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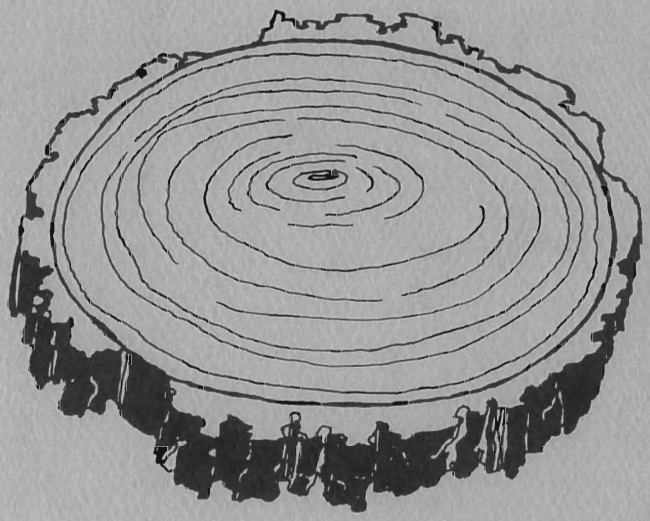
The Near-Term Potential and Present Utilization of Forest Products Manufacturing Residues for Energy in Minnesota



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Abstract

Diminishing raw material resources have brought about the need for the identification of alternative energy resources and increased conservation of conventional ones. This study presents a case for the increased utilization of the alternative resource, wood residues, by presenting information to facilitate their utilization as an energy source in Minnesota.

A partial survey of state forest products industries and interviews with state and industry personnel were carried out to obtain quantitative and qualitative information on the supply and demand for primary and secondary manufacturing residues. Survey findings reported on 849,010 green tons of residue produced annually. Of this, 34 percent was utilized for energy generation, 37 percent found use in other applications, and 29 percent went unused. The majority of residue was produced by primary manufacturers in the northern half of the state. From information obtained from the survey, it was estimated that 414,184 green tons are burned annually; this would be equivalent to 3.5 trillion Btu's. With increased utilization of unused quantities toward energy generation, supplemented by additional residue supplies from new businesses, this amount could be raised to 6.4 trillion Btu's in the near term, nearly double the current production.

Residue supply data were organized to give county and regional totals as well as quantities at each site. Descriptions are given of present burning installations in the state and related projects. Information from the survey was also used to describe some aspects of the state wood residue market. The high cost of transportation was of major importance in this area. Eighty percent of the residue utilized for energy generation was consumed at the site of production.

Introduction

It has become apparent that the United States should decrease its reliance upon non-renewable fossil fuels. Major alternative fuel sources such as solar energy, coal, large scale biomass conversion, and nuclear energy presently lack the technology to adequately or safely replace oil as the predominant fuel supply (55). Utilization of forest product residues as an energy resource could assist in decreasing this reliance in some areas while the appropriate technologies for these other alternative sources are developed. Using wood residues for energy should also prove beneficial in the development of a broad base of diverse fuel supply sources. Such a resource base is desirable to avoid a similar single resource reliance in the future.

In a typical harvest of northern hardwoods, only about 25 percent of the biomass of merchantable trees actually ends up as a finished product such as lumber (18). This means that about 75 percent of the biomass ends up as logging and mill residue with limited or no market value. Within this 75 percent, mill residues can most readily be utilized as a source of fuel (56,17).

Primary conversion operations consist mainly of sawmills, plywood and veneer mills, and woodpulp mills. Primary mills contribute the majority of residue quantities. Lumber manufacture provides residue in the form of bark, slabs, edgings, trim, planer shavings, and sawdust (Figure 1). Plywood and veneer manufacturing produce bark, a chippable core, sander dust, and chippable veneer material not suitable for commercial use. Woodpulp manufacture generates bark and chemically treated wood fiber solutions (17). Residues generated in the production of secondary products, such as millwork, pallets, fencing, and furniture, are usually in the form of sawdust, planer shavings, planer dust, and small pieces of lumber.

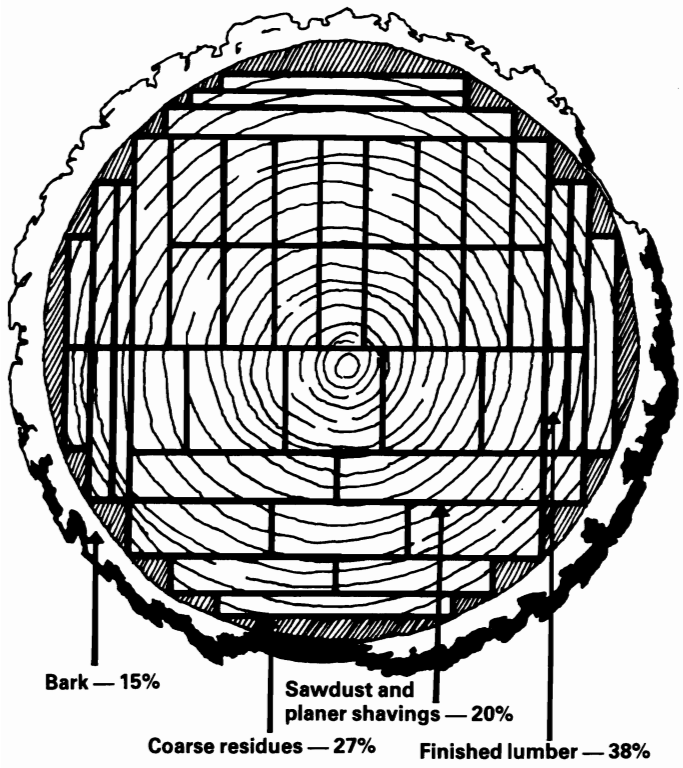


Figure 1. Cross section of a small log showing some sources of wood residue in hardwood lumber manufacture. Source: Howlett, et al. (17).

It has been estimated that wood currently supplies about 1.5 percent of the United States' energy consumption (11). Forecasts of the potential contribution generally fall around 5 percent (1,15,58,59). Since the forest products industry accounts for 2 percent of the total national energy consumption, it has been suggested that the forest industries concentrate on becoming energy self-sufficient (24). In addition to this goal, it would seem obvious for wood fuels to be used wherever appropriate. Thus, it would make sense for institutions with access to wood fuel to investigate the possibility of a wood-fired energy system.

Minnesota has 13.7 million acres of commercial forest land, constituting 27 percent of its total land area. The forest products industry ranks as one of three basic resource industries in the state. Some 40 large sawmills, an undetermined number of smaller mills which may range from 100 to 600, eight paper mills, and more than 1,300 other wood product manufacturers make up the industry. The value of forest products harvested in the state plus value added in secondary manufacture was estimated to have been $1.5 billion in 1977 (52,22,51).

Recognizing the potential of increased wood utilization, the Minnesota Energy Agency issued a report in 1977 making several recommendations to the state legislature (19). Among these recommendations are:

> ". . . a study should be conducted which would develop information on wood residues not being utilized. Publishing this information would encourage industry to consider it for their energy plans" (pg. 12).
>
> "Encourage users and suppliers of wood residues into a communicating relationship that will allow the development of total utilization of our timber resource" (pg. 10).
>
> "Commission a study to develop information on wood residues including both the currently used and unused portions of the resource. The study objective should be the publication of a detailed report listing wood residue availability, location, suppliers, form and necessary changes for marketability, potential markets and uses, potential market locations, and users and costs" (pg. 7).

This report accomplishes a portion of the tasks recommended above. Current information on wood residue supply and demand was collected from a survey and interviews taken during the summer of 1979. Information is given on residue quantities, form, location, and method of disposal utilized.

1979 Survey of Mill Residues and Results

A survey to determine residue quantities from primary and secondary conversion operations was carried out during the summer of 1979. Questions included in the survey pertained to residue form, method of disposal, residue processing equipment, transportation of residue sold, how sales transactions are carried out, and residue market prices.

An initial list of those to be sent questionnaires was derived from the 1979 Minnesota Directory of Manufacturers. Lesser producing sites were excluded on the basis of annual sales volume. Cut-off levels were $500,000 for sawmills and $1 million for other firms. Eighteen Standard Industrial Classification (SIC) categories were included. The list was supplemented with additional addresses from forest products extension personnel at the University of Minnesota and the *1979 Directory of the Forest Products Industry* (21).

The final list included 139 Minnesota enterprises. A roster of the S.I.C. categories solicited, and how they responded is included in Appendix D with a copy of the survey form. Responses were received from 87 percent of those sent surveys. Thirty-four percent of those surveyed reported they had no residues; most of these firms were in millwork or a related business.

Financial and time considerations prohibited a more comprehensive survey including all Minnesota wood products manufacturers. Instead, the list prepared contained most of the larger producers on the assumption that their production would encompass the major portion of the state's total. Whether or not this is actually the case is difficult to establish. No accurate and recent total production figures exist for state wood product manufacturers.

James Blyth of the USDA Forest Service North Central Forest Experiment Station has estimated that 38 sawmills, or 19 percent of the operating sawmills, were responsible for 80 percent of the state's lumber production in 1975 (52). A very rough estimate of total

Minnesota primary mill residues was made using 1977 state sawlog removals and 1978 state pulpwood removals. 1977 timber removals for lumber, logs, and bolts were reported as 37,050,000 cubic feet (14). Assuming 80 cubic feet of wood per cord, this would be equivalent to 463,125 cords. 1978 pulpwood removals equaled 1,228,800 cords (9). Twenty-three percent of the above volumes were comprised of thin-bark species, as denoted in Appendix E (14). Using the cord residue conversion factors listed in Appendix E, the quantity of bark residue from pulplogs, plus bark, coarse, and fine residues from sawlogs can be estimated as follows:

pulpwood:	bark residue	= [(.23)x(.17 + (.77)x(.285)]x (1,228,000)	= 319,488
sawlogs:	bark residue	= [(.23)x(.17) + (.77)x(.285)]x (463,125)	= 120,413
	coarse residue	= (.67)x(463,125)	= 310,293
	fine residue	= (.39)x(463,125)	= 180,619
		total = 930,813 green tons	

Such a total would be modified if information were available on timber exports and imports, the amount of pulpwood going to non-paper product manufacturing plants, and the percentage of sawmills with band head saws versus circular head saws. The 930,813-green-ton figure was derived using circular head saw conversion factors and would be slightly less if band head saw volumes were known and incorporated into the residue calculations. To facilitate a comparison, the 1979 survey total of 849,010 green tons was reduced by eliminating those firms believed to be involved only in secondary manufacture. The primary mill residue quantity equaled 622,225 green tons. This figure represents 67 percent of the 930,813 green tons based on timber removals. Thus, a rough estimate would show that the 1979 survey represents approximately 70 percent of the state's primary mill residue. As mentioned previously, no totals are yet available for timber harvested in 1979, making it difficult to determine a reliable estimate of the percentage of total mill residue this survey describes.

Residue quantities reported were qualitatively distinguished as either bark, coarse, or fine. Material defined as coarse included slabs, edgings, chips, planer shavings, and veneer cores. Fine material consisted primarily of sawdust. The differentiation was made assuming the three residue groups would have different market values and uses. Firms were also asked to identify the disposal alternatives utilized. Six specific methods and two additional choices, "miscellaneous" and "not used or sold," were listed. Response to this portion of the survey was very good.

Detailed results of the survey are presented in Appendices A and C. Appendix A lists the 73 firms which indicated they were producing residues.

Data presented in Appendix C give an indication of residue supply characteristics and disposal practices in different areas of the state. The data are organized by state, survey unit, and county. Figure 2 shows the location of the survey units and counties. Figure 3 gives a geographical picture of survey unit quantities.

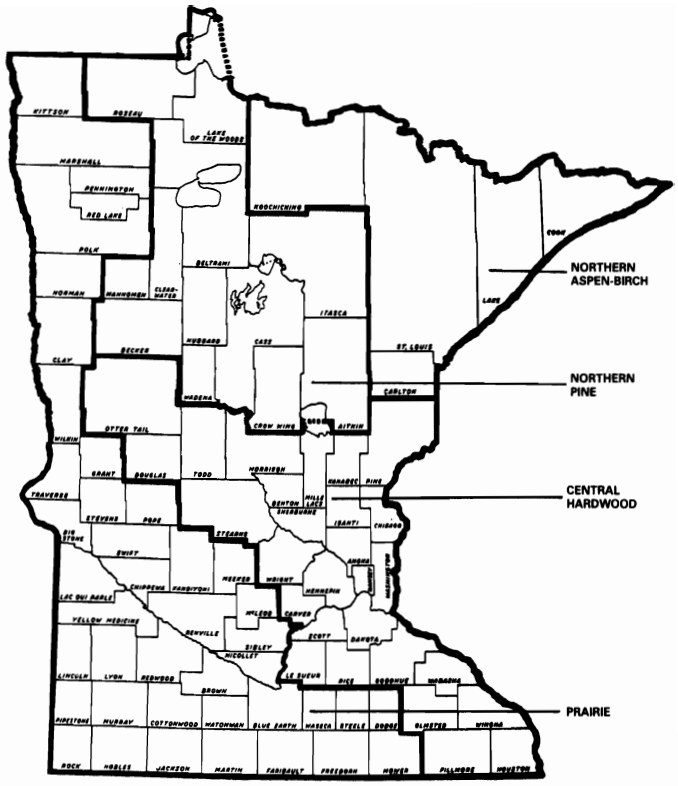


Figure 2. State survey units and counties.

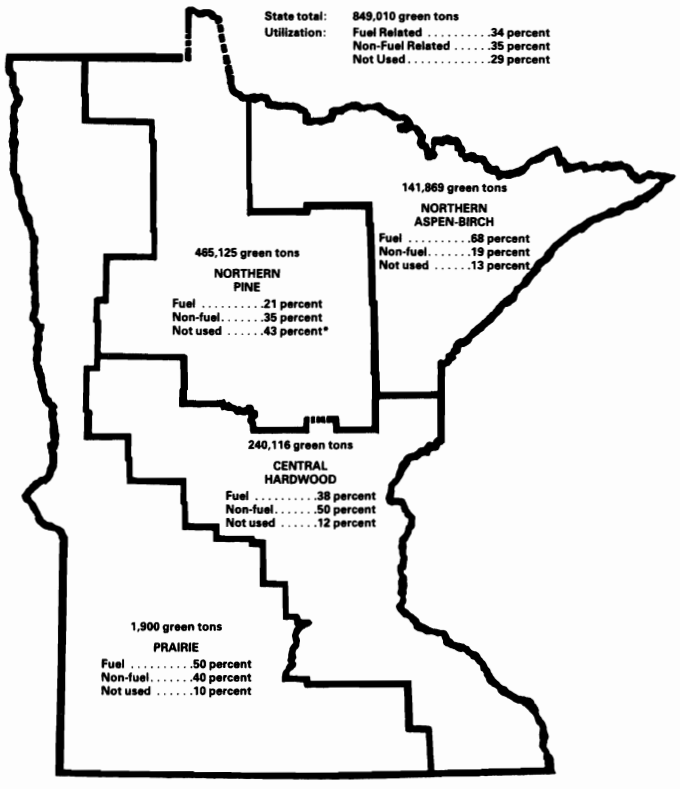


Figure 3. Reported residue quantities and utilization method by survey unit.

*This figure can be expected to change soon due to energy related projects now under construction. Most of the 43 percent not used will be utilized for energy production.

The firms surveyed reported a total of 849,010 green tons for annual Minnesota residue production. This assumes a 100 percent moisture content, based on the dry weight, as suggested in the literature (6).

The Northern Pine survey unit with 465,125 green tons, was responsible for 55 percent of the state total. The Central Hardwood region reported 240,116 green tons, 28 percent of the state total, while the Northern Aspen Birch region had 141,869 green tons or 17 percent of the state total. One county in the Prairie region provided that area's total of 1,900 green tons.

The top five counties producing residue were: Itasca, 240,657 green tons; Washington, 152,669 green tons; Beltrami, 71,841 green tons; Carlton, 59,412 green tons; and Aitkin, 49,740 green tons. The 10 highest producing counties accounted for 85 percent of the state's total. All of these except Washington County are in the northern and north-central portions of the state. Counties are ranked by annual residue production in Table 1.

Table 1. Reported county residue quantities and method of utilization.

County	Total (tons green)	Utilization		
		Fuel related %	Non-fuel related %	Not used %
Itasca	240,657	11	38	51[1]
Washington	152,669	37	63	–
Beltrami	71,841	58	15	26
Carlton	59,412	80	20	–
Aitkin	49,740	10	48	42
Koochiching	34,150	84	–	16
Wadena	32,623	19	9	71
Roseau	32,076	29	58	13
Benton	30,793	87	3	10
St. Louis	19,307	18	51	31
Cass	17,784	31	54	15
Cook	15,880	100	–	–
Fillmore	14,394	35	13	52
Hubbard	14,373	36	16	48
Lake	13,120	–	47	53
Mille Lacs	13,000	–	79	21
Houston	9,279	–	48	52
Hennepin	8,920	16	31	53
Clearwater	5,360	2	5	93
Ramsey	4,461	6	45	48
Ottertail	3,536	–	38	62
Freeborn	1,900	50	40	10
Goodhue	1,480	–	–	100
Wright	743	–	–	100
Dakota[2]	683	–	49	3
Crow Wing	348	–	–	100
Mahnomen	323	100	–	–
Scott	158	67	33	–

[1] The large portion of unused residues in Itasca County should be expected to decrease substantially over the next two years due to energy related projects now under construction in the area.
[2] The method of utilization was not reported for 48 percent of the residue in Dakota County.

A little less than half of the residue reported was from low density hardwoods with most of this being aspen. Of the remaining residue, softwoods accounted for 40 percent and dense hardwoods accounted for 15 percent. Bark, coarse, and fine residue percentages appeared to be evenly divided when compared on a state-wide basis; each constituted approximately a third of the total. However, the residue form percentage breakdown varied in different areas of the state. Bark accounted for 41 percent of the residue in the Northern Pine and Northern Aspen Birch survey units while it represented only 8 percent of the Central Hardwood survey unit total. This trend was further exaggerated in comparisons of high residue-producing counties. The two highest producing northern counties, Itasca and Beltrami, showed bark residue components of 54 percent and fine residue components of 23 percent. Washington and Benton, the two highest producing Central Hardwood counties, had bark making up 5 percent of the residue, while fine material made up 61 percent. Such differences would be expected considering the predominance of primary manufacturers in the northern counties and secondary manufacturers in the southern and central counties.

Twenty-nine percent of the residue produced annually was reported to be either dumped or given away. A slightly smaller amount, 27 percent, is utilized as fuel by the firm producing the residue. Other major uses were panel product furnish, 13 percent; agricultural use (mostly animal bedding), 12 percent; and wood pulp, 10 percent. Other disposal categories included were residue sold for industrial fuel, 5 percent; residue sold for residential fuel, 2 percent; and miscellaneous, 2 percent. Miscellaneous uses reported were ore car bottoms and using shavings in oil filters. Eighty percent of the unused residue was located in the Northern Pine survey unit with half of the unused residue in Itasca County. Firms in the Northern Aspen Birch region appear to utilize wood residues as fuel to the greatest extent; 68 percent of the residue produced in that forest survey unit goes toward energy production. As would be expected, residue utilization for agricultural uses is higher in the central and southern portions of the state.

Table 2. Utilization of residues for primary and secondary manufacturers.

	No. of firms reporting	Green tons	Percentage utilized as fuel	Percentage utilized in non-fuel applications	Percentage not used or sold
Primary manufacturers	42	622,225	32	30	38
Secondary manufacturers	31	226,785	37	56	7

Table 2 illustrates utilization patterns for primary and secondary manufacturers while Table 3 gives this information for sawmill, millwork, and papermill manufacturers. There is a marked dissimilarity between the percentage of residue going unused in primary as opposed to secondary manufacturing operations. The cleaner, drier material from secondary manufacturers found much more use in panel product furnish and agricultural applications. Table 3 gives totals for the

three industries, as determined by S.I.C. categories, reporting the highest annual production levels. The trends noted in Table 2 are further exemplified in this comparison Thirty-nine percent of the sawmill residues go unused while only 2 percent of the millwork residues are not utilized. Clearly, papermills make the fullest use of residues for the production of energy.

Table 3. Utilization of residues for sawmills and planing mills, millwork, and papermills.

	No. of firms reporting	Green tons	Percentage utilized as fuel	Percentage utilized in non-fuel applications	Percentage not used or sold
Sawmills & planing mills, general	28	406,139	23	38	39
Millwork	13	205,442	38	60	2
Papermills	4	124,879	63	9	27

The response to the other survey questions was less complete. Information included in this portion of the survey was intended to be helpful in determining residue market characteristics such as pricing and logistics. Eight questions from the survey and the responses to those questions were:

1. **What do you estimate the present market price of residue in your locality?**
   Thirty-six firms responded, giving a wide variation of prices for the different residue types. Figures are given in Table 4 for reported prices per green ton in the Northern Aspen Birch, Northern Pine, and Central Hardwood survey units. Due to the high variability of reported prices, the average prices should not be taken as a valid representation of what a buyer would be expected to pay. Rather, they should be used as an indication of the area around which the price would be expected to fall. An individual interested in current prices in a given region would get the most reliable information by contacting one of the firms in that area selling residue. There were two notable exceptions to prices exhibited in Table 4. One company in Washington County reported sawdust and planer shaving prices of $53 per dry ton and a Wadena County firm sells planer shavings for $61.50 per dry ton.
2. **Does your operation include any residue processing capabilities?**
   Twenty-eight firms replied that they have equipment for processing wood residues. The equipment consisted of 25 residue hogs or hammermills, 11 chippers, and 7 screens. Screen sizes varied from 5/8 inch to 4 inches. Of the 28 firms with equipment, 12 were located in the Northern Pine survey unit, nine in the Central Hardwood survey unit, six in the Northern Aspen Birch unit, and one in the Prairie unit. Many of these companies with processing equipment are also large residue producers. Survey totals show that 359,756 green tons of residue were sold. Seventy percent of that total was sold by firms with some type of processing equipment.
3. **Are you currently selling residue?**
   Of the 73 companies responding, 40, or 55 percent, indicated they were selling residue.
4. **Do you plan to sell residue or would you like to sell residue in the future?**
   Of the 33 firms that produced but did not sell residue, only 21 replied to this question. Fourteen said they hoped to begin selling residue, while seven answered they had no intentions of selling their residue. Reasons given for not wanting to sell residue were that the company utilized all its residue on site or that the bother of extra handling for residue sale was not worth the extra income it would provide.

Table 4. Survey unit residue prices ($/green ton).

Northern Aspen-Birch survey unit

Type of residue	Number of firms reporting	Low	High	Average
Bark	3	2.00	10.00	7.00
Slabs	1	—	—	10.00
Edgings and trim	1	—	—	10.00
Chips	2	10.00	16.00	13.00
Planer shavings	2	8.00	10.00	9.00
Sawdust	2	0.00	10.00	5.00

Northern Pine survey unit

Type of residue	Number of firms reporting	Low	High	Average
Bark	6	2.00	10.00	6.00
Slabs	2	2.00	10.00	6.00
Edgings and trim	2	2.00	10.00	6.00
Chips	5	2.00	20.00	12.00
Planer shavings	7	2.00	31.00	14.00
Sawdust	5	2.00	10.00	6.00

Central Hardwood survey unit

Types of residue	Number of firms reporting	Low	High	Average
Bark	2	8.00	10.00	9.00
Slabs	1	—	—	20.00
Edgings and trim	6	5.00	20.00	10.00
Chips	4	14.00	20.00	17.00
Planer shavings	5	4.00	27.00	16.00
Sawdust	11	2.00	27.00	9.00

5. **Is your firm's residue production seasonal?**
   Fifty-six companies answered. Thirty-five said production was even throughout the year and 21 said they had peak and low periods. The 21 with seasonal production represented 39 percent of the 56 firms' total residue quantity. Most had highest production levels in the summer and lowest levels in December and January. For these companies, average summer-month production was 10 percent of annual volumes, while winter monthly production was 4 percent of annual volumes.

6. **If your firm is currently selling residue, how is the residue transported?**

   Thirty-three responses revealed that no company used barges, two firms employed the railroad, and all 33 used truck transportation. The two companies using the railroad shipped large quantities by rail and had tracks adjacent to their manufacturing site. Their combined volume transported via rail equaled 30 percent of the reported 359,756 green tons sold annually.

7. **What is the distance from your plant to rail and barge access?**

   Very few firms answered the question on distance to barge access, indicating that this perhaps is not a practical consideration. On the question pertaining to rail access distance, 25 companies said they had track access adjacent to their plant. Thirty firms reported distances varying from one-quarter of a mile to 50 miles. The annual residue volumes of the 25 companies with immediate access represented 64 percent of the total annual production of the 55 companies reporting.

8. **Do you, or would you consider delivering residue?**

   Sixty firms replied. Thirty-one indicated they were willing to deliver residue, 29 said they would not deliver residue. A comparison of these two groups based on the annual volume of residue sold showed that they represent nearly equal quantities of residue.

9. **If you are currently selling residue, are you in a long-term (two years or more) contractual agreement with any buyers?**

   Of 41 replies, only four said they were engaged in such a contract. The annual sales volume of these four companies represented 8 percent of the 41 reporting companies' annual sales volume.

10. **How are sales transacted?**

    According to responses received to this question, most sales are conducted directly between the buyer and seller. As can be seen in Table 5, half of the residue volume passes through a market intermediary. Though only eight firms reported that they sell to a wholesaler, this channel accounted for 49 percent of the sales on a volume basis. Sales of two firms constituted most of this 49 percent.

Table 5. Channels of distribution for residue sales.

Distribution channel	Number of responses	Percent of sales volume
Firm directly solicits business from user	13	25
User directly solicits business from firm	21	25
Agent/middleman buys from firm	1	1
Wholesaler/middleman buys from firm	8	49

Present Utilization of Wood Residues as an Energy Source in Minnesota

This portion is concerned with existing and impending demand for wood manufacturing residues as an energy source.

The number of establishments burning wood residues in Minnesota has been rapidly increasing. Industrial and municipal concerns have converted to wood residues from natural gas and oil, both with and without government financial backing. As of fall 1979, several large projects were being considered, some wood burning installations were under construction, and many others were supplying heat and power. Descriptions of many of these applications are given in this section. A list of wood-fired systems now in operation is given in Appendix B. The information was taken from telephone conversations with the Minnesota Energy Agency, the Minnesota Department of Natural Resources, the Minnesota Department of Economic Security, the Minnesota Department of Economic Development, and for the most part, individuals at the institution or company involved. Harlan Petersen of the University of Minnesota Forest Products Department also supplied information (51). The authors believe all descriptions to be accurate at the time of the informal survey, but have no way of knowing the current accuracy of the descriptions.

New or Proposed Projects Utilizing Wood Residues as a Fuel

The Minnesota Department of Economic Security is involved in the development of new wood densification plants for the state. Federal money may be available through the Community Services Administration, though no money has been committed.The money is earmarked for densification plants in Minnesota, Wisconsin, and Michigan. Four sites were chosen in Minnesota: Rushford in the southeast, St. Cloud in central Minnesota, the White Earth Indian Reservation in the northwest, and an undetermined location in the northeast (39).

The St. Cloud site involves the Four Rivers Development Corporation producing pressed roundwood fireplace logs. The White Earth Indian Reservation project involves the production of fuel pellets in an operation similar to that of Aspen Fiber Products in Marcell, Minnesota. Project leaders estimated costs of such densification plants to be approximately $1 million. It was assumed that other state and federal money would be forthcoming once the Community Services Administration supplied a funding base (35,53).

District heating has been proposed for two towns in northern Minnesota. Aitkin is investigating the implementation of district heating with or without cogeneration. An original proposal was written by the Woodland Container Company, which produces large

volumes of wood residues in Aitkin, calling for the production of hot water from wood-fired boilers. The water would be piped into the city under pressure at temperatures of 250-270 degrees F. The town is now writing a new feasibility study using money from the Blandin Foundation and the Minnesota Energy Agency. The new study will consider systems involving cogeneration as well as heat and hot water sources (41).

The Bagley Industrial Development Corporation is considering a cogeneration plant for the town of Bagley. An initial proposal has been completed and now, with money from the Minnesota Energy Agency, an economic feasibility study is underway. As with the Aitkin project, the study is administered locally. The proposed system involves burning western coal with wood residues collected largely within a 50-mile radius of the town. Additional residue may be made available by taking advantage of empty grain trucks traveling Highway 2. Trucks returning empty from the Duluth harbor could pick up wood residue along the way and deposit it in Bagley. The project leader estimated that a cogeneration plant could be in operation in four years (28).

The Cook County Hospital, Nursing Home, and Clinic have investigated the possibility of connecting to the Grand Marais school system's wood-residue-fired heating system (described later). A feasibility study has been completed and the only remaining task is to finance the estimated $180,000 cost of the project. The county was unable to find outside backers and did not have the necessary funds. It plans now to have the school finance the new system. Then, the county will make monthly payments to the school for steam and purchase of the system. By the end of the four years, the county will own the steam lines and will continue to purchase steam from the school (31).

Minnesota Department of Natural Resources personnel report that other schools are interested in establishing wood-residue-fired heating systems. Those schools include Northome, McGregor, Menahga, Virginia, Hibbing, Vermillion Junior College, and Bemidji State University. Bemidji State has carried out a test burn. One of its three boilers can accept wood residue fuel, the other two would need modifications. The university may burn some wood in the upcoming winter. The McGregor school can burn wood pellets instead of the coal it is now burning and is looking for a pellet source (33,32).

Northome recently completed a new building for kindergarten through twelfth grade with a heating system designed for fuel oil. The school is now interested in purchasing a gasification unit and substituting wood gas for fuel oil in its boiler. Costs of a silo, conveyor system, and gasifier are estimated to be $100,000. Northome is now trying to find a source of funding. The school would use either pellets or chips in the gasifier (44).

A regional Department of Natural Resources complex to be built in Grand Rapids will be wood heated. The plans call for a $225,000 boiler which will burn wood residue in the form of green chips (32).

Two of the larger paper mills in the state are constructing cogeneration systems for their plants. Blandin Paper Company, Grand Rapids, is building two units that will burn coal and wood to produce steam, electricity, and heat. Forty percent of the energy output from the two units is expected to come from wood residue, mostly bark. The remaining 60 percent will come from an annual consumption of 160,000 tons of western coal. High-pressure steam will power a generator to produce electricity, while the resulting low-pressure steam and exhaust will be used to dry paper and heat the buildings. The system is expected to meet 40 percent of the mill's electrical needs. Wood residue will come from the paper mill, the nearby Blandin Wood Products mill (which produces waferboard), and other close sources. Blandin Wood Products will continue to use natural gas for its fuel needs. Construction was scheduled for completion in October, 1980 (29).

Potlatch Corporation at Cloquet also hoped to have its single unit cogeneration plant operating in October, 1980. Its new boiler is capable of burning 75,000 pounds of bark and sawdust per hour. Residue will come from the paper mill and the adjacent Potlatch stud mill. All the heat energy needs of the two mills will be met by the wood-fired system. The boiler will burn wood waste and coal together, with the wood waste producing as much as 80 percent of the energy. The company also said that within two years Potlatch will be operating new waferboard plants near Bemidji and Cook, that will utilize residues for energy purposes (46).

Dietmar Rose, of the University of Minnesota College of Forestry, has a study in progress to assess the amount of forest material available for energy use in a portion of north-central Minnesota. Rose is interested in determining whether there are adequate resources and whether harvesting and transportation costs can be sufficiently minimized to support the building of a small wood-fueled power plant (25 MW) in or around Bemidji. His analysis should provide new information in a comprehensive, updated forest inventory for the area. It will also provide financial analyses of harvesting and transport operations, wood fiber production systems, and a proposed wood-fueled power plant (50).

Existing Facilities Utilizing or Processing Wood Residues as a Fuel.

Minnesota has two wood densification plants. Guaranty Fuels, Inc. in Stillwater currently supplies the Stillwater prison, and Aspen Fiber Corporation in Marcell began pellet production in February, 1980.

Guaranty Fuels is a Kansas-based firm which built a densification plant on the Stillwater prison grounds in 1978. The total cost of the new plant was estimated to be $1.2 million. The company received a $550,000 grant as incentive from the Minnesota Department of Corrections, which got the money from the Department of Natural Resources and the U.S. Department of Agriculture. The prison is the company's primary customer. However, should pellets in excess of the

prison's needs be produced, the product will be marketed to other concerns (4). The plant's output capacity is 35,000 tons of pellets per year, with a raw material input of 70,000 tons of green chips per year. It anticipates drawing wood residues from a 100-mile radius of the plant. The company hopes to use diseased metropolitan elms. The green chips are first dried, then ground, and then heat and pressure are used to form pellets out of the ground material. The pellet specifications are (54):

Moisture content — 10 percent
Btu content — 8,000 Btu/pound
Density — 40 pounds/cubic foot
Ash — 2 percent
Sulfur — 0.1 percent

Aspen Fiber Corporation in Marcell initiated pellet sales in February, 1980. Costs for the new facility should fall just below $1 million. The company received a $168,000 loan from the Minnesota Department of Economic Development and a $475,000 loan from the Small Business Administration. The remainder of the money came from the private sector. Thirty to 40 percent of the raw material will come from the adjacent Marcell Mill and Lumber Company. The remaining wood residue input will come from primary and secondary mill operations within 60 miles of the densification plant. Industrial and commercial markets are the intended sales targets, though the residential fuel market may be approached if fuel oil prices rise enough. The plant expects an output of about 10 tons per hour (5,34). Green material is ground, dried, reground, and then pressure-formed into pellets. Marcell's pellet specifications are (7):

Moisture content — 8-10 percent M.C. can be raised or lowered as required
Btu content — @ 8 percent M.C., 8,000 Btu/pound
Density — 36 pounds/cubic foot
Ash — Less than 3 percent
Size — Standard size of 1/4" diameter, 1/2"-1/4" in length. Size can be altered as required.

Forest product industries make up the majority of those facilities burning wood residues for energy. Some municipalities and other industries have recently converted to this practice as well. The selected list of wood burning installations described here is by no means comprehensive due to the large number of small businesses burning on a lesser scale and the rapidly increasing number of firms and other institutions that have begun to switch over since the recent increases in fossil fuel prices. Appendix B gives a roster of facilities currently utilizing wood wastes for energy. A short description of some of the cases listed in Appendix B is detailed below:

☐ Andersen Corporation in Bayport has utilized the waste from its millworking operation since the company began in 1903. Wood energy heats its buildings and process steam is utilized to power parts of its manufacturing process and its air conditioning system. The company has two hammermills to convert all its wastes to sawdust (26).

☐ Advance Machine in Spring Park converted to wood in 1979. The company does not produce wood products and planned on utilizing diseased elm chips. It now gets most of its chips from other state sources. Its conversion to wood entailed building a new heating plant, storage silo, and automatic transfer system. The company uses the energy to heat its buildings. Chips are burned green though the boiler can be adapted to accept different fuel moisture contents. Fuel input is estimated to be 2,500 to 3,000 tons per year (27).

☐ Busch Greenhouses in Hamel converted in 1977 and consumes 4,000 tons annually. Wood is used to heat the greenhouses for six months of the year (30).

☐ The Grand Marais school system began burning wood in the spring of 1978. A new heating plant was built and the school purchased a 398-h.p. boiler, a storage silo, and pipes. Wood energy is used to heat the buildings and water. The system currently operates from September to April using sawdust purchased from Hedstrom Lumber in Grand Marais. The system was originally built to include the Cook County Hospital and Nursing Home (36).

☐ Lake Elmo Hardwood recently converted from natural gas to wood to heat one building and operate six kilns with a total capacity of 240,000 board feet. A chipper was purchased to convert the company's shavings, sawdusts, edgings, and slabs to a more uniform fuel (37).

☐ Poly-Foam in Lester Prairie does not heat directly with wood, but rather purchased a 350-h.p. boiler to generate high pressure steam from wood waste. The company burns between one and two tons per hour to generate steam to power its manufacturing processes (45).

☐ Rajala Timber Company bought used boilers four years ago and uses wood residue in its Deer River and Big Fork operations. The Deer River plant has two wood boilers burning sawdust and bark to heat kilns with a capacity of 200,000 board feet. The Big Fork plant burns bark alone to heat buildings and kilns with a 60,000-board-foot capacity (48).

☐ Woodcraft Industries, Inc. in St. Cloud began installation of a wood waste burning system in October, 1977, and completed it in March, 1978. The company estimates that 1,500 tons of plant residue will be burned annually, supplying heat for 85,000 square feet of building space and generating steam to operate dry kilns with 200,000 board foot capacity. Cost of the system was $140,000. Residue used consists of 80 percent oak, 15 percent elm, and 5 percent maple (51,2).

☐ Minnesota Sawdust & Shavings in Anoka modified its animal bedding product line to a cleaner grade, resulting in 15 percent more wood waste. To utilize the increased residue volume, the company installed a $29,000 wood waste boiler. The new boiler produces seven million Btu's per hour from an input of 800 pounds of wood waste per hour (42).

☐ The Stillwater prison in Bayport has contracted with Guaranty Fuels, Inc. to purchase 18,000 tons of wood pellets annually. The fuel pellets are expected to meet all of the prison's fuel requirements. The prison would have had to spend roughly $1 million to upgrade its former coal burning system to meet pollution requirements. Costs of the new wood burning system were estimated to be less than $329,000. The Guaranty Fuel densification plant was built on prison grounds with unused prison farm buildings being used for storage. Pneumatic tubes transfer the pellets from storage to the boiler. Operation began in early 1979, but had to be curtailed due to problems with the pellets disintegrating in the pneumatic transfer system. The wood pellets were put into full use again in the summer. September usage was 16 to 18 tons per day. Estimated cold weather usage is 60 to 65 tons per day (4,49).

☐ Northern States Power generates electricity with a wood and coal mixture at its peaking facility in Red Wing. This small generating plant is used only when electricity demand surpasses the company's supply from other plants. Due to the erratic usage rate, raw material inputs are hard to estimate. The fuel mixture burned is 30 percent wood waste and 70 percent coal. Wood waste comes from a Webster Company sawmill in Bay City, Wisconsin. Northern States Power is negotiating to purchase Ramsey County's municipal wood waste. A portion of that wood waste would come from the county's diseased elm trees. The company is also considering establishing a larger wood and coal burning plant in the Twin City metropolitan area. If built, county wood waste would provide the needed wood residue raw material (43).

Trends and Near-Term Potential

The 1979 survey reports that 285,738 green tons of wood mill waste were burned to supply energy. By using the fuel equivalencies listed in Table 6, an evaluation of the energy supplied can be determined. At 8.5 x 10^6 Btu ton, 285,738 green tons of wood waste would yield 2.4 trillion Btu's. If one takes fuel combustion efficiency into account, using 65 percent for wood, the figure would be reduced to 1.6 trillion Btu's. Using effective heating values from Table 6, a comparison shows that this amount would be equal to 320,000 barrels of residual fuel oil, 110,000 tons of western coal, or 21,000,000 Ccf of natural gas.

The figures refer to quantities reported in the 1979 survey and do not represent the state total. To facilitate a comparison with the present state fuel sources, a rough estimate can be calculated employing utilization patterns from the 1979 survey. Such a calculation is carried out here to obtain an estimate of the contribution of wood fuel toward energy consumption in the state's industrial sector. Thirty percent of the primary mill residues are used for production of energy in the industrial sector. Applying this percentage to the estimated 930,813 green tons of primary mill residue produced annually yields 280,000 green tons utilized for industrial energy generation. Total state residue production from secondary manufacturers is unknown. The 1979 survey reported 82,645 green tons utilized as industrial fuel; this figure can be used as a conservative estimate. Adding the 30,239 green tons reported by industrial wood fuel consumers yields a total of 392,884 green tons. At 8.5 x 10^6 Btu per ton, the energy equivalent of this amount would be 3.3 trillion Btu's.

Table 6. Fuel combustion values.

Fuel	Units	Heating value per unit* 10^6 Btu	Combustion** efficiency %	Effective heating value 10^6 Btu
Natural gas	Ccf	.10	76	.076
Residual fuel oil	barrels	6.3	80	5.04
Western coal	tons	17.6	80	14.1
Wood residue (100 percent M.C. oven dry basis)	tons	8.5	65	5.525

*Source: Bergvall, *et al.* (8), Arola (6), Minnesota Energy Agency (23).
**Source: Bergvall, *et al.*, (8).

A comparison of this figure with the fuel data in Table 7 suggests that wood waste fuel plays a small role at the present time. Natural gas, fuel oil, coal, and electricity are the predominant industrial fuel sources in the state. Natural gas is the largest source, having provided 120.1 trillion Btu's to the industrial sector in 1978. If mill wastes were incorporated into the industry fuel consumption column in Table 7, their energy contribution would fall above kerosene and below liquid propane gas.

Table 7. 1978 state fuel consumption in the industrial sector.

	10^{12} Btu*	Percentage
Natural gas	120.1	41
Coal	41.4	14
Distillate fuel oil	30.8	10
Residual fuel oil	18.1	6
Gasoline	30.9	10
Liquid propane gas	10.8	4
Kerosine	0.9	–
Electricity	41.8	14
	294.8	
**Wood, mill residues	3.3	

Source: Minnesota Energy Agency, unpublished data (40).
*Does not take into account combustion efficiencies.
**This figure was calculated using results of the 1979 mill survey and information from firms presently utilizing residues for energy production. This total does not include energy produced from logging residues or take into account residential firewood.

These comments should not be interpreted as evidence that mill residues represent an unimportant fuel source. On the contrary, by estimating an equivalent fuel value for combusted wood waste it can be shown that mill residues represent a substantial monetary value to the firms utilizing them for energy generation. The monetary worth of 392,884 green tons utilized for

industrial energy generation can be ascertained by using the fuel conversion factors from Table 6 in the following manner:

Btu production from wood residue:
(392,884 green tons) x (5.525 x 10^6 Btu/green ton)
= 2,200,000 x 10^6 Btu

Natural gas equivalent:
2,200,000 x 10^6 Btu)/(.076 x 10^6 Btu Ccf)
= 28,900,000 Ccf @ $0.257/Ccf, monetary value
= ($0.257/Ccf) x (28,900,000 Ccf) = $7,400,000

Residual fuel oil equivalent:
(2,200,000 x 10^6 Btu)/(5.04 x 10^6 Btu barrel)
= 440,000 barrels @ $22.68/barrel,
monetary value = (440,000 barrels) x
$22.68/barrel) = $10,000,000

Coal equivalent:
(2,200,000 x 10^6 Btu)/(14.1 x 10^6 Btu/ton)
= 160,000 tons @ $30.00/ton, monetary value
= (160,000 tons) x ($30.00/ton) = $4,800,000

Such an analysis reveals that the reported wood products manufacturing residues represent a $4.8- to $10-million annual fuel saving value for the state.

In addition to the 392,884 green tons supplied to the industrial sector, wood residues were also sold as a residential heating fuel. The 1979 survey showed that 2 percent of the primary mill residue was utilized in such a manner. Two percent of 930,813 green tons equals 19,000 green tons. The survey also indicated that 2,300 green tons of secondary mill residues were sold in the residential fuel market. Annual wood residue utilization toward industrial and residential energy production is then found to equal 414,184 green tons.

To develop a more accurate portrayal of the total energy contribution from wood fuels, other sources would also have to be considered. Two major sources not accounted for in this study are residential firewood and logging residues. Firewood supplies considerable energy for the state's residential sector and logging residues potentially could contribute to both the industrial and residential sectors. Accurate estimates of the fuel contribution from these two sources are not currently available.

The amount of wood residue utilized for energy purposes can be expected to increase in the near future. Increases will come from fuller utilization of present residue supplies and increased state residue production from new manufacturing operations. Certainly, as fossil fuel prices escalate further, wood residues that are presently dumped or given away will be used for fuel. Thirty-eight percent of the residue produced by primary manufacturers is not used or sold. Thirty-eight percent of 930,813 green tons is equal to 350,000 green tons of wood biomass. Seven percent of the secondary mills' residue supply, equal to 16,000 green tons, are similarly unutilized. If half of the unutilized total were directed toward energy generation, this would entail an additional 183,000 green tons to the state's annual wood fuel supply.

Near-term major expansion of the state's forest products industry will come from four new aspen waferboard plants that are either planned or under construction. Potlatch Corporation has broken ground for new plants in Bemidji and Cook; Northwood Pulp and Timber, Ltd. has broken ground for a new plant in Bemidji; and Louisiana Pacific Corporation has plans for a plant in Minnesota. Thomas Smrekar, Minnesota wood products manager for Potlatch, estimated the plants would have an annual input of 120,000 to 130,000 cords of aspen (47). Smrekar and Bill Jacobs, waferboard sales manager for Louisiana Pacific, both said the new plants will utilize all their residue to generate all energy needs other than electricity (38). The Bemidji Potlatch plant should be on line in early 1981 and the Cook plant sometime in 1982. The state's existing waferboard plant, Blandin Wood Products Company in Grand Rapids, is also expanding production. Its current annual timber consumption will increase by 60,000 cords (3).

Energy production from increased wood residue production should be substantial. Four new waferboard plants, each with an annual input of approximately 120,000 cords, plus a 60,000 cord increase at Blandin Wood Products, would cause an annual timber consumption increase of 540,000 cords of aspen. Using a conversion factor of .285 tons per cord as indicated in Appendix E, the increased production would generate 154,000 green tons of bark residue.

Thus, the wood manufacturing residue fuel resource could increase by 337,000 green tons over the next three years. Adding this amount to the 414,184 green tons currently used for energy production yields an annual fuel supply source of approximately 750,000 green tons. At 8.5 x 10^6 Btu's per ton, this is equivalent to 6.4 trillion Btu's. Again, this figure is too small to supplant any of the larger diminishing fossil fuel sources. It is, however, sufficient energy to have a substantial impact on an individual industry or some local communities.

Residue quantity increases from wood manufacturing expansion in the state appear to have been designated towards energy generation at the site of production. Blandin Paper Company has said it plans to utilize residue increases from Blandin Wood Products in a cogeneration facility now under construction. This means that while the state forest products industry may move more in the direction of energy self-sufficiency, little of the increased residue production will likely be available to the outside public sector. Other industries and communities interested in converting to wood combustion systems fueled by manufacturing residues will have to look to those companies with unutilized or underutilized residue supplies.

Whether or not these wood residues are utilized to the fullest extent depends on how successfully they can be marketed. Certainly, significant residues are available and a market for them as a fuel source exists. The majority of residues are produced via primary manufacturing operations in the northern half of the state. As indicated in Table 2, 38 percent of the primary residues are disposed of at either a net loss or no revenue to the firm producing them.

The market for wood residues appears to be poorly developed at best. This is most likely due in part to the material historically being a cost inducing rather than a revenue producing by-product. Also, because of handling costs, it is normally best used at the site where generated. The high variability of prices reported in the 1979 survey would indicate that the material's true worth has yet to be established in many areas. Prices are generally higher in the Central Hardwood region where the supply of residues is less.

Though half of the residue volume sold passes through a wholesale intermediary, the majority of firms sell residue through a less sophisticated, direct route. Most of the wholesale volume is accounted for by two large secondary manufacturers producing a relatively clean and dry residue product. Thirty-four firms reported direct sales of residue while only nine said they made use of an intermediate distribution channel. Market supply might be expected to be slightly depressed during December and January in some areas. Uneven seasonal production would not appear to be a significant deterrent, though, since 60 percent of the residue currently sold is produced uniformly throughout the year.

The major limiting market parameter of wood residue sales is probably transportation costs. As with other low cost commodity goods, the size of the market area may be defined by the distance from the site of production. The major marketing advantage of wood residue is its low cost. As the distance between the points of consumption and production increases, the low cost competitive edge rapidly diminishes. The 1979 survey showed that 80 percent of the reported residue utilized for energy generation was consumed at the site of production.

Figure 4 demonstrates the significance of transportation costs in determining market size. This figure was constructed using effective values from Table 6, average current industrial sector fuel prices from state fuel suppliers, and trucking transportation costs from Table 8. At a price of $10 per green ton, wood residues were competitive with residual fuel oil only within a 25- to 30-mile radius of the production site. If the price was $5 per green ton, the market size would increase to a 40- to 45-mile radius of the point of production.

Reducing the moisture content of the wood material would substantially increase the size of the marketing area. Wood biomass at 50 percent moisture content (oven-dry basis) will produce one and one-half times the Btu's produced by wood at 100 percent moisture content (M.C.). Completely dry material, 0 percent M.C., has twice the Btu content of the 100 percent M.C. material (6). Secondary manufacturers, providing residue at low moisture contents, are able to market their residue product over a much larger area. The vast majority of unused mill residue is not at such a reduced moisture content. Thus, there may be a cost inducement for firms to consider a residue processing scheme that would decrease the moisture content of their product.

Figure 4. Costs of wood residue fuels vs. fossil fuels. (1979 Minnesota industrial sector)

A – wood residue, 100 percent M.C. oven dry basis, @ $20/ton.
B – wood residue, 100 percent M.C. oven dry basis, @ $15/ton.
C – wood residue, 100 percent M.C. oven dry basis, @ $10/ton.
D – wood residue, 100 percent M.C. oven dry basis, @ $ 5/ton.
E – residual fuel oil.
F – natural gas.
G – coal.

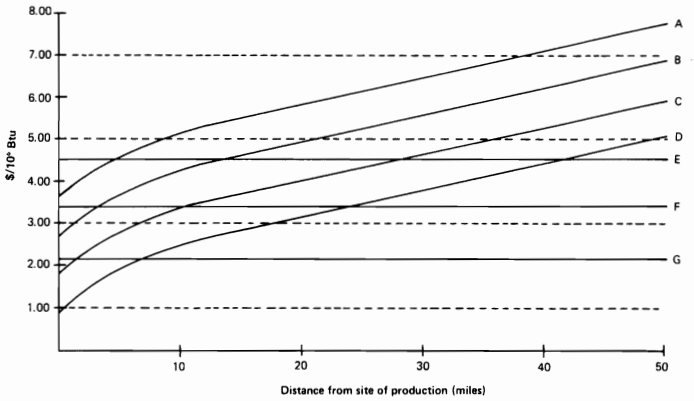


Table 8. Mill residue transportation costs.

Distance	Truck	Rail
	Costs per ton-mile*	
10 miles	$.1620	$.5680
20 miles	.1109	.5680
30 miles	.0947	.5680
40 miles	.0860	.5680
50 miles	.0840	.5680
60 miles	.0767	.0987
70 miles	.0743	.0880
80 miles	.0720	.0799
90 miles	.0707	.0746
100 miles	.0698	.0704

*Assumes 100 percent M.C. oven dry basis.

Source: Bergvall, *et al.* (8).

Survey findings indicate that trucks transport most of Minnesota's residue sales. Two large secondary manufacturers utilized rail transportation. Both sold large quantities of a dry residue product. As can be seen in Table 8, rail costs are significantly more than trucking costs until the distance hauled exceeds 100 miles. Thus, truck transportation would appear to be more appropriate for a predominant segment of the residues. Half of the residue volume marketed was sold by companies that expressed a willingness to undertake delivery of the material.

High transportation costs tend to encourage the utilization of the unused portion of residues at locations close to the site of production. Though there is a strong market for animal bedding in the south, central, and western parts of the state, the majority of residue

originates in the north-central and northeastern parts of the state. Also, the wood panel and paper manufacturers should not be expected to use a large portion of the unused residue. There are only four paper mills in the state which are significant wood consumers. Three of these are located in counties without substantial unused residue supplies.

Wood fuel markets, on the other hand, are plentiful and widely dispersed throughout the areas where unutilized residue supplies exist. This fuel demand can be separated into two distinct markets, residential and industrial or institutional consumers. The former would desire a more selective product, probably limited to slabs and some edgings, while the latter would be better able to utilize the different forms of manufacturing residues. Also, the 1979 survey showed that 70 percent of the residue sold in the state was sold by companies with residue processing equipment. This equipment generally renders a hogged fuel more appropriate for industrial sized boilers. Demand in the residential market can be expected to increase due to fuel oil and natural gas shortages as well as higher prices. Despite this, residential consumption should be limited because of the residue form restrictions of the market. The industrial and institutional consumers, facing the same fossil fuel dilemma, should be able to more fairly exploit the mill residue resource.

The five counties with the largest supplies of unused residue are Itasca, 123,000 green tons; Wadena, 23,200 green tons; Aitkin, 21,000 green tons; Beltrami, 18,900 green tons; and Fillmore, 7,500 green tons. Using effective heating values from Table 6, Itasca's excess residue supply is equal to $.68 \times 10^{12}$ Btu's or, in residual fuel oil equivalency, 40,500 barrels annually. This figure will change soon due to Blandin Paper's cogeneration project and Aspen Fiber Corporation's wood densification project. More than 90 percent of Itasca's unused residue is earmarked for these two facilities. The Department of Natural Resources' new building with wood heat will utilize a portion of what residues are left.

The next three counties — Wadena, Aitkin, and Beltrami — perhaps represent the areas with the most unrealized energy generation potential. The city of Aitkin appears to be trying to take advantage of this via its district heating proposal. In Beltrami County, more than 16,000 tons went unutilized in Kelliher. A similar situation exists in Menahga, in Wadena Conty, where 23,000 tons are available annually for fuel use. In each of these areas, it would appear that reliance upon fossil fuels could be lessened by utilizing the local mill residue resources that are currently not marketed.

Conclusion

The 1979 survey reported an annual residue production of 849,010 green tons. This survey covered only the larger producers and accounted for approximately 70 percent of all residue generated by primary processing. Fifty-five percent of the residue was located in the Northern Pine survey unit. Itasca, Washington, and Beltrami were the highest producing counties. Thirty-four percent of the residue was utilized for energy production, 35 percent was utilized in non-fuel related applications, and 29 percent was not used or sold. Major non-fuel related applications were pulp and paper manufacture, wood panel furnish, and agricultural uses.

Forty sites were located where residues are currently used for industrial or institutional energy generation. Thirty-four of the 40 utilize wood waste produced on site. Combustion systems employed ranged from the modification of existing boilers to the construction of cogeneration facilities at two paper companies. Other related projects include district heating proposals and two wood densification plants presently producing pellets.

Annual energy production from wood residue was estimated to be 3.5 trillion Btu's from 414,184 green tons. This material was shown to represent an annual fuel savings for the state of $10 million when compared to the cost of an equivalent amount of fuel oil. The addition of one-half of the unused portion plus increased residue production from new waferboard plants in Minnesota would bring the wood residue fuel supply to approximately 750,000 green tons annually. Thus, manufacturing residues from forest products industries have the potential to supply more than 6.4 trillion Btu's in the near term.

While this amount is insufficient to supplant any of the currently predominant fossil fuel supplies, wood residues do have the potential to dramatically reduce fossil fuel dependence of some specific industries or small communities. Wood processing residues appear to be most appropriate for industrial or institutional energy generation applications. High transportation costs encourage their use close to the site of production. Many of the firms currently selling residue have the capacity to reduce the material to a readily combustible hog fuel.

Numerous companies have already successfully converted to a wood-fired system. Business firms, schools, hospitals, and other institutions investigating economical and secure energy production systems have considered wood residue fuel sources. Should excess or underutilized manufacturing residues be present in the community, such a fuel source could prove to be quite practical.

Appendix A

Surveyed Firms That Produced Residue

Table 9. Residue producing firms surveyed and reported method of residue utilization.

Company	County	Fuel	Non-Fuel	Not Used
Andersen Corporation Bayport	Washington	XXX	XXX	
Bagley Kiln & Component Parts — Bagley	Clearwater	XXX	XXX	
Bell Pole Co. New Brighton	Ramsey		XXX	
Blandin Paper Co. Grand Rapids	Itasca			XXX
Blandin Wood Products Grand Rapids	Itasca			XXX
Boise Cascade Corp. International Falls	Koochiching	XXX		XXX
Brager, Inc. Maple Grove	Hennepin			XXX
Cole Forest Products, Inc. Grand Rapids	Itasca		XXX	XXX
Corcoran Timber Bemidji	Beltrami	XXX		XXX
Diamond International Co. Cloquet	Carlton	XXX		
Dickinson Lumber Co. Bemidji	Beltrami	XXX		
Dura Supreme, Inc. Cokato	Wright			XXX
Durkee Manufacturing Co., Inc. — Pine River	Cass	XXX	XXX	XXX
Erickson Mills, Inc. Kelliher	Beltrami			XXX
Ferche Millwork, Inc. Rice	Benton	XXX		XXX
Foreston Dimension Co. Foreston	Benton	XXX	XXX	XXX
Green Forest, Inc. Littlefork	Koochiching	XXX		XXX
Greif Bros. Corp. St. Paul	Ramsey	XXX		
Greif Bros. Corp. Grand Rapids	Itasca	XXX		XXX
Gustafson Sawmill Aitkin	Crow Wing			XXX
Hedstrom Lumber Co., Inc. Grand Marais	Cook	XXX		
Hill Wood Products, Inc. Cook	St. Louis	XXX	XXX	XXX
J. C. Campbell Co. Two Harbors	Lake		XXX	XXX
J. J. J. Specialty Co. Minneapolis	Hennepin			XXX
Jordan Sawmill Jordan	Scott	XXX	XXX	
Kullberg Manufacturing Co. Minneapolis	Hennepin		XXX	XXX
Lake Elmo Hardwood Lumber — Lake Elmo	Washington	XXX		
Lof Lumber Co. Nevis	Hubbard			XXX
Marcell Mill & Lumber Co. Marcell	Itasca	XXX	XXX	XXX
G. R. Martin Shevlin	Clearwater			XXX
Marvin Lumber & Cedar Co. Warroad	Roseau	XXX	XXX	
Medallion Kitchens Fergus Falls	Ottertail			XXX
Merillat Industries, Inc. Lakeville	Dakota		XXX	
Midwest Pallet Co. Farmington	Dakota		XXX	
Mill City Plywood Co. St. Louis Park	Hennepin			XXX
Minnesota Forest Products Menahga	Wadena	XXX	XXX	XXX
Minnesota Wood Specialties St. Paul Park	Washington	XXX		XXX
North Star Log & Lumber Menahga	Wadena	XXX		XXX
Northwood Specialty Co. Parkers Prairie	Ottertail		XXX	XXX
Ojibwa Forest Products Waubun	Mahnomen	XXX		
Par Mark, Inc. Kelliher	Beltrami			XXX
Pauls Woodcraft Plymouth Village	Hennepin			XXX
Pine Point Wood Products, Inc. — Dayton	Hennepin	XXX		XXX
Potlatch Corp. Cloquet	Carlton	XXX	XXX	
Pre-Hung Doors, Inc. St. Paul	Dakota			XXX
Publishers Paper Co. Virginia	St. Louis			XXX
Rajala Timber Co. Deer River	Itasca	XXX	XXX	XXX
Ratzlaff Logging & Lumber Princeton	Mille Lacs		XXX	XXX
Red Lake Indian Mill Redby	Beltrami	XXX	XXX	
Reinert Homes, Inc. SaukRapids	Benton	XXX		XXX
Riviera Kitchens Red Wing	Goodhue			XXX
Root River Hardwood, Inc. Preston	Fillmore	XXX	XXX	XXX
Rudy Liila Lumber Sales Grand Rapids	Itasca			XXX
St. Croix Manufacturing Co. Bayport	Washington	XXX		
St. Regis Paper Co. Sartell	Benton	XXX		
Scherer Bros. Lumber Minneapolis	Hennepin		XXX	
Shaw Lumber Co. St. Paul	Ramsey			XXX
Sico, Inc. Edina	Hennepin			XXX
Stein Industries, Carlson Division — Farmington	Dakota	— unspecified —		
Stillwater Manufacturing Co. Stillwater	Washington			XXX
Superwood Corp., Nu-Ply Division — Bemidji	Beltrami	XXX		
Thompson Hardwood Lumber Co. — Bloomington	Hennepin	XXX		
Tri-State Forest Products Hokah	Houston		XXX	XXX
Tuohy Furniture Corp. Chatfield	Fillmore	XXX	XXX	
Villhume Industries, Inc. St. Paul	Ramsey		XXX	XXX
Wadena Sawmills Wadena	Wadena	XXX	XXX	XXX
Walsh Lumber Co. Park Rapids	Hubbard	XXX	XXX	XXX
Warner Manufacturing Co. Akeley	Hubbard		XXX	XXX
Warren Shade Co., Inc. Minneapolis	Hennepin			XXX
Weyerhaeuser Co. Albert Lea	Freeborn	XXX	XXX	XXX
Woodcraft Industries St. Cloud	Benton	XXX	XXX	
Woodland Container Co. Aitkin	Aitkin	XXX	XXX	XXX
Younghanns Supply Co., Inc. Palisade	Aitkin			XXX

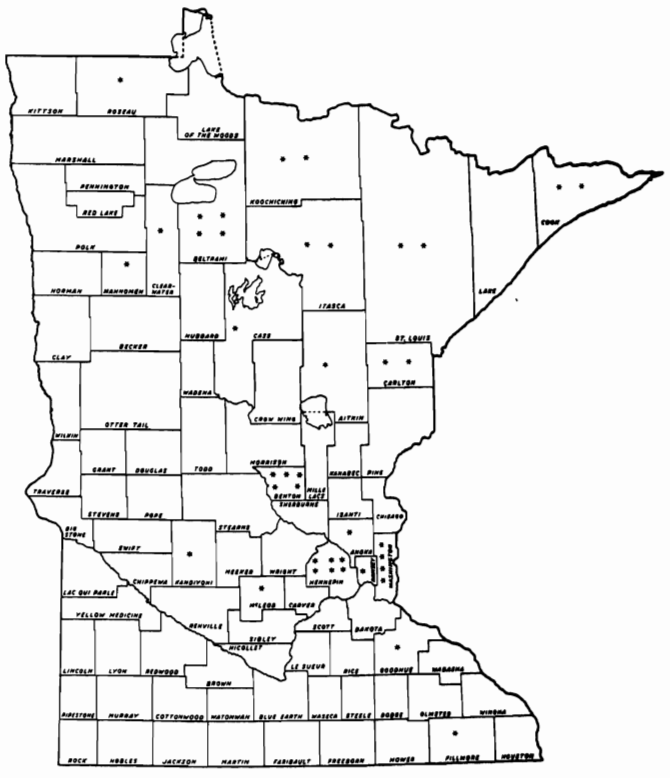
Appendix B

Residue Burning Installations

Table 10. Energy production from wood residue — state consumers.

Company or institution	County	Utilize residue produced on-site	Purchase residue from out-side sources
Andersen Corporation Bayport	Washington	X	
Advance Machine Co. Spring Park	Hennepin		X
Bagley Kiln & Component Parts, Inc. — Bagley	Clearwater	X	
Boise Cascade Corp. (paper mill) International Falls	Koochiching	X	
Busch Greenhouse Hamel	Hennepin		X
Arron Carlson Co., Minneapolis	Hennepin	X	
Corcoran Timber Co. Bemidji	Beltrami	X	
Diamond International Corp. Cloquet	Carlton	X	
Dickinson Lumber Co. Bemidji	Beltrami	X	
Durkee Manufacturing Co., Inc. — Pine River	Cass	X	
Ferche Millwork, Inc. Rice	Benton	X	
Foreston Dimension Co. Foreston	Benton	X	
Grand Marais School Grand Marais	Cook		X
Greif Bros. Corp. St. Paul	Ramsey	X	
Green Forest, Inc. Littlefork	Koochiching	X	
Hedstrom Lumber Co., Inc. Grand Marais	Cook	X	
Hill Wood Products, Inc. Cook	St. Louis	X	
Keewatin Sawmill Co. Keewatin	Itasca	X	
Lake Elmo Hardwood Lake Elmo	Washington	X	
Marvin Lumber & Cedar Co. Warroad	Roseau	X	
Minnesota Sawdust and Shavings — Anoka	Anoka	X	
Minnesota State Prison Stillwater	Washington		X
Molenaar, Inc. Willmar	Kandiyohi	X	
Northern States Power Red Wing	Goodhue		X
Ojibwa Forest Products Waubun	Mahnomen	X	
Pine Point Wood Products, Inc., Dayton	Hennepin	X	
Poly-Foam, Inc. Lester Prairie	McLeod		X
Potlatch Corp., Northwest Paper Division — Cloquet	Carlton	X	
Rajala Timber Co. Deer River	Itasca	X	
Rajala Timber Co. Big Fork	St. Louis	X	
Red Lake Indian Mill Redby	Beltrami	X	
Reinert Homes, Inc. Sauk Rapids	Benton	X	
St. Croix Manufacturing Co. Bayport	Washington	X	
St. Regis Paper Co. Sartell	Benton	X	
Scherer Bros. Lumber Minneapolis	Hennepin	X	
Superwood Corp., Nu-Ply Division — Bemidji	Beltrami	X	
Thompson Hardwood Lumber Co. — Bloomington	Hennepin	X	
Tuohy Furniture Corp. Chatfield	Fillmore	X	
Woodland Container Co. Aitkin	Aitkin	X	
Woodcraft Industries, Inc. St. Cloud	Benton	X	

Figure 5. Sites where residues are currently being used for fuel.



*** — indicates one installation within the county.**

Appendix C

Reported Residue Qualities, Form, and Utilization Methods by Geographic Areas

Table 11. Reported mill residue quantities for state, survey unit, and county.

(green tons)

State total	849,010
Northern Aspen-Birch	141,869
Northern Pine	465,125
Central Hardwood	240,116
Prairie	1,900
Northern Aspen-Birch	141,869
Carlton County	59,412
Cook County	15,880
Koochiching County	34,150
Lake County	13,120
St. Louis County	19,307
Northern Pine	465,125
Aitkin County	49,740
Beltrami County	71,841
Cass County	17,784
Clearwater County	5,360
Crow Wing County	348
Hubbard County	14,373
Itasca County	240,657
Mahnomen County	323
Roseau County	32,076
Wadena County	32,623
Central Hardwood	240,116
Benton County	30,793
Dakota County	683
Fillmore County	14,394
Goodhue County	1,480
Hennepin County	8,920
Houston County	9,279
Mille Lacs County	13,000
Ottertail County	3,536
Ramsey County	4,461
Scott County	158
Washington County	152,669
Wright County	743
Prairie	1,900
Freeborn County	1,900

Table 12. Type of residue as a percentage of the reported residue by survey unit.

		Percentage								
		Softwood			Dense hardwood			Soft hardwood		
Survey unit	Total	Bark	Coarse	Fine	Bark	Coarse	Fine	Bark	Coarse	Fine
Northern Aspen-Birch	17	5	2	2	1	1	1	3	1	1
Northern Pine	55	4	4	2	2	2	2	15	14	9
Central Hardwood	28	1	7	11	1	2	4	1	1	1
Prairie	–									
State total	100	10	14	16	3	5	7	18	15	10

Table 13. Method of residue utilization as a percentage of the reported residue by survey unit.

Survey unit	Percentage								
	Total	Fuel used on site	Industrial fuel, sold	Residential fuel	Panel products	Paper products	Agriculture use	Miscellaneous	Not used or sold
Northern Aspen-Birch	17	10	1			3			2
Northern Pine	55	7	4	1	7	7	3	3	24
Central Hardwood	28	10		1	6		8		4
Prairie	–								
State total	100	27	5	2	13	10	12	2	29

Appendix D

1979 Survey Form and Industries Solicited

A copy of the survey form is shown in Figure 6. Table 14 reports on the different types of businesses surveyed and how they responded. Sawmills accounted for 48 percent of the total residue. Other larger residue-producing sectors of the industry were millwork, with 24 percent of the total, and papermills, with 15 percent of the total.

The large number of responses with no quantities reported is the result of using the Minnesota Directory of Manufacturers. The directory makes no distinction between firms carrying out manufacturing operations and firms involved only in fabrication and distribution. Reasons given for these responses, as reported on the survey form, were:

Reason	Number of firms
1. Produce little or no residue	22
2. Do not manufacture here	11
3. Didn't know, wouldn't estimate (all said they had small amounts)	6
4. Wouldn't say	3
5. Residue quantities reported in another company's survey	4
6. Out of business	2
	48

Table 14. Businesses included in survey.

SIC Number	Business	Number sent	Number responses: Residue	Number responses: No residue	Number of nonrespondents	Green tons
2421	Sawmills and planing mills, general	37	28	6	3	406,139
2426	Hardwood dimension and flooring	5	2	2	1	15,813
2429	Special product sawmills, NEC	2	1	1		19,300
2431	Millwork	29	13	16		205,442
2434	Wood kitchen cabinets	10	5	3	2	4,058
2435	Hardwood veneer and plywood	1	1			644
2439	Structural wood members NEC	1	1			1,900
2441	Nailed wood boxes and shook	1	1			3,651
2448	Wood pallets and skids	3	2	1		3,662
2449	Wood containers, NEC	3	2	1		1,865
2491	Wood preserving	4	1	2	1	599
2492	Particleboard	1	1			7
2499	Wood products, NEC	17	7	5	5	57,732
2511	Wood household furniture	4	1	3		2,651
2517	Wood TV and radio cabinets	2		1	1	–
2531	Public building and related furniture	5	2		3	62
2541	Wood partitions and fixtures	4	1	2	1	330
2591	Drapery hardware and blinds and shades	3	1	2		276
2621	Papermills, except building paper	7	4	2	1	124,879
2631	Paperboard mills	1		1		–

Figure 6. 1979 survey form.

Plant or Company Name: _____

Address: _____

County: _____ Product(s): _____

Person filling out survey: _____

1. Annual Production.

   a. If sawmill please answer, otherwise go on to question 1.b.

Average Small End Log Diameter	Mill Type
☐ 5 - 10 inches	☐ circular head-saw or scragg mill
☐ 11 - 13 inches	☐ band head-saw
☐ 14 - 16 inches	☐ band head-saw with cant gang saw
☐ 17 inches or more	☐ chipping head rig

   b. Quantity Produced Annually.

   Please give residue amounts in tons if known, otherwise in cubic feet. If residue quantity is unknown give quantity of wood produced or processed annually and indicate what unit of measure is used.

Type of Wood	Quantity
softwoods	
dense hardwoods	
aspen	
other low-density hardwoods	

Unit of Measure

☐ tons (green)
☐ tons (dry)
☐ cubic feet
☐ board feet
☐ cords
☐ other (_____)
specify

2. Make-up of Residue

Bark	Slabs, Edgings, Chips, Planer Shavings, and Veneer Cores	Sawdust and Veneer Clippings	
%	%	%	= 100%

3. Present Disposal of Residue. Please see that each column adds up to either 0 or 100%.

Of the residue you produce how much is used as or sold for:	Residue Classes								
	Bark			Slabs, Edgings, Chips, Planer Shavings, and Veneer Cores			Sawdust and Veneer Clippings		
	softwood %	dense hardwood %	low-density hardwood %	softwood %	dense hardwood %	low-density hardwood %	softwood %	dense hardwood %	low-density hardwood %
Used as industrial fuel at this plant									
Sold for industrial fuel									
Sold for manufacture of wood panel products, ie., particleboard and hardboard									
Sold for pulp and paper manufacture									
Sold for residential fuel									
Sold for agricultural use, ie., mulch and animal bedding									
Sold for conversion to charcoal or chemicals									
Sold, other (_____) specify									
Not sold or used, includes burned as waste, landfill, etc.									
	100%	100%	100%	100%	100%	100%	100%	100%	100%

4. Does your operation include any residue processing capabilities?

☐ Dryer ☐ Chipper ☐ Other (_____) specify

☐ Screen (size) ☐ Hog or Hammermill

5. Seasonality of Residue Production.

% of Annual Residue Production

Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
												= 100%

6. Dryness of Residue.

What % of your residue is green (wood has not been kiln-dried or air-dried)? _____ %

What % of your residue is dry (wood has been kiln-dried or air-dried)? _____ %

7. Are you presently selling residue? ☐ Yes ☐ No

8. Do you plan to sell residue or would you like to sell residue in the future?
   ☐ Yes
   ☐ No

9. What would you estimate the present market price to be, for the types of residue listed below, in your locality?
   Price may be reported in: $/Ton (green), $/Ton (dry), $/Cubic Foot, Other (_____)
   specify

   Please indicate unit used in each box below.

Bark	Slabs	Edgings & Trim	Chips	Planer Shavings	Veneer Cores	Sawdust	Veneer Clippings

10. If your firm is currently selling residue how is the residue sold transported?

Truck	Rail	Barge	
%	%	%	= 100%

11. Do you or would you consider delivering residue?
    ☐ Yes
    ☐ No

12. Distance from your plant to:
    Rail access: _____ miles
    Barge access: _____ miles

13. How are sales transacted?

% of Residue Sold (by weight)	
%	You directly solicit business from user.
%	User directly solicits business from you.
%	Agent/middleman (does not take title) transacts sales.
%	Wholesaler/middleman (takes title but than resells goods) buys from you.
100%	

14. If you are currently selling residue are you in a long-term (two years or more) contractual agreement with any buyers?
    ☐ Yes
    ☐ No

Comments: _____

Appendix E

Conversion Factors Used

Residue quantities were reported on the survey in the following units: tons green, tons dry, cubic feet green, cubic feet dry, cords of timber processed, and board feet of lumber processed. Approximately 50 percent of the data were reported as tons green. One-quarter came in as board feet processed. Of the remaining residue data, most were in tons dry, followed by cords processed, with cubic foot measurements constituting only about 1 percent of the total. Green tons were assumed to be at 100 percent moisture content oven-dry basis (equal to 50 percent moisture content green basis) as suggested for mill residues in the literature (17,6). Quantities recorded in dryer conditions were transformed to equivalent weights at 100 percent moisture content oven-dry basis. Conversions from cubic feet, board feet processed, and cords processed to tons of residue were carried out as indicated in the following descriptions:

Cubic feet

The following equation was used:

$$\text{oven-dry tons} = \frac{(\text{ft}^3 \text{ swe})\ (\text{Sg})\ (62.4)}{2{,}000}$$

where: ft^3 swe = reported cubic feet of residue, solid wood equivalent

SG = specific gravity

Solid wood equivalents were determined using the residue packing densities developed by Dobie and Wright (12). These are displayed in Table 15. Green and dry specific gravities were taken from the literature (57,13,16,20). Table 16 shows specific gravities for principle Minnesota species groups. Data on 1973 timber removals revealed the following species groups, listed in decreasing order, constituted the majority of timber harvested in Minnesota: aspen, jack pine, spruce, balsam fir, paper birch, red pine, red oak, and white pine (10).

Table 15. Residue packing densities.

Residue type	Volume	Solid wood equivalent (SWE)
	cubic feet	cubic feet
Pulp chips	200	72
Sawdust	200	80
Planer shavings	200	50
Bark	200	81
Hogged fuel	200	73

Source: Dobie, J. and D. M. Wright (12).

Table 16. Wood and bark specific gravities.

	Wood		Bark	
	Green	Dry 12 percent M.C. oven dry	Green	Dry 0 percent M.C. oven dry
Balsam Fir	.34	.36	.37	.64
Jack Pine	.40	.43	.32	.77
Red Pine	.41	.46	.26	.32
Spruce	.37	.40	.29	.63
White Pine	.34	.35		.56
Aspen	.35	.38	.50	.66
Paper Birch	.48	.55	.52	.69
Oak	.56	.63		.79

Source: USDA Forest Service (57).
Erickson, John R. (13).
Harkin, John M. and John W. Rowe (16).
Lamb, F. M. and R. M. Marden (20).

Board Feed Processed

Residues generated were estimated using industry conversion factors developed by Joe Perry (25). These conversion factors varied according to four log size categories and four mill type categories. Perry's conversion factors were used to derive oven-dry tons per thousand board feet of wood processed. Tables 17 and 18 list the conversion factors for sawmills and other wood product industries, respectively.

Cords Processed

Quantities reported in cord units were revised to give tons using conversion factors developed by personnel at the U.S.D.A. North Central Forest Experiment Station and Minnesota, Michigan, and Wisconsin Departments of Natural Resources personnel. These factors, shown below, give green tons of residue produced per cord of timber input.

		tons/cord
Bark:	thin bark species —	0.17
	thick bark species —	0.285
Coarse:	band head saw —	0.67
	circular head saw —	0.67
Fine:	band head saw —	0.225
	circular head saw —	0.39

Thin-bark species consist of balsam fir, beech, cedar, spruce, and tamarack. All other species are classified as having thick bark.

Table 17. Converting factors for estimating tons of wood residue per MBF of lumber produced[1].

Mill[2] type	Small end[3] diameter	Softwood						Hard hardwood						Soft hardwood					
		Bark		Chippable		Fine[6]		Bark		Chippable		Fine		Bark		Chippable		Fine	
		G[4]	OD[5]	G	OD	G	OD	G	OD	G	OD	G	OD	G	OD	G	OD	G	OD
A, B, C, H and I	1	0.46	0.31	1.57	0.78	0.98	0.48	0.75	0.53	1.84	1.04	1.26	0.71	0.75	0.53	1.27	0.72	0.86	0.49
	2	0.42	0.29	1.18	0.58	0.92	0.45	0.64	0.45	1.53	0.87	1.34	0.76	0.64	0.45	1.06	0.60	0.91	0.52
	3	0.41	0.28	1.07	0.53	1.00	0.49	0.50	0.35	1.17	0.66	1.08	0.61	0.50	0.35	0.81	0.46	0.74	0.42
	4	0.31	0.21	0.88	0.43	0.91	0.45	0.44	0.31	1.03	0.58	1.05	0.60	0.44	0.31	0.72	0.41	0.72	0.41
D and E	1	0.29	0.20	1.57	0.78	0.90	0.45	0.75	0.53	1.84	1.04	0.92	0.52	0.75	0.53	1.27	0.72	0.63	0.36
	2	0.29	0.20	1.18	0.58	0.76	0.38	0.64	0.45	1.53	0.87	0.84	0.48	0.64	0.45	1.06	0.60	0.58	0.33
	3	0.29	0.20	1.07	0.53	0.71	0.35	0.50	0.35	1.17	0.66	0.84	0.48	0.50	0.35	0.81	0.46	0.58	0.33
	4	0.29	0.20	0.88	0.43	0.64	0.32	0.44	0.31	1.03	0.58	0.80	0.45	0.44	0.31	0.72	0.41	0.55	0.31
F	1	0.29	0.20	1.57	0.78	0.98	0.48	0.75	0.53	1.84	1.04	1.26	0.71	0.75	0.53	1.27	0.72	0.86	0.49
	2	0.29	0.20	1.18	0.58	0.92	0.45	0.64	0.45	1.53	0.87	1.34	0.76	0.64	0.45	1.06	0.60	0.91	0.52
	3	0.29	0.20	1.07	0.53	1.00	0.49	0.50	0.35	1.17	0.66	1.08	0.61	0.50	0.35	0.81	0.46	0.74	0.42
	4	0.29	0.20	0.88	0.43	0.91	0.45	0.44	0.31	1.03	0.58	1.05	0.60	0.44	0.31	0.72	0.41	0.72	0.41
G	1	0.29	0.20	1.90	0.94	0.57	0.28	0.75	0.53	2.23	1.28	0.53	0.28	0.75	0.53	1.54	0.88	0.36	0.20
	2	0.29	0.20	1.34	0.66	0.60	0.30	0.64	0.45	1.72	0.98	0.65	0.37	0.64	0.45	1.19	0.68	0.45	0.25
	3	0.29	0.20	1.17	0.58	0.61	0.30	0.50	0.35	1.29	0.73	0.72	0.41	0.50	0.35	0.89	0.51	0.50	0.28
	4	0.29	0.20	0.98	0.48	0.54	0.28	0.44	0.31	1.15	0.65	0.68	0.38	0.44	0.31	0.80	0.46	0.47	0.26

1. To use these converting factors first decide the mill type, which is based on equipment; then determine the average scaling diameter of the logs. If the equipment indicates a mill type B and the average scaling diameter is 13 inches, then look in Section B, line 2. This line shows that for every thousand board feet of softwood sawed 0.42 tons of bark, 1.18 tons of chippable material, and 0.92 tons of fines are produced, green weight. Expressed in oven-dry weights, the same thousand board feet yields 0.29 tons of bark, 0.58 tons of shippable material, and 0.45 tons of fines. Equivalent hard hardwood and soft hardwood data are also given.
Shaving converting factors omitted as they are 0 for sawmills.

2. **Mill type:**
   - A. Circ. head-saw with or without trim saws.
   - B. Circ. head-saw with edger and trim saw.
   - C. Circ. head-saw with vertical band resaw, edger, trim saw.
   - D. Band head-saw with edger, trim saws.
   - E. Band head-saw with horizontal band resaw, edger, trim saw.
   - F. Band head-saw with Cant gangsaw, edger, trim saws.
   - G. Chipping head rig.
   - H. Round log mill.
   - I. Scragg mill.

3. Average small end log diameter classes:
   1. 5 to 10 inches.
   2. 11 to 13 inches.
   3. 14 to 16 inches.
   4. 17 inches and over.

4. G — Green weight or initial condition, with the moisture content of the wood as processed.

5. OD — Oven-dry. It is the weight of 0 percent moisture.

6. Fine is sawdust and other similar size material.

Source: Perry, Joe D. and Robert T. Gregory (25).

Table 18. Converting factors for estimating tons of wood residue per MBF of wood used for wood products industries other than sawmills.

	Softwood								Hard hardwood								Soft hardwood							
	Bark	% MC	Chip-pable	% MC	Shave-ings	% MC	Fine[3]	% MC	Bark	% MC	Chip-pable	% MC	Shave-ings	% MC	Fine	% MC	Bark	% MC	Chip-pable	% MC	Shave-ings	% MC	Fine	% MC
Planing mill	–	–	0.04	19	0.38	19	–	–	–	–	0.04	19	0.49	19	–	–	–	–	0.02	19	0.35	19	–	–
Wood chip mill[4]	0.46	50	–	–	–	–	–	–	0.90	60	–	–	–	–	–	–	0.62	88	–	–	–	–	–	–
Hardwood flooring	–	–	–	–	–	–	–	–	–	–	0.15	6	0.73	6	0.30	6	–	–	–	–	–	–	–	–
Hardwood dimension (cutstock)[5]	–	–	0.11	7	0.53	7	0.22	7	–	–	0.15	7	0.73	7	0.30	7	–	–	0.10	7	0.50	7	0.21	7
Handle blanks[6]	–	–	–	–	–	–	–	–	0.67	60	2.65	65	–	–	1.27	65	–	–	–	–	–	–	–	–
Wooden furniture frames	–	–	0.45	12	0.79	12	0.14	12	–	–	0.37	9	0.80	9	0.15	9	–	–	0.25	9	0.55	9	0.10	9
Shingles and cooperage stock	0.46	50	2.66	100	–	–	0.47	100	0.63	60	2.66	65	–	–	0.47	65	–	–	–	–	–	–	–	–
Mill work	–	–	0.45	12	0.79	12	0.14	12	–	–	0.37	9	0.74	9	0.14	9	–	–	0.26	9	0.52	9	0.12	9
Kitchen cabinets	–	–	0.19	12	–	–	0.17	12	–	–	0.25	9	–	–	0.10	9	–	–	0.18	9	–	–	0.07	9
Hardwood veneer and plywood	–	–	–	–	–	–	–	–	0.63	60	2.63	65	–	–	1.10	9	0.44	88	1.83	65	–	–	0.76	9
Softwood veneer and plywood	0.44	50	1.83	100	–	–	0.76	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Structural parts N.E.C.	–	–	0.05	12	0.02	12	0.01	12	–	–	0.06	9	0.02	9	0.01	9	–	–	0.04	9	0.01	9	0.01	9
Boxes and shook	–	–	0.19	100	0.09	100	0.28	100	–	–	0.18	65	0.09	65	0.27	65	–	–	0.12	65	0.06	65	0.18	65
Pallets and skids	–	–	0.49	60	0.24	60	0.08	60	–	–	0.58	60	0.29	60	0.10	60	–	–	0.40	60	0.20	60	0.07	60
Wirebound boxes	–	–	–	–	–	–	–	–	0.63	60	2.63	65	–	–	1.10	65	0.44	88	1.83	65	–	–	0.76	65
Veneer and plywood containers	–	–	–	–	–	–	–	–	0.63	60	2.53	65	–	–	1.10	65	0.44	88	1.83	65	–	–	0.76	65
Cooperage	–	–	–	–	–	–	–	–	–	–	–	–	0.50	19	0.12	19	–	–	–	–	–	–	–	–
Mobile homes	–	–	0.04	12	–	–	0.01	12	–	–	0.08	9	–	–	0.02	9	–	–	0.06	9	–	–	0.01	9
Prefabricated buildings	–	–	0.05	12	–	–	0.02	12	–	–	0.29	9	–	–	0.01	9	–	–	0.21	9	–	–	0.01	9
Log homes	0.42	50	2.21	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Preservative treating plants	0.67	50	0.40	100	0.65	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Particleboard	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.21	6
Other wood products	–	–	0.45	12	–	–	0.93	12	–	–	0.37	9	–	–	0.95	9	–	–	0.25	9	–	–	0.65	9
Wooden handles[7]	–	–	–	–	–	–	–	–	–	–	0.02	12	1.56	12	0.01	12	–	–	–	–	–	–	–	–
Furniture	–	–	0.45	12	0.79	12	0.14	12	–	–	0.37	9	0.80	9	0.15	9	–	–	0.25	9	0.55	9	0.10	9
Pulp and paper	0.60	70	–	–	–	–	–	–	0.90	60	–	–	–	–	–	–	0.62	88	–	–	–	–	–	–
Gum and wood chemicals	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Boot and shoe cut stock	–	–	0.45	12	0.79	12	0.14	12	–	–	0.37	9	0.80	9	0.15	9	–	–	0.25	9	0.55	9	0.10	9
Farm machines and textile machines	–	–	0.03	12	0.54	12	0.14	12	–	–	0.03	9	0.49	9	0.15	9	–	–	0.02	9	0.35	9	0.10	9
Industrial patterns	–	–	0.15	12	0.73	12	0.30	12	–	–	0.15	9	0.73	9	0.30	9	–	–	0.10	9	0.50	9	0.20	9
Transportation equipment	–	–	0.45	12	0.79	12	0.14	12	–	–	0.37	9	0.80	9	0.15	9	–	–	0.25	9	0.55	9	0.10	9
Musical instruments	–	–	0.45	12	0.79	12	0.14	12	–	–	0.37	9	0.80	9	0.15	9	–	–	0.25	9	0.55	9	0.10	9
Games and toys	–	–	0.11	9	0.50	9	0.21	9	–	–	0.15	9	0.73	9	0.30	9	–	–	0.11	9	0.50	9	0.21	9
Sporting goods	–	–	0.08	9	0.50	9	0.08	9	–	–	0.12	9	0.73	9	0.12	9	–	–	0.08	9	0.50	9	0.01	9
Pencils	–	–	0.09	8	0.54	8	0.63	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Artists' materials	–	–	0.03	8	0.54	8	0.02	8	–	–	0.03	8	0.49	8	0.02	8	–	–	0.02	8	0.35	8	0.02	8
Brooms and brushes	–	–	0.03	12	0.54	12	0.04	12	–	–	0.25	12	0.49	12	0.05	12	–	–	0.20	12	0.35	12	0.03	12
Signs and advertising displays	–	–	0.03	12	–	–	0.01	12	–	–	0.01	12	–	–	0.01	12	–	–	0.01	12	–	–	0.01	12
Burial caskets and coffins	–	–	0.20	6	0.10	6	0.10	6	–	–	0.30	6	0.12	6	0.15	6	–	–	0.20	6	0.08	6	0.09	6
Wood manufacturers N.E.C.	–	–	0.03	12	0.54	12	0.04	12	–	–	0.25	12	0.49	12	0.05	12	–	–	0.20	12	0.35	12	0.03	12

1. For shingles and cooperage stock the table indicates that for every MBF of softwood logs used you could expect 2.66 tons of chippable material, with an average moisture content (MC) of 100 percent, based on oven-dry weight. If the average MC of lumber is greater or less than 100 percent, you could expect a proportionally greater or lesser weight of material.
2. Chippable is material large enough to warrant size reduction before being used by the paper, particleboard, or metallurgical industry.
3. Fines are considered to be sawdust or sanderdust.
4. For chipping mills, with debarkers only.
5. Some softwood cut stock is produced.
6. From roundwood only.
7. Factors are for handles from blanks. Residue for finished handles from roundwood is the sum of the residues produced when converting from roundwood to blanks plus the residues produced converting blanks to handles.

Source: Perry, Joe D. and Robert T. Gregory (25).

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