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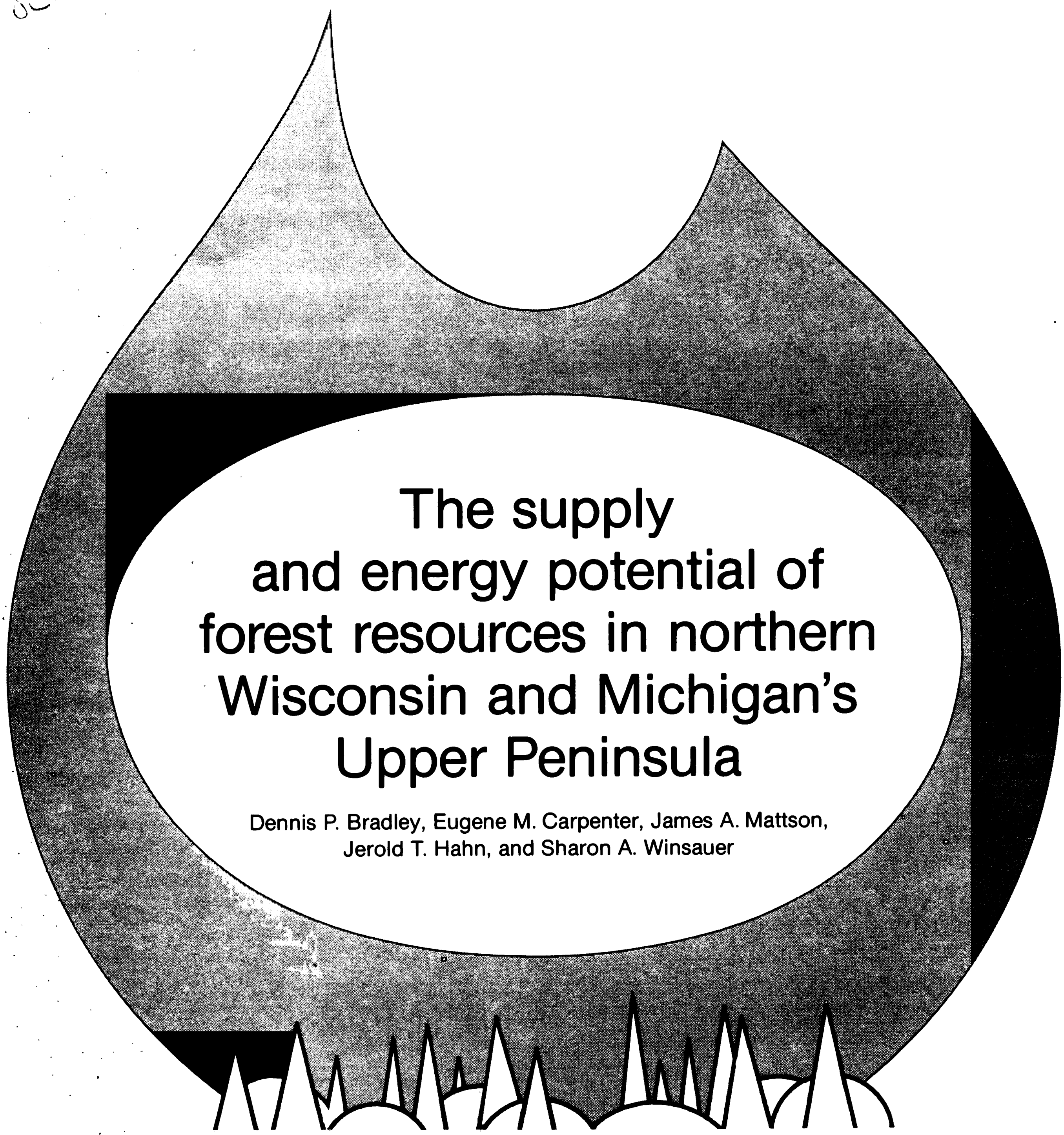

The supply and energy potential of forest resources in northern Wisconsin and Michigan's Upper Peninsula

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CONTENTS

Page

METHODS 3
Managed Harvest Procedure 3
Harvest Costs 6
Transport Costs 9
Supply Curve Construction 10
Estimating Stumpage Costs 12

RESULTS
Mead Corporation , Escanaba, Michigan 12
Ten-mill Study Area—Northern Wisconsin
and Upper Michigan 15

SUMMARY 18

SELECTED BIBLIOGRAPHY 19

THE SUPPLY AND ENERGY POTENTIAL OF FOREST RESOURCES IN NORTHERN WISCONSIN AND MICHIGAN'S UPPER PENINSULA

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Studies have shown that wood fuel has only a small potential for alleviating the national energy shortage; however, the opportunities for the pulp and paper industry are excellent. Because it is close to the wood resource, skilled in wood harvest and transport, familiar with wood properties, and already providing close to half of its energy needs from wood residues, the pulp and paper industry is ideally suited to gain complete energy independence through the use of wood-based fuels.

This report contains two related assessments of forest energy potential. First, a detailed study (fig. 1) was made of Mead Corporation's pulp and paper mill in Escanaba, Michigan. This mill has a procurement area covering most of Michigan's Upper Peninsula and a small part of northeastern Wisconsin. Second, a broader evaluation was made for 10 of the 21 pulp and paper mills in the four Forest Survey Units of northern Wisconsin and Upper Michigan (fig. 2).

For both the case study and the regional analysis, four questions were asked:

1. How much wood is annually harvestable for solid wood products, for wood fiber, and/or wood fuel?
2. How much will it cost to harvest and deliver?
3. What are the energy requirements of the mill or mills, their current sources of energy, and their individual opportunities for converting to wood fuel?
4. At what prices can wood fuel compete with fossil fuels and purchased electricity?

The first two questions address the **supply** of wood and the last two the **demand.**

This study integrates existing forest survey methods, which describe physical characteristics, with methods that add essential economic perspectives. Traditionally, Forest Survey identifies current forest conditions and suggests appropriate strategies for national and regional forest management. Although these analyses have important economic implications, primarily in regard to regional timber balances, they are not designed to answer economic questions of greatest interest to indiviual firms: where is the harvestable timber, and how much will it cost to harvest and transport? While the specific objective of this report is to assess forest energy potentials in northern Wisconsin and Michigan, our approach, which combines silvicultural projections with harvest and transport cost estimates, should have wide application in forest resource appraisals.

The study assumes that field chipping will be a part of all the harvest systems considered and that chips will be produced from the pulpwood portions of trees as well as from branches, tops, rough and rotten trees, and small sound trees. When the quantity of saw logs warrants it, they will be recovered before chips, but round pulpwood **will not** be considered. In other words, only two products will result: saw logs and chips.

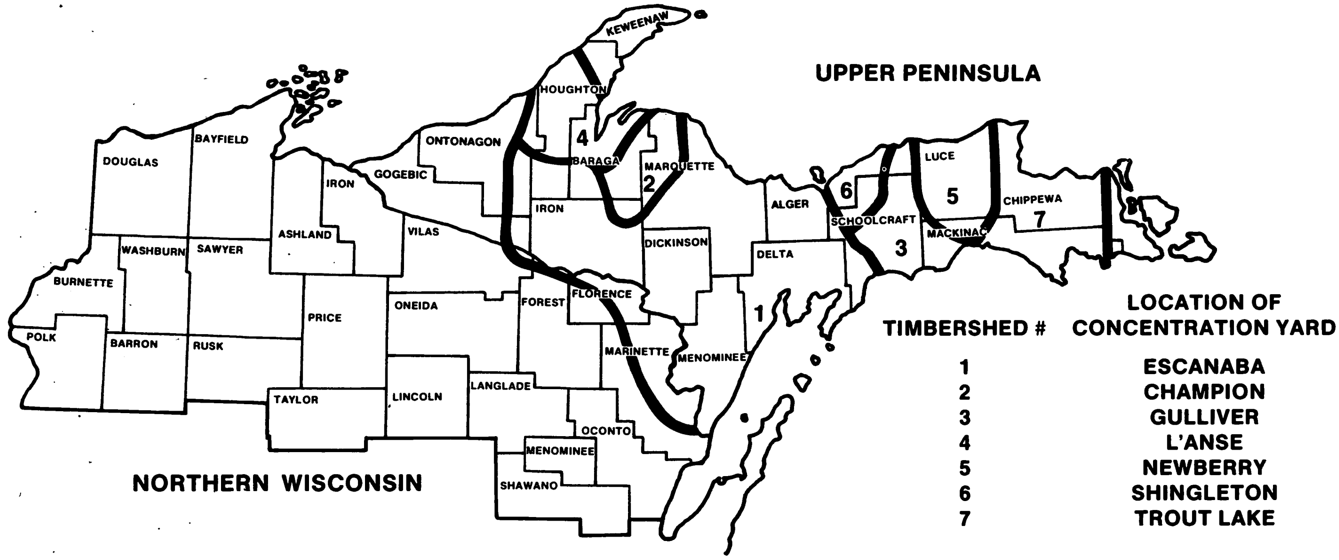

Figure 1.—*Seven timbersheds for Mead Corporation's Escanaba, Michigan, mill.*

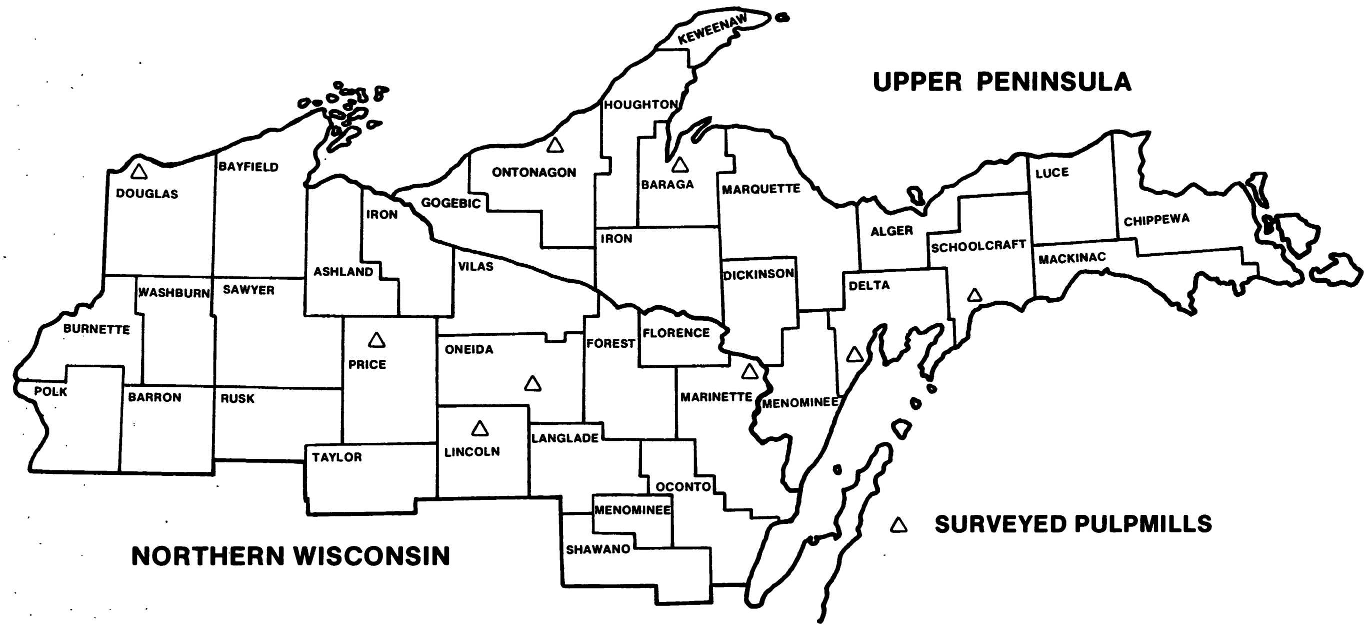

Figure 2.—*Forest residues energy program study area and the locations of surveyed pulpmills.*

This is a considerable departure from current practices. But the productivity of chippers, the rapidly improving technology for cleaning and sorting chips, and the difficulties of recovering branches, tops and similar residues in any other way all point to the need for this assumption. The ultimate use of the chipped portion will depend on many factors, but it seems likely that the industry will find the way to "pulp the best and burn the rest".

METHODS

Five major tasks were carried out for both the regional analysis and Mead case study.

1. Using field plot data, a "managed harvest" procedure was used to calculate the amount of timber that should be cut each year from each of 164 "harvest opportunities". Each harvest opportunity represents the area and timber volume having the same general characteristics such as type, age, size, and stocking. These characteristics in turn determine harvest method as well as harvest costs.

2. Given tree size and stocking characteristics for each of these 164 harvest opportunities, harvest costs were estimated using a computer simulation of the selected harvest systems.

3. Transport cost distributions were determined by measuring the distance from plot to delivery point for all plots in each harvest opportunity and assuming similar distributions of transport costs for all the volume each harvest opportunity represents.

4. A mill energy study based on detailed interviews and a brief engineering analysis was used to estimate total wood requirements and the price that wood residues would have to meet to be competitve for each mill.

5. Finally, mill price and supply curves were compared to see if both fuel and fiber requirements could be met by the forest resource.

Managed Harvest Procedure

Central to this analysis was a "managed harvest" procedure developed by the Renewable Resource Evaluation Project (RREP) of the North Central Forest Experiment Station (NCFES).

It must be emphasized that Managed Harvest is based on existing forest conditions and does not represent a fully regulated or intensively managed harvest level. **However, managed harvest is the amount of timber that should be cut each year for the next 10 years[1] to move the forest toward a more fully regulated condition.** This approach extends previous methods used to calculate "allowable" or "desirable" cut. In simplest terms, **a regulated forest** has an even distribution of trees in each age class, and a constant proportion is harvested each year and immediately regenerated to begin the cycle anew. **An unregulated forest,** in contrast, has an uneven distribution of age classes which, if harvested under strict age or tree size rules, would result in widely fluctuating annual harvests. By this definition, existing forests, whether public or private, are generally unregulated.

Previous measures of timber supply conducted by the NCFES in Michigan and Wisconsin provided almost 4,700 sample plots for this study. In addition, 4,300 sample plots were provided from surveys carried out by the State of Michigan and Mead Corporation, for a total of 9,000 plots.

Deciding how to achieve a more regulated forest requires a set of rules for determining how each timber stand should be treated in the next 10-year planning period. The set of rules we used was adopted from guides used on National Forests in the Lake States and follows recommended silvicultural practices (table 1). From this regional consensus, 20 type/site index combinations were identified. Each combination elicits a recommendation from the guide—whether to cut it, thin it, or leave it alone. An example of the guide recommendations for the paper birch type is shown in a "decision tree" format (fig. 3).

Based on the timber management guides and the two basic silvicultural systems practiced in the Lake States (even-aged and uneven-aged management), three harvest methods were assumed for this study:

1. **Clear cutting of:** Even-aged types at or past rotation age, any stand so poorly stocked that maintaining the few trees to rotation age is not economical, and stands judged unsuitable for the site (should be converted to another type).
2. **Thinning of:** Selected types (both even-aged and uneven-aged) of less than rotation age or mature size, but for which stocking is too dense for best growth.
3. **Selection improvement cutting of:** Saw log stands of northern hardwood, oak-hickory, and swamp hardwood types. In this category, harvesting will be assumed to take place in two stages. First, because full-tree skidding of large, mature trees damages residual crop trees, saw log trees will be cut manually, bucked in the woods, and forwarded as logs to the landing. Second, a mechanized relogging operation will recover saw log tops, cull trees, and undersized trees scheduled for cutting.

[1]*Ten years is an arbitrary projection period based on the current Renewable Resource Evaluation Project schedule to remeasure each State. In 10 years, a new survey will identify different forest conditions and calculate a new managed harvest.*

Table 1.—*Timber management guide summary*[1]

Forest type	Site index	Rotation age	Management objective[2]	Schedule of intermediate cuts: Stand age	Minimum BA	Residual BA
		Years		*Years*	*sq. ft./acre*	*sq. ft./acre*
Jack pine	<60	50	PW	([3])	—	—
	60+	60	PW	([3])	—	—
Red pine	all sites	100	ST	0-20	([4])	—
				20-90	100	90
White pine	all sites	120	ST	20-110	130	110
Balsam fir	all sites	50	PW	([3])	—	—
White spruce	all sites	90	ST	35-80	130	100
Black spruce	<40	100	PW	([5])	—	—
	40+	70	PW	([5])	—	—
Tamarack	all sites	100	PW	([5])	—	—
Northern white-cedar	all sites	100	ST	([5])	—	—
Aspen	<60	40	PW	([3])	—	—
	60+	50	PW/ST	([3])	—	—
Paper birch	<60	50	PW	([3])	—	—
	60+	80	ST	30-50	95	70
Swamp hardwoods	all sites	120	ST	30-100	100	75
Oak	<60	—	convert	([6])	—	—
	60+	100	ST	30-60	115	90
				70-80	90	65
				90	75	45
Northern Hardwoods	<45	—	convert	([6])		
	45+	([7])	ST	all ages	110	90
Nonstocked[8]	all sites	—				

[1]All stands at or above rotation age are clearcut.
[2]ST = Sawtimber PW = Pulpwood.
[3]No intermediate cuts, clearcut at rotation age.
[4]Remove overstory if one remains.
[5]No intermediate cuts, strip cut at rotation age.
[6]Clearcut and convert to a more desirable type.
[7]The objective is to achieve and maintain 90 sq. ft. of basal area distributed 60 sq. ft. in sawtimber, 20 sq. ft. in poletimber, and 10 sq. ft. in samplings. All cull and short log trees are removed first.
[8]These stands have less than the minimum basal area required for type classification.

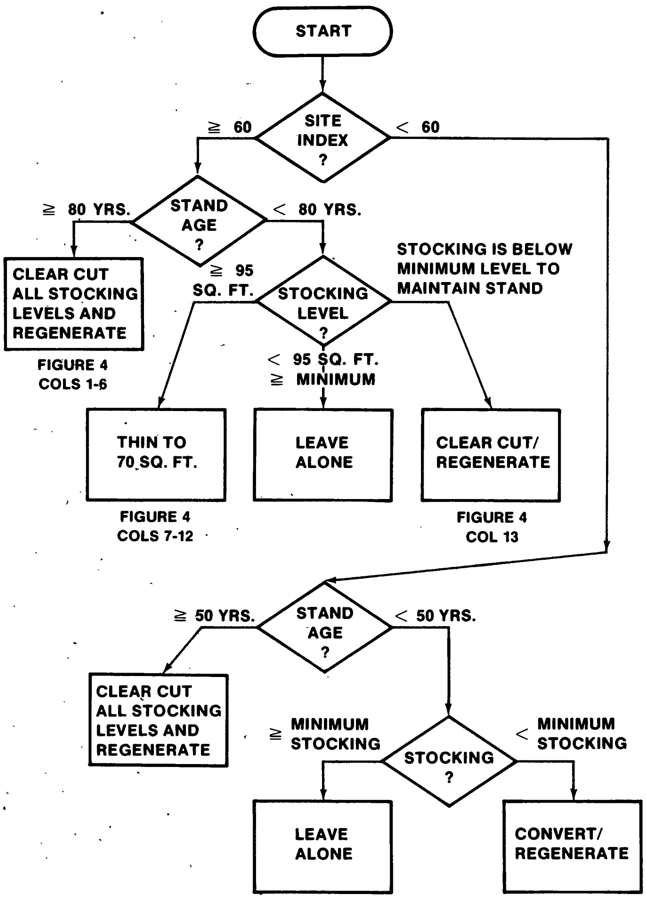

Figure 3.—*Management guide for paper birch type.*

Ordinarily, a calculation of harvested volume includes only sound, straight portions of trees—material larger than 4 inches for pulpwood, 7 inches for softwood saw logs, and 9 inches for hardwood saw logs. It ignores rough, rotten, and short-log trees, cull sections, branches, tops, and trees less than 5 inches d.b.h. In addition, areas with less than 3 cords of "usable" material per acre are considered uneconomical to log and are left out. However, because fuel is an ideal use for much of this material, our analysis of plot data includes these very significant quantities.

In this report, managed harvest tonnages are presented in terms of (1) saw log portions of trees, (2) pulpwood portions of trees, (3) rough and rotten trees, (4) branches, tops, and saplings (trees less than 5 inches d.b.h.).

Forest Survey has traditionally measured volume in cubic feet. However, in this study the green weight per cubic foot was determined for each species in the study area; these factors were used to convert volume to weight:

Species	Pounds/cu. ft.
White pine	37
Red pine	49
Jack pine	40
White spruce	36
Black spruce	42
Balsam fir	46
Hemlock	50
Tamarack	48
Northern white-cedar	32
Oak	60
Yellow birch	56
Sugar maple	56
Red maple	51
Beech	58
White ash	48
Black ash	52
Balsam poplar	50
Cottonwood	48
Paper birch	52
Bigtooth aspen	49
Quaking aspen	47
Basswood	44
Black cherry	48
Elm	55

Harold Young at the University of Maine was the principal source of information for developing crown and sapling weight estimates. A universal equation (Young 1977) relating d.b.h. to complete tree weight in pounds was modified to determine total tree weight by d.b.h. for all species. Correction factors were then used to adjust these weights for individual species. Young estimates total tree weight to be distributed 20 percent stump and roots, 55 percent bole, and 25 percent tops and limbs. When only above-stump components are considered, the distribution is approximately 69 percent bole and 31 percent tops and limbs. Based on this distribution, the top and limb weight was estimated from the bole weight. These crown weights were then adjusted for poletimber and sawtimber trees, by species, using factors developed from various biomass studies.

Based on the timber management guides, the managed harvest program, and the inventory plots, we developed a set of 20 computer-generated type/site index tables. The general characteristics of these tables are shown for paper birch/site index ≥ 60 (fig. 4). Each table has 13 columns summarizing area, total tonnage, tons per acre, and other average stand characteristics. Columns one through six report areas and tonnages from clear cuttings. Columns seven through 12 report areas and tonnages from thinnings of stands that are to continue in the same type and for which management will proceed normally to rotation. Column 13 reports tonnages and areas too sparse to justify maintaining them to merchantable sizes.

Altogether, there are 260 possible columns summarizing harvest opportunities. However, because some types never require a thinning and other existing types will not be maintained, the number of harvest opportunities can be reduced to 164. Average d.b.h. and basal area for each of these 164 harvest opportunities are used in the subsequent estimation of harvest costs.

Harvest Costs

Using a computer-based harvest system simulator, which models the harvesting equipment and production in various stands, harvest costs were estimated for each of the 164 harvest opportunities. The simulators used in this study were written in GPSS (IBM 1974) and represent the activities of the machines and operating rules for harvesting various stands of trees (Bradley *et al.* 1976, Bradley and Winsauer 1976a). These models duplicate the essential features of typical whole-tree chipping systems and the relogging harvest system.

Thirty-three hypothetical stands representing most combinations of six average stand diameters (3 to 18 inches d.b.h.) and six basal areas (30 to 180 square feet) were developed. Selected characteristics of these stands are shown in table 2.

AREA AND VOLUMES OF HARVEST AND THINNINGS BY STAND VOLUME CLASS AND FUEL PRODUCT CLASS

NORTHEASTERN WISCONSIN ,1977

PAPER BIRCH SI 61+

	HARVEST						THINNINGS							
	PERCENT OF GROWING STOCK VOLUME IN SAWTIMBER TREES													
	33%			<33%			33%			<33%			<33%	
	GROWING STOCK CUT VOLUME PER ACRE													
	0-399	400-1199	1200+	0-399	400-1199	1200+	0-399	400-1199	1200+	0-399	400-1199	1200+	UNDER STOCKED	TOTAL
COLUMN	1	2	3	4	5	6	7	8	9	10	11	12	13	
	(THOUSAND ACRES)													
AREA	0	.17	.38	0	0	.85	0	0	0	1.24	.98	0	.24	3.86
VOLUMES BY FUEL/PRODUCT CLASSES	(TOTAL GREEN TONS)													
SAWLOGS	0	6694.	29012.	0	0	14023.	0	0	0	2040.	2754.	0	1790.	56313.
PULPWOOD	0	738.	12386.	0	0	53569.	0	0	0	10537.	15285.	0	2025.	94540.
ROUGH+ROTTEN	0	556.	457.	0	0	4263.	0	0	0	3130.	2221.	0	3198.	13825.
BRANCHES+TOPS	0	4632.	19511.	0	0	47096.	0	0	0	12202.	19106.	0	2927.	105474.
TOTAL	0	12620.	61366.	0	0	118951.	0	0	0	27909.	39366.	0	9940.	270152.
VOLUMES PER ACRE BY FUEL/PRODUCT CLASSES	(GREEN TONS PER ACRE)													
SAWLOGS/ACRE	0	39.	76.	0	0	16.	0	0	0	2.	3.	0	7.	15.
PULPWOOD/ACRE	0	4.	33.	0	0	63.	0	0	0	8.	16.	0	8.	24.
ROUGH+ROT./ACRE	0	3.	1.	0	0	5.	0	0	0	3.	2.	0	13.	4.
BRANCHES+TOPS/A	0	27.	51.	0	0	55.	0	0	0	10.	19.	0	12.	27.
TOTAL	0	74.	161.	0	0	140.	0	0	0	23.	40.	0	41.	70.
NUMBER OF PLOTS	0	1.	2.	0	0	5.	0	0	0	5.	4.	0	1.	0

Figure 4.—*Managed harvest output table for paper birch/site index 60.*

Table 2.—*Selected characteristics of the 33 test stands used in the harvest simulation*

Average d.b.h.	Average height	Basal area (square feet per acre) 30	60	90	120	150	180
		TREES PER ACRE (number)					
Inches	*Feet*						
3	39	486	967	1,452	—	—	—
6	43	129	265	395	526	660	790
9	51	61	123	186	246	308	370
12	57	36	72	108	143	179	215
15	62	24	47	71	94	118	141
18	66	17	34	50	67	84	101
		GROSS VOLUME (cubic feet per acre)					
3	39	613	1,221	1,833	—	—	—
6	43	756	1,511	2,267	3,023	3,778	4,534
9	51	896	1,793	2,689	3,585	4,482	5,378
12	57	1,002	2,005	3,007	4,009	5,012	6,014
15	62	1,086	2,171	3,257	4,342	5,428	6,513
18	66	1,182	2,363	3,545	8,727	5,908	7,090
		TREE SPACING (feet)					
3	39	9.5	6.7	5.5	—	—	—
6	43	18.4	12.8	10.5	9.1	8.1	7.4
9	51	26.7	18.8	15.3	13.3	11.9	10.7
12	57	34.8	24.6	20.1	17.5	15.6	14.2
15	62	42.6	30.4	24.8	21.5	19.2	17.6
18	66	50.6	35.8	29.5	25.5	22.8	20.8

Detailed machine speeds and capacities were collected from a number of sources and supplied to the simulator. Machine operating characteristics are as follows:

Two feller bunchers were considered in this study. The first is a rubber-tired, frame-steered machine with an accumulating shear mounted in front. This machine must drive up to each tree. The second feller buncher has a rotating boom and accumulating shear mounted on crawler tracks. It does not have to approach each tree, but can swing and extend the shear while maintaining a fairly straight path.

Bunches are picked up with an hydraulic grapple mounted on a rubber-tired, frame-steered skidder. Only one kind and size of skidder was considered in this analysis. At the landing, bunches are disassembled by the chipper's loader, chipped and blown immediately into a waiting van. When warranted, saw logs are first bucked, set aside and only the tops are chipped.

Two chipper sizes were used, based on maximum acceptable butt diameter: small (12 inches and less) and large (22 inches and less).

Full-tree skidding and saw log sorting at the landing in thinned or selectively cut sawtimber stands of oak-hickory, northern hardwoods, and swamp hardwoods result in too much damage to remaining crop trees. For these types, and in stands with average d.b.h. greater than 9 inches and basal areas in excess of 90 square feet, saw logs are assumed to be removed by a short log operation, with the remaining material harvested by a topwood harvester.

The topwood harvester which is undergoing development at the Forest Engineering Laboratory in Houghton, Michigan, has a rotatable and highly maneuverable shear mounted on a rubber-tired, frame-steered chassis. In addition to felling and bunching non-saw-log trees, its flexible shear is used to sever large limbs and compact the tops from the large sawtimber trees cut earlier. The compacted tops and other smaller trees can then be removed with little damage to the remaining stand.

Given the equipment specifications and test stands, the simulator was used to select the combination of equipment that produced maximum net revenue per hour for each of the three harvest methods. Tables 3, 4, and 5 show the configuration, productivity, and cost of each system finally chosen. These decisions were reached by the following procedures:

1. Costs per hour were calculated for each machine, based on estimated purchase price, machine life, scheduled and actual hours to be worked each year, and cost of repairs, wages, insurance, taxes, fuel, and lubricants.

2. Overhead costs and a margin for profit and risk were added to machine costs.

3. Various combinations of machines, their speeds, capacities, costs, and the stand description were tested by the simulator. Each computer run resulted in an estimate of production per hour in cubic feet and tons. Because the chipper was the limiting factor, the number of skidders was increased until skidder output closely matched the chipper and net revenue per hour was maximized.

4. The simulated production rates were adjusted to realistic levels using industry-developed estimates of achievable operator efficiency and machine utilization.

Table 3.—*Harvest systems selections—equipment, output, and cost—for clearcuts*

SYSTEM OUTPUT (green tons per hour)

	Basal area (square feet per acre)					
D.b.h.	**30**	**60**	**90**	**120**	**150**	**180**
3[1]	6.00R[2]	6.03R	5.95R	—	—	—
6	22.34R	23.19R	19.89	20.46	22.15	22.66
9	35.93R	38.13R	33.85	34.44	36.10	36.78
12	46.40R	43.39	48.80	51.56	53.49	55.11
15	61.43	65.84	68.24	71.83	73.49	74.42
18	85.93	86.19	91.42	94.91	00.67	02.54

SYSTEM COST (dollars per green ton)

3[1]	20.78R	20.40R	20.43	—	—	—
6	8.03R	7.56R	8.60	8.38	7.82	6.72
9	4.74R	4.39R	4.81	4.70	4.49	4.40
12	3.56R	3.69	3.28	3.08	2.96	2.87
15	2.78	2.43	2.33	2.19	2.13	2.10
18	2.05	1.91	1.74	1.65	1.56	1.50

[1]Two skidders and small chipper; for all other diameters, 3 skidders and large chipper.

[2]R = rubber-tired feller-buncher; No R = track-type feller buncher.

Table 4.—*Harvest system selections-equipment, output, and cost for thinning*

SYSTEM OUTPUT (green tons per hour)

	Basal area (square feet per acre)				
D.b.h.	**60**	**90**	**120**	**150**	**180**
6[1]	22.40R[2]	22.80R	23.20R	23.20R	24.40R
9	34.50R	37.60R	38.70R	38.90R	39.06R
12	47.07R	54.29R	54.89R	46.44	48.77
15	62.45	61.61	61.52	68.81	66.49
18	82.85	86.13	84.21	90.37	91.43

SYSTEM COST (dollars per green ton)

6[1]	7.95R	7.71R	7.46R	7.34R	7.05R
9	4.95R	4.47R	4.31R	4.22R	4.17R
12	3.54R	3.03R	2.96R	3.44	3.27
15	2.77	2.68	2.61	2.33	2.38
18	2.11	1.91	1.94	1.79	1.74

[1]For all diameters, 3 skidders and large chipper.

[2]R = rubber-tired feller-buncher; No R = track-type feller buncher.

Table 5.—*Harvest system selections—equipment[1], output, and cost for relogging*

SYSTEM OUTPUT (green tons per hour)

	Basal area (square feet per acre)			
D.b.h.	**90**	**120**	**150**	**180**
9	15.28	15.28	15.28	15.28
12	13.96	13.96	13.96	13.96
15	16.05	16.05	16.05	16.05
18	22.05	22.05	22.50	22.05

SYSTEM COST (dollars per green ton)

9	13.85	12.77	12.41	12.16
12	13.35	12.99	12.87	12.71
15	11.21	11.00	10.76	10.73
18	8.11	8.04	8.00	7.94

[1]Equipment used: 1 topwood harvester, 3 grapple skidders, 1 large chipper, for all conditions.

Because the sawmill industry is concerned about the loss of saw logs due to field chipping, we identified stand conditions that would justify sorting saw logs before chipping. First, all species were ranked by their relative "woods run" saw log prices. Second, 2,000 board feet or roughly 10 tons per acre was arbitrarily chosen as the minimum tonnage recoverable during chipping for the most valuable saw logs. The minimum recoverable tonnages for the other types were then ranked accordingly:

Type	**Minimum saw log tonnage per acre**
Jack pine	no saw logs recovered
Red pine	12
White pine	12
Balsam fir	no saw logs recovered
White spruce	15
Black spruce	no saw logs recovered
Tamarack	no saw logs recovered
Northern white-cedar	10
Aspen	20
Paper birch	10
Elm-ash-cottonwood	15
Oak-hickory	10
Northern hardwoods	10

Finally, after all 164 harvest opportunities were matched to the proper cell in the three harvest-cost matrixes, all stands not relogged and having more than the minimum saw log tonnage for the type were assumed to be harvested by a field chipping and saw log sorting system. The cost of chips from this combined operation was increased as follows:

$$\text{Cost of chips} = \text{"chips-only" cost/ton} \times \left(1 + \frac{\text{sawtimber tons/acre}}{\text{total tons/acre}}\right).$$

Thus, if an aspen stand had a "chips-only" cost of \$6.00/ton, a sawtimber volume of 26 tons/acre, and a total volume of 100 tons/acre, the cost of chips from the saw log and chip operation would be \$6.00 $\times \left(1 + \frac{26}{100}\right) =$ \$7.56/ton.

Transport Costs

Recall that each harvest opportunity summarizes the acreage and volume of an entire type/site index, age, harvest method, cutting level, etc. Some of the stands in a harvest opportunity are close to the road and to delivery points, while others are far away. By measuring the transport distance from each plot to delivery point, we were able to estimate the distribution of transport distances and costs for each harvest opportunity. The process required one assumption: total harvestable areas and tonnages in the entire harvest opportunity are distributed by distance and cost to delivery point in the same proportion as sample plot areas and tonnages.

In the Mead case study, distances from the plots in each of seven timbersheds were measured to the mill or concentration yard. For the regional analysis, because eventual delivery points were unknown, distances were measured from each plot to the county center. However, when managed harvest was summarized for each survey unit, all counties were combined into one transport cost distribution. The analysis assumed that all chipped material would be hauled in 35-ton vans using per-ton charges provided by Mead Corporation.

An example of managed harvest output is shown in figure 5 for Mead timbershed 1 (aspen-type/site index < 60). The boxed-in portion (column 3) shows one harvest opportunity. Using a "harvest and transport cost program" based on a method called ACCESS (Bradley 1972), the 55 plots from column 3 in the managed harvest table were distributed in a "harvest and transport cost table" (fig. 6). Each plot represents 1/55 of the area in column 3, but the plots are now distributed across the table by distance to delivery point.

AREA AND VOLUMES OF HARVEST AND THINNINGS BY STAND VOLUME CLASS AND FUEL PRODUCT CLASS

TIMBER SHED 1

ASPEN SI 0-60

	HARVEST						THINNINGS							
	PERCENT OF GROWING STOCK VOLUME IN SAWTIMBER TREES													
	≧ 33%			<33%			≧ 33%			<33%			<33%	
	GROWING STOCK CUT VOLUME PER ACRE													
	0-399	400-1199	1200+	0-399	400-1199	1200+	0-399	400-1199	1200+	0-399	400-1199	1200+	UNDERSTOCKED	TOTAL
	(THOUSAND ACRES)													
AREA	.39	3.66	1.11	3.51	6.43	1.26	0	0	0	0	0	0	12.72	29.08
VOLUMES BY FUEL/PRODUCT CLASSES	(TOTAL GREEN TONS)													
SAWLOGS	4918.	80679.	63568.	5286.	31389.	18054.	0	0	0	0	0	0	9956.	213850.
PULPWOOD	2355.	50197.	30380.	50683.	216604.	59345.	0	0	0	0	0	0	24488.	434052.
ROUGH+ROTTEN	460.	7183.	3539.	4337.	7393.	1907.	0	0	0	0	0	0	3629.	28448.
BRANCHES+TOPS	3241.	66113.	42580.	34233.	149472.	43792.	0	0	0	0	0	0	33880.	373311.
TOTAL	10974.	204172.	140067.	94539.	404858.	123098.	0	0	0	0	0	0	71953.	1049661.
VOLUMES PER ACRE BY FUEL/PRODUCT CLASSES	(GREEN TONS PER ACRE)													
SAWLOGS/ACRE	13.	22.	57.	2.	5.	14.	0	0	0	0	0	0	1.	7.
PULPWOOD/ACRE	6.	14.	27.	14.	34.	47.	0	0	0	0	0	0	2.	15.
ROUGH+ROT./ACRE	1.	2.	3.	1.	1.	2.	0	0	0	0	0	0	0.	1.
BRANCHES+TOPS/A	8.	18.	38.	10.	23.	35.	0	0	0	0	0	0	3.	13.
TOTAL	28.	56.	126.	27.	63.	98.	0	0	0	0	0	0	6.	36.
NUMBER OF PLOTS	8.	46.	55.	39.	140.	76.	0	0	0	0	0	0	25.	0

Figure 5.—*Example of managed harvest output table.*

HARVEST AND TRANSPORT COSTS
OF ALLOWABLE CUTS.

STATE: MICHIGAN T. SHED: 1 TYPE: ASPEN S.I.: 0-60 TOTAL ACRES: 1110 TABLE #: 11

% SAWTIMBER BY VOLUME: ≥33% CUT VOLUME PER ACRE (CU.FT.): 1200+ TOTAL PLOTS: 55 COLUMN #: 3

KIND OF HARVEST: CLEAR CUT DBH CLASS: 9 BASAL AREA CLASS: 120

	DISTANCE TO MILL - MILES										
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	180 +	ALL PLOTS TOTAL
NUMBER OF PLOTS	1	2	27	7	17	0	0	0	0	0	54*
% TOTAL PLOTS	1.85	3.70	50.00	12.96	31.48	.00	.00	.00	.00	.00	
ACRES	20	41	555	143	349	0	0	0	0	0	1110
AVE DIST IN MILES	16.50	25.50	52.67	73.32	91.07	.00	.00	.00	.00	.00	65.76
AVE DIST BY ROAD QUALITY											
PAVED	11.75	24.12	44.86	70.64	84.82	.00	.00	.00	.00	.00	59.40
GRAVELED	2.50	.00	4.55	1.82	3.51	.00	.00	.00	.00	.00	3.66
ALL WEATHER	.00	.00	1.69	.11	1.18	.00	.00	.00	.00	.00	1.23
DRY WEATHER	2.00	.00	.96	.32	1.22	.00	.00	.00	.00	.00	.94
SEASONAL	.25	1.00	.33	.29	.07	.00	.00	.00	.00	.00	.27
CROSS-COUNTRY	.00	.38	.28	.14	.26	.00	.00	.00	.00	.00	.25
Row A – HARVEST AND TRANSPORT COST PER TON	$ 11.44	$ 11.70	$ 12.49	$ 13.09	$ 13.60	$ .00	$ .00	$ .00	$ .00	$ .00	
SAWTIMBER VOL (TONS)	1177	2354	31784	8240	20012	0	0	0	0	0	63567
ACCUMULATIVE VOL	1177	3531	35315	43555	63567	63567	63567	63567	63567	63567	
PULPWOOD VOL (TONS)	562	1125	15190	3938	9564	0	0	0	0	0	30379
ACCUMULATIVE VOL	562	1687	16877	20815	30379	30379	30379	30379	30379	30379	
ROUGH & ROTTEN (TONS)	65	131	1769	458	1114	0	0	0	0	0	3537
ACCUMULATIVE VOL	65	196	1965	2423	3537	3537	3537	3537	3537	3537	
TOPS AND LIMBS (TONS)	788	1577	21290	5519	13404	0	0	0	0	0	42578
ACCUMULATIVE VOL	788	2365	23655	29174	42578	42578	42578	42578	42578	42578	
Row B-1 -- TOTAL TONS-3 PRODUCTS	1415	2833	38249	9915	24082	0	0	0	0	0	
B-2 ---- TOTAL ACC TONS	1415	4248	42497	52412	76494	76494	76494	76494	76494	76494	
C-1 TOTAL COST-3 PRODUCTS	$ 16187	$ 33146	$ 477730	$ 129787	$ 327515	$ 0	$ 0	$ 0	$ 0	$ 0	
C-2 TOTAL ACC COST	$ 16187	$ 49333	$ 527063	$ 656850	$ 984365	$ 984365	$ 984365	$ 984365	$ 984365	$ 984365	
C-3 ---- ACC COST/TON	$ 11.44	$ 11.61	$ 12.40	$ 12.53	$ 12.87	$ 12.87	$ 12.87	$ 12.87	$ 12.87	$ 12.87	

SAWLOG VOLUMES NOT INCLUDED - THE SAWLOGS HAVE BEEN SORTED OUT AT THE CHIPPER

Figure 6.—*Example of harvest and transport cost output.*

One plot representing 20 acres and 1,415 tons is 16.50 miles from the mill, 27 plots representing 555 acres and 38,249 tons are 52.67 miles from the mill. These 1,415 tons and 38,249 tons are harvestable and transportable to the mill at an average cost of $11.44 and $12.49 per ton, respectively.

Supply Curve Construction

Marginal and average delivered cost curves can be constructed from the harvest and transport cost tables for practically any combination of (a) type/site index, (b) proportion of sawtimber in the stand, (c) growing stock volume cut per acre, and (d) kind of harvest (clear cut, mechanized thinning, or selection cut/relogging).

Each harvest and transport cost table (fig. 6), already includes marginal and average cost calculations for the "three-product total" of pulpwood, rough and rotten, and tops and limbs. Row A shows the harvest and transport cost for the volumes found in each distance class. Row B-1 shows the individual volumes of the "three-product total" in each distance class that are deliverable at the costs shown in row A. Row B-2 shows the cumulative volumes of the "three-product total" that can be delivered **at or below** the cost shown in row A.

A marginal delivered cost curve can now be constructed by plotting row B-2 against row A (fig. 7). This curve shows **marginal cost** or the cost of delivering the last ton of any volume desired. For example, the mill would have to pay $13.60/ton (row A, 80-100 miles) to recover the last of 76,494 tons (row B-2, 80-100 miles). That is, this cost would be paid for each of the last 24,082 tons (row B-1, 80-100 miles). If only 52,412 tons are needed (row B-2, 60-80 miles), the cost of the last ton would be $13.09/ton (row A, 60-80 miles). Of course, at either level of demand, some wood would cost substantially less; the delivered cost of the first 1,415 tons would be $11.44/ton.

A more useful measure of supply is the **average cost.** That is, what price must be paid on the average to recover any desired amount? This is more useful because it is the average cost that will be compared to average revenue earned by the firm. Average cost is

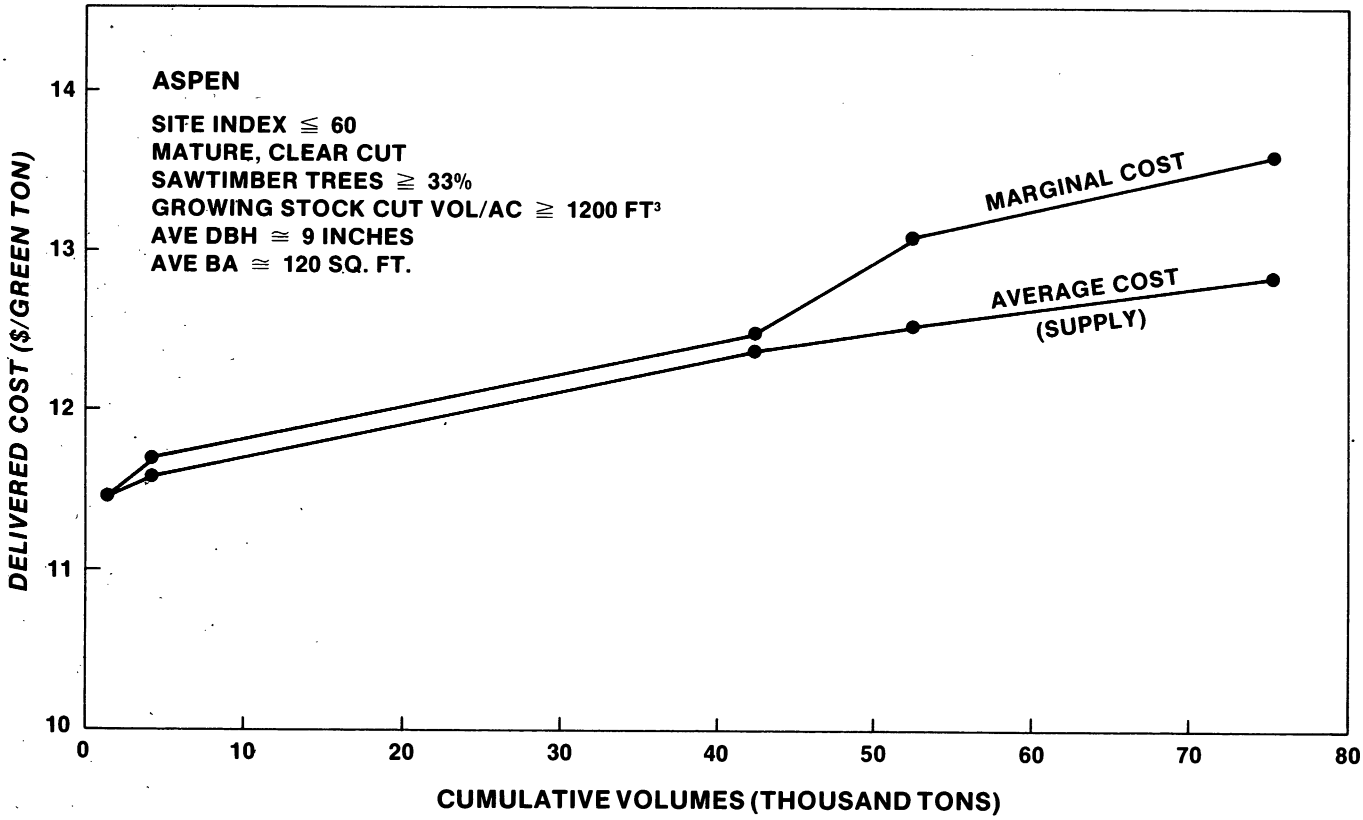

Figure 7.—*Example of marginal and average delivered cost curves.*

shown in row C-3. For any distance class, it is the cumulative cost of the "three-product total" (row C-2) divided by the cumulative tonnage (row B-2). This curve is plotted in figure 7 along with marginal cost. Row C-3 in every harvest and transport cost table shows the average cost of the cumulative volumes up to each specific distance class.

In the results section to follow, the average cost curves are called **supply curves** because they represent the average cost of meeting a specific demand for wood. Figure 7 shows the supply of timber from all the aspen stands in Mead's timbershed 1 with a site index ≤ 60 and with the other following characteristics:

a. mature stand clearcut,
b. sawtimber trees as a percent of growing stock trees ≥ 33 percent,
c. growing stock cut volumes/acre ≥ 1,200 cubic feet,
d. average d.b.h. ≅ 9,
e. average d.b.h. ≅ 120 ft.^{2}.

The harvest cost portion of delivered cost for this harvest opportunity is $5.36 per ton, and was derived in the following way: Because a clear cut was recommended, table 3 (Harvest system selections-clear cuts) was examined for the stand averaging 9 inches d.b.h. and 120 square feet basal area. A harvest cost of $4.70/ton was indicated. However, this cost assumed that all the trees weighed 55 pounds per cubic feet and it was multiplied by the ratio of assumed tree weights to actual tree weights for the aspen type.

$$\$4.70/\text{ton} \times (55\ \text{lbs./ft.}^3 \div 48.20\ \text{lbs./ft.}^3) = \$5.36/\text{ton}$$

The harvest cost portion of each table is the same in each distance class, but of course, transport costs increase from left to right. Similar harvest and transport cost tables were prepared for each of the 164 harvest opportunities.

Generally, individual havest and transport cost tables are not based on enough data to be significant. Therefore, most of the supply curves used in the analysis are aggregates of several tables.

Estimating Stumpage Costs

The supply curves do not include stumpage cost because of the wide variation among owners and the complexity of the calculations (which often include volume per acre, accessibility, wood quality, road construction costs, and size of area). Therefore, anyone who wishes to use the delivered cost curves should add his own estimate for stumpage.

However, for the approximate comparisons of supply and demand to follow, we estimated an average stumpage cost for the combined volumes of roundwood and residues by species groupings. Residues, including rough and rotten trees and tops, branches, and saplings, were valued at less than the minimum price now paid for mixed hardwood roundwood, as estimated in the Wisconsin Forest Products Price Review (1977).

Species	Estimated stumpage price, all products	
	$/cord	$/ton
Pine	9.14	3.97 at 2.3 tons/cord
Other softwoods	4.82	2.01 at 2.4 tons/cord
Aspen	4.00	1.67 at 2.4 tons/cord
Mixed hardwoods	2.15	0.77 at 2.8 tons/cord

Since mixed hardwood stumpage was valued at about $0.77/ton, we assumed that all categories now classed as residues would be worth no more than $0.50/ton.

Next, we used the following ratios of residues to roundwood for the species groups found in Michigan's Upper Peninsula:

Species groups	Ratio: Residue volume/ Roundwood volume
Pine	0.64
Other softwood	.67
Aspen	.66
Mixed hardwoods	.78

That is, for pine, if a stand has 1 ton of roundwood per acre, it has 0.64 tons of rough, rotten, branches, tops, and saplings.

Finally, using (1) the average roundwood stumpage price for each species group, (2) the assumed residue price of $0.50/ton, and (3) the roundwood/residue ratios above, we determined a combined roundwood and residue weighted stumpage cost/ton. For example:

1 ton of pine roundwood at $3.97/ton =	$3.97
+ .64 tons of pine residue at $ .50/ton =	.32
	$4.29

$4.29/1.64 tons = $2.62/ton

This resulted in the following tabulation for each species group:

Species group	Weighted stumpage cost (roundwood and residue $/ton)
Pine	$2.62
Other softwoods	1.41
Aspen	1.20
Mixed hardwoods	0.60
Overall average	$1.04

The last step was the calculation of an overall average, weighted by the proportion of similar species groups found in the managed harvest for Michigan's Upper Peninsula.

Mill Demand for Fiber and Fuel

This study assumed that the entire demand for wood fiber and wood fuel of 10 of the 21 mills in the region would be met from the regions forest resource (fig. 2). Four steps were required.

First, interviews were conducted at each of the 10 mills to determine mill process and technology; wood procurement program; energy requirements, sources, and current levels of energy independence; internal steam, steam-electric, and hydro-electric facilities; and current unused residues.

Second, a brief engineering analysis for each mill estimated the opportunities (and costs) to achieve complete energy independence by either converting existing boilers or constructing new ones.

Third, current and projected prices were determined for the major fossil fuels as well as for purchased electricity.

Fourth, using current and projected fuel prices and the costs of each conversion or new construction opportunity, the price advantage of wood over existing fuels that just balanced capital costs was established. This advantage was then subtracted from each mill's existing fuel costs to establish the highest price that each mill could afford to pay for wood fuel.

RESULTS

Mead Corporation, Escanaba, Michigan

Supply of wood fiber and fuel

The combined area of Mead's seven timbersheds in Michigan's Upper Peninsula and northeastern Wisconsin is 8.9 million acres, of which 7.7 million acres are classed as commercial forest land. This is distributed as follows:

Timbershed	Total land area	Commercial forest
	(acres)	
1 Escanaba mill	5,023,600	4,338,900
2 Champion	494,600	458,200
3 Gulliver	778,100	665,400
4 L'Anse	760,100	671,700
5 Newberry	614,100	550,900
6 Shingleton	275,400	241,600
7 Trout Lake	997,600	790,500
	8,943,400	7,717,200

Almost 3.5 million of the above acres are in public ownership, divided equally between State and National Forests. These acres have not been reserved for single use and presumably can be harvested as the timber matures. Two million acres are owned by forest industry. Roughly 33 percent of this area is in softwood types, 22 percent is in aspen and paper birch, and 37 percent is in northern hardwoods. Because over 50 percent of the area and inventory is in timbershed 1, the analysis will focus on this timbershed.

Managed harvest recommendations for Mead's timbershed 1 call for the annual harvest of 146,000 acres of all types, yielding over 7.4 million tons of all products (table 6). This total in timbershed 1 includes more than 1.4 million tons of saw logs assumed to be sorted during chipping or removed before relogging. The remaining saw log volumes are considered insufficient per acre to warrant separation, and are to be chipped with the remaining stand. Thus, for timbershed 1, 6 million tons of wood, not including most saw logs, are deliverable at an average cost of $14.37/ton not including stumpage cost (fig. 8). Over one-half, or 3 million tons are available from rough and rotten trees and tops and branches. These tonnages are shown by type groupings below:

Type	Volume (tons, less most sawtimber)	Maximum average delivered cost ($/ton less stumpage cost)
Pine	287,000	13.57
Other softwood	1,086,000	13.12
Aspen	1,662,000	13.71
Northern hardwoods	1,979,000	16.18
Other hardwoods	952,000	13.44
All Types	5,966,000	14.37

If all material included in the managed harvest estimates is harvested, cost per ton will average $14.37. If less material is desired, the average price will decrease assuming that a mill can avoid stands with high harvest and transport costs. For example, for all types in timbershed 1, if only half the material is needed, average price will drop to $11.33.

Although the preponderance of the northern hardwood type is clear, its average delivered costs are higher than the overall average cost by almost $2/ton. However, if only half this type were harvested, 1 million tons could be delivered at an average cost of $12.30/ton, a considerable decrease from $16.18/ton.

No timber removal data are available for Mead's timbersheds. However, the latest survey of removals for Michigan shows that in 1972, 101 million cubic feet of growing stock was harvested in the Upper Peninsula. This volume converts roughly to 3 million tons of all species. But recall that growing stock does not include rough and rotten trees, branches, tops, nor saplings. From ratios of merchantable roundwood to residues determined in this study, we know that roughly 0.7 tons of residue are generated for every ton of roundwood. Applying this ratio to growing-stock removals results in total removals of growing stock plus residues of nearly 5 million tons/year of all species in the Upper Peninsula.

Without a breakdown by type we can make no precise comparison with managed harvest data, but in timbershed 1 alone our calculations show that 7.4 million tons of wood and wood residues should be harvested each year. And this timbershed contains only 60 percent of Upper Michigan's commercial forest land.

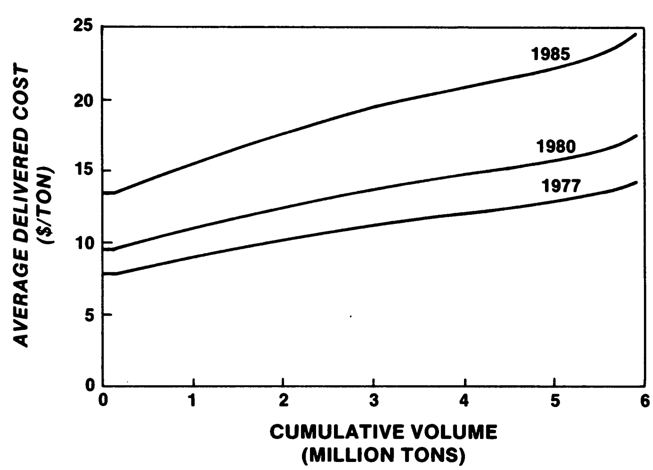

Figure 8.—*Supply curve for Mead Timbershed 1, all forest types.*

Table 6.—*Managed harvest by fuel/product classes, Mead timbershed 1*
(In green tons)

Type/Site Index	Saw logs	Pulpwood	Rough and rotten	Tops, branches, saplings	Total	Acres
Jack pine <60	59,573	50,038	4,353	54,231	168,195	7,640
Jack pine ≥60	6,453	4,747	578	5,746	17,524	390
Red pine	50,104	12,691	8,961	44,939	116,695	5,120
White pine	37,983	11,182	1,710	21,907	72,782	1,200
Balsam fir	191,914	192,076	18,098	230,881	632,929	8,170
White spruce	31,919	22,482	2,636	30,927	87,964	4,570
Black spruce <40	9,485	25,393	133	23,269	58,280	3,940
Black spruce ≥40	19,035	12,865	1,024	18,496	51,420	860
Tamarack	4,743	11,832	44	12,033	28,652	1,760
Northern white-cedar	137,236	84,473	23,354	139,035	384,098	5,430
Aspen <60	213,850	434,052	28,448	373,311	1,049,661	29,080
Aspen ≥60	224,991	288,434	35,393	337,396	886,214	14,840
Paper birch <60	24,230	92,096	10,627	74,656	201,609	4,520
Paper birch ≥60	6,509	29,593	10,639	29,627	76,368	1,910
Elm-ash-cottonwood	145,209	114,455	40,420	200,572	500,656	10,680
Oak-hickory <60	58,103	144,719	5,032	142,930	350,784	4,780
Oak-hickory ≥60	5,066	6,091	738	7,456	19,351	140
Maple-birch-beech <45	371,874	364,014	79,909	501,439	1,317,236	18,670
Maple-birch-beech ≥45	451,064	315,633	94,633	528,326	1,389,656	14,460
Nonstocked	0	289	4,515	2,263	7,067	8,070
TOTAL	2,049,341	2,217,155	371,245	2,779,440	7,417,141	146,230

Demand for wood fiber and fuel

The mill energy study showed that Mead now uses 887,000 tons of wood annually, about 100,000 tons of which goes to meet approximately 7 percent of its own energy needs (table 7). An additional 36 percent of Mead's energy requirements are met by black liquor burning and hydroelectricity. Total energy independence would require the additional purchase of about 1 million tons of wood fuel, bringing total wood use to about 1.9 million tons.

Energy independence for Mead, or for any other existing plant, could rarely be achieved in one step. A preliminary engineering analysis made for the Mead mill shows the opportunities for reaching self-sufficiency (table 8).

One question remains: Is there enough wood and wood fuel to satisfy these needs at a price Mead can afford?

Supply and demand

Although Mead does not get all its wood from timbershed 1, we have used this timbershed to illustrate the point that Mead has an abundance of wood at affordable prices. The following exercise will bear this out. On the horizontal axis of figure 8, locate Mead's demand in 1980, the time at which total energy independence could be achieved: 1.9 million tons for all purposes (fuel and pulp). Draw a vertical line from this point on the horizontal axis to the 1980 supply curve. Then run horizontally to the average delivered price less stumpage on the vertical axis: \$12.50/ton. To this add the average stumpage value for all species, calculated earlier: \$1.04 + \$12.50 = \$13.54/ton. This indicates that timbershed 1 can provide 1.9 million tons each year at an average delivered cost per ton including stumpage of \$13.54, given the assumptions made in the analysis.

Table 7.—*Wood fuel requirements for the ten study mills*

	I	II	III	IV	V	VI	VII	VIII	IX	X
BILLION BTU's REQUIRED PER YEAR										
Total	9,688	1,108	5,445	631	3,355	2,402	1,290	6,575	1,362	4,885
Current wood-fired	837	20	0	262	257	209	0	79	157	1,000
New wood-fired	8,851	1,088	5,445	369	3,098	2,193	1,290	6,496	1,205	3,885
WOOD FUEL REQUIRED (Thousand tons per year)										
Total	1,140	130	641	74	395	283	152	774	160	575
Current wood use	99	2	0	31	30	25	0	9	18	118
New wood	1,041	128	641	43	365	258	152	765	142	457
HIGHEST AFFORDABLE WOOD FUEL PRICE (Dollars per million BTU's)										
1977	.77	1.51	.81	1.70	1.79	1.03	1.03	1.39	1.06	1.34
1980	1.66	2.03	1.02	2.52	2.19	1.49	1.47	1.89	1.76	1.77
1985	2.78	2.84	1.46	3.91	3.07	2.34	2.41	2.93	2.91	2.63
(Dollars per green ton)										
1977	6.12	12.84	6.88	14.45	15.22	8.76	8.76	11.82	9.01	11.39
1980	14.11	17.26	8.67	21.42	18.62	12.66	12.50	16.06	14.96	15.04
1985	26.63	24.14	12.41	33.24	26.10	19.89	20.48	24.90	24.74	22.36

Table 8.—*Opportunities for reaching self-sufficiency at the Mead Mill*

Step	Cap. cost ($\$-10^6$)	Annual saving ($\$-10^6$)	Increase in energy (Percent)	Energy independence required	Additional fuel wood (ton/yr.)
Present wood energy use			—	43	
Modify an existing boiler	.3	4.2	7	50	75,000
Convert a boiler	1.4	.6	10	60	113,000
Replace a boiler	15.3	6.0	34	94	769,000
Replace direct heating	2.0	.6	6	100	77,000
				TOTAL	1,034,000

From the mill energy study, the maximum average price Mead would be able to pay in 1980 was estimated at $14.11/ton based on projected price increases in fossil fuels (table 7). Thus, by 1980, timbershed 1 could meet Mead's entire demand well within the projected cost limit. It must be emphasized that this price will meet not only Mead's fuel requirements, but its fiber needs as well—and with no loss of raw material to the sawmill industry.

Other fuel/product opportunities

The fiber available from some forest types, especially northern hardwoods, would cost significantly more than that from others. We have prepared three other supply curves to explain why, and to demonstrate some other facets of the analysis.

The first shows the supply of wood and wood residues (minus most sawtimber) that resulted from mechanized thinning (fig. 9). This harvest technique was applied to overstocked, uneven-aged types for which average stand diameter was less than 9 inches; it was also applied to all overstocked, even-aged types. Because of small tree size, full-tree skidding is not too damaging and a strip cut can remove the excess basal area (Biltonen *et al.* 1976).

This curve shows that despite the fairly large tonnages (over 420,000 tons/year), mechanized thinning is expensive. To harvest all thinnings would require a 1977 price, not including stumpage, of close to $13.80/ton, and a 1980 price of $15.81. The large volumes and high recovery costs suggest further study of ways to reduce the cost of mechanized thinning. Perhaps the development of specialized equipment could be justified if the market for fuel and fiber were larger.

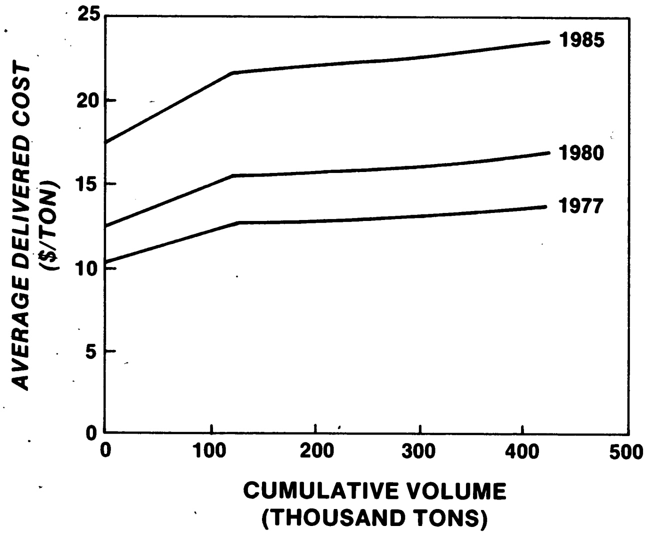

Figure 9.—*Supply curve for Mead Timbershed 1, thinnings from all forest types.*

The next curve shows the supply of chips when saw logs are bucked and sorted before chipping (fig. 10). This material resulted from both thinnings and clearcuttings, and overlaps material contained in the thinning supply curve. Figure 10 illustrates a significant point: 1.6 million tons left after sorting can be recovered, at an average cost of $12.33/ton. Thus, a huge volume of material is available for fuel or fiber at a low price, and over 1 million tons of saw logs are saved from the chipper. We need to develop efficient ways to carry out saw log sorting and field chipping operations.

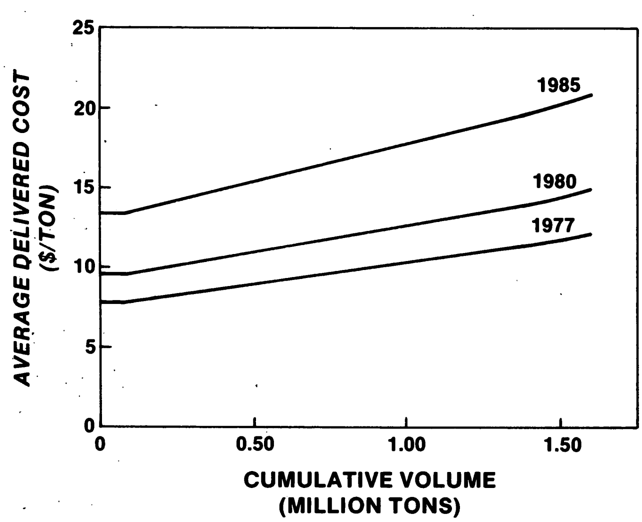

Figure 10.—*Supply curve for Mead Timbershed 1, remaining volume after saw log sorting.*

Another supply curve represents the cost of relog ging large sawtimber stands in which full-tree skid ding is not recommended (fig. 11). The trees wit large crowns in these stands would cause unaccepta ble damage to future crop trees if skidded whole to th landing. We have assumed that all saw logs will b removed in separate, short-log operations. The larg tops and the other trees to be removed could then b harvested with the topwood harvester, grapple skid ders, and conventional chipping at the landing.

This opportunity is large, but also expensive. Th supply curve shows that 712,000 tons are deliverabl at an average price of $20.30/ton in 1977 an $23.24/ton in 1980, not including stumpage. For th time being at least, much of this wood is out of Mead' price range. But here, as with thinning, the need fo research and development of cheaper ways to recove this material is obvious.

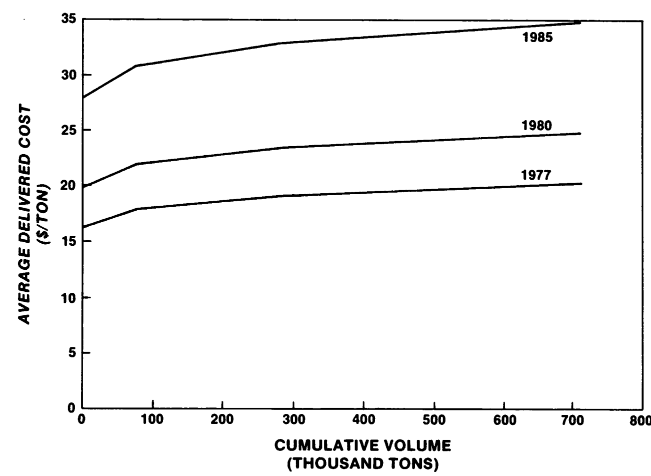

Figure 11.—*Supply curve for Mead Timbershed 1 relogging opportunities.*

Ten-mill Study Area—Northern Wisconsin and Upper Michigan

Managed harvest area and volumes

Earlier survey reports for northern Wisconsin and Upper Michigan show more than 18 million acres o commercial forest land equally distributed betweer the two States. Total inventory of growing stock ap proaches 15 billion cubic feet, and this volume con verts roughly to 700 million green tons, including residue. Of the total area, 10.5 million acres, or 58 percent, is in two types: northern hardwoods and aspen. Volumes are similarly distributed—close to 60 percent of the volume is found in the northern hardwood and aspen types.

Estimates of managed harvest levels for the two States show that about 300,000 acres containing close to 19.5 million tons including residue could be harvested from each (tables 9 and 10). However, there are some differences in the distribution of managed harvest by type: northern Wisconsin has a recommended harvest for aspen of 5.4 million tons including residues, compared with 3.2 million for Upper Michigan. But northern Wisconsin has a recommended harvest of only 5.5 million tons of northern hardwoods, compared with 10.3 million tons for Upper Michigan. Northern Wisconsin also has more oak-hickory and elm-ash-cottonwood than Upper Michigan, 4.4 million tons to 1.9 million tons.

Three more supply curves were constructed for the regional study area: (1) northern Wisconsin, all types, (2) Upper Michigan, all types, and (3) both regions, all types (figs. 12, 13, and 14).

In northern Wisconsin, 15.9 million tons of fiber and fuel wood (most sawtimber not included) can be delivered at an average cost of $14.42/ton in 1977 and $16.51/ton in 1980, not including stumpage cost. For Michigan, a similar comparison shows 14.5 million tons at an average delivered cost of $13.62/ton in 1977 and $15.59/ton in 1980. For both regions combined, 30.5 million tons are deliverable at an average cost of $14.05/ton in 1977 and $16.07/ton in 1980. Again, stumpage costs have not been included in any of these comparisons, and the tonnages do not include most of the saw logs, which were assumed to be recovered during saw log sorting or prior to relogging.

Regional demand

The 10 pulp and paper mills in the study area now use 2.44 million tons of wood, 13.6 percent or 332,000 tons of which goes to meet their own energy needs. If all study mills were able to achieve energy independence, a total of 6.43 million tons would be required, 4.32 million tons of which would be used as wood fuel.

The opportunities for achieving full energy independence vary widely among mills. The brief engineering cost analysis for each mill suggested that 5 of the 10 could now justify some increased use of wood for fuel at a cost of $10/green ton or less (table 7). Further incentives may be provided by government policies affecting fuel prices, fuel availability, and investment tax credits.

By 1980 all mills except one will probably find wood fuel attractive. These nine mills presently use 2.39 million tons of wood annually. For energy independence, they would need an additional 3.35 million tons of wood annually for a total of 5.74 million tons of

Table 9.—*Managed harvest by fuel/product classes, northern Wisconsin*
(In green tons)

Type/Site Index	Saw logs	Pulpwood	Rough and rotten	Tops, branches, saplings	Total	Acres
Jack pine <60	128,842	187,696	19,400	217,789	553,727	8,440
Jack pine ⩾60	53,847	58,921	6,608	71,856	191,232	2,900
Red pine	294,403	91,440	19,777	237,435	643,055	14,430
White pine	166,537	19,258	15,665	86,113	287,573	4,450
Balsam fir	293,656	321,940	38,325	493,393	1,148,314	14,200
White spruce	5,327	10,037	1,270	12,666	29,300	1,020
Black spruce <40	8,450	14,894	1,349	58,235	82,928	2,930
Black spruce ⩾40	11,998	7,440	3,763	21,098	44,299	820
Tamarack	10,006	46,584	5,889	50,367	112,846	4,910
Northern white-cedar	60,016	51,835	9,235	82,179	203,265	3,950
Aspen <60	200,339	567,511	91,876	688,586	1,548,312	34,730
Aspen ⩾60	609,310	1,440,085	206,939	1,598,304	3,854,638	57,370
Paper birch <60	61,885	151,273	14,553	170,870	398,581	6,010
Paper birch ⩾60	81,029	186,198	41,626	210,435	519,288	9,650
Elm-ash-cottonwood	327,214	285,334	183,169	614,211	1,409,928	37,140
Oak-hickory <60	368,895	635,377	311,681	1,106,666	2,422,619	42,190
Oak-hickory ⩾60	171,688	119,823	83,655	234,606	609,772	9,670
Maple-birch-beech <45	150,045	139,834	73,566	328,954	692,399	12,980
Maple-birch-beech ⩾45	1,515,844	1,059,042	349,566	1,860,487	4,784,939	48,480
Nonstocked	4,110	3,695	27,028	39,811	74,644	18,380
TOTAL	4,523,441	5,398,217	1,504,940	8,184,061	19,610,659	334,650

Table 10.—*Managed harvest by fuel/product classes, Upper Michigan*
(In green tons)

Type/Site Index	Saw logs	Pulpwood	Rough and rotten	Tops, branches, saplings	Total	Acres
Jack pine <60	142,186	197,598	12,879	179,296	531,959	17,18
Jack pine ≥60	8,990	25,759	851	20,838	56,438	80
Red pine	162,189	79,467	25,195	167,994	434,845	15,99
White pine	88,304	28,430	3,164	51,403	171,299	2,75
Balsam fir	369,657	339,073	34,733	441,517	1,184,980	19,12
White spruce	55,195	42,527	3,416	56,763	157,901	5,35
Black spruce <40	63,451	83,309	2,779	93,884	243,423	10,29
Black spruce ≥40	51,703	27,600	3,121	46,942	129,366	2,55
Tamarack	25,881	22,641	1,817	28,100	78,439	4,15
Northern white-cedar	357,545	191,204	46,177	333,768	928,694	15,25
Aspen <60	408,320	677,383	51,848	625,087	1,762,638	47,25
Aspen ≥60	344,926	486,300	41,091	544,361	1,416,678	21,51
Paper birch <60	56,960	139,094	13,986	118,478	328,428	7,08
Paper birch ≥60	42,200	55,424	10,908	62,949	171,481	2,16
Elm-ash-cottonwood	409,768	311,565	75,899	536,308	1,333,540	26,35
Oak-hickory <60	89,464	217,625	14,597	236,978	558,664	7,97
Oak-hickory ≥60	5,066	14,181	738	16,056	36,041	59
Maple-birch-beech <45	1,806,138	1,086,079	299,053	1,936,209	5,127,479	62,79
Maple-birch-beech ≥45	1,936,779	977,994	302,873	1,921,446	5,139,092	47,96
Nonstocked	0	1,951	6,341	3,905	12,197	9,98
TOTAL	6,424,722	5,005,204	951,376	7,422,282	19,803,582	327,07

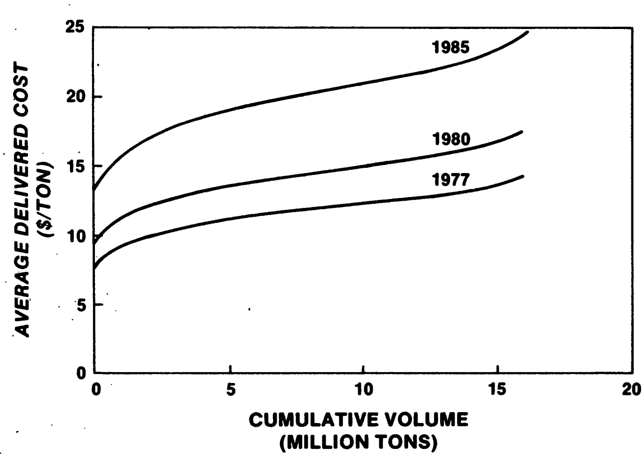

Figure 12.—*Supply curve for northern Wisconsin, all forest types.*

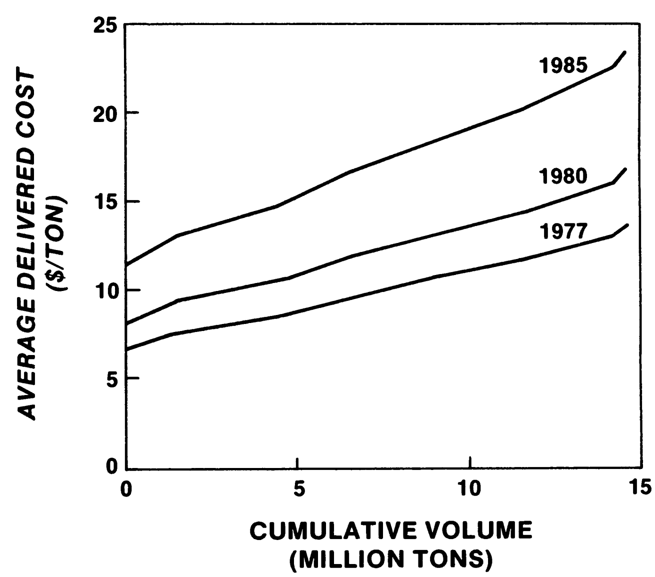

Figure 13.—*Supply curve for Upper Michigan, al forest types.*

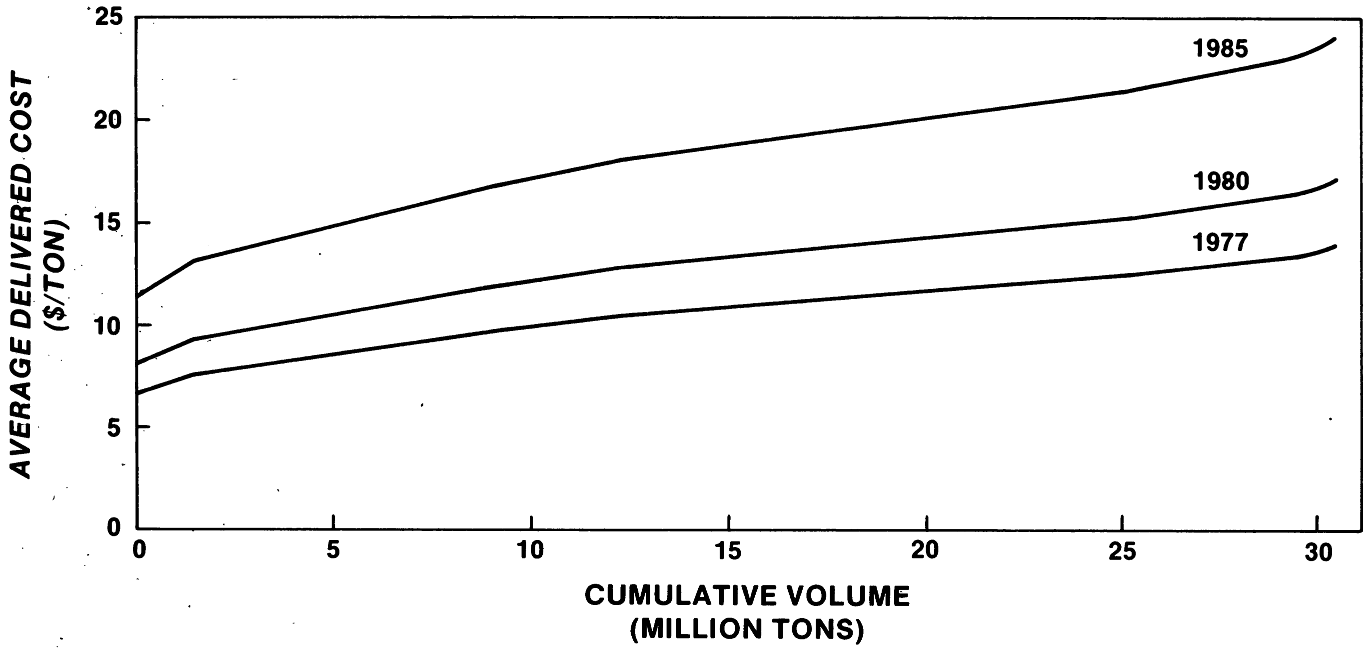

Figure 14.—*Supply curve for all regions, all forest types.*

fiber and fuel. Thus, in 1980, the increased demand of nine mills plus the existing demand of the tenth mill could equal 5.79 million tons for all needs. Given these assumptions, the following questions remain: Can the existing forest resource sustain these demands, and most important, at a price the mills can afford?

Table 7 shows maximum affordable prices that each mill can pay in 1977, in 1980, and in 1985. It seems that even in 1977 at least five mills could afford to pay more than $10/ton to achieve independence. In 1980, the demand of the 10 mills, if nine achieve independence, is estimated to be 5.8 million tons. Using the 1980 curve in figure 14, it can be seen that this 5.8 million tons of fuel and fiber can be delivered at a cost of $10.50/ton + $1.04/ton = $11.54/ton, including stumpage. This price is well below the maximum that nine of the mills can afford. And this volume is far below the 30.5 million tons of material suitable for fiber or fuel that our calculations suggest should be harvested each year.

SUMMARY

The Mead case study and the regional analysis indicate that both fuel and fiber needs can be supplied from the forest resource with significant cost savings. Mead now uses almost 900,000 green tons each year; about 100,000 tons of this provide 7 percent of its energy needs. Achieving energy independence would require an additional 1 million tons, bringing total wood use to 1.9 million tons. From a volume point of view, this projected consumption can be favorably compared to the recommended harvest of 6 million green tons from only one of Mead's seven timber sheds.

The analysis of costs in this same timbershed suggests that the 1.9 million tons could be harvested and delivered for $13.54 per green ton in 1980. This is $0.57 per ton less than the wood's equivalent fossil fuel value based on projected fossil fuel prices in 1980. Thus, achieving energy independence would result in direct energy cost savings to Mead at these same price and volume levels of at least $570,000 per year.

For the broader analysis of 10 pulp and paper mills, current wood consumption is 2.4 million green tons of which 330,000 tons go for energy. Energy self sufficiency by all 10 mills would require the added harvest of 4.0 million tons, bringing total wood use to 6.4 million tons.

Our comparison of regional supply and the specific opportunities for using more wood fuel suggests that only 9 of these 10 mills could economically achieve independence by 1980. Total wood use for this situation would be 5.8 million green tons. Again, this level must be compared to the total recommended harvest for the study region of more than 30 million green tons of fiber and fuel material.

The analysis also describes in detail several key residue opportunities that are not now being exploited: (1) thinnings from pole timber stands, and (2) tops and nonsaw log trees from selectively harvested sawtimber stands. In Mead's largest timbershed for example, these two opportunities could yield over 1 million green tons each year, over 17 percent of the total recommended harvest. However, existing harvest systems are not designed for these tasks and these harvest cost estimates are significantly higher than the costs of clearcutting. However, research and development of new equipment and methods for these improvement harvests should be able to reduce costs and permit these over-stocked stands to achieve even higher productivity and tree quality in the future.

A key factor in this analysis was the managed harvest procedure which estimated annual potential harvests based on existing forest conditions; it found some 30 million green tons suitable for either fiber or fuel or 39 million green tons if sawtimber is included. However, it must be emphasized that these estimates are in no way an upper limit on the region's forest potential. It is easily conceivable that in a regulated condition, northern Wisconsin and Upper Michigan could produce two to three times as much wood as reported here.

Closely related to the issue of increasing productivity, is a need to change residue definitions. Classifying trees as saw logs or pulpwood when they will fall down before they are needed obscures more realistic opportunities. Indeed, their use as a fuel now if no other market exists is especially appropriate. Cutting more to produce more, is not a contradiction, but is the principal means of achieving truly productive forests in the future.

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