USDA FOREST SERVICE
RESEARCH PAPER NC-200

# HARVESTING WOOD FOR ENERGY

ENERGY

ENERGY

ENERGY

Rodger A. Arola and Edwin S. Miyata

North Central Forest Experiment Station
Forest Service, U.S. Department of Agriculture

## CONTENTS


*Page*

Case Studies .......... 1
Case I—Mechanized Thinning of Pole-Sized Hardwoods .......... 1
Case II—Mechanized Thinning of Pole-Sized Hardwoods .......... 6
Case III—Northern Hardwood Land Clearing Operation .......... 10
Case IV—Whole-Tree Harvesting of Low-Value Hardwoods for Stand Conversion .......... 12
Case V—Recovery of Hardwood Saw Log Tops and Limbs .......... 16
Conclusions .......... 19
Literature Cited .......... 19
Appendix .......... 21



**North Central Forest Experiment Station**
**Forest Service—U.S. Department of Agriculture**
**1992 Folwell Avenue**
**St. Paul, Minnesota 55108**

**Manuscript approved for publication April 15, 1980**
**1981**

# HARVESTING WOOD FOR ENERGY

**Rodger A. Arola,** *Principal Research Engineer*
*and* **Edwin S. Miyata,** *Research Industrial Engineer*
*Houghton, Michigan*

Although energy production is the greatest single world-wide use of wood, there has been relatively little interest in using wood for fuel in this country since the turn of the century. In the last few years, however, due to the spiraling fuel costs and the scarcity of petroleum fuels, there has been renewed interest in the use of wood fuel in the United States. Forest and mill residues, especially, have received considerable attention to supplement conventional fossil fuels.

Trade journals repeatedly cite case histories of forest industries which have converted to wood fuel; most of these facilities currently rely on primary and secondary mill residues. Mill residues, however, although they may presently be the most economical source of energy wood, will not be sufficient to satisfy the increasing industrial wood fuel demands of the future. A far greater potential lies in the large volumes of currently unutilized wood fiber in existing forest stands.

This potential can be at least partially realized through conventional harvesting operations with existing equipment and technology. Some of the benefits, in addition to more efficient use of the resource, would include reduction of logging slash, thinning of overcrowded stands, and conversion of low-quality, understocked stands. To illustrate the potential of harvesting wood for industrial energy, we have detailed the results of five harvesting operations.

## CASE STUDIES

There is a lack in the literature of well documented information on the costs and productivity of timber harvesting with various types of commercial logging equipment. Since each logging operation is different, each must be analyzed independently, taking into account the equipment used, the stand conditions, and other considerations.

The objective of this paper is to present pertinent cost and productivity data for several harvesting operations. These operations were not all conducted to provide wood fuel, but the information is still of value to those considering the harvest of wood for energy.

The case studies are based on the following harvesting operations:

- Two mechanized thinning operations in pole-sized hardwoods.
- One hardwood land-clearing operation (for agricultural land).
- One hardwood land-clearing operation (for site conversion).
- One relogging operation of hardwood tops and limbs resulting from a saw log harvest.

All of the studies were conducted between 1974 and 1978. For convenience and uniformity, all harvesting costs have been converted to 1980 dollars.

## CASE I—MECHANIZED THINNING OF POLE-SIZED HARDWOODS

### Stand Description

In 1974, a 50-acre, predominantly pole-sized stand of mixed northern hardwoods containing a few saw log trees on the Mishwabic State Forest in Michigan's Upper Peninsula was selected for mechanized thinning trials (fig. 1)(Biltonen *et al.* 1976). The soil was a sandy loam and the terrain had only minor changes in elevation. Approximately one-half mile of existing woods haul road was improved to facilitate chip-van transport. Landings were located 1,650 feet apart at each end of the woods haul road.

The stand contained 13 cords of hardwood pulpwood per acre and close to 2,700 board feet of sawtimber per acre in trees 10 inches diameter breast height

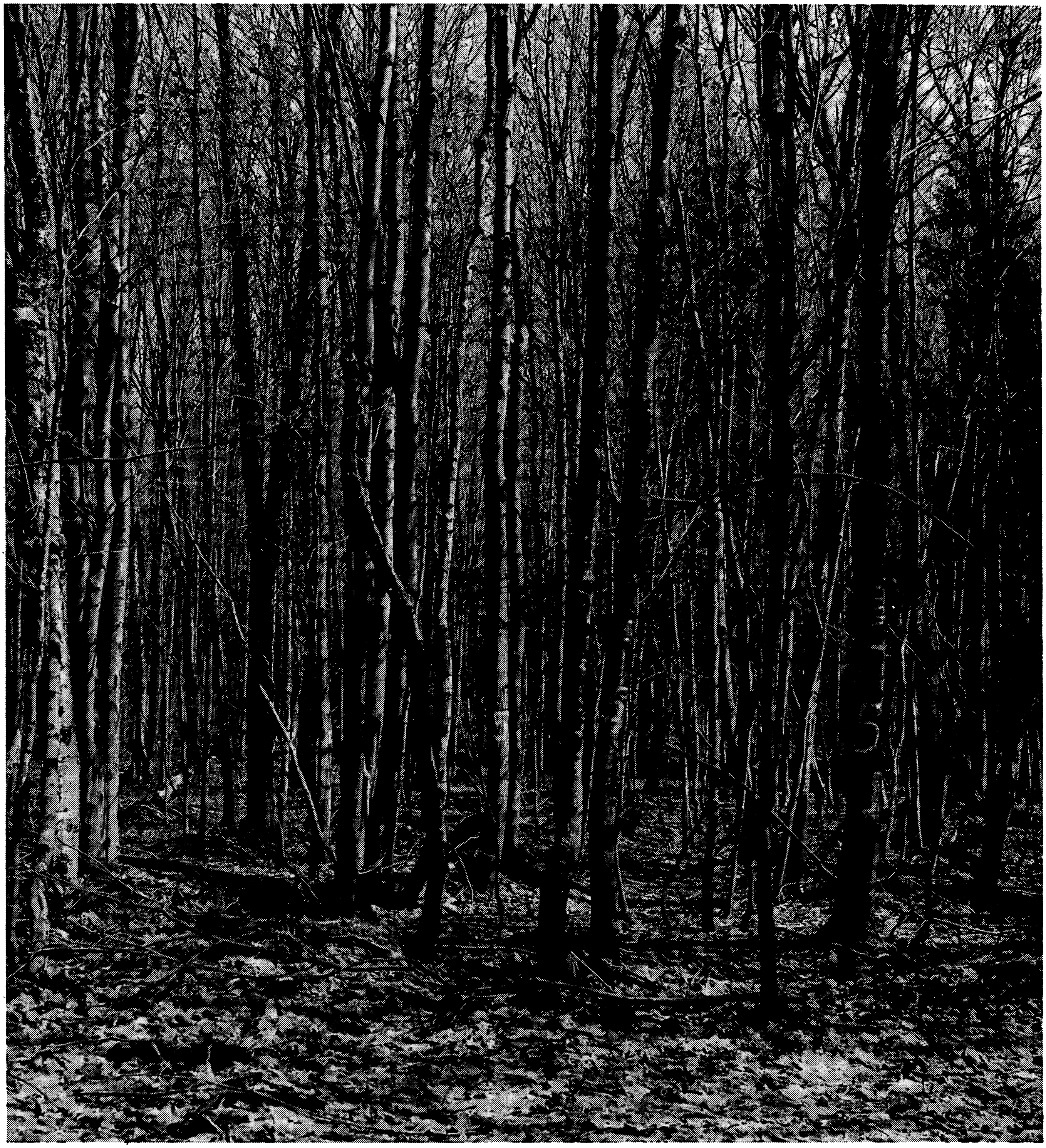

Figure 1.—*Typical pole-sized hardwood stand before thinning—Case I.*

(d.b.h.) and larger. Basal area was about 100 square feet per acre in trees 6 inches d.b.h. and larger. Ring counts of the larger trees revealed that the virgin hardwood timber had been heavily cut in the late 1920's and early 1930's. Tree diameters at the time of harvest ranged from less than 2 inches d.b.h. to a maximum of 28 inches, with an average of slightly less than 6 inches. The stand was dominated by red maple (55 percent) and sugar maple (25 percent). Pole-sized trees (5 to 9 inches d.b.h.) accounted for 63 percent of the 217 trees per acre greater than 5 inches d.b.h. The initial stand, counting trees of all sizes, contained approximately 350 trees per acre. The stand was overcrowded, of poor quality, and in need of timber stand improvement.

## Operation and Equipment

The purpose of this case study was to determine the costs of using a completely mechanized system to thin a northern hardwood pole stand, chip the harvested trees, and transport the chips to the mill. The goal was to demonstrate that mechanized hardwood timber stand improvement (TSI) could be done profitably without prohibitively damaging the residual stand. The thinnings were converted to pulp chips because of an existing market, but could as well have been used as fuel chips.

Conventional, selective thinning by chain saw, besides being wasteful, is labor-intensive and costly. In Michigan, TSI costs for such thinnings typically range from $35 to $48 per acre (average $42 per acre[1]). This study demonstrated that given the proper equipment and market, TSI in northern hardwoods can be transformed from a labor-intensive, costly practice into an operation providing immediate monetary return to the landowner and logger.

Five thinning treatments, four fully mechanized, with two replications per treatment, were tested. The four mechanized treatments were: (1) clearcut strip only; (2) clearcut strip with selection thinnings between strips; (3) selection thinning only; (4) shelterwood cut. The fifth treatment was a conventional chain saw thinning in which the selectively felled trees were left as forest floor residue.

The stand was thinned from a density of 100 square feet of basal area per acre to a residual density of 65 square feet (with the exception of the shelterwood cut, in which a 70-percent crown cover was left).

Harvesting and wood processing were done with three major pieces of equipment: a Rome shear[2] with accumulator top clamp mounted on a John Deere 544 loader; a Clark Ranger 667 GS grapple skidder; and a Trelan D-60 whole-tree chipper (fig. 2).

The chips were transported 22 miles to a pulpmill. Two truck-tractor units were used in combination with four chip vans. Auxiliary equipment consisted of one loader to feed the chipper, one maintenance truck, one fuel truck, one chain saw, and a landing truck for spotting vans. Five men were required for the operation—four equipment operators alternated every 3 or 4 hours between machines to reduce operator fatigue.

Time studies of all operations were done to determine cost and productivity. The equipment, the estimated purchase price, plus fixed and operating costs are listed in table 1.

## Results

Although four mechanized treatments were used, specific results are presented only for the two most promising ones—the clearcut strip with selection thinning between strips (fig. 3) and the shelterwood (fig. 4). Average results are presented for all the mechanized treatments (table 2).

Including all delays, the feller buncher cut an average of 89 stems per hour to produce 17.5 green tons per hour. It handled about three stems per cycle in preparing skidder bunches, each containing about 11 stems. The grapple skidder averaged 72 stems per hour, or almost 17 green tons per hour. Load per skidder turn was approximately 2.3 green tons (11 stems). Average skid time, including delays, ranged from 8.6 to 9.4 minutes; average skid distance, including woods and road, ranged from 1,100 to 2,000 feet. Over the entire study, the chipper produced, including delays, an average of 17 green tons per hour. Without delays, average productivity would be nearly 35 green tons per hour. At an average of 1.6 stems per chipping cycle, it took 84 minutes to fill a van with chips. Each van load contained approximately 24 green tons (116 stems at an average weight of 413 pounds per stem). An average of 47 green tons per acre were removed in each of the four mechanized treatments (table 3).

As previously indicated, the costs from this 1974 study have been converted to 1980 dollars. Felling,

---

[1] *Information obtained by telephone from Michigan Department of Natural Resources.*

[2] *Mention of trade names does not constitute endorsement of the product by the USDA Forest Service.*

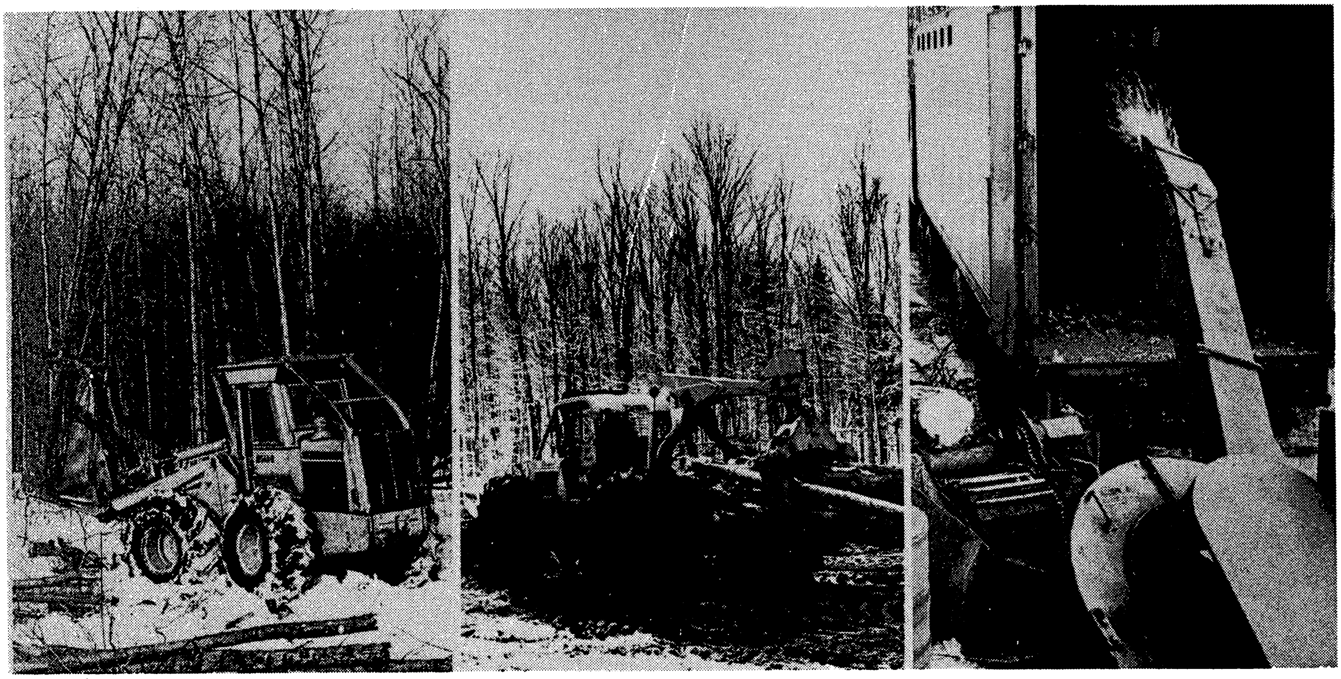

Figure 2.—*Major equipment used—Case I: (left) John Deere 544 feller/buncher with Rome accumulator shear; (center) Clark Ranger 667 grapple skidder; and (right) Trelan D-60 whole-tree chipper.*

Table 1.—*Harvesting equipment and machine rate for 1974 thinning study—Case I*
(In January 1980 dollars)

| Equipment | Estimated purchase cost[2] | | Machine rate[1] without labor Fixed cost | Operating cost |
|---|---|---|---|---|
| 1 John Deere 544 with Rome shear | 80,000 | (39,900) | 17.24 | 15.87 |
| 1 Clark Ranger 667 grapple skidder | 85,000 | (38,943) | 24.17 | 17.92 |
| 1 Trelan chipper | 70,725 | (34,000) | 13.87 | 10.22 |
| 1 Barko loader | 33,500 | (17,122) | 9.08 | 4.85 |
| 5 Chip Vans @ $12,000 ea. | 60,000 | (25,980) | .12/mi | .06/mi. |
| 2 Truck-tractors @ $45,000 ea. | 90,000 | (56,100) | .37/mi | .39/mi. |
| 1 Maintenance van | 2,000 | ( 2,000) | .28/SH[3] | .02/mi. |
| 1 Fuel truck | 2,000 | ( 1,500) | .55 | 2.50 |
| 1 Landing truck | 6,000 | ( 2,500) | 2.38 | 4.24 |
| 1 Chain saw | 312 | ( 280) | .66 | .86 |
| Total Investment Cost | 429,537 | (218,815) | — | — |

[1]Machine rates are based on productive hours. Fuel cost is assumed to be $1.00 per gallon.
[2]1974 dollars are shown in parentheses.
[3]Scheduled hours.

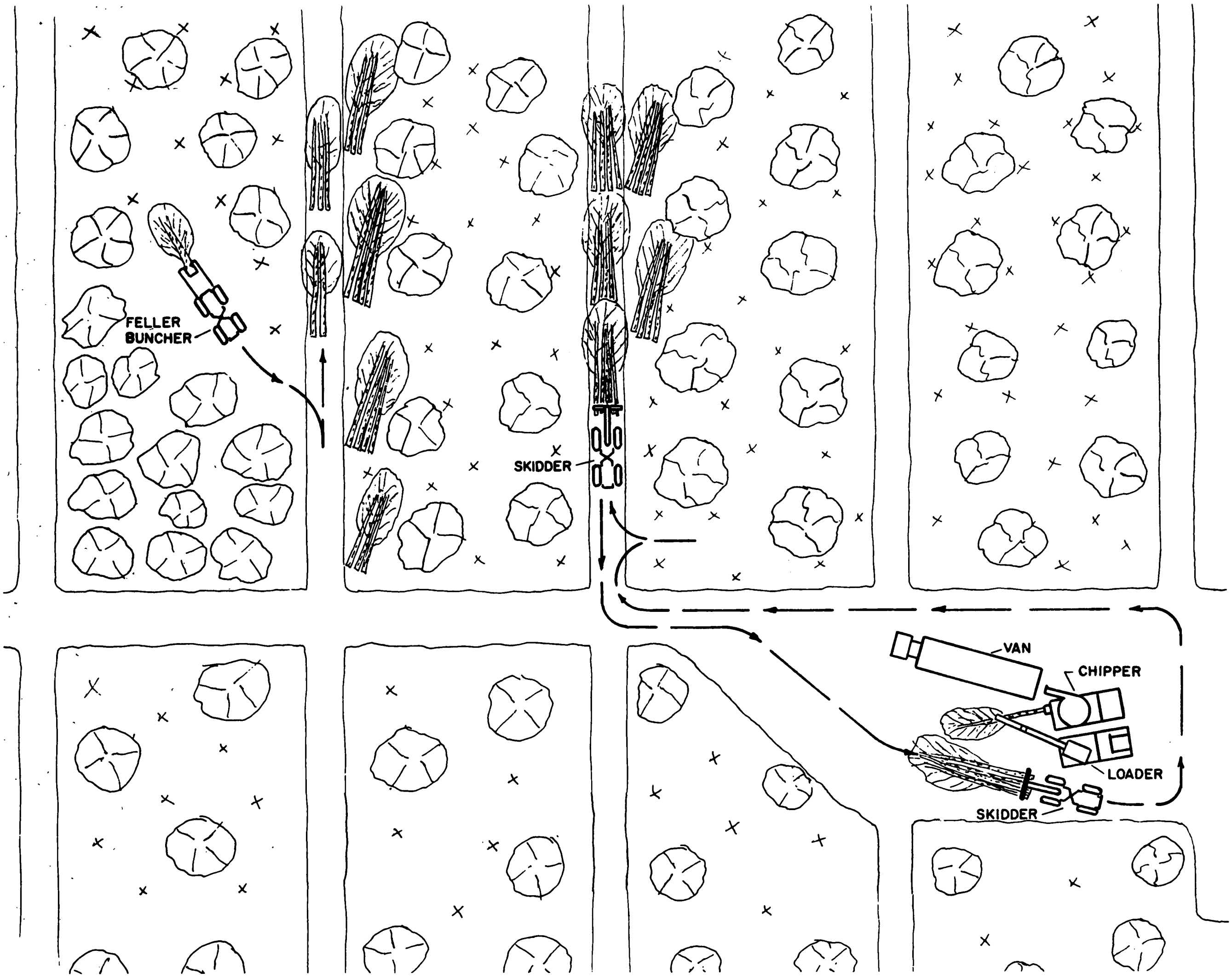

Figure 3.—*Simplified schematic of clearcut strip with selection thinning—Case I.*

Table 2—*Productivity by thinning treatment—Case I*

| Thinning treatment | | Feller/buncher | | Skidder | | Chipper | |
|---|---|---|---|---|---|---|---|
| | | Stems/hr | Tons/hr | Stems/hr | Tons/hr | Stems/hr | Tons/hr |
| Strip | (without delays) | 139.7 | 24.0 | 121.3 | 22.3 | 154.4 | 29.4 |
| | (actual) | 89.6 | 16.4 | 87.4 | 16.0 | 93.7 | 18.2 |
| Shelterwood | (without delays) | 133.8 | 25.0 | 133.2 | 28.8 | 185.2 | 36.1 |
| | (actual) | 87.4 | 17.2 | 71.2 | 15.9 | 77.1 | 15.0 |
| Selective | (without delays) | 137.2 | 29.7 | 143.0 | 36.9 | 174.9 | 37.6 |
| | (actual) | 79.7 | 17.3 | 61.8 | 16.1 | 75.7 | 16.3 |
| Strip with selective | (without delays) | 129.1 | 26.7 | 143.4 | 31.3 | 170.6 | 37.2 |
| | (actual) | 85.7 | 21.5 | 75.2 | 17.0 | 88.2 | 19.3 |
| Average (weighted) | (without delays) | 133.3 | 27.2 | 135.0 | 31.3 | 172.3 | 34.8 |
| | (actual) | 88.8 | 17.5 | 72.5 | 16.8 | 82.2 | 17.2 |

Table 3.—*Summary of material removed with best two thinning treatments—Case I*

| Treatment | Area | Chips removed | Saw logs removed | Total removed | Total removed per acre | Stems removed per acre |
|---|---|---|---|---|---|---|
| | *Acres* | *Tons* | *Bd. ft.* | *Green tons* | | *Number* |
| Shelterwood | 9.61 | 470 | 2,670 | 486 | 50.6 | 255.0 |
| Clearcut strip with selective thinning | 9.50 | 513 | 2,830 | 531 | 55.9 | 263.9 |

skidding, chipping, and transport accounted for over 80 percent of the $13.27 per green ton (including labor) required to produce whole-tree chips from the recovered thinnings (table 4). Transport costs alone over the 22-mile haul was $3.66 per ton, or 27 percent of the total.

Figure 4.—*Pole-sized hardwood stand following shelterwood harvest.*

# CASE II—MECHANIZED THINNING OF POLE-SIZED HARDWOODS

## Stand Description

In August of 1978, a mechanized thinning study was conducted on 13 acres of pole-sized hardwoods in Alger County, Michigan, approximately 26 miles southeast of Marquette (Johnson *et al.* 1979). The study, which took place on State forest land, was a cooperative effort between Michigan Technological Univeristy, the Michigan Department of Natural Resources, the Marquette Board of Light and Power, and the USDA Forest Service.

The stand, which was predominantly pole-sized with a scattering of saw log trees, consisted of 73 percent sugar maple and 22 percent American elm and the remaining five percent was basswood, quaking aspen, and black cherry. The topography was level and the soil sandy. The precutting stocking was 254 trees per acre, with 116 square feet of basal area. Because of the presence of Dutch elm disease, all of the elm was harvested. This precluded uniform residual stocking, but also increased the yield.

Table 4.—Breakdown of costs—Case I[1]

(In January 1980 dollars)

| Item | Dollars per green ton: Equipment | Labor[2] | Total | Percent of total |
|---|---|---|---|---|
| Feller/buncher | 1.93 | .99 | 2.92 | 22 |
| Skidder | 2.55 | .97 | 3.52 | 27 |
| Chipper | 1.35 | — | 1.35 | 10.2 |
| Loader | .78 | .97 | 1.75 | 13.2 |
| Truck-tractor | 1.40 | 1.93 | 3.33 | 25 |
| Chip van | .33 | — | .33 | 2 |
| Maintenance van | .03 | — | .03 | .2 |
| Fuel truck | .01 | — | .01 | .1 |
| Landing truck | .02 | — | .02 | .2 |
| Chain saw | .01 | — | .01 | .1 |
| TOTAL | 8.41 | 4.86 | 13.27 | 100 |

[1]Average of all thinning treatments on 40 acres.

[2]Crew members: five operators @ $10 per hour, including all fringe benefits.

## Operation and Equipment

The purposes of the study were: (1) to further test and evaluate mechanized strip thinning in a pole-sized hardwood stand and (2) to provide whole-tree chips for a trial burn in a coal-fired electrical generating plant. Based on findings of the previous case study, the thinning method consisted of clearcutting narrow strips and selectively thinning the alternating "leave" strips. Following the marking of leave trees (they were painted with rings that could be easily seen from all directions), feller/buncher routes were laid out by locating east-west compass lines 55 feet apart and perpendicular to the access road. As the feller/buncher proceeded into the stand, the operator cut a nominal 15-foot-wide strip and selectively removed all unmarked trees up to 20 feet on both sides of the strip (fig. 5). The operator formed bunches between the standing trees in the selectively thinned strips on both sides of the clearcut strips. Trees were placed butts toward the clearcut strips to facilitate skidding (fig. 6). On egress from the stand, the feller/buncher operator laid the bunches of trees behind the machine with all butts pointing in the direction of skidding. Following this felling pattern, the thinned stand contained 40-foot bands of selectively thinned stand bordered by 15-foot clearcut strips. Residual stocking was 68 square feet of basal area per acre in the selectively thinned strips and 55 square feet per acre overall.

Harvesting and wood processing were done with a tracked Drott 40 feller/buncher, a John Deere 740 grapple skidder, and a Morbark Chipper (fig. 7, table 5).

## Results

Based on data from 744 felling cycles, the average production rate of the Drott 40 feller/buncher, including all delays, was 72 trees per hour. (A felling cycle is defined as the sum of the motions a feller/buncher performs in reaching for trees, positioning, shearing, lifting, swinging and bunching, and traveling to the next group to be harvested.) The average numbers of trees per cycle and bunch were 1.3 and 11.0, respectively. It should be noted that the accumulator arm was not functioning for a major portion of the study which required the feller/buncher to work 30 percent longer each day to keep up with the skidder.

Skidder distances were reduced by moving the chipper to stations about every 300 feet along the

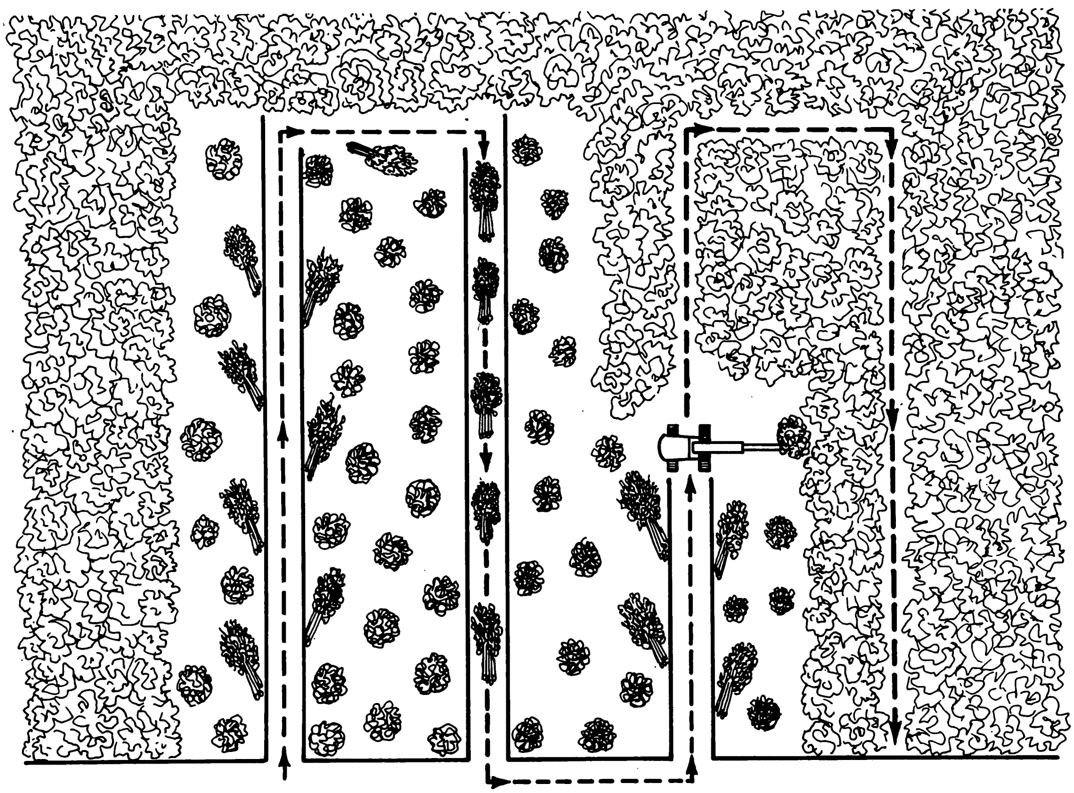

Figure 5.—*Simplified schematic of clearcut strip with selection thinning—Case II (15-foot strips, 40 feet between strips).*

Figure 6.—*Prebunched trees prepared by Drott 40 feller/buncher during travel into the stand—Case II.*

access road. This resulted in average distances of 320 feet, enabling one skidder to supply the chipper. The average skidder production was 11.4 stems (4.2 green tons) per turn and cycle time was 5.1 minutes. The skidder was periodically used for dozing, clearing slash, and grading.

Skid bunches, which were dropped to either side of the chipper, were converted to whole-tree chips and blown into waiting 25-ton-capacity vans at an average rate of 41.5 green tons per productive hour. This rate was achieved by chipping an average of 1.6 stems per chipper cycle. (A chipping cycle is defined as the sum of the motions a chipper performs in reaching for trees, positioning and grappling, lifting, swinging and feeding, and processing.) It took an average of 69 stems or 6 skidder loads to fill a van. Although the chipper was scheduled to do 33 hours of productive work, 25 percent of this time was recorded as delay. Waiting for vans was the principal cause of delay. A single-lane access road and rain adversely affected transportation efficiency.

The Marquette Board of Light and Power wanted only 1,000 green tons of chips for their trial with energy wood. With 25-ton-capacity chip vans, 40 van

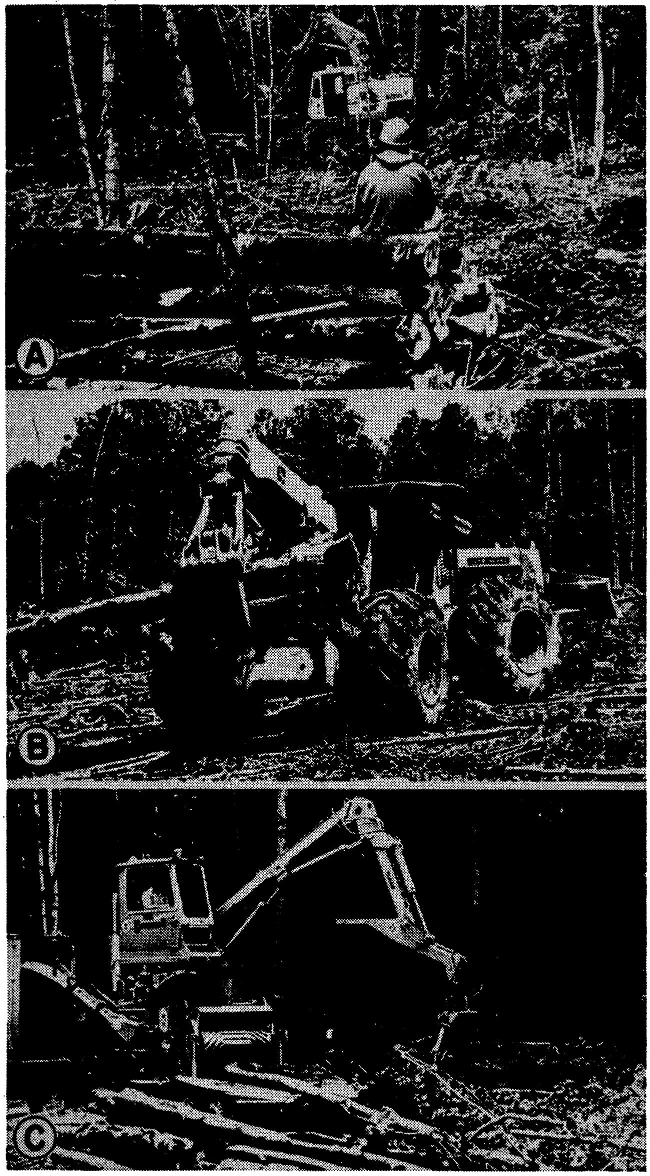


Figure 7.—*Major equipment used—Case II: (A) Drott 40 feller/buncher; (B) John Deere 740 grapple skidder; and (C) Morbark 22-inch chipper.*

Table 5.—*Equipment costs for 1978 mechanized thinning study—Case II*

(In January 1980 dollars)

| Equipment[1] | Purchase cost (f.o.b. delivered cost) |
|---|---|
| 1 Drott 40 LC feller/buncher | $139,000 |
| 1 John Deere 740 grapple skidder | 95,000 |
| 1 Morbark chipper | 152,500 |
| 5 Truck/tractors @ $45,000 ea. | 225,000 |
| 5 Chip vans @ $12,000 ea. | 60,000 |
| TOTAL INVESTMENT COST | $671,500 |

[1]The crew included a feller/buncher operator, a skidder operator, a chipper operator, and five truck drivers.

loads were required to achieve this amount. The 13 acres harvested yielded an estimated 2,740 trees averaging 730 pounds per tree, for a per-acre yield of 78.1 green tons.

This yield was considerably greater than the 46.8 green tons per acre from the Case I study, primarily due to the large harvest of elm trees. Because contractor cost data were not available, independent cost analyses were made which required certain assumptions (table 6).

The capital cost of equipment in 1980 dollars was $671,500 (table 5). Based on field-recorded production data and the assumptions made, the estimated total cost for felling, skidding, and chipping was $5,140; the transporting cost was $3,610. Thus, for a production of 1,000 green tons, the unit cost was $5.14 per green ton for all logging operations and $3.61 per green ton for transport. By including $0.60 per green ton for stumpage plus a conservative allowance of 15 percent for overhead, the total average delivered cost was estimated at $10.66 per green ton.

Table 6.—*Assumptions[1] for cost analysis—Case II*

| Equipment | Estimated economic life | Working days per year | Scheduled hrs. or mi./yr. | Machine utilization |
|---|---|---|---|---|
| | *Years* | *Number* | | *Percent* |
| Feller/buncher | 5 | 250 | 2,000 hr. | 65 |
| Skidder | 3 | 250 | 2,000 hr. | 67 |
| Chipper | 5 | 250 | 2,000 hr. | 75 |
| Truck-tractor | 4 | 250 | 40,000 mi. | — |
| Chip vans | 8 | 250 | 20,000 mi. | — |

[1] Other assumptions included: Stumpage at $0.60 per green ton, based on "Forest Residues Energy Program" USDA—Forest Service, 1978; overhead at 15 percent; and labor cost at $10.00 per hour including fringe benefits.

# CASE III— NORTHERN HARDWOOD LAND CLEARING OPERATION

## Stand Description

In August of 1978, a land clearing operation was conducted in a 25-acre northern hardwood stand located north of the town of Ontonagon in Michigan's Upper Peninsula. The stand consisted mainly of large-diameter aspen (9-inch average d.b.h.) with small amounts of red maple and black cherry. The terrain was flat to gently rolling. The soil was a loose, dry clay.

## Operation and Equipment

The landowner wished to convert this northern hardwood stand to pasture. Although the operation was a commercial clearcut (fig. 8) only stems 4 inches d.b.h. or greater were chipped. The whole-tree chips were sold to Champion International Paper Mill in Ontonagon, Michigan. One-way haul distance was approximately 10 miles. The equipment and the estimated purchase costs (1980 dollars, f.o.b. delivered) are summarized in table 7. Personnel from the U.S. Forest Service's Houghton Laboratory conducted work measurement studies to establish system cost and productivity.

Table 7.—*Itemized cost of harvesting equipment for 1978 clearcutting study—Case III*

(In January 1980 dollars)

| Equipment[1] | Purchase cost (f.o.b. delivered) |
|---|---|
| 2 Drott 40 LC feller/bunchers @ $139,000 ea. | $ 278,000 |
| 2 John Deere 740 grapple skidders @ $95,000 ea. | 190,000 |
| 1 Morbark 22-inch chipper | 152,500 |
| 1 Pettibone chain flail PM850 | 90,000 |
| 1 Caterpillar D7G bulldozer | 150,000 |
| 4 Truck-tractors @ $45,000 ea. | 180,000 |
| 5 Chip vans @ $12,000 ea. | 60,000 |
| 1 Maintenance van | 2,000 |
| 1 Fuel truck | 2,000 |
| 2 Chain saws @ $312 ea. | 624 |
| TOTAL CAPITAL INVESTMENT | $1,105,124 |

[1]The crew included two feller/buncher operators, two skidder operators, one chipper operator, one operator for bulldozer and chain flail, and three truck drivers.

Figure 8.—*Drott 40 feller/buncher in a northern hardwood land clearing operation—Case III.*

## Results

The shear with accumulator load ranged from one to eight stems, depending on tree size. Bunches ranging from 4 to 18 stems were skidded to an intermediate landing for chain flailing prior to chipping (fig. 9). The purpose of the chain flailing was to remove the majority of small branches and twigs, which yield inferior chips and cause handling and conveyence problems.

Chain flailing took 2 to 8 minutes, depending on the bunch size and bulkiness of the tops. After flailing, bunches were skidded to either side of the chipper, which was equipped with a knuckle-boom and grapple. The chips were blown directly into 25-ton-capacity chip vans; fill time averged 20 minutes (fig. 10). The average transportation speed from chipper (landing) to mill was 45 miles per hour. Trucks and vans spent an average of about 45 minutes at the mill, depending on mill traffic. Although the dozer was used principally to clear the landing area, it was also used to move bunches at the chipper and maintain the haul road. The two feller/bunchers were scheduled to operate 10 hours a day and to work 1 day prior to start-up of other equipment to maintain supply. Other equipment averaged 9 scheduled hours per day. Over the 2-week study period, production reached a mill quota of 60 vans per week, and productivity ranged from 11 van loads to 16 van loads per day. To establish costs from the time study data, the following assumptions were made (table 8):

A stumpage price of $0.60 per green ton; an overhead cost of 15 percent of logging and transportation cost was assumed for overhead; a labor cost of $10.00 per hour including fringe benefits. Based on the recorded data and assumptions made, the production costs ($/green ton) for a range of daily production rates were summarized (table 9).

The hauling distance of 10 miles is less than the typical site-to-mill transport distance. Therefore, to expand the usefulness of these data, the effects on production cost of hauling distances of 20, 30, and 40 miles were projected (table 10). For each haul distance, two or three alternative transportation systems are presented to carry the tabulated amount of chips. For example, for the 20-mile haul distance with a daily productivity of 11 or 12 van loads, three truck-tractors and four chip vans would do the job at the cost of $14.26 and $13.53 per green ton, respectively. However, if the productivity increased from 13 to 16 van loads, four truck-tractors and five chip vans would be required at a cost range of $12.41 to $11.07 per green ton, respectively.

Figure 9.—*Landing site showing chain flailing of trees prior to whole-tree chipping—Case III.*

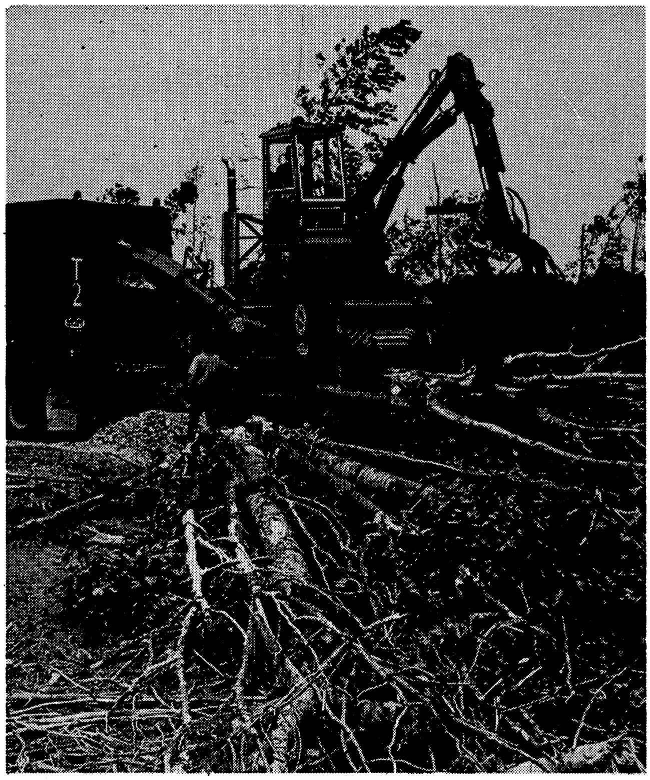

Figure 10.—*Whole-tree chipping and chip van loading—Case III.*

# CASE IV—WHOLE-TREE HARVESTING OF LOW-VALUE HARDWOODS FOR STAND CONVERSION

## Stand Description

In 1978, a 20-acre, predominantly low-value stand of pole-sized northern hardwoods located on the Mishwabic State Forest in Michigan's Upper Peninsula was selected for fully mechanized whole-tree chip harvesting and subsequent stand conversion. The terrain was essentially flat, and the soil was a sandy loam. The area contained usable logging roads and was bordered by a blacktop highway.

A preliminary survey indicated that the predominant species were red maple, sugar maple, yellow birch, and cherry, with lesser amounts of oak, white pine, and hemlock. The stand, which was about 50 years old, contained 803 stems per acre in trees 1 inch to 12 inches d.b.h., and a basal area of 118 square feet per acre. A preharvest estimate indicated a potential yield of about 100 tons of chips per acre.

Table 8.—*Cost analysis and machine rate assumptions—Case III*
(In January 1980 dollars)

| Equipment | Economic life | Scheduled hours/yr. | Utilization | Productive hours/yr. | Interest, insurance and taxes[1] | Repair cost multiplier | Machine rate[3] Fixed Cost | Operating cost |
|---|---|---|---|---|---|---|---|---|
| | *Years* | | *Percent* | | *Percent* | | | |
| Feller/buncher | 5 | 2,000 | 65 | 1,300 | 21 | 100[2] | $32.38 | $24.18 |
| Skidder | 3 | 2,000 | 67 | 1,340 | 21 | 60[2] | 27.31 | 20.87 |
| Chipper | 5 | 2,000 | 75 | 1,500 | 21 | 60 | 30.38 | 20.60 |
| Chain flail | 5 | 2,000 | 60 | 1,200 | 21 | 60 | 21.20 | 13.16 |
| Bulldozer | 5 | 2,000 | 60 | 1,200 | 21 | 100[2] | 37.85 | 28.07 |
| Maintenance van | 5 | 2,000 | — | | 19 | 5 | .28/SH[4] | .02/mi. |
| Fuel truck | 5 | 2,000 | 50 | 1,000 | 19 | 100 | .55 | 2.50 |
| Chain saw | 1 | 2,000 | 25 | 500 | 16 | 100[2] | .66 | .86 |
| Truck-tractor | 4 | 40,000/mi. | — | — | 21 | 50 | .37/mi. | .39/mi. |
| Chip vans | 8 | 20,000/mi. | — | — | 21 | 10 | .12/mi. | .06/mi. |

[1]Rate of interest = 15 percent, insurance = 3 percent, and taxes = 3 percent. (Maintenance van and fuel truck: rate of interest = 15 percent, insurance 2 percent, and taxes 2 percent.)
[2]The percentage rate by which the hourly depreciation is multiplied to estimate hourly repair costs. (See Warren, B. Jack. 1977. Logging cost and production analysis. Timber Harvesting Report 4, 42 p. LSU/MSU Logging and Forestry Operation Center, Bay St. Louis, Miss.)
[3]Based on productive hours and a fuel cost of $1.00 per gallon.
[4]Scheduled hours.

Table 9.—*Daily production costs for a one-way hauling distance of 10 miles (based on 75 percent chipper utilization)—Case III*

(In dollars)

| Number of van loads[1] | Tons | Logging cost | Transportation cost | Stumpage | Overhead[2] | Total |
|---|---|---|---|---|---|---|
| 11 | 275 | 9.35 | 1.73 | .60 | 1.66 | 13.34 |
| 12 | 300 | 8.57 | 1.65 | .60 | 1.53 | 12.35 |
| 13 | 325 | 7.91 | 1.58 | .60 | 1.42 | 11.52 |
| 14 | 350 | 7.35 | 1.52 | .60 | 1.33 | 10.80 |
| 15 | 375 | 6.86 | 1.47 | .60 | 1.25 | 10.18 |
| 16 | 400 | 6.43 | 1.43 | .60 | 1.18 | 9.64 |
| 17 | 425 | 6.05 | 1.39 | .60 | 1.12 | 9.16 |

[1]Van capacity = 25 tons.
[2]Fifteen percent of logging and transportation cost.

Table 10.—*Daily production costs for one-way hauling distances of 20, 30, and 40 miles—Case III (based on 75 percent chipper utilization)*

(In January 1980 dollars)

| Number of van loads | Green tons | Logging cost | Transportation cost | Subtotal | Stumpage | Overhead (15 percent) | Total |
|---|---|---|---|---|---|---|---|
| | | | 20 MILES | | | | |
| 11[1] | 275 | 9.35 | 2.53 | 11.88 | .60 | 1.78 | 14.26 |
| 12[1] | 300 | 8.57 | 2.67 | 11.24 | .60 | 1.69 | 13.53 |
| 13[2] | 325 | 7.91 | 2.36 | 10.27 | .60 | 1.54 | 12.41 |
| 14[2] | 350 | 7.35 | 2.46 | 9.81 | .60 | 1.47 | 11.88 |
| 15[2] | 375 | 6.86 | 2.57 | 9.43 | .60 | 1.41 | 11.44 |
| 16[2] | 400 | 6.43 | 2.67 | 9.10 | .60 | 1.37 | 11.07 |
| | | | 30 MILES | | | | |
| 11[2] | 275 | 9.35 | 2.72 | 12.07 | .60 | 1.81 | 14.48 |
| 12[2] | 300 | 8.57 | 2.88 | 11.45 | .60 | 1.72 | 13.77 |
| 13[2] | 325 | 7.91 | 3.04 | 10.95 | .60 | 1.64 | 13.19 |
| 14[3] | 350 | 7.35 | 2.75 | 10.10 | .60 | 1.52 | 12.22 |
| 15[3] | 375 | 6.86 | 2.88 | 9.74 | .60 | 1.46 | 11.80 |
| 16[3] | 400 | 6.43 | 3.01 | 9.44 | .60 | 1.42 | 11.46 |
| | | | 40 MILES | | | | |
| 11[2] | 275 | 9.35 | 3.30 | 12.65 | .60 | 1.90 | 15.15 |
| 12[2] | 300 | 8.57 | 3.51 | 12.08 | .60 | 1.81 | 14.49 |
| 13[3] | 325 | 7.91 | 3.17 | 11.08 | .60 | 1.66 | 13.34 |
| 14[3] | 350 | 7.35 | 3.34 | 10.69 | .60 | 1.60 | 12.89 |
| 15[4] | 375 | 6.86 | 3.09 | 9.95 | .60 | 1.49 | 12.04 |
| 16[4] | 400 | 6.43 | 3.23 | 9.66 | .60 | 1.45 | 11.71 |

[1]Three truck-tractors and four chip vans match the chipper's production and transportation round trip time.
[2]Four truck-tractors and five chip vans match the chipper's production and transportation round trip time.
[3]Five truck-tractors and six chip vans match the chipper's production and transportation round trip time.
[4]Six truck-tractors and seven chip vans match the chipper's production and transportation round trip time.

## Operation and Equipment

Two feller/bunchers equipped with accumulator shear heads felled the trees and placed them in skidder-sized bunches with all butts facing toward a centrally located landing. A grapple skidder transported the bunches from the felling area to the landing. Prior to chipping, all skid bunches were delimbed with a chain flail. The chips were blown into chip vans and transported to the mill. Because the site has not been replanted, total conversion costs cannot be presented. The equipment used and the labor force were as follows:

| Equipment | Crew |
|---|---|
| Drott 40 LC feller/bunchers with accumulator shear | 2 feller/buncher operators |
| 1 John Deere 740 grapple skidder | 1 chipper operator |
| | 1 skidder operator |
| 1 Morbark Chiparvester (22-inch) | 1 chainflail and dozer operator |
| 1 Pettibone PM850 chain flail | 4 truck drivers |
| 1 Caterpillar D7G bulldozer | |
| 4 truck-tractors | |
| 13 chip vans | |
| 1 maintenance van | |
| 1 fuel truck | |

## Results

Because most trees were less than 10 inches d.b.h., the accumulator shear head was especially efficient. The felling rate was 132 trees per scheduled hour (155 trees per productive hour). The average skidding distance to the chain-flail site was about 370 feet. The skidding time was 4.25 minutes per turn including all delays, or 3.64 minutes per turn without delays. The average number of stems per skid load was 20.

Removal of twigs and small branches by chain flailing took from 2 to 7 minutes, depending upon the size of the skid load and bulkiness of the tops. Chain-flailed bunches were skidded to either side of the chipper with loader. The chips were blown directly into waiting vans. Including delays, the chipping rate was 43.5 green tons per scheduled hour; without delays, it was 53.1 green tons per hour.

The gross production data for this land clearing operation are summarized below (tonnages are based on actual mill scale weights):

- Total chipper productive hours 28
- Total green tons delivered to the mill 1,479
- Number of van loads 52
- Average van load (green tons) 28
- Total area harvested (acres) 20
- Yield per acre (green tons) 74
- Total trees harvested 9,600
- Average number of trees per ton 6.5
- One-way hauling distance (miles) 22

The yield of 74 tons per acre was significantly less than the preharvest estimate of 100 tons per acre. Chain flailing removed perhaps 15 to 20 percent of the total above-ground biomass, and an additional 5 to 10 percent may have been left as harvesting residue. Had chain flailing not been required, perhaps 85 to 90 tons per acre might have been recovered.

The costs (in 1980 dollars) associated with this clearcut operation were calculated on the basis of equipment scheduled and productive hours (tables 11-13). Based on the total green chip production of 1,479 tons, the combined cost of logging and transportation was estimated at $8.66 per green ton (table 14). Adding an assumed $1.20 per green ton for stumpage and 15 percent for overhead, the total cost per green ton was estimated at $11.16.

Table 11.—*Scheduled and productive hours for equipment used—Case IV*

| Equipment | Scheduled hours | Productive hours | Utilization |
|---|---|---|---|
| | | | *Percent* |
| 2 Feller/ bunchers | 73 | 62.0 | 85 |
| 1 Skidder | 34 | 29.1 | 86 |
| 1 Chipper | 34 | 27.8 | 82 |
| 1 Chain flail | 34 | 27.6 | 81 |
| 1 Bulldozer | 34 | 3.4 | 10 (est.) |
| 1 Maintenance van | 34 | — | — |
| 1 Fuel truck | 34 | 13.6 | 40 (est.) |

Table 12.—*Cost analysis assumptions—Case IV*

| Equipment | Economic life | Scheduled hours/yr. | Utilization | Productive hours/yr. | Interest, insurance and taxes[1] | Repair cost multiplier[2] |
|---|---|---|---|---|---|---|
| | *Years* | | *Percent* | | *Percent* | |
| Feller/buncher | 5 | 2,000 | 65 | 1,300 | 21 | 100[2] |
| Skidder | 3 | 2,000 | 67 | 1,340 | 21 | 60[2] |
| Chipper | 5 | 2,000 | 75 | 1,500 | 21 | 60 |
| Chain flail | 5 | 2,000 | 60 | 1,200 | 21 | 60 |
| Bulldozer | 5 | 2,000 | 60 | 1,200 | 21 | 100[2] |
| Truck-tractor | 4 | 40,000 mi. | — | — | 21 | 50 |
| Chip van | 8 | 20,000 mi. | — | — | 21 | 10 |
| Fuel truck | 5 | 2,000 | 50 | 1,000 | 19 | 100 |
| Mainentance van | 5 | 2,000 | — | — | 19 | 5 |

[1]Rate of interest = 15 percent, insurance = 3 percent, and taxes = 3 percent. (Maintenance van and fuel truck: rate of interest = 15 percent, insurance 2 percent, and taxes 2 percent.)

[2]The percentage rate by which the hourly depreciation is multiplied to estimate hourly repair costs. (See Warren, B. Jack. 1977. Logging cost and production analysis. Timber Harvesting Rep. 4, 42 p. LSU/MSU Logging and Forestry Operation Center, Bay St. Louis, Miss.)

Table 13.—*Equipment costs—Case IV*

(In January 1980 dollars)

| Equipment | Purchase cost | Machine rate without labor cost[1] | |
|---|---|---|---|
| | | Fixed cost | Operating cost |
| 2 Drott 40 LC feller/bunchers @ $139,000 ea. | $ 278,000 | 32.38 | 24.18 |
| 1 John Deere 740 grapple skidder | 95,000 | 27.31 | 20.87 |
| 1 Morbark 22-inch Chiparvester | 152,500 | 30.38 | 20.60 |
| 1 Pettibone chain flail PM850 | 90,000 | 21.20 | 13.16 |
| 1 Caterpillar D7G bulldozer | 150,000 | 37.85 | 28.07 |
| 4 Truck tractors @ $45,000 ea. | 180,000 | .37/mi. | .39/mi. |
| 13 Chip vans @ $12,000 ea. | 156,000 | .12/mi. | .06/mi. |
| 1 Fuel truck | 2,000 | .55 | 2.50 |
| 1 Maintenance van | 2,000 | .28/SH[2] | .02/mi. |
| Total cost | $1,105,500 | | |

[1]Based on productive hours and a fuel cost of $1.00 per gallon.

[2]Scheduled hours.

Table 14.—*Calculation of logging and transportation costs—Case IV (Based on productive hours)*

(In January 1980 dollars)

| Equipment | Time on job: Scheduled hours | Time on job: Productive hours | Machine rate: Fixed cost | Machine rate: Operating cost | Fixed cost | Total operating cost | Total labor cost[4] | Total machine with labor cost | Cost per ton | Percent of total |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 Feller/bunchers | 73 | 62 | 32.38 | 24.18 | 2,007.56 | 1,499.16 | 730 | 4,236.72 | 2.86 | 33 |
| 1 Skidder | 34 | 29.1 | 27.31 | 20.87 | 794.72 | 607.32 | 340 | 1,742.04 | 1.18 | 14 |
| 1 Chipper | 34 | 27.8 | 30.38 | 20.60 | 844.56 | 572.68 | 340 | 1,757.24 | 1.19 | 14 |
| 1 Chain flail | 34 | 27.6 | 21.20 | 13.16 | 585.12 | 363.22 | 303 | 1,251.34 | .84 | 10 |
| 1 Maintenance van[1] | 34 | | .28/SH[2] | .02/mi. | 9.52 | .88 | — | 10.40 | .01 | ([5]) |
| 1 Fuel truck | 34 | 13.6 | .55 | 2.50 | 7.48 | 34.00 | — | 41.48 | .03 | ([5]) |
| 1 Bulldozer | 34 | 3.4 | 37.85 | 28.07 | 128.69 | 95.44 | 37 | 261.13 | .18 | 2 |
| 13 Chip vans[3] | — | — | .12/mi. | .06/mi. | 274.56 | 137.28 | — | 411.84 | .28 | 3 |
| 4 Truck-tractors[3] | — | — | .37/mi | .39/mi. | 846.56 | 892.32 | 1,360 | 3,098.88 | 2.09 | 24 |
| Total cost | — | — | — | — | 5,498.77 | 4,202.30 | 3,110 | 12,811.07 | 8.66 | 100 |

[1]Maintenance van: fixed cost = \$0.28/scheduled hr. × 34 scheduled hours = \$9.52; operating cost = \$0.02/mi. × 44 mi. = \$0.88.
[2]Scheduled hours.
[3]Transportation: 22 miles (one-way distance) and 52 loads or round trips.
[4]Labor cost: \$10 per scheduled hour for each operator, including all fringe benefits.
[5]Less than 0.5 percent.

# CASE V—RECOVERY OF HARDWOOD SAW LOG TOPS AND LIMBS

## Stand Description

Significant volumes of tops and limbs are left in the forest each year after harvesting of hardwood saw logs (fig. 11). In 1978, a 21-acre northern hardwood stand at Michigan Technological University's Ford Forestry Center, about 10 miles south of L'Anse, Michigan, was selected for a unique trial in topwood recovery. The preharvest inventory indicated a volume of 7,000 board feet (net Scribner) and 6 cords of pulpwood per acre with a basal area stocking of 116 square feet per acre. The soil was classified as Allouez—a well-drained, coarse, gravelly loam. The tract was on level terrain and traversed by an all-weather road.

Previous selective logging operations had been conducted in 1938 and 1967. Sugar maple and American elm were the major species, with basswood, yellow birch, red maple, and hemlock contributing minor volumes. The 1977 selective harvest removed 1,800 board feet per acre (net Scribner) and 5.1 tons of pulpwood per acre. Fifty-two percent of the saw log volume harvested was sugar maple, 38 percent American elm, 4 percent basswood, and the remaining 6 percent yellow birch, red maple, and hemlock. This reduced the basal area from 116 square feet to 80 square feet per acre in trees 5 inches d.b.h. and larger. A total of 304 trees were felled on the 21-acre study area, averaging 14.5 trees per acre. Of these, 237 (78 percent) were saw log trees and 67 (22 percent) were pulpwood trees (less than 11 inches d.b.h.). In preparation for this case study all residue tree tops were marked prior to recovery.

## Operation and Equipment

The objectives of this case study were: (1) to test the capability of an experimental topwood processor designed and built by the Forestry Sciences Laboratory, Houghton, Michigan; and (2) to evaluate the economic feasibility of recovering hardwood saw log tops and limbs.

The crew and equipment used were:

- 1 prototype topwood processor (12-inch-diameter shear head)
- 1 Clark Ranger 667 grapple skidder
- 1 Morbark chipper
- 1 chain saw
- 4 men—a topwood processor operator, a skidder operator, a chipper operator, and a sawyer.

The experimental topwood processor was designed to reduce bulky tops to a manageable size in the woods, thus permitting skidding to roadside without damaging the residual stand (figs. 12 and 13). Small

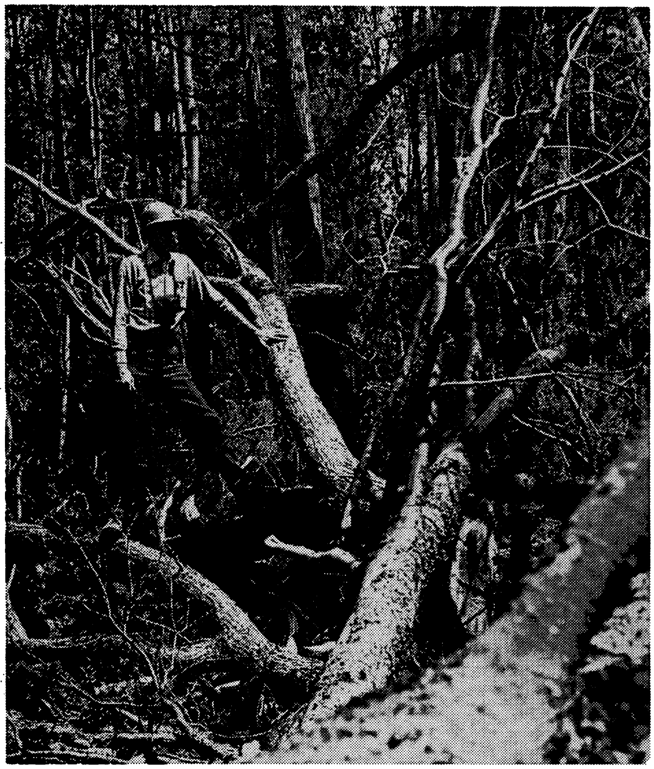

Figure 11.—*Residue hardwood tops and limbs following saw log removal—Case V.*

tops not large enough to cause residual stand damage when skidded intact were not processed with this experimental device. All tops delivered to the landing site were chipped and blown into a pile at the landing (fig. 14). A time study established costs and productivity.

## Results

The prototype topwood processor was used to process 115 tops. A maximum of seven limbs per top were severed, with a mean of about two. Limb diameters ranged from 2 to 11 inches, with an average of 6.5 inches. The average time required to process the tops was 4 minutes without delays, and slightly under 6 minutes including delays. Productivity of the topwood processor was 10.2 tons or 14.6 tops per hour without delays.

Two skidding methods were tried: (1) direct skidding of processed and unprocessed tops from the woods to the landing, and (2) "shuttle" skidding, in which the skidder built larger loads from individual tops at the service road before skidding the remaining distance to the landing. The purpose of trying "shuttle" skidding was to determine the productivity and costs for a multiple skidder system. Using the shuttle skidding, the average payload was 1.12 tons,

Figure 12.—*Experimental topwood processor used for compacting hardwood saw log tops and limbs prior to skidding—Case V.*

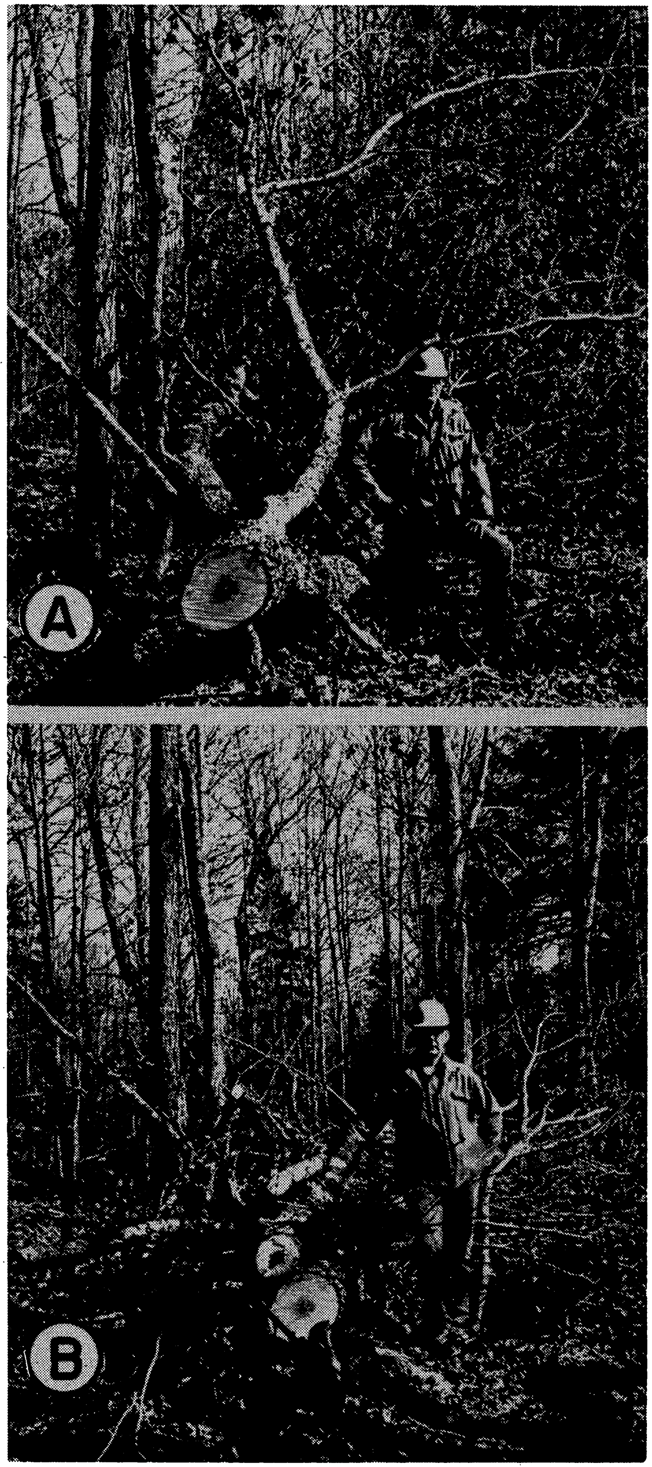


Figure 13.—*Hardwood saw log top (A) before and (B) after compaction with the experimental topwood processor—Case V.*

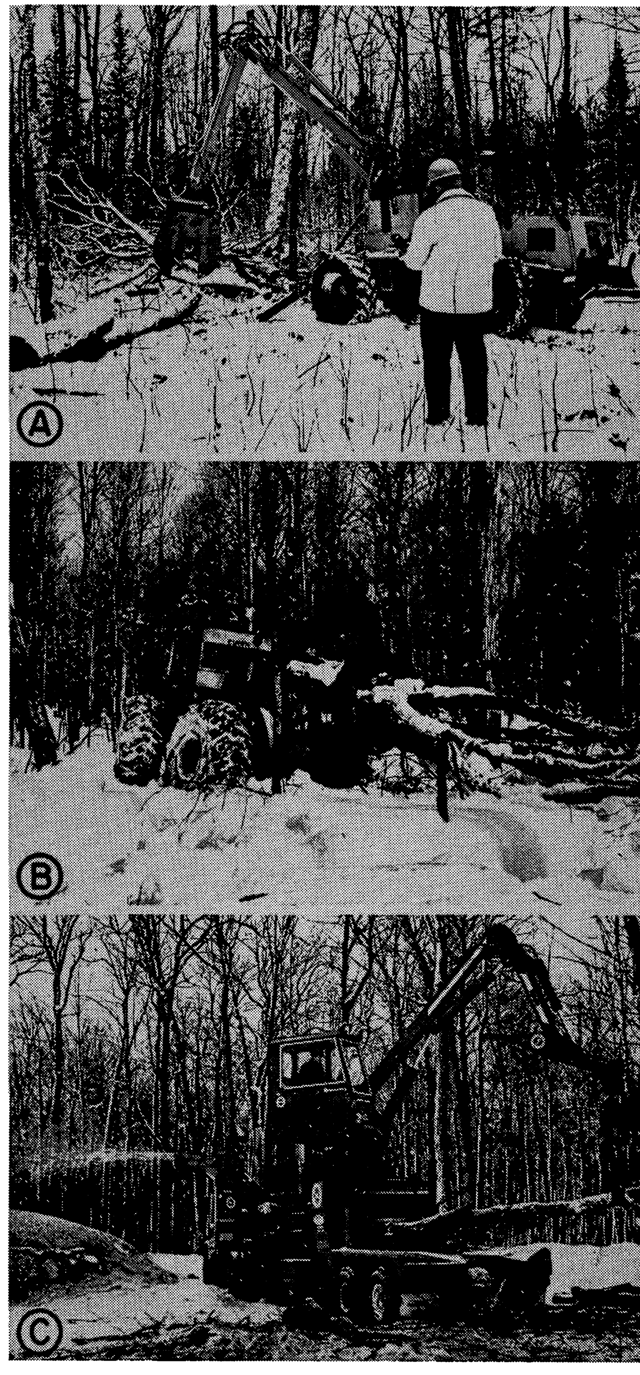


Figure 14.—*Major equipment used—Case V: (A) experimental topwood processor; (B) Clark Ranger 667 grapple skidder; and (C) Morbark 22-inch chipper.*

compared with 0.84 tons for direct skidding. Productivity, without delays, was 14.8 tons, or 21.1 tops per hour for the shuttle method, and 6.3 tons or 8.9 tops per hour for direct skidding.

Chipper productivity was very low because only one skidder was used. Productivity for direct skidding was less than 5 tons per hour due to the delay involved in waiting for tops and the need to sever limbs and short protruding stubs made by the topwood processor. The shuttle skidding method increased chipper productivity to 25.7 tons per hour (from 17.5 tons with direct skidding method) because the skidder loads were larger, allowing the chipper operator to increase the size of grapple loads when feeding the chipper.

Due to inadequacies in the topwood processor, there was still a need to sever some of the remaining limb stubs which could not be fed into the chipper. This in itself was not time consuming, but resulted in added chipper delay. The chain saw cost was $0.30 per green ton (see fig. 15 for cost assumptions). An improved topwood processor would remove limbs closer to the main stem and eliminate the short stubs. The productivity data and cost data showed that the weakest link in the operation was skidding—chipping averaged 1 ton of material in 2.3 minutes or 26 tons per hour, compared with skidding a green ton in 4.1 minutes. Total production cost, excluding transportation, ranged between $10.00 to $16.50 per green ton depending on skidding method used. The reader is cautioned that these costs should be tempered by the fact that they are the result of a single case study with an experimental machine.

Post-harvest inspection showed damage to the residual stand to be relatively minor. This was partially because of the deep snow which acted as a cushion, and also because skidding was done during winter when the bark was tight. We did learn some things in this first attempt at recovering hardwood tops and limbs with an experimental topwood harvester. For example, we found it was much easier to skid small tops intact rather than cutting them up, because small severed limbs occasionally slipped out of the grapple when the load shifted. A skidder with a constant pressure grapple would lessen this problem.

Data on the weight of typical sugar maple tops and limbs for trees of various diameters (fig. 16) were obtained from independent residue studies. With this information, we can determine the potential heat energy available in hardwood tops and limbs. For example, a typical top from a 20-inch d.b.h. sugar maple tree weighs 1,800 pounds (green) (fig. 17). Assuming 40-percent moisture content and an oven-dry heat value of 8,500 BTU's/lb., the as-fired heat value is about 5,100 BTU/lb. Thus, the 1,800-pound top has a heat potential of 9.2 million BTU's. This is equivalent to slightly less than one 42-gallon barrel of oil.

# CONCLUSIONS

Companies, researchers, and others investigating the potential of forest resources as a source of energy need better information on the costs and productivity of various harvesting operations. While it is impossible to cover all harvesting situations and variety of equipment, documentation of the type provided here will be useful for estimating systems performance and costs involved in recovering energy from our underutilized forest resources. It is hoped that others follow this lead and similarly document costs and productivity of logging operations.

# LITERATURE CITED

Arola, R. A. 1976. Wood fuels—how do they stack up? *In* FPRS energy and the wood products industry Meeting Proceedings P-76-14, p. 34-35. Atlanta, Georgia.

Biltonen, Frank E., W. A. Hillstrom, H. M. Steinhilb, and R. M. Godman. 1976. Mechanized thinning of northern hardwood pole stands, methods and economics. U.S. Department of Agriculture Forest Service, Research Paper NC-137, 17 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Erickson, John R. 1972. The moisture content and specific gravity of the bark and wood of northern pulpwood species. U.S. Department of Agriculture Forest Service, Research Note NC-141, 3 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Johnson, J. A., W. A. Hillstrom, E. S. Miyata, and S. G. Shetron. 1979. Strip selection method of mechanized thinning in northern hardwood pole size stands. Ford Forestry Center Research Note 27, 13 p. Michigan Technological University, Houghton, Michigan.

Mattson, James A., R. A. Arola, and W. A. Hillstrom. 1978. Recovering and chipping hardwood cull trees having heavy limbs. *In* Complete-tree utilization of southern pine Symposium Proceedings. USFS/FPRS/IUFRO, p. 120-130. New Orleans, Louisiana.

MACHINE RATE

**Description**

Manufacture ____ Model (PROTOTYPE) TOP HARVESTER H.P 65 DIESEL

Purchase cost: $ 60,000.00 (EST.)

Less: Tire cost - 6,000.00 @ 1,500.00 EA

Total Initial Investment (P) $ 54,000.00

Salvage Value (s) (20 % of P) ------------------$ 10,800.00

Estimated Life (n) 5 years

Working days/year 250 days

Scheduled hours/year 2,000 SH

Utilization (U) 65 %

Productive hours/yr (PH) 1300 PH

Average value of Investment (AVI) = $\frac{(p - S)(n + 1)}{2n} + S$ = $ 36,720.00 /yr

II. Fixed cost

| | |
|---|---|
| Depreciation (D) = $\frac{P-S}{n}$ = | $ 8,640.00/yr |
| Interest 15 % | |
| Insurance 3 % | |
| Taxes 3 % | |
| Total 21 % X (AVI = $ 36,720.00 /yr) | $ 7,711.20/yr |
| Total fixed cost per year | $ 16,351.20/yr |
| fixed cost per SH | $ 8.18/SH |
| fixed cost per PH (A) | $ 12.58/PH |

III. Operating cost

| | |
|---|---|
| Maintenance and Repair ( 60 % of $\frac{(P-S)}{n \times PH}$) | $ 3.99/PH |
| Fuel Cost | $ .84/PH |
| Oil & Lubricants | $ .03/PH |
| Tires = $\frac{1.15 \text{ X Tire price}}{\text{total tire life in hrs (miles)}}$ | 1.73/PH |
| Total Operating Cost Per PH (B) | 6.59/PH |
| *Machine Rate per PH (A + B) | $ 19.17/PH |

IV. Labor cost

| | |
|---|---|
| $ 10.00 /SH ÷ .65 (V) | $ 15.38 /PH |
| Machine Rate with Labor Cost Per PH | $ 34.55/PH |

MACHINE RATE

**Description**

Manufacture CLARK Model RANGER 667 GRAP. SKIDDER H.P 112 DIESEL

Purchase cost: $ 85,000.00

Less: Tire cost - 8000. @ $ 2000. EA

Total Initial Investment (P) $ 77,000.00

Salvage Value (s) (20 % of P) ------------------$ 15,400.00

Estimated Life (n) 3 years

Working days/year 250 days

Scheduled hours/year 2,000 SH

Utilization (U) 67 %

Productive hours/yr (PH) 1340 PH

Average value of Investment (AVI) = $\frac{(p - S)(n + 1)}{2n} + S$ = $ 56,466.67/yr

II. Fixed cost

| | |
|---|---|
| Depreciation (D) = $\frac{P-S}{n}$ = | $ 20,533.33 /yr |
| Interest 15 % | |
| Insurance 3 % | |
| Taxes 3 % | |
| Total 21 % X (AVI = $ 56,466.67 /yr) | $ 11,858.00 /yr |
| Total fixed cost per year | $ 32,391.33 /yr |
| fixed cost per SH | $ 16.20 /SH |
| fixed cost per PH (A) | $ 24.17 /PH |

III. Operating cost

| | |
|---|---|
| Maintenance and Repair ( 60 % of $\frac{(P-S)}{n \times PH}$) | $ 9.19 /PH |
| Fuel Cost | $ 4.14 /PH |
| Oil & Lubricants | $ 1.52 /PH |
| Tires = $\frac{1.15 \text{ X Tire price}}{\text{total tire life in hrs (miles)}}$ | 3.07/PH |
| Total Operating Cost Per PH (B) | 17.92/PH |
| *Machine Rate per PH (A + B) | $ 42.09/PH |

IV. Labor cost

| | |
|---|---|
| $ 10.00 /SH ÷ .67 (V) | $ 14.93 /PH |
| Machine Rate with Labor Cost Per PH | $ 57.02 /PH |

MACHINE RATE

**Description**

Manufacture MORBARK Model 22 XL CHIPARVESTOR H.P 380 DIESEL

Purchase cost: $ 152,500.00

Less: Tire cost - 2000.00 @ $ 250.00 EA

Total Initial Investment (P) $ 150,500.00

Salvage Value (s) (20 % of P) ------------------$ 30,100.00

Estimated Life (n) 5 years

Working days/year 250 days

Scheduled hours/year 2000 SH

Utilization (U) 75 %

Productive hours/yr (PH) 1500 PH

Average value of Investment (AVI) = $\frac{(p - S)(n + 1)}{2n} + S$ = $ 102,340.00/yr

II. Fixed cost

| | |
|---|---|
| Depreciation (D) = $\frac{P-S}{n}$ = | $ 24,080.00/yr |
| Interest 15 % | |
| Insurance 3 % | |
| Taxes 3 % | |
| Total 21 % X (AVI = $ 102,340.00 /yr) | $ 21,491.40/yr |
| Total fixed cost per year | $ 45,571.40/yr |
| fixed cost per SH | $ 22.79/SH |
| fixed cost per PH (A) | $ 30.38/PH |

III. Operating cost

| | |
|---|---|
| Maintenance and Repair ( 60 % of $\frac{(P-S)}{n \times PH}$) | $ 9.63/PH |
| Fuel Cost | $ 9.38/PH |
| Oil & Lubricants | $ 1.28/PH |
| Tires = $\frac{1.15 \text{ X Tire price}}{\text{total tire life in hrs (miles)}}$ | .31/PH |
| Total Operating Cost Per PH (B) | 20.60/PH |
| *Machine Rate per PH (A + B) | $ 50.98/PH |

IV. Labor cost

| | |
|---|---|
| $ 10.00 /SH ÷ .75 (V) | $ 13.33 /PH |
| Machine Rate with Labor Cost Per PH | $ 64.31 /PH |

MACHINE RATE

**Description**

Manufacture HOMELITE Model 350 AO CHAIN SAW H.P 57 CC

Purchase cost: $ 312.00

Less: Tire cost - ——

Total Initial Investment (P) $ 312.00

Salvage Value (s) (10 % of P) ------------------$ 31.20

Estimated Life (n) 1 years

Working days/year 250 days

Scheduled hours/year 2000 SH

Utilization (U) 25 %

Productive hours/yr (PH) 500 PH

Average value of Investment (AVI) = $\frac{(p - S)(n + 1)}{2n} + S$ = $ 312.00 /yr

II. Fixed cost

| | |
|---|---|
| Depreciation (D) = $\frac{P-S}{n}$ = | $ 280.80 /yr |
| Interest 16 % | |
| Insurance — % | |
| Taxes — % | |
| Total 16 % X (AVI = $ 312.00/yr) | $ 49.92 /yr |
| Total fixed cost per year | $ 330.72 /yr |
| fixed cost per SH | $ .17 /SH |
| fixed cost per PH (A) | $ .66 /PH |

III. Operating cost

| | |
|---|---|
| Maintenance and Repair ( 100 % of $\frac{(P-S)}{n \times PH}$) | $ .56 /PH |
| Fuel Cost | $ .20 /PH |
| Oil & Lubricants | $ .10 /PH |
| Tires = $\frac{1.15 \text{ X Tire price}}{\text{total tire life in hrs (miles)}}$ | —— /PH |
| Total Operating Cost Per PH (B) | .86/PH |
| *Machine Rate per PH (A + B) | $ 1.52/PH |

IV. Labor cost

| | |
|---|---|
| $ ____ /SH ÷ ____ (V) | $ ____ /PH |
| Machine Rate with Labor Cost Per PH | $ ____ /PH |

Figure 15.—*Calculation of machine rate for equipment used in topwood harvesting operation.*

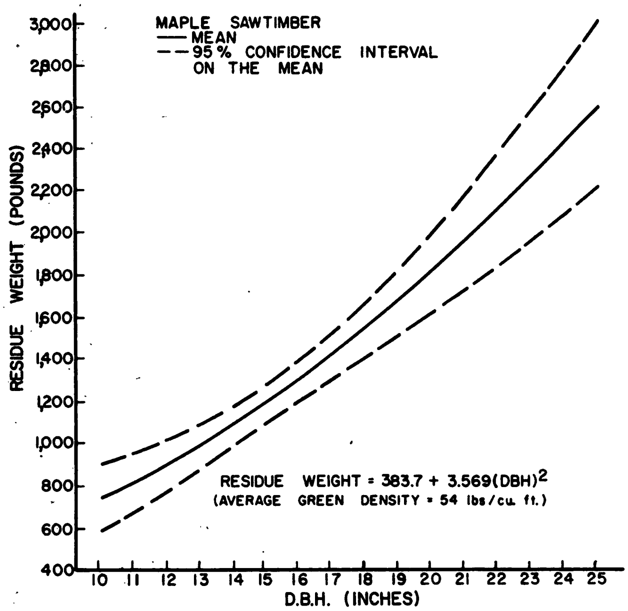


Figure 16.—*Residue weight of sugar maple sawtimber in terms of d.b.h.*

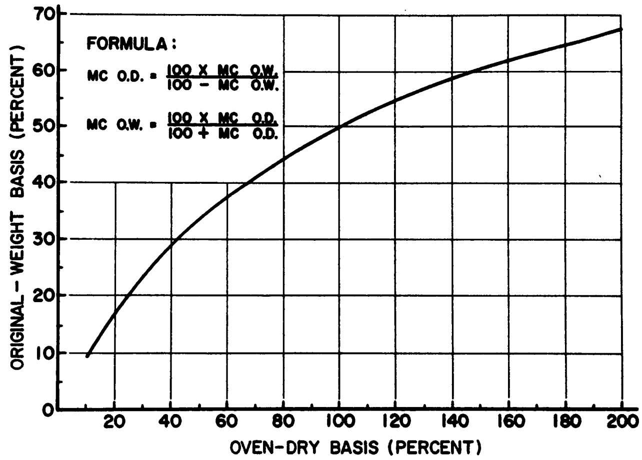


Figure 17.—*Moisture content comparison.*


Steinhilb, H. M., and S. A. Winsauer. 1976. Sugar maple: tree and bole weights, volumes, centers of gravity and logging residue. U.S. Department of Agriculture Forest Service, Research Paper NC-132, 7 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

U.S. Department of Agriculture, Forest Service. 1978. Forest residues energy program. Final report. Prepared for the Department of Energy. Contract E-(49-26)-1045, 295 p.


# APPENDIX

## ENERGY-RELATED INFORMATION

**Heat value.**—The oven-dry heating value of wood is presented (tables 15-17) along with those of conventional fossil fuels (table 18). Direct comparisons are difficult because heat values of solid fuels are typically expressed in Btu/lb., liquid fuels in BTU/gal., and gaseous fuels in Btu/cu. ft. (liquified gas, however, is usually expressed in Btu/gal). Many engineering manuals list the conversion factors, such as pounds per gallon for liquid fuels, making it simple to directly compare alternate fuels on a unit-value basis.

**Rule of thumb equivalency.**—Fossil fuel and wood or bark fuel equivalency can be easily calculated on a theoretical basis (100-percent efficiency) or by accounting for the differences in combustion efficiencies. However, for estimating purposes (accounting for differences in combustion efficiencies), a ton of green wood (50 percent moisture content—green weight basis) is approximately equivalent to 6,500 cu.ft. of natural gas, 1/4 ton of coal, or a barrel of oil. If the wood is ovendry, the equivalency is about twice the above values.

**Moisture content.**—Moisture in wood-based fuels not only lowers the heat value and causes problems with combustion, it also causes confusion among people calculating moisture content. Moisture content of wood is expressed either on an ovendry basis or a green-weight basis. Combustion equipment people usually express it on a green-weight basis as follows:

M.C. green-weight basis =

$$\frac{(\text{greenweight} - \text{ovendry weight}) \times 100}{\text{green weight}}.$$

Table 15.—*Typical heating values for hardwoods*[1]

(In Btu per pound)

**WOOD**

| Species | Heating value (dry) Average | Low | High |
|---|---|---|---|
| White ash | | 8,246 | 8,920 |
| Beech | | 8,151 | 8,760 |
| Birch, wood refuse | 8,870 | | |
| Paper birch | | 8,019 | 8,650 |
| Hickory | | 8,039 | 8,670 |
| Elm | | 8,171 | 8,810 |
| Maple | | 7,995 | 8,580 |
| Maple, wood refuse | 8,190 | | |
| Black oak | | 7,587 | 8,180 |
| Red oak | | 8,037 | 8,690 |
| White oak | | 8,169 | 8,810 |
| Poplar | | 8,311 | 8,920 |

**BARK**

| Species | Heating value (dry) |
|---|---|
| Red alder | 7,947 |
| Quaking aspen | 8,433 |
| Beech | 7,640 |
| Paper birch[2] | 9,434 |
| Paper birch[2] | 10,310 |
| Yellow birch | 9,200 |
| Blackgum | 7,936 |
| American elm | 6,921 |
| Elm, soft | 7,600 |
| Hard maple | 8,230 |
| Soft maple | 8,100 |
| Sugar maple | 7,301 |
| Northern red oak | 8,030 |
| White oak | 6,995 |
| Poplar | 8,810 |
| Sweetgum | 7,450 |
| Sycamore | 7,403 |
| Black willow | 7,168 |

[1]See Arola 1976.

[2]Paper birch data obtained from two different sources.

To convert moisture content on an ovendry basis to a green-weight basis the following expression is used:

$$\text{M.C. green-weight basis} = \frac{100 \times \text{M.C. dry}}{100 + \text{M.C. dry}}$$

A conversion chart can be readily used to convert either way (fig. 17). Typical moisture contents on a green-weight basis of northern forest species is provided in table 19.

**As-fired heating value.**—The best indicator of any fuel is its "as-fired" heating value. With green wood or bark, the as-fired value is considerably lower than with oven-dry wood or bark. If the as-fired heating value for moisture-laden wood or bark is not available, it may be computed using the green moisture contents (table 19) and the oven-dry heating values (tables 15, 16, 17):

As-fired heating value =

$$\frac{(100 - \text{M.C. green weight basis})}{100} \times \text{ovendry heating value.}$$

**Comparison of fuel values.**—A convenient nomograph can be used to quickly show the relative value of wood or bark as a replacement for or supplement to fossil fuels (fig. 18). Comparing as-fired heating values alone is not sufficient. The most meaningful comparison between wood or bark and fossil fuels is not based on heat per unit of measure, but rather dollars per million Btu. The nomograph in figure 19 allows that comparison. For example, given the current delivered price for a particular fossil fuel, one can determine the comparable value of wood or bark. The nomograph is not a substitute for a detailed fuel analysis, but does allow a quick comparison of fuel values that will determine whether a detailed analysis is warranted. Use of the nomograph is illustrated in the following example:

**Given:** The price of 12,000 Btu/lb. coal is $41.50 per ton; it can be combusted at 80-percent efficiency.

**Problem:** What would be the dollar value of whole-tree chips as a replacement for this coal if the chips were combusted at

Table 16.—*Typical heating values for softwoods*[1]

*(In Btu per pound)*

| WOOD | | | |
|---|---|---|---|
| | Heating value (dry) | | |
| **Species** | **Average** | **Low** | **High** |
| White cedar | | 7,780 | 8,400 |
| Western red cedar | 9,700 | | |
| Cypress | | 9,234 | 9,870 |
| Fir, Douglas[2] | 9,050 | | |
| Fir, Douglas[2] | | 8,438 | 9,050 |
| Fir, Douglas[2] | 8,900 | | |
| Fir, white | 8,200 | | |
| Hemlock, eastern | 8,885 | | |
| Hemlock, western[2] | 8,620 | | |
| Hemlock, western[2] | | 8,056 | 8,620 |
| Pine sawdust | 9,130 | | |
| Jack pine wood refuse | 8,930 | | |
| loblolly pine stemwood | 8,600 | 8,310 | 9,352 |
| Pitch pine | | 10,620 | 11,320 |
| Ponderosa pine | 9,100 | | |
| White pine | | 8,308 | 8,900 |
| Yellow pine | | 8,927 | 9,610 |
| Redwood | | 8,498 | 9,040 |
| BARK | | | |
| Balsam, all varieties | 9,100 | 8,900 | 9,210 |
| Balsam fir | 8,861 | | |
| Douglas-fir | 9,800 | | |
| Hemlock, eastern[2] | 8,890 | | |
| Hemlock, eastern[2] | 8,802 | | |
| Hemlock, western | 9,400 | | |
| Western larch | 8,204 | | |
| Jack pine | 8,930 | 8,690 | 9,170 |
| Lodgepole pine | 10,190 | | |
| Ponderosa pine | 9,100 | | |
| Slash pine | 9,002 | | |
| Western white pine | 8,085 | | |
| Black spruce | 8,610 | 8,150 | 8,710 |
| Engelmann spruce | 8,359 | | |
| Pine spruce (1 ft. above ground) | 8,985 | 8,870 | 9,140 |
| Pine spruce (mid height) | 8,825 | 8,650 | 8,910 |
| Pine spruce (4 in. top) | 8,700 | 8,550 | 8,825 |
| Red spruce | 8,630 | | |
| White spruce | 8,530 | 8,340 | 8,630 |
| Tamarack | 9,010 | | |

[1]See Arola 1976.

[2]Two or more entries per species indicate data obtained from different source.

60-percent efficiency at an as-fired heating value of 5,000 Btu/lb.?

**Solution:** Enter the nomograph at $41.50 per ton for coal along a vertical line to 12,000 Btu/lb. Then move horizontally to the 80-percent combustion efficiency. The cost of steam (on the top horizontal scale) is about $2.10 per million Btu. To determine the value of wood chips at this same $2.10 per million Btu of steam, follow a vertical line down to the 60-percent combustion efficiency for wood and then horizontally to an as-fired value of 5,000 Btu/lb. Then move vertically to the lower horizontal scale and read the value.

**Answer:** About $13 per ton as-fired.

Table 17.—*Typical oven-dry heating values of wood and bark*[1]

(In Btu per pound)

| | Range | Average |
|---|---|---|
| Hardwoods | | |
| Wood | 7,590- 8,920 | 8,530 |
| Bark | 6,920-10,310 | 8,040 |
| Softwoods | | |
| Wood | 7,780-11,320 | 8,910 |
| Bark | 8,200-10,190 | 8,950 |

[1]See Arola 1976.

Table 18.—*Typical fossil fuel heating values*[1]

| COAL | Btu/pound |
|---|---|
| Anthracite | 13,900 |
| Bituminous | 14,000 |
| Sub-bituminous | 12,600 |
| Lignite | 11,000 |
| **HEAVY FUEL OILS AND MIDDLE DISTILLATES** | **Btu/gallon** |
| Kerosene (6.814 lb./gal.) | 134,000 |
| No. 2 burner fuel oil (7.022 lb./gal.) | 140,000 |
| No. 5 heavy fuel oil (7.612 lb./gal.) | 144,000 |
| No. 5 heavy fuel oil (7.676 lb./gal.) | 150,000 |
| No. 6 heavy fuel oil, 2.7% sulfur (8.082 lb./gal.) | 152,000 |
| No. 6 heavy fuel oil, 0.3% sulfur (7.401 lb./gal.) | 143,800 |
| **GAS** | |
| Natural | [2]1,000 |
| Liquefied butane | 103,300 |
| Liquefied propane | 91,600 |

[1]From Energy Conservation Program, Guide for Industry and Commerce, U.S. Chamber of Commerce, National Bureau of Standards Handbook No. 115, Washington, D.C., 1974.

[2]Btu/cu. ft.

Table 19.—*Approximate moisture contents of typical Northern forest species*[1]

(In percent, green weight basis)

| Species | Wood | Bark |
|---|---|---|
| Bolewood: | | |
| Aspen | 50 | 47 |
| Hard maple | 36 | 38 |
| Balsam fir | 58 | 52 |
| Jack pine | 49 | 55 |
| Red pine | 51 | 55 |
| White spruce | 48 | 61 |
| Topwood: | | |
| Aspen | 48 | 48 |
| Hard maple | 37 | 41 |
| Balsam fir | 56 | 55 |
| Jack pine | 55 | 66 |
| Red pine | 60 | 62 |
| White spruce | 55 | 64 |

[1]See Erickson 1972.

☆U.S. GOVERNMENT PRINTING OFFICE: 1982-565-966/219

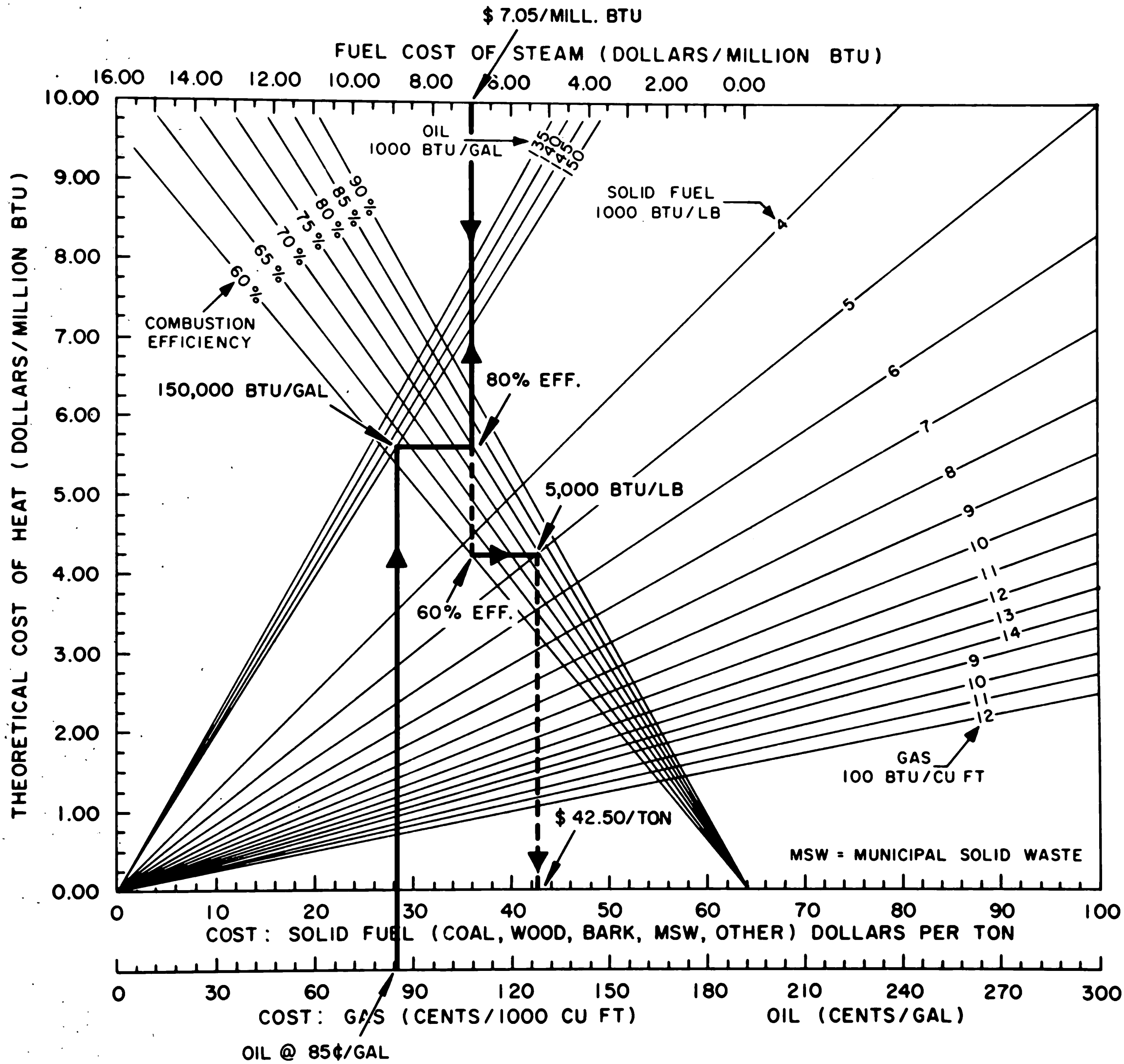


Figure 18.—*Fuel value nomograph.*

Arola, Rodger A., and Edwin S. Miyata.

1981. Harvesting wood for energy. U.S. Department of Agriculture Forest Service, Research Paper NC-200, 25 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Illustrates the potential of harvesting wood for industrial energy, based on the results of five harvesting studies. Presents information on harvesting operations, equipment costs, and productivity. Discusses mechanized thinning of hardwoods, clearcutting of low-value stands, and recovery of hardwood tops and limbs. Also includes basic information on the physical and fuel properties of wood.

KEY WORDS: Logging, whole-tree chipping, fuelwood, mechanized thinning, clearcutting, residues.