated on the assumption that they were made in 1979. Some logging operators in the Blue Mountains believe that acquiring used or rebuilt equipment is economical for certain items that are operated only intermittently. Equipment that is worked heavily or continuously should be acquired new if possible. Whether equipment is acquired new generally depends on the type and scale of operation and on the availability of investment capital. Items of equipment and facilities used on the study units are listed below, along with indications of whether they were acquired new or used. Costs are estimated as of 1979 for the general region of the Blue Mountains.

Equipment	Horsepower	New/used	cost
			(dollars)
Mobile chipper	380	new	165,000
Mobile log trimmer	160	new	154,000
Feller buncher	105	new	75,000
Grapple skidder	120	new	70,000
Tracked dozer	200	used	70,000
Log loader		used	30,000
Maintenance truck, tools		used	25,000
Road grader	135	used	22,000
Low-boy trailer		used	16,000
Truck tractor		used/rebuilt	12,000
Fire truck/water tank		used	4,000
Fuel tank truck		used/rebuilt	4,000
Miscellaneous equipment (chain saws)			1,000
Maintenance shop facility and tools			55,000
Pickup truck		leased	150/month

Annual capital recovery cost is calculated by the so-called exact capital recovery formula, as follows:

$$\text{Annual Capital Recovery} = (P-L)\left(\frac{i(1+i)^n}{((1+i)^n-1)}\right) + (i)(L)$$

Where, n = number of years of useful life or capital recovery period,
P = amount of initial investment,
L = salvage value at the end of n years,
and, i = interest rate of capital or borrowed money.

Hourly costs to recover capital investment in equipment are based on estimated annual costs and time scheduled annually for use of each item. Major equipment (feller bunchers, skidders, chipper, and log trimmer), are usually scheduled for full-time operation daily. Mechanized harvesting in the Blue Mountains, however, is limited to about ***8*** months of the year because of weather or soil conditions in winter and spring. Scheduled machine hours are therefore limited to about 1,400 hours per year, based on a 40-hour work week, and this is the number used in this analysis for all equipment.

The expected useful life of new diesel-powered timber-harvesting equipment is typically about 10,000 hours. With potential operating time set at 1,400 hours per year, an appropriate capital recovery period is 7 years, and this period was used for equipment in this analysis. The salvage value of all equipment is set at 10 percent of initial investment at the end of 7-years.

Maintenance Costs

Costs for parts replacement, supplies, and outside repairs vary with equipment. Maintenance costs increase as equipment ages or is used more heavily. **A** formula that can be used to estimate average annual maintenance costs for harvesting equipment is derived from a commonly used rule of thumb. **I**t suggests that total maintenance costs over the life of a piece of equipment are roughly 50 percent of the purchase price for parts and supplies, and **is** expressed as follows:

$$\text{Annual maintenance cost} = \frac{(F)\quad(P)}{n};$$

where, F is maintenance cost factor (percent of purchase price),

P is the initial purchase price,

and, n is the number of years of useful life.

One local equipment supplier in the Blue Mountains suggested that an appropriate cost factor for the above formula would be 45 percent. Information provided by the logging operator and observations of maintenance required during the study suggest that the following factors are appropriate for calculating annual maintenance cost:

	Percent of initial cost
Chipper, skidders, feller bunchers	55
Log trimmer, loader, dozer, truck tractor, and fire truck	45
Other equipment items	30

The cost of tire replacement is an additional major expense for certain equipment. The following summary indicates the cost of replacing tires and assumptions about average tire life used in this analysis:

Equipment	Tires per vehicle	Replacement cost per tire	Average tire life
		1979 dollars	*Years*
Grapple skidder	**4**	900	1.0
Feller buncher	**4**	900	.5
Mobile chipper	**8**	350	3.5
Log trimmer	**4**	900	2.0
Log loader	6	500	3.5
Maintenance truck	6	150	3.5
Road grader	**4**	900	3.5
Low-boy trailer	8	200	3.5
Truck tractor	10	200	1.0
Fire truck	6	150	3.5
Fuel truck	**4**	100	3.5
Pickup truck	**4**	150	2.0

Replacement costs are averaged on both annual and hourly bases. Average annual cost is estimated by the following formula:

$$\text{Average annual cost of replacing tires} = \frac{\text{(Number of tires) per set} \left(\text{Cost of each tire}\right)}{\text{Years of average tire life}}.$$

Labor Costs

Cost of labor to operate equipment is an additional expense computed in the hourly costs for major equipment. Cost of supervision and maintenance are included in overhead costs. Labor rates include hourly wages plus fringe benefits, coverage required by State Workers' Compensation laws, and Social Security employer contributions, amounting altogether to 57 percent of basic wages.

Labor rates used in this study are those that prevailed in the Blue Mountains region in 1979 as follows:

	Wage	Fringe benefits and employer's contributions	Total
		*Dollars **per** hour*	
Operators of log trimmer and chipper	9.50	5.50	15.00
Operators of feller buncher, skidder, loaders, maintenance personnel	8.75	5.00	13.75

Labor rate for the supervisory foreman is $30,000 per year

Fuel and Lubricant Costs

Fuel consumption and lubricant requirements of major equipment were monitored periodically and are reported as observed. All major equipment had diesel engines. Several items had been in service for a number of years. Shearing and chipping is considered to be generally more difficult in dry, dead lodgepole than in live timber. Difficulty of terrain and elevation (about 4,000 feet) may also have affected fuel consumption.

Lubricant requirements may reflect special difficulties or requirements peculiar to harvesting dead timber in the Blue Mountains, or problems specific to the particular equipment. Requirements reported here are based on limited data and may have limited application to other harvest operations, even under similar conditions. Fuel and lubricant requirements for major equipment were as follows:

	Horsepower	Fuel	Oil	Grease
		Gallons per hour	*Gallons* per *day*	*Pounds* per *day*
Feller buncher	105	7	1.0	1.0
Grapple skidder	120	7	1.5	.3
Log trimmer	160	6.5	.6	1.0

The mobile chipper (380 hp) used 12.5 gallons of fuel per van load of chips.

Overhead Costs

Annual administrative, supervisory, and maintenance overhead costs for the entire logging operation in 1979 were as follows:

Administrative overhead	$ 65,000
Supervisory overhead	35,000
Maintenance facility (capital recovery, taxes, insurance)	7,900
Maintenance labor	46,800
Total	$154,700

Dividing the total annual cost by 1,400 (hours per year of scheduled time) gives a cost of $110.50 per scheduled hour. Because the study units made up only half the total harvest operation, $55.25 per hour of scheduled time was used to figure the cost for administrative, supervisory, and maintenance overhead.

Administrative overhead includes salaries and travel expenses of personnel who negotiate contracts and arrange product sales. Supervisory overhead includes the salary and travel and planning expenses of the foreman. A 45-year period is used to derive capital recovery costs of the maintenance building and 7 years for maintenance facility equipment. Maintenance personnel are assumed to be employed for an average of 1,700 hours per year.

Hourly Costs

The hourly costs of major harvesting activities (felling and bunching, skidding, chipping, log-making and loading) are calculated by determining the hourly cost of operating each piece of major equipment and applying these costs to the machine hours listed for each harvest unit in tables 3-8. Hourly costs for major equipment are reported in table 9. Costs of capital, insurance, taxes, maintenance, and tires are calculated in dollars per scheduled hour. Costs of labor are per hour of payroll time. Costs of fuel and lubricants are per productive hour of actual operation.

Hourly costs for auxiliary equipment are tabulated in table 10. No labor costs are included because auxiliary equipment was operated intermittently by operators of major equipment and all crew labor is accounted for in the costs of major equipment to which crew members were regularly assigned.

Harvest Costs by Harvest Unit

The total costs for harvesting each of six units are tabulated in table 11. Costs are based on the number of scheduled machine hours, crew hours, and hours fueled for each type of machine and the appropriate hourly cost (table 9). Auxiliary equipment costs are determined from tables 3-8 and 10 in a similar manner.

Administrative, supervisory, and maintenance costs for each harvest unit were determined by multiplying the administrative hours on that unit (table 3) by the hourly overhead cost of $55.25.

Additional overhead expenses include Forest Service stumpage fees, road maintenance, and environmental protection fees. A stumpage price of $0.50 per thousand board feet was paid for the salvage sale that included the six study units. A conversion factor commonly used for small timber sales in the Blue Mountains is: one thousand board feet, log scale, is equivalent to 2.5 ovendry tons. This conversion gives a stumpage cost of $0.20 per ovendry ton of products recovered. Additional fees for road maintenance, slash disposal, and erosion control are also assessed to logging operations. On the timber sale that included the study units these additional fees amounted to $5.19 per thousand board feet, or about $2.10 per ovendry ton of products recovered. Total Forest Service fees, therefore, amounted to $2.30 per ovendry ton of products recovered.

Harvest Costs of Logs and Chips Compared

To calculate harvest costs separately for logs and chips, we assigned appropriate costs to log harvest and chip harvest (table 12). The cost of operating the chipper was assigned to chips; the cost of the log trimmer and log loader was assigned to logs. After these costs were subtracted from total costs for each harvest unit, the remaining costs of felling, bundling, and skidding logs to landings were prorated to logs and chips on the basis of wet weight (table 2).

To find costs to be prorated on harvest unit 4, for example, we subtracted log costs and chipping costs from total harvest costs of $28,148, leaving $18,237 to be prorated. The wet weight of logs was 154.8 tons, the wet weight of chips, 802.2 tons, or 16.2 and 83.8 percent, respectively, of total products. Multiplying $18,237 by 16.2 (the percentage of green log weight) gave $2,954 as the share of harvest costs assigned to log production. Adding the costs of log trimming ($3,263), log loading ($1,128), and the prorated share of other harvest costs ($2,954) gave a total cost of $7,705 for harvesting logs. Dividing by units of logs produced (154.8 wet tons) gave a unit cost of $49.77 per wet ton. The cost per board foot of logs was $7,705 divided by 46.0 (thousand board feet produced on unit 4) for a cost of $74.16 per thousand board feet.

Table 9—Hourly costs for major equipment acquired in 1979, based on a capital recovery period of 7 years and interest at 12 percent, salvage value at 10 percent of investment, and annual scheduled machine hours of 1,400

	Per scheduled hour					Per crew hour	Per productive hour
Equipment	Capital recovery	Insurance 1/	Local taxes 2/	Maintenance 3/	Tires	Labor	Fuel and lubrication 4/
				Dollars			
Feller buncher 5/	11.21	0.82	0.49	4.21	4.77	13.75	5.20
Grapple skidder 6/	10.46	.77	.46	3.92	2.20	13.75	5.38
Mobile chipper 7/	24.66	1.81	1.09	9.26	.29	15.00	11.25
Log trimer 8/	23.01	1.69	1.01	7.08	.92	15.00	4.80
Log loader 9/	4.48	.32	.21	1.38	.31	13.75	2.63

1/Insurance = 2.5 percent of average investment.
2/Local taxes = 1.5 percent of average investment.
3/Parts, supplies, outside repairs.
4/Fuel at $0.70 per gallon, oil at $2.40 per gallon.
5/Cost $75,000 new.
6/Cost $70,000 new.
7/Cost $165,000 new.
8/Cost $154,000 new.
9/Cost $30,000 used.

Table 10—Hourly costs for auxiliary equipment

	Per scheduled hour					Per productive hour
Equipment	Capital recovery	Insurance and taxes	Maintenance	Tires (or tracks)	Total	Fuel and lubricants
			Dollars			
Tracked dozer	10.46	1.23	3.22	0.20	15.11	5.70
Maintenace truck	3.74	.44	.46	.09	4.73	3.75
Road grader	3.29	.39	.67	.37	4.72	3.38
Low-boy trailer	2.39	.28	.48	.16	3.31	--
Truck tractor	1.79	.21	.55	1.22	3.77	6.00
fire truck	.60	.07	.18	.09	.94	3.75
fuel tank truck	.06	.07	.18	.04	.89	3.75
Miscellaneous (chain saws)	.15	.02	.03	--	.20	.38
Pickup truck rental	.94	--	.21	.06 x 2	2.42	3.00
Total per scheduled hour					36.09	

Table 11—Summary of harvest costs by harvest unit

	Equipment 1/								
Harvest unit	Feller bunchers	Grapple skidders	Mobile chipper	Log trimmer	Log loader	Auxiliary equipment	Overhead 2/	Fees 3/	Total
					Dollars				
4	3,779	4,461	5,160	3,623	1,128	2,361	6,050	1,576	28,138
46	3,331	1,986	3,465	0	0	2,401	5,857	1,281	18,321
42	4,564	3,184	4,557	0	0	2,298	5,470	1,861	21,934
26	6,666	5,675	4,251	4,969	1,943	2,554	6,105	2,351	34,514
5H	3,969	4,863	7,274	5,916	1,871	5,489	14,807	1,683	45,872
11H	3,490	2,675	1,638	4,083	1.568	2,549	6.381	1,206	23,590

1/Equipment costs include hourly costs for major equipment (table 9) multiplied by number of machine hours (tables 3-8). Auxiliary equipment costs include scheduled hours (tables 3-8) multiplied by cost per scheduled hour (table 10, bottom line) plus productive hours for each piece of equipment multiplied by cost per productive hour (table 10).
2/Administrative time (tables 3-8) multiplied by $55.25 per hour (half the total hourly overhead costs).
3/Ovendry tons of product (table 2) multiplied by Forest Service fees of $2.30 per ovendry ton.

Table 12—Harvest costs prorated to logs and chips by percent weight

	costs					Total weight		Weight proportion		Total costs		Cost per ton	
Harvest unit	Total	Chipper	Trimer	Loader	Amount prorated	Logs	Chips	Logs	Chips	Logs	Chips	Logs	Chips
	Dollars					Wet tons		Percent		Dollars			
4	28,148	5,160	3,623	1,128	18,237	154 8	802.2	16.2	83.8	7,705	20,443	49.77	25.48
46	18,321	0	0	0	0	0	707.3	0	100.0	0	18,321	0	25.90
42	21,934	0	0	0	0	0	1,088.2	0	100.0	0	21,934	0	20.16
26	34,504	4,251	4,969	1,943	23,341	286.7	973.9	22.7	77.3	12,210	22,294	42.59	22.89
5H	45,482	7,274	5,916	1,871	30,811	481.6	408.0	54.1	45.9	24,456	21,416	50.78	52.49
11H	23,590	1,638	4,083	1,568	16,301	462.0	191.9	70.6	29.4	17,160	6,430	37.14	33.51
Total or average	172,979	18,323	18,591	6,510	--	1,385.1	4,170.5	--	--	61,531	110,838	44.42	26.58

The cost of producing chips on harvest unit 4, for example, included the chipping cost of $5,160 (table 12) plus costs prorated to chips. Prorated cost was $18,237 multiplied by 0.838 (chip weight percent), or $15,283. The total harvest cost of chips then was $20,443 ($15,283 plus $5,160). The cost per wet ton was $25.48 ($20,443 divided by 802.2). Costs of chips per ovendry ton was found by dividing total costs of chip harvest ($20,443) by 570.1 (dry tons from table 2) to give a cost of $35.86 per ovendry ton. Costs per bone-dry unit of 2,400 pounds was $35.86 multiplied by 1.2, or $43.02.

Costs of producing logs and chips from all harvest units are summarized in table 12.

Transportation Costs

Transportation represents the final expense in the total cost of delivered chips or log products. Most delivery points were located 50 miles from harvest units. The rate for hauling logs was about $400 per day, per truck. Trucks could deliver about three loads per day at a cost of approximately $133 per truckload. Chips were hauled in vans at $2.00 per mile one way ($2 per loaded mile). Transportation costs, based on total truckloads and vanloads of materials transported from study units, are reported in table 13.

Delivered Costs

Delivered costs (table 14) are the sum of harvest costs plus transportation costs. The delivered costs of logs ranged from a low of $43.19 per wet ton (unit 11H) to a high of $56.57 (unit 5H). The average cost for all units was $50.28. The delivered cost of logs is also shown per ton, ovendry, and per thousand board feet.

The delivered cost of chips varied from $30.10 per ton, wet (unit 4) to $57.64 (unit 5H). The average cost for all units was $31.30. The delivered cost of chips is also shown per ton, ovendry, and per bone-dry unit (2,400 pounds).

Variables That Affect Product Costs

Timber Characteristics

Harvest costs are determined to some extent by stand characteristics. Size of timber, tree denisty, and stand volume affect the efficiency of harvesting and influence costs. Two of the six study units (46 and 11H) provide examples of differences in characteristics of lodgepole pine, the only species harvested on the salvage sale. Characteristics of the timber were reported accurately in a survey done before the harvest. It provides the following detail:

	Unit 46	Unit 11H
Average number of stems per acre	452	337
Average stem diameter (d.b.h. in inches)	5.93	8.52
Basal area (square feet per acre)	84.03	129.42
Stem volume (cubic feet per acre)	2,469.2	3,186.8
Average height (feet)	54.9	69.0
Dry weight of biomass (tons per acre):		
Stems and bark	30.87	40.37
Branches and needles	5.05	5.76
Average stem volume (cubic feet per stem)	5.46	9.45

Without reference to the preharvest survey data, the logging operator decided to recover roundwood and chips from unit 11H and only chips from unit 46. He based his decision only on observation of timber size, and it appeared to be supported by data from the survey indicating larger average stem diameter and average stem volume on unit 11H, compared with unit 46.

Table 13—Transportation costs by harvest unit

Unit	Logs produced				Chips produced				costs 1/			
									Logs		Chips	
	Number of loads	Tons, wet	Tons, ovendry	Thousand board feet	Number of loads	Tons, wet	Tons, ovendry	Bone-dry units	Per ton, wet	Per thousand board feet	Per ton, wet	Per bone-dry unit
									Dollars			
4	6	154.8	115.0	46.0	37	802.2	570.1	475	5.16	17.35	4.61	7.79
46	--	--	--	--	34	707.3	557.0	464	--	--	4.81	7.33
42	--	--	--	--	49	1,088.2	809.0	674	--	--	4.50	7.27
26	13	286.7	257.8	103.9	47	973.9	762.4	635	6.03	16.40	4.83	7.40
5H	21	481.6	397.8	159.1	21	408.0	334.1	278	5.80	17.55	5.15	7.55
11H	21	462.0	378.8	151.5	9	191.1	145.5	121	6.05	18.43	4.71	7.44
Total or average 2/	61	1,385.1	1,149.4	460.5	3/197	4,170.7	3,178.1	2,647	5.76	17.43	4.77	7.46

1/Costs are based on $133 per load of logs and $100 per load of chips for an average haul of 50 miles.
2/Loads of logs averaged 22.7 tons, wet (18.9 tons, ovendry), and 7.55 thousand board feet; loads of chips averaged 21 tons, wet (16 tons ovendry) or 13.4 bone-dry units. Loads of logs or chips from live lodgepole pine timber would average more nearly 4.5 thousand board feet or 8.75 bone-dry units, based on wet weight twice that of dry weight (50 percent moisture).

Table 14—Delivered cost of logs and chips, by harvest unit and unit of production

Harvest unit	Production				costs			Delivered cost per unit of production			
	Tons wet	Tons ovendry	Bone-dry unit 1/	Thousand board feet 2/	Harvest	Trans-portation	Total harvest	Ton wet	Ton ovendry	Thousand board feet	Bone-dry unit
					Dollars						
					LOGS						
4	154.8	115.0	--	046.0	7,705	798	8,503	54.93	73.94	184.85	--
26	286.7	259.8	--	103.9	12,210	1,729	13,939	48.62	53.65	134.16	--
5H	481.6	397.8	--	159.1	24,456	2,793	27,248	56.57	68.50	171.26	--
11H	462.0	378.8	--	151.5	17,610	2,343	19,953	43.19	52.67	131.70	--
All units	1,385.1	1,149.4	--	460.5	61,531	7,663	69,643	50.28	60.59	151.23	--
					CHIPS						
4	802.2	570.1	475.1	--	20,443	3,700	24,143	30.10	42.35	--	50.82
46	707.3	557.0	464.0	--	18,321	3,400	21,721	30.17	39.00	--	46.80
42	1,088.2	809.0	674.0	--	21,934	4,900	26,834	24.66	33.17	--	39.80
26	973.9	762.4	635.0	--	22,294	4,700	26,994	27.72	35.41	--	42.49
5H	408.0	334.1	278.0	--	21,416	2,100	23,516	57.64	70.39	--	84.47
11H	191.1	145.5	121.0	--	6,430	900	7,330	38.36	50.38	--	60.45
All units	4,170.7	3,178.1	2,647.1	--	110,838	19,700	130,538	31.30	41.07	--	49.31

1/1 bone-dry unit = 2,400 pounds or 1.2 tons ovendry.
2/1,000 board feet = 2.5 tons ovendry.

Costs of harvesting timber of smaller diameter are usually expected to be higher because more stems must be handled per unit of production. Results on units 46 and 11H are somewhat contradictory. Total harvest costs of $18,321 for unit 46 and $23,590 for unit 11H (table 11) are proportional to the estimated total dry weights of stems and bark for the two units. Total recovery of products from unit 46, however, was 557 dry tons of chips or 30.94 dry tons per acre. This was 100 percent of the estimated biomass (excluding branches and needles). But on unit 11H, only 379 dry tons of logs and 145 dry tons of chips (total 524 dry tons) or 27.59 dry tons per acre were recovered. This was only 68 percent of the estimated biomass.

This apparent contradiction in the expected relationship between timber size and harvest cost may have resulted from the combined factors of a limited number of study units and the operator's experience. As noted previously, the operator had had considerable previous experience in converting all stems to chips, as he did on unit 46, but no experience in sorting for both log and chip production, as on unit 11H.

Moisture Content

Moisture content may have conflicting effects on costs. Lower moisture content means lower weight per volume and permits trucks to haul larger loads of logs or chips, thus reducing transportation costs. Chipping dry, dead wood, on the other hand, increases wear on the chipper knife and increases costs directly, because parts must be replaced earlier and/or sharpened, and, indirectly, by increasing delay time. Dry branches from dead trees are stiffer than those from green trees and more likely to puncture tires on feller-bunchers and skidders. Earlier replacement of tires and time lost for tire changes add to harvest costs.

The moisture content of logs in this study was determined by cutting cross-sectional samples from a number of logs on each harvest unit. These were weighed before and after ovendrying. The weight lost, as a percent of initial weight (wet) is the moisture content. Average moisture content of logs from harvest units 4, 26, 5H and 11H was 25.7, 9.4, 17.4, and 18.0 percent, respectively. These figures were used to convert ovendry weight of logs to wet weight as shown in tables 2 and 13. Dry weight of logs was determined by multiplying the scaled cubic volume by a density of 25 pounds per cubic foot. At 200 cubic feet per thousand board feet (gross log scale) this conversion amounts to 2.5 dry tons per thousand board feet.

In all, the 61 loads of logs averaged 7.75 thousand board feet, gross log scale. At an average moisture content of 17 percent (all logs), the wet weight per load was 22.7 tons. For live lodgepole pine at 50 percent moisure content (50 pounds per cubic foot) a maximum load of 22.7 tons, wet, would correspond to 4.54 thousand board feet, gross log scale, or less than 60 percent of the volume of a load of dead lodgepole pine.

Each vanload of chips was weighed at the chip purchaser's plant,. A sample of chips was taken from each load to determine the average moisture content. The measured moisture content was then used to calculate the dry weight of chips and the number of bone-dry units (2,400 pounds) as the basis for payment.

The average moisture content of chips from harvest units varied from 18 percent on unit 5H to 29 percent on unit 4. Overall moisture content averaged 24 percent, compared with 17 percent for logs. The difference can be attributed largely to the fact that the relatively smaller stems going to chip production included a higher proportion of material from live trees.

Energy Comparisons

A person considering the production of wood fuel from dead lodgepole pine must compare the energy that will be expended in harvesting with the potential energy that can be recovered from fuel.

In examining this question, we have assumed that conventional mechanized harvest systems, as used in eastern Oregon in 1979, will remain the most economical and efficient systems in the foreseeable future, and that all direct energy used during harvesting and transporting it is derived from oil. It is conceivable, however, that alternative fuels such as alcohol or wood gas could replace some of the oil fuel without greatly affecting the harvest system. We have also assumed that all harvesting material is recovered as chips.

Producing Chips Only

Whole-tree chips could have been produced exclusively from all harvest units in this study without significantly modifying the harvesting system. Felling, bucking, and skidding operations would have been the same. Trimming, loading, and transportation of logs would have been eliminated. Operation of the mobile chipper and truck tractor would have increased in proportion to the additional weight of chips produced. All other activities, including use of auxiliary equipment, would have remained the same.

The following tabulation shows amounts of chips that would have been produced if chips had been the only product from the six study units. Tons of wet chips include the wet weight of logs that were actually produced from four of the units (4, 26, 5H, and 11H). Tons of ovendry chips were calculated on the basis of the moisture content of logs that were produced.

Harvest unit	Wet	Ovendry	Vanloads
	Tons		
4	957.0	685.1	45
46	707.3	557.0	34
42	1,088.2	809.0	52
26	1,260.6	1,022.2	60
5H	889.6	731.9	42
11H	653.1	524.3	31
Total	5,555.8	4,329.5	264

Energy Required for Harvesting and Transportation

Energy required for harvesting and transportation is mainly in the form of diesel oil but includes minor quantities of gasoline, lubricating oil, and grease. The average amounts of energy required to harvest and deliver a ton of ovendry chips is estimated in gallons of diesel fuel and British thermal units (Btu's).

	Gallons	Btu's
Feller buncher	0.782	109,000
Grapple skidder	.701	98,000
Mobile chipper	.745	104,000
Auxiliary equipment	.808	113,000
Transport and delivery	1.192	167.000
Total	4.228	591,000

Fuel requirements are converted to gross energy on the basis of 140,000 British thermal units per gallon of oil. In International System (SI) units, joules per kilogram are obtained by multiplying Btu per ton by a factor of 1.1639.

The total energy requirements shown in table 15 are based on the simulated production of chips only. Some minor indirect energy inputs are not included. Energy output is based on the heating value of lodgepole pine at 8,700 Btu's per pound, ovendry, or 17.4 million Btu's per ton. The energy balance indicates that gross energy required to harvest and deliver chips from dead lodgepole pine represents only 3.4 percent of the gross energy output of the chips produced. From an energy standpoint, harvesting dead lodgepole for fuel appears likely to become more practical and economical as energy (particularly fuel oil) becomes more expensive, all other considerations being the same.

More important from an energy standpoint is the higher efficiency achieved in burning dead lodgepole pine, compared with most other wood fuels. Lodgepole pine at an average moisture content of 20 percent should burn with about 75 percent efficiency. By comparison, oil is generally fired at 80 percent efficiency and fuel from live timber at 65 percent or less efficiency.

Table 15—Estimates of energy that would be required to harvest and deliver dead lodgepole pine from 6 harvest units as ovendry chips

Harvest unit	Chip production	Feller buncher	Grapple skidder	Mobile chipper	Auxiliary equipment	Transport van 1/	Total	Equivalent per ton of chips
	Ovendry tons	Gallons of diesel oil 2/						
4	685.1	348	441	538	451	860	2,638	3.85
46	557.0	494	283	425	469	680	2,351	4.22
42	809.0	642	470	613	573	980	3,278	4.05
26	1,022.0	946	884	750	658	1,200	4,456	4.36
5H	731.9	406	517	525	811	840	3,153	4.31
11H	524.3	533	387	375	583	600	2,433	4.64
Total or average	4,329.3	3,369	3,036	3,226	3,545	5,160	18,309	4.23

1/Estimated at 20 gallons per 50-mile trip.
2/Petroleum fuels and lubricants.

The economic feasibility of harvesting dead lodgepole for fuel depends on harvest costs and market opportunities. Buyers who intend to use dead lodgepole for fuel must pay the market price. Although the search for alternative energy sources has led to greater consideration of wood as fuel, use of wood for other products has also increased. Thus, the market determines which products are produced from dead lodgepole. A buyer interested in using dead lodgepole for fuel may represent only one market opportunity for a logging operator.

Opportunities for Marketing Dead Lodgepole Pine

Sawmills designed and specially equipped to process timber smaller than 12 inches in diameter have recently appeared in many areas of the West. Operators of these sawmills encounter some difficulties and occasional advantages in processing beetle-killed lodgepole pine. The principal difficulties are that less lumber is recovered from dead timber that has drying checks and a disproportionate amount is low-grade lumber. Several studies of lumber recovery and problems associated with utilization of dead timber in sawmills have been reported (1, 2, 3).

House Logs

A relatively new industry in many areas of the West is producing commercial log homes. About 100 independent firms were manufacturing log homes in 1978 **(4).** Typically, these firms operate facilities located near the timber source. In the West, these firms usually manufacture and assemble log homes at their manufacturing facilities, then disassemble the structures and ship to buyers for on-site construction. Log-home packages and components are often shipped several hundred miles from manufacturing facilities. Log homes have a variety of uses, ranging from recreational homes to primary residences and commecial buildings such as stores and restaurants. Modern log homes have a certain rustic charm, generally appear to be solidly built, and are often attractive.

Some firms prefer dead lodgepole as a raw material because it is already dry and, therefore, maintains dimensional stability. Drying checks appear to pose serious problems for some firms, but not for others.

Paper and Board Products

Pulpmills are major consumers of wood in the West. Whole-tree chips from dead lodgepole pine are suitable for most types of paper or composition board products. In the West, however, more than three-fourths of the raw material for the pulp and board industries comes from residue of the lumber and plywood industries.

The unique dependence of the pulp industry in the West on sawmills, veneer mills, and plywood mills for raw material, results in a relationship between lumber production and the demand for chips by the pulp industry. When the housing market is strong, sawmills produce large quantities of lumber and generate large quantities of residue that becomes a source of low-cost raw material for the pulp industry. But, when the housing market slumps, lumber and residue production declines and prices for pulpmill raw material are likely to increase. When that occurs, loggers of marginal quality timber of low value may find it advantageous to produce chips rather than logs.

Wood Fuel

Although the heat energy recoverable from different fuels can be compared directly, the comparative economic values of fuels are more ambiguous. If one ton, ovendry weight, of dead lodgepole pine has heating value equivalent to about 106 gallons of fuel oil, and fuel oil sells for $1 per gallon, the maximum value of the wood would be $106 per ton. Fuelwood, however, is less convenient than oil because it is bulky and requires large storage areas. Combustion systems for fuelwood often require more costly equipment, maintenance, and operation than oil- or gas-fired systems of the same heating capacity. The value of fuelwood is therefore generally lower than would be indicated by direct comparisons of heating values of other types of conventional fuels, with the possible exception of coal.

One alternative to direct combustion of harvested wood chips is to produce densified wood fuel. In this process wood is hammermilled to small particles, then compacted or forced through dies to produce densified fuel, commonly referred to as "pellets," "briquets," or "stoker fuel." Densification does not increase the heating value of wood per unit of weight but does increase the density or weight per unit of volume. Densification can triple the weight per unit of volume compared with whole-tree chips.

Densification causes three important effects. First, it reduces transportation costs where weight is not a limiting factor, as it is in over-the-road transportation, where weight limits the amount of material than can be hauled per load. In rail or barge transportation, however, volume is the limiting factor. Because densified wood can have three times the weight of the same volume of chips, more fuel can be transported per load by rail or barge. Second, densified wood requires roughly one-third as much storage space (cubic volume) as whole tree chips. Third, densification of wood produces a fuel that is similar to coal in combustion and handling characteristics. Densified wood can therefore be substituted almost directly for coal at coal-fired facilities.

Summary

The study reported here was undertaken to determine the economic potential of dead lodgepole pine timber in northeastern Oregon as fuel or other products. This timber represents a major resource on extensive areas in the western United States. Although the harvesting costs determined in this study cannot be applied directly to other situations, the methods used should be useful in assessing the potential of other stands of dead timber.

During the 3 months of experimental logging in 1979, a highly mechanized system of harvesting was used to produce 3,178 tons, ovendry, of whole-tree chips and 1,151 tons, ovendry, (460 thousand board feet) of logs. Harvesting equipment included feller-bunchers, rubber tired skidders, a mobile chipper, a log-limbing and bucking machine, and a mobile log loader. The 197 vanloads of chips were hauled by a contractor to a plant that produces wood fiber insulation board. The logs were hauled to stud mills, house-log manufacturers, or a re-sorting yard where some were chipped. The costs reported for producing whole-tree chips from dead lodgepole pine are considered quite representative for the locality because of the operator's experience. Costs of producing logs are considered less reliable because of his inexperience in log-making and sorting methods and coordinating the production of logs and chips.

On harvest units where both chips and logs were produced, the cost of producing whole-tree chips and delivering the chips 50 miles was $31.30 per ton, wet; $41.07 per ton, ovendry; or $49.30 per bone-dry unit. Where chips only were produced (as on units 46 and 42), the average delivered cost of chips was $35.55 per ton, ovendry. This indicates that optimum coordination of producing logs and chips was not achieved during the 3-month study. Size of trees and condition of the dead lodgepole pine, as represented by the six harvest units, did not justify the expense of operating a limbing and bucking machine. Use of a log-loader to sort and load logs may have been justified but was not tested.

Logs that were produced along with chips on four of the harvest units cost an average of $50.28 per ton, wet, or $60.49 per ton, ovendry, delivered an average distance of 50 miles. The delivery costs ranged from $73.94 per ton, ovendry, on unit 4 to $52.67 on unit 11H. The average cost of $60.49 per ton converts to $151.23 per thousand board feet at 2.5 tons per thousand board feet.

We estimate that if all the material from the six harvest units had been chipped, 4,329 tons of ovendry chips would have been produced. The fuel equivalent per ton of ovendry chips would have been 17.4 million British thermal units, and the energy required to harvest and deliver each ton would have been 0.59 million Btu's, or only 3.4 percent of the energy available in the chips. More significant is the fact that dead lodgepole pine can be burned at an average efficiency of 75 percent, compared to an average efficiency of 65 percent, or less, for most wood fuel now used by industry.

Metric Equivalents

1 ton = 0.9072 tonne
1 acre = 0.4047 hectare
1 cubic foot = 0.0283 cubic meter
1 board foot = approximately .00566 cubic meter, at 5 board feet per cubic foot
1 Btu = 1 056 joules
1 gallon = 3.7853 liters
1 pound = 0.4536 kilogram

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The cost of harvesting and recovering round wood logs and whole-tree chips from small diameter lodgepole pine ***(Pinus*** contorta) infested by mountain pine beetle (Dendroctonus sp.) was studied in the Blue Mountains of eastern Oregon in 1979. Mechanized harvest operations were conducted on six study sites totaling 134 acres. The average cost of producing chips was $31.30 per ton, wet, delivered 50 miles from harvest sites. The average cost of logs was $50.28 per ton, wet, delivered the same distance. A gross energy balance indicates that energy required by harvesting was about 3.4 percent of the gross energy content of the delivered products.

Keywords: Logging enterprise costs, lodgepole pine (dead), wood utilization, energy, insect damage (-forest products, mountain pine beetle.

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