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ENERGY AND RAW MATERIAL POTENTIALS OF WOOD RESIDUE IN THE PACIFIC COAST STATES-

A SUMMARY OF A PRELIMINARY FEASIBILITY INVESTIGATION

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ABSTRACT

Results are reported of a protiminary investigation of feasibility of using wood residue to meet energy and raw material needs in the Pacific Coast States. Magnitude of needs was examined and volume of logging residue and unused mill residue was estimated. Costs of obtaining and preprocessing logging residue for energy and pulp and particle board raw material were estimated and compared with selling values of mill residue fuel, pulp chips, and particle board. Marginally feasible energy use seemed best suited for inplant steam and power production by the wood industry, Although raw material selling values make wood residue use for products more attractive than for electric power generation, even these returns are seldom sufficient to meet the high costs of delivering logging residue fur such use alone. Production of higher valued products or public absorption of extra costs of utilization can make these residue management alternatives more feasible.

Keywords: Wood residues, raw material pulp and paper industry, energy.

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We hope the contributions represented here will be useful to all who had a part in the report.

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INTRODUCTION

This report presents findings from a preliminary investigation of using wood residue to meet growing needs for electric power and as raw materials for products. The study was prompted by the longstanding concern of forest managers and the wood-processing industry to reduce the smoke from slash and mill residue burning, to improve the appearance of timber harvest areas, and to use the forest resource more effectively. Wood residue, as defined in the study, includes all material left on the ground after timber is harvested (logging residue) and the material developed in the manufacture of such primary products as lumber, plywood, shingles, and poles (mill residue). The investigation covered both categories of residue in the Pacific Coast States of Alaska, California, Oregon, and Washington; it is especially pertinent for residues from public forest lands.

An overall objective of the study was to encourage and obtain increased use of residue, especially from logging to: (1) improve the environment by treating a solid waste problem, and (2) provide an additional supply of wood raw material. Electric power generation as an energy outlet for wood residue was given special emphasis because of mounting speculation that logging residue can be put to such use. In particular, the current energy shortages in the Pacific Northwest and elsewhere point to the need for exploring new sources of electric power generation. As the costs and problems of availability of alternative fuels continue to increase, the potential for electric power generation from wood residue will appear more favorable.

Residue is viewed as a huge disposal problem, made up of hundreds of localized and often remote disposal situations. These situations now are handled by burning, leaving in place as logging residue, or landfilling with mill residue. Logging residue is also viewed as a public and private land management problem, where removal of unused material is desirable to make the land more accessible for reforestation and subsequent management and the appearance more in keeping with public standards of conservation, scenic quality, and concern for the environment. Thus, public benefits from land management are also important, along with energy or commodity values, in measuring costs of treatment or of use.

The investigation was conducted primarily during the period October to December 1972, drawing upon cooperators and contractors as well as personnel from several Forest Service research units, working through the Forest Residues Reduction Program of the Pacific Northwest Forest and Range Experiment Station, Since limited distribution of an interim report[1/] of initial findings was made, some pertinent information has become available and is included in this report, slightly modifying earlier conclusions.

[1/] J. M. Pierovich, J. B. Grantham, E. M. Estep, H. Tarkow, and T. C. Adams. Energy and raw material potentials of wood residues in the Pacific Coast States. Unpublished interim report, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 1973.

VOLUME OF UNUSED WOOD RESIDUE

Timber harvesting and wood processing operations in the Pacific Coast States generate huge volumes of wood and bark residue each year. So far, use has been limited almost entirely to mill residue, the wood and bark by-products of primary manufacturing. Although the bulk is being used as fuel or raw material, about one-fourth of the mill residue and almost all the logging residue remains, requiring some disposal action.

More than 21 million dry tons[2/] of the wood residue accumulated annually in the Pacific Coast States remains unused. Residue left after harvesting of timber in Alaska, California, Oregon, and Washington is estimated to be over 14 million tons annually (table 1); added to this is an estimated 7 million tons of unused wood and bark from manufacturing plants.

Logging residue.-- Estimates of the gross and net volumes of logging residue left in 1969 on publicly and privately owned forest lands of the Pacific coast have been reported by Howard (1973). The average gross volume reaches almost 57 dry tons per acre on cutover lands in the National Forests of western Oregon and Washington

2/ Residue volumes are expressed in "dry tons" (moisture free) throughout this report. See appendix for other units of measure commonly used for wood residue.

Table 1.--*Unused* residue accumulated annually in the Pacific Coast States

(In thousands of dry tons)

State	Logging residue[1/]	Mill residue
Alaska[2/]	375	(3/)
California	5,355	[4/] 3,168
Oregon	4,764	[5/] 2,990
Washington	3,800	5'1,113
Total	14,294	7,271

1/ Except for Alaska, logging residue volume estimates were derived from Howard (1973) and include live and dead material at least 4 inches in diameter and 4 feet long left on the ground after logging operations in 1969.

2/ U.S. Forest Service R-10 estimate, memo dated 11/30/72.

3/ Negligible.

4/ Barrette et al. [n.d.].

5/ Manock et al. (1970).

6/ Bergvall and Gedney (1970).

and drops to about 5 tons in those of eastern Oregon and Washington (table 2). Gross residue volumes estimated for other public and private ownerships vary, and net or usable fiber volume for all ownerships ranges from 69 to 89 percent of total residue volume. In Alaska, the residue was estimated at more than 16 dry tons per acre on National Forest and State lands logged in 1971.

If the minimum dimensions of logging residue considered are increased from the minimum dimensions measured, the volumes available on National Forest clearcuts are reduced (table 3).

Mill residue. -- Byproducts (wood and bark) are produced in converting logs to primary products at the rate of about 1-1/4 dry tons per thousand board feet of lumber cut and about one-half ton of residue per thousand square feet (3/8-inch basis) of plywood output (Corder 1973). Almost 23 million dry tons of wood residue and more than 6 million tons of bark were produced in 1968 by mills in California, Oregon, and Washington (Barrette et al. [n. d.], Manock et al. 1970, Bergvall and Gedney 1970). Over 7 million tons of this annual residue production was not used. These unused mill residues are characterized in table 4.

Table 2.--*Average gross and net weight of logging residue,*[1/] *by State, region, and ownership, 1969*[2/]

State, region, and ownership	Logging residue	
	Gross weight	Net weight[3/]
	Dry tons per acre	*Percent*
OREGON AND WASHINGTON			
Douglas-fir region			
National Forest	56.9	39.1	69
Other public	33.1	25.3	76
Private	18.6	16.6	89
Ponderosa pine region			
National Forest[4/]	4.5	3.6	80
Private	5.0	4.4	88
CALIFORNIA (ALL REGIONS)			
National Forest[4/]	18.3	14.6	80
Private	23.8	17.1	72

[1/] Pieces at least 4 inches in diameter and 4 feet long.

[2/] Derived from Howard (1973), using 80 cubic feet of bone dry wood per ton.

[3/] Includes sound portions of all pieces with at least 10 percent of gross volume suitable for pulp chips.

[4/] Includes "other public."

Table 3.--*Relationship of residue quantity to log volume harvested on National Forest clearcuts of the Doughs-fir region of Oregon and Washington in 1969*[1/]

(In dry tons of residue per thousand board feet of logs harvested)

diameter (inches)	8 feet	12 feet	20 feet
	Gross weight of residue		
4	0.95	0.77	0.44
8	.90	.73	.42
12	.80	.64	.38
	Net weight of residue suitable for chips		
4	.65	.52	.29
8	.60	.49	.27
12	.50	.40	.23

[1/] Derived from Howard (1973).

Other potentially usable wood residue.--Trees killed by fire, insect, or disease in the forest outside logging areas represent significant volumes of wood residue but must be considered separately because of their sporadic and scattered occurrence; for example, the beetle- and fire-killed white spruce on the Kenai Peninsula near Cook Inlet in Alaska. This material represents a potential source of nearly 10 million tons of wood which is physically suitable for either fiber or energy production.

Other wood residue with unknown utilization potential includes: (1) the huge quantity of driftwood along beaches such as those in southeast Alaska, (2) wood not salvaged in building demolition, and (3) the wood and wood-fiber portion of municipal waste normally incinerated or buried in landfills. Accurate projections of volume or value are not available for these potentially useful residue resources.

ENERGY AND RAW MATERIAL NEEDS AND WOOD RESIDUE

The basic properties of residue wood fiber are not significantly different from those normally accepted for many uses of wood. Increasing use of mill residue bears this out and points toward a potential for even wider use of mill and logging residue. In this context, energy and raw material needs and the potential of wood residue to meet these needs were investigated.

Table 4.--*Characterization of unused mill residue on the Pacific coast, 1968*

(In thousands of dry tons)

Location and source industry	Wood			Bark
	Coarse 1/	Medium 2/	Fine 3/	
California: 4/				
Veneer and plywood	73.1		6.2	113.0
Lumber	822.9	309.4	786.6	1,053.2
Other			5/ 12.7	1.0
Oregon: 6/				
Veneer and plywood	243.7		35.3	434.3
Lumber	462.8	176.3	601.8	908.5
Shake and shingle	27.8		59.8	40.0
Washington: 7/				
Veneer and plywood	89.0		4.3	103.5
Lumber	134.9	91.1	170.7	231.7
Shake and shingle	69.0		124.6	94.1
Total	1,923.2	576.8	1,792.0	2,979.3

1/ Veneer trim, cores, and panel trim from plywood plants; slabs, edgings, and trim from sawmills.

2/ Planer shavings.

3/ Sanderdust from plywood plants; sawdust.

4/ Barrette et al. [n.d.].

5/ Class of residues not specified.

6/ Manock et al. (1970).

7/ Bergvall and Gedney (1970).

Energy Use Increasing

Total energy consumption of the United States in 1968 amounted to 60.5 x 10^{15} Btu. Total energy consumption by sector of the economy is shown in table 5; also shown are the major sources of energy. Increased dependence upon imports of fossil fuels for the period 1970–85 is illustrated in figure 1; although total United States energy consumption is projected to grow at an average rate of 4.2 percent per year during the 1971–85 period, growth seen for the electric utility market is 6.7 percent.[3/]

Oregon and Washington.-- Pacific Northwest regional power needs for the future indicate a slightly lower growth rate, 5.8 percent, but a deficit is expected nonetheless.[4/] The comparatively inexpensive source of power provided by the region's hydroelectric facilities cannot be increased sufficiently to meet all of this larger electric power demand. Furthermore, subnormal waterflows limit generating capability of existing facilities. Major hydro sites are no longer available, and increased capacity planned for existing hydropower facilities will primarily serve peakloads without adding much dependable energy. Thermal powerplants are under construction to meet the growing energy demand but the time schedule planned in the hydrothermal program probably will not be met. This may result in power deficits for several years, especially if low streamflows

3/ National Petroleum Council. U. S. energy outlook: an initial appraisal by the New Energy Forms Task Group 1971-1985. 1971.

4/ Pacific Northwest River Basins Commission. Twenty questions on electric power loads and resources in the Pacific Northwest. 18 p., November 1972.

Table 5.--*Energy consumption in the United States, 1968*[1/]

(In trillions of Btu)

Sector	Coal	Natural gas	Petroleum products	Hydro and nuclear	Subtotal	Purchased electricity
Residential	0	4,600	3,200	0	7,800	1,400
Commercial	600	1,800	3,400	0	5,800	1,100
Industrial	5,600	9,300	4,500	0	19,400	2,000
Transportation	0	600	14,500	0	15,100	0
Electric utility	7,100	3,200	1,200	900	12,400	(-4,500)
Total	13,300	19,500	26,800	900	60,500	0

1/ Adapted from "Patterns of energy consumption in the United States." Report to Office of Science and Technology, Executive Office of the President of the United States, by Stanford Research Institute, 1972.

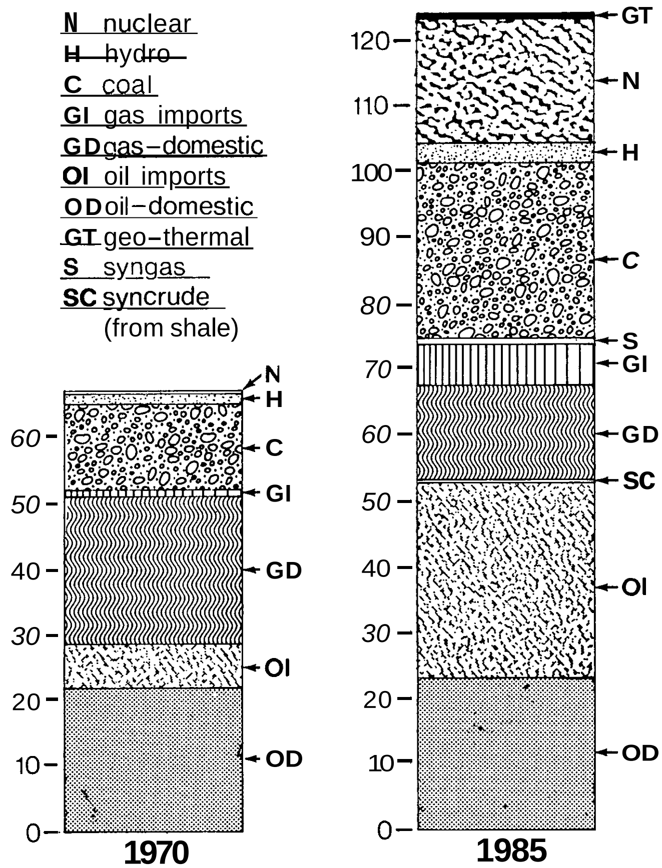

Figure 1.--Estimates of domestic and imported energy sources for United States consumption (Btu x 10^{15}), 1970 vs. 1985. (Source: National Petroleum Council (1971), used with permission.)

occur. The severity of economic and social consequences of the power deficit is not known, but the consequences are expected to be felt widely by both industrial and residential electric power users.

California.--This State also faces a power-short future. The Rand Corporation emphasized the State's critical energy shortage in a report stating that California needs to build twenty-three 1,200 megawatt (MW) powerplants before 2000, even if annual growth in demand is reduced to 3 percent (Anonymous 1972a). To meet demands arising from the actual current annual growth rate of more than 8 percent would require 130 such plants. An indication of the size of a 1,200-MW plant may be obtained by noting that 5 tons of pulverized coal are burned each minute to fuel a plant of similar capacity at Bull Run, Tennessee.

Alaska. --Although Alaska differs in several respects from the national pattern of power production, distribution, and consumption, a steadily rising demand for electrical power generation is in prospect (fig. 2).

The increasing use of fossil fuel on which this rise has been based must be evaluated in light of the difficulty of transporting bulk materials in Alaska. Even Alaska's limited population may feel power shortages in the not-so-distant future, unless development of known petroleum resources makes fuel more readily available.

Raw Material Requirements Rising

A comprehensive review of United States timber resources and projections of wood product needs (USDA Forest Service **1973)** indicates increasing demand for products for which wood residue is a suitable raw material. Some residue will be of a size and quality permitting use for lumber and plywood, but much of it will be suitable primarily as raw material for pulp and paper or building boards.

The projected increase in the

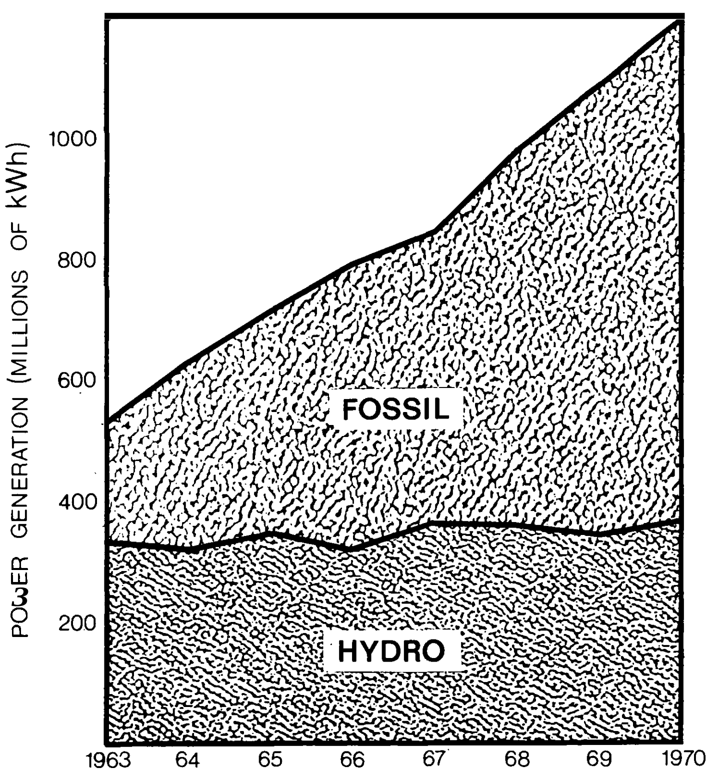

Figure 2.--Electrical power generation in Alaska by energy source, 1963-70 (U.S. **Department of the Interior 1972).**

demand for domestic roundwood, illustrated in figure 3 and summarized in table 6, is the medium of three demand projections.

Estimated increases in domestic demand for roundwood by 2000 are: saw logs, 1.5 billion cubic feet; veneer logs, 0.8; and pulpwood, 5.1. Demands for export logs, fuelwood, and miscellaneous products are expected to change little. The overall increase of 7.4 billion cubic feet (65 percent) is expected to be supplied from an increase of 2.5 billion cubic feet of sawtimber and 4.9 billion cubic feet from cull and dead trees, trees under 5.0 inches in diameter, logging residue, etc. The anticipated increase in use of mill residue (1.8 billion cubic feet) represents additional recovery from the roundwood used.

Lumber. --Projected national domestic demand for lumber at a medium level shows a rather sharp rise to a 1980 level of 51 billion board feet, up from a total consumption of 39.5 billion board feet in 1970. After 1980, with leveling off of housing-related demands, projected medium demand increases more slowly to about 62 billion board feet in 2000, a volume about 1.6 times that of 1970.

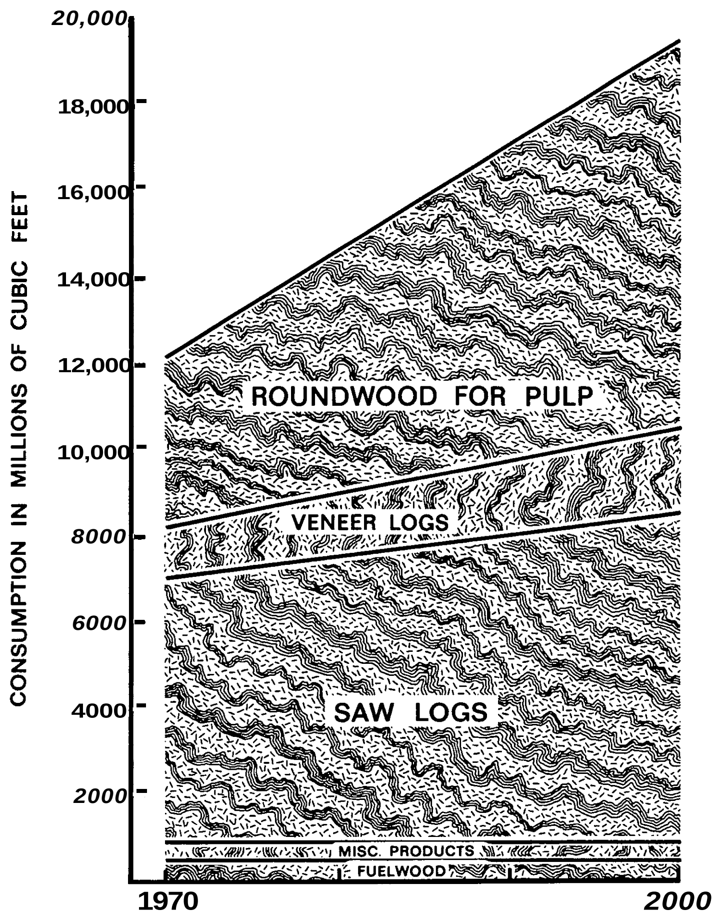

Figure 3.--Domestic roundwood consumption, 1970, and projected consumption, 2000 (USDA Forest Service 1973).

Table 6.--*Domestic roundwood and mill residue consumption in the United States in 1970 and projected consumption in 2000* 1/ 2/

(In millions of cubic feet)

Product group	Reported consumption, 1970		Projected consumption, 2000	
	Roundwood	Mill residue 3/	Roundwood	Mill residue 3/
Saw logs	6,100	--	7,600	--
Veneer logs	1,200	--	2,000	--
Pulpwood	4,000	1,600	9,100	2,800
Miscellaneous products 4/	400	600	400	1,200
Fuelwood	500	700	500	700
Total	5/ 12,200	2,900	5/ 19,600	4,700

1/ Based on medium level of projected demand and prices 10 to 30 percent above 1970 levels.

2/ USDA Forest Service (1973, tables 149 and 150).

3/ Residue developed in converting roundwood to such primary products as lumber and plywood. It is used chiefly for pulp, particle board, and fuel.

4/ Includes roundwood for cooperage, poles, piling, mine timbers, shingles, and some board products; it also includes the residue used primarily for building boards.

5/ The totals include an estimated 7,900 (1970) and 10,400 (2000) million cubic feet of sawtimber. The balance in each case is roundwood from such sources as cull and dead trees, trees less than 5.0 inches in diameter, and logging residue.

Export demand for lumber is expected to continue through the projection period at about the 1-billion-board-foot-per-year volume averaged since the mid-1960's. If prices are assumed to rise 30 percent between 1970 and 2000, Canadian imports are then expected to supply about 12.6 billion board feet, leaving need for domestic production of 41.5 billion board feet. Domestic lumber production in 1970 was 34.7 billion board feet. Closely tied to lumber supply and demand are log exports which amounted to 3.9 billion board feet (International 1/4-inch log rule) in 1970. Softwood log exports, principally from the west coast to Japan, are not expected to exceed 4.5 billion board feet annually.

Plywood.--Projected growth in construction and manufacturing uses of plywood contributes heavily to a medium projection of domestic demand in 2000 for 36.8 billion square feet (3/8-inch basis), slightly more than double consumption in 1970. Only modest increases in plywood exports are foreseen. Domestic plywood production in 1972 reached 20.5 billion square feet--more than four times the output in the early 1950's--and rapid growth to 33.3 billion square feet is projected for 2000.

Building boards.--Medium projection of domestic demand for building boards (particle board, hardboard, and insulation board) in 2000 is 28 billion square feet (3/8-inch basis)--some three times the volume consumed in 1970. Projected demands for particle board and hardboard show the largest increases, continuing trends of recent years. Exports and imports of building boards are expected to remain small. If the particle board and hardboard industries more than double their capacity and the insulation board industry increases by 50 percent, growth in domestic production will require an additional 800 million cubic feet of wood, all of which is expected to come from residue.

Pulpwood.--Trends in the use of paper, board, and other pulp products have led to a medium projection of domestic demand for woodpulp in 2000 of 106.4 million tons, a 2.4-fold increase over 1970 consumption. In addition, exports of woodpulp are projected to rise from 2.3 million tons in 1972 to 3.5 million tons in 2000. Demand for domestic and imported pulpwood for United States woodpulp production is expected to be 146 million cords[5/] in 2000, up from about 72 million cords in 1972. In addition to the demands of United States mills, a continuing export demand for pulpwood (including chips) is anticipated. Exports rose to 2 million cords in 1972, but further increases in pulpwood exports probably will be limited to about 3 million cords. A separate analysis of west coast chip exports to Japan indicates that the 1.8 million cords shipped in 1971 may grow to 3.5 million cords by 1975.

Potential for Using Wood Residue

The potential outlets for forest residue are primarily the pulp and paper and the building board industries. Both industries have demonstrated ability to use wood of many species in almost any form. In 1970, the United States pulp industry obtained 1,600 million cubic feet (20 million cords) or about 30 percent of its domestic pulpwood requirements from residue (table 6). In the same year, the Pacific coast pulp industry relied on wood residue from timber-based manufacturing plants, mostly sawmills

5/ Roughly, 1 dry ton of softwood chips = 1 cord.

and veneer mills, for 10.5 million cords or 76 percent of its pulpwood requirements.

U.S. manufacturers of insulation board, hardboard, and particle board rely almost entirely on wood residue from timber-based manufacturing plants for their raw material and are expected to increase their annual residue use from 600 million to 1,200 million cubic feet by 2000. Current annual residue use for board products on the Pacific coast is about 180 million cubic feet per year (2.25 million cords). The building board industry expects nearly all its raw material to be supplied by wood residue from lumber, plywood, or other primary wood product manufacture for an indefinite period.

The pulp and paper industry's projected increase in domestic wood consumption of 62.5 million cords of roundwood and 15 million cords of mill residue by the year 2000 offers a potential outlet for practically all the logging and mill residue that may be recovered. However, expanded capacity in the pulp industry may not coincide with the principal concentrations of residue. For example, major pulp industry expansion may occur in the Southeastern States, but major residue accumulations are in the West.

Meanwhile, the energy shortage is creating renewed interest in wood and bark residue as fuel, especially in the pulp and paper industry. It is estimated that this industry on the Pacific coast could use the equivalent of 7 million cords of wood and bark annually to replace the natural gas and oil now burned in its power boilers. On the basis of average efficiencies, that total volume of residue fuel could release the equivalent of about 20 million barrels of oil per year for use elsewhere.

Fuel values for selected wood residue materials are shown in table 7. Although the heating values shown and residue volumes available may have potential significance for energy production in local areas and to forest industry plants, the overall impact of Pacific coast wood residue on the region's energy needs would be relatively small. Two years' growth in electric energy consumption could absorb all the energy obtainable from logging and mill residue created annually on the Pacific coast. Despite this limit of wood residue for meeting total expected power needs, any additional fuel source is of interest and may be a solution to power needs of a local area or individual plant.

Future availability of logging residue as well as of mill residue is somewhat uncertain. As timber harvesting in western forests shifts from old-growth to young-growth timber, less logging residue will be created. This shift, expected to be almost complete by 2020, as well as the trend toward increased utilization, will affect the volume of unused residue available for fuel and will require careful evaluation of future supplies for residue-based power installations. But, even though the potential contribution of wood residue to energy production on the Pacific coast is a short-term one, it could serve a useful purpose while the Nation perfects other energy systems.

Table 7.--*Approximate densities and heating values of some western woods and barks*

Kind of wood or bark	Density (green volume basis)		Moisture content (wet basis)	Heating value[2]
	Ovendry weight[1]	Green weight		
	- - Pounds per cubic foot - -		*Percent*	*Btu per dry lb.*
Douglas-fir:				
Wood	28	38	26	8,900
Bark	27	38	29	9,800
Western hemlock:				
Wood	26	50	48	8,400
Bark	29	51	43	9,400
Ponderosa pine:				
Wood	23	44	48	9,100
Bark	21	24	12	9,100
True firs:				
White fir wood	23	47	51	8,200
Western redcedar:				
Wood	20	--	--	9,700

1/ Maeglin and Wahlgren *(1972)*.

2/ Corder (1973), averages of values shown in his table 5.

COST OF DELIVERING LOGGING RESIDUE FOR USE

Although wood fiber from logging residue is not basically different from that obtained from mill residue, economic differences significantly affect utilization opportunities.

Availability of relatively concentrated supplies of mill residue, often at low cost, has been a primary reason for its use. Despite the appreciable total volume of unused mill residue available, amounts in individual areas are frequently inadequate or too scattered to form a satisfactory raw material base for wood residue-using industries that are expanding or for new ones. Potential users are therefore beginning to **look** to the larger volumes of logging residue as an additional source of supply.

When a potential user turns to logging residue for raw material, however, he finds cost uncertain and frequently discouraging. Logging residue is a heterogeneous scattered material, usually quite distant from a point of potential use. Volume and size of material left on the timber sale area vary with market conditions for primary wood products. Today's equipment and methods to collect, load, and transport logging residue are generally uneconomic --unless end-product values or new marketing arrangements can be found.

Table 8 presents costs estimated for delivering and preparing logging residue for use as fuel or as chips for pulp or particle board. Field sampling of logging areas in the Douglas-fir timber type on the western slope of the Cascade Range provided gross and net residue volumes and piece counts. With the aid of a simulation model, this information has been used to estimate costs of removing residue to three minimum sizes. The preliminary data used were the best available, but further research and development using the simulation model will probably yield results more appropriate to local situations.

Howard **(1973)** has published average net and gross volume data for logging residue found in 1969 on National Forest, other public, and private lands in California, Oregon, and Washington. Volumes are presented by residue diameter and length classes, aiding potential users of residue in decisions about target sizes and volumes of residue for a utilization program. This is important since recovery of material below 8 inches in diameter and less than 8 feet in length contributes small additional volume at disproportionately high cost (table 8). Least cost per dry ton of residue results from working only with larger pieces of logging residue.

Many options affecting costs are available to a potential user of logging residue, including establishing the minimum size of residue to remove and the location of any preprocessing operations that may be required. Although debarking and chipping could be accomplished in the woods to reduce transportation costs, satisfactory disposal of bark, rot, and fines would have to be considered. Forest managers and others are concerned about possible adverse effects on reforestation from leachates and reduced planting space that may result from leaving concentrations of these materials on the sale area. In the model yielding the results summarized in table 8, preprocessing operations were located at a plant where portions not used for chips could be diverted to fuel or other uses. When opportunities

Table 8.--*Estimated costs for collection, delivery, and preprocessing of Zogging residue for selected uses, to three minimum sizes*

(In dollars per dry ton)

Costs	Minimum size A1/		Minimum size &'		Minimum size C3/	
	Hogged fuel	Chips4/	Hogged fuel	Chips4/	Hogged fuel	Chips4/
Yarding5/	13.84	13.84	10.42	10.42	9.26	9.26
Loading	2.54	2.54	1.61	1.61	.91	.91
Transport6/	11.56	11.56	11.56	11.56	11.56	11.56
Subtotal--to plant	27.94	27.94	23.59	23.59	21.73	21.73
Preprocessing	5.45	7.89	4.52	6.96	3.82	6.26
Subtotal--to processing	33.39	35.83	28.11	30.55	25.55	27.99
Margin for profit and risk (20 percent)	6.68	7.17	5.62	6.11	5.11	5.60
Total--to processing	40.07	43.00	33.73	36.66	30.66	33.59

1/ 4-inch minimum diameter, 4-foot minimum length--gross volume, 37 dry tons of residues removed per acre; net, 22.

2/ 8-inch minimum diameter, 8-foot minimum length--gross volume, 28 dry tons of residues removed per acre; net, 16.

3/ 12-inch minimum diameter, 8-foot minimum length--gross volume, 22 dry tons of residues removed per acre; net, 11.

4/ Suitable for pulp or particle board production.

5/ Yarding of some residue to central piles may be required as part of a residue treatment (e.g., yarding unutilized material) regardless of removal.

6/ Based on one-way, 70.75-mile hauling distance (0.15 mile of spur road, 13.6 miles of main line haul road, and 57 miles of State highway). This is not the average hauling distance for the region (about 40 miles) but is actual mileage from example timber sale areas to proposed point of use.

to use material not suitable for chips are not available, unused portions create a solid waste disposal problem that has simply moved from the forest to the mill. In any evaluation of logging residue utilization, satisfactory disposal of unused portions of residue in the forest or at a plant, including cost, must be considered along with the obvious cost of getting logging residue to the point of use.

Ideally, wood residue should be directed to the process or product affording the highest return and thus the most favorable opportunity to recover costs incurred in collecting, delivering, and preprocessing for use. Residue should be used for lumber production whenever feasible. The quantity of such residue 'available at a particular location may be insufficient, however, to offset the cost of the required extra handling to insure highest value use.

Sometimes, an individual operator, harvesting the bulk of the residue for one use, may be able to profitably divert small volumes of selected material to a higher value use. On the other hand, size of the landing itself or other physical or mechanical limitations may prevent the necessary sorting or special handling.

As utilization standards continue their natural response to a growing population's needs or as change is accelerated by economic incentives, the benefits of sorting for highest use will increase. Improvements in equipment and procedures for collecting and sorting for highest value use are probable and can in part overcome the high costs now associated with use of logging residue.

Currently, the costs shown in table 8 (with no sorting for highest use) greatly exceed delivered prices normally paid for mill residue-derived pulp chips, planer shavings, or fuel. As pressures to develop uses of logging residue increase, industrial enterprise can be expected to find ways to lower or offset costs to narrow the gap between delivered cost of logging residue and delivered price of residue.

ENERGY FROM WOOD RESIDUE

Wood was once a primary industrial and domestic fuel; since energy shortages are now being experienced, many persons have suggested that unused wood residue should be tapped as an energy source. A preliminary investigation of the feasibility of wood-to-energy conversion was a major part of this study. Special attention was given to production of process steam and to central electric generating plants burning wood residue alone or in combination with municipal refuse. Conversion by pyrolytic and other indirect processes which would yield gases and oils was also considered.

Electricity from Central Generating Plants

Central electric generating plants operating on wood fuel are rare today. In the Pacific Northwest there are few such plants, With one important exception, they are old installations used a little each year and maintained as standby facilities. Even in total, their generating capability is small.

The exception is the steam-electric powerplant operated by the Eugene Water and Electric Board of Eugene, Oregon. That plant was built in 1931 for standby electricity generation and has since been extensively modified and modernized. Basic fuel for the plant's boiler and generating capacity (32 MW) is hogged wood and bark, available at low cost from nearby mills. Using mill residue fuel, the plant provides steam for Eugene's steam heat utility on a year-round basis; and the balance of its steaming capacity is used to generate electricity for 8 months. It is on standby for electric power generation for the remaining 4 months each year.

The success of the Eugene plant in using wood residue for power generation has contributed to the current interest in and study of expanded use of the area's wood residue for power. Wood residue-fueled plants can be constructed in a minimum timespan, compared with lead time required for hydro and most thermal generating plants, and can be used as delays occur in the region's hydrothermal program.[6]

The special circumstances of the Eugene plant's operation notwithstanding, wood residue as the source of fuel for central electric powerplants is questionable. High costs associated with use of wood residue fuel cannot be ignored. They must be weighed with overall escalating power cost and decreasing availability of fossil fuels, or perhaps the higher cost power from residue-fired plants should be averaged with large amounts of lower cost power from other sources.

Analysis of the economics of using hogged fuel for power generation indicated that a medium-size plant would have annual capital and operating costs (except fuel) amounting to 8.5 mills per kilowatt hour (kWh) for a privately financed 50-MW capacity plant (table 9). For such a plant, gross revenue from power sales would have to exceed 8.5 mills per kWh before there would be any margin to provide for fuel costs or profit. As shown in table 9, if a 50-MW plant could be built with public funds as a grant for environmental and energy purposes, a gross revenue of only 2.1 mills per kWh would be required to provide for operating costs, with additional revenue from power sales available for fuel and profit.

Mater (see footnote 6) and Mason et al.[7] have reported on economics of directly converting wood residues to electrical power in a range of generating plant sizes. Although somewhat different assumptions were part of their separate studies, there is remarkable similarity and agreement in important conclusions reached. One of these is economy of scale effect of plant size. Generally, larger electric powerplants can be operated more efficiently and economically than smaller plants. As an example, comparative costs are estimated to be somewhat higher for a 25-MW capacity plant constructed with private or public capital than for a similarly constructed 50-MW plant (table 9).

Problems of supplying huge amounts of wood fuel to plants larger than 50-MW capacity tend to overshadow economy in scale gains, however, and plants larger than 50-MW were not considered in this analysis. Plants of less than 25-MW

[6] Jean Mater. Report on study of direct conversion to electrical power of forest residues from the Pacific Coast States and Alaska. Unpublished report to Pacific Northwest Forest and Range Experiment Station by the Dr. Jean Mater Bark Utilization Research Institute, Corvallis, Oregon, 59 p., 1972.

[7] H. C. Mason, D. H. Edel, and G. O. Tolman. Study and report on the direct conversion to electrical power of forest residues. Unpublished report to Pacific Northwest Forest and Range Experiment Station by H. C. Mason and Associates, Inc., Gladstone, Oregon, 29 p., 1972.

Table 9.--*Estimated annual costs (except fuel)* for *publicly and privately financed centra2 electric generating plants fueled by hogged wood and bark*[1]

Costs	25-MW capacity plant				50-MW capacity plant			
	Publicly financed		Privately financed		Publicly financed		Privately financed	
	Thousand dollars	*Mills per kWh*	*Thousand dollars*	*Mills per kWh*	*Thousand dollars*	*Mills per kWh*	*Thousand dollars*	*Mills per kWh*
Plant capital investment[2]	7,590	--	7,590	--	14,000	--	14,000	--
Amortization of private capital at 16 percent[3] per year for 25 years (including depreciation, interest, and taxes)	0	0	1,214	6.8	0	0	2,240	6.4
Annual plant operating costs[2]	540	3.0	540	3.0	739	2.1	739	2.1
Average annual costs (except fuel)		3.0		9.8		2.1		8.5

1/ Based on full-time plant operation at 80 percent of rated capacity.

2/ Adapted from a 1972 report by the Dr. Jean Mater Bark Utilization Research Institute to the Pacific Northwest Forest and Range Experiment Station. Although the possibility exists for establishment of a generating plant with a public grant (and no amortization charge), this may be the exception rather than the rule. There is more apt to be some capital charge in mast publicly financed plants.

3/ Lesser percentage rate may be more appropriate in localized feasibility analyses.

capacity appear to be too small to operate since scale economy is lost; above 50-MW, fuel supply requirements are limiting. For example, a wood residue-fueled plant of 25-MW capacity is estimated to require about 174,000 dry tons of residue annually, or almost 25 dry tons per hour (see footnote 6)--an amount equivalent to the residue from timber harvesting operations on two Ranger Districts of a National Forest in western Oregon.

Plant costs per kWh shown in table 9 and gross power sales rates required to offset these costs (and provide a margin for fuel and profit) do not answer the question of economic feasibility of wood for fuel. Current rates charged to utilities for power from existing sources must be recognized. Perhaps of even greater importance are projected costs of alternative power to meet peak demands and the availability of gas and oil. Power sales revenues allowing sufficient margin to provide for the high fuel delivery costs shown in table 8 will also be important because the large volume of wood required for a central generating plant almost invariably would require the use of logging residue. Such high electric power prices are certainly drawing closer. Fossil fuel costs are rising, and increases in hydropower rates are already scheduled. Even rather optimistic viewers see power costs continuing to climb. The delays experienced in increasing hydro and thermal capacity will adversely affect the supply-demand picture.

Figure 4 shows margins available for fuel (at no profit) for a range of power sales rates and the plant costs of table 9. The lowest sales rate used is the approximately 3 mills per kWh that Bonneville Power Administration charges its utility customers; the highest rate shown is 18 mills per kWh, a rate near the average received nationally by investor-owned utilities in 1971 from power sales to customers (Anonymous 1972c). Margins available for fuel would be zero or positive for a plant constructed with a public grant. For privately financed plants, the margin for fuel changes from negative to positive as power sales rates increase. Examination of figure 4 shows that a busbar electricity rate of 13 mills per kWh from a privately financed 50-MW plant would allow a margin of about $4 per dry ton of fuel. Nuclear power costs are expected to be 6 to 9 mills per kWh in 1974 and 9 to 13 mills by 1981.

Corder (1973) quotes a range of $2 to $4 per unit for Douglas-fir and hemlock sawdust and hogged bark fuel. Roughly, one unit of mixed fuel is the equivalent of 1 dry ton. Margins are not sufficient, however, to meet the full delivered costs shown for logging residue fuel (table 8), unless some of the yarding, loading, and transport costs are borne by higher value products or offset by recognized public benefits.

Although potential exists for reducing costs of logging residue, the lower costs of mill residue make it an obvious choice. Again, by use of plant costs from table 9, the effect of fuel cost on the cost of producing electricity is illustrated in figure 5, for 25- or 50-MW central generating plants fueled by hogged wood and bark. Obviously, in locations where suitable supplies of mill residue exist, high demand for electric power and willingness to accept higher costs for extra increments of power may increase use of these residues.

Process Steam Production

Generally, central electric generating plants below 25-MW capacity do not appear to be sufficiently competitive to warrant investment by public utilities.

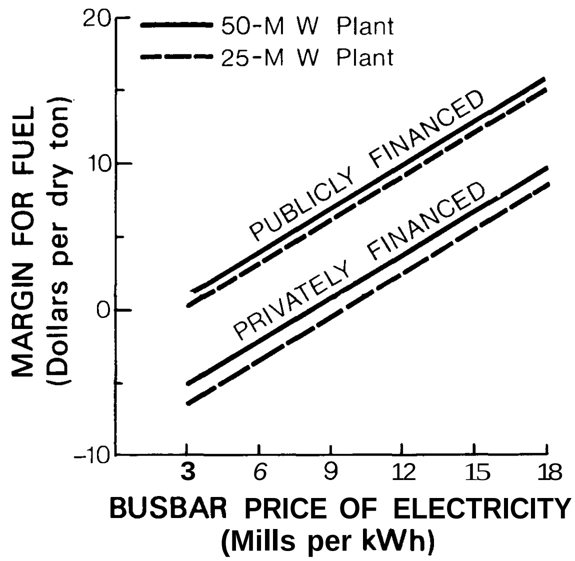

Figure 4.--Estimated margin for fuel (at no profit) for central electric generating plants fueled by hogged wood and bark, for varying power sales rates.

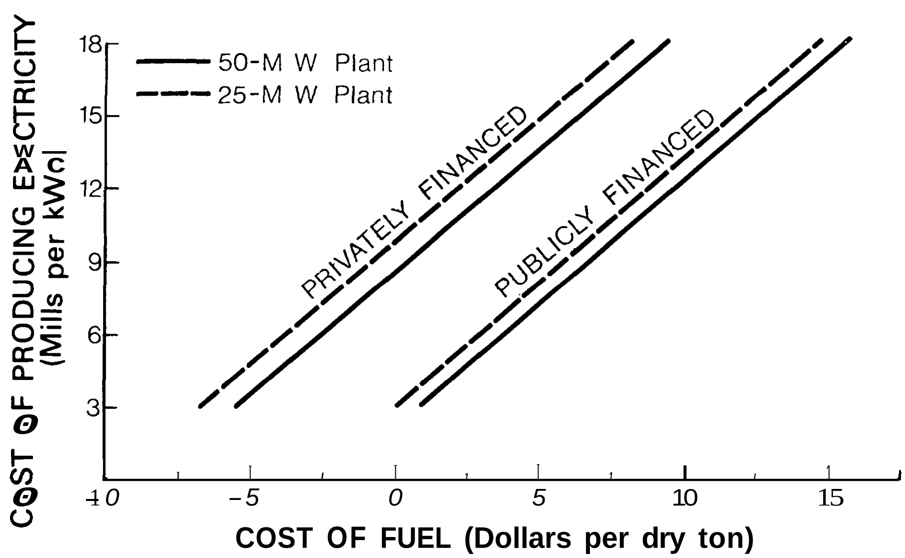

Figure 5.--Cost of producing electricity at central electricity generating plants fueled by hogged wood and bark, for varying costs of fuel.

However, some plants develop process steam equivalent to as little as 2 MW of electrical energy for industrial uses such as heating, cooling, drying, and hot-pressing.

Whitman discusses opportunities to use wood residue to produce steam as a primary purpose and electrical power generation as a secondary possibility.[8] He suggests institutional use (hospitals and community colleges) and industrial use (chemical manufacturing and food processing). Whitman concludes, however, that forest industry plants are the most logical users of wood residue for steam production. The pulp and paper industry is a good example since the equivalent of almost 50 million Btu is required per ton of paper produced. Twenty percent of this gross energy demand is used as electrical energy. The rest of the demand, or about 40 million Btu, is used to make process steam for the pulping and papermaking operations. Not having to convert all the Btu to electrical energy greatly improves the overall efficiency in generation,[9] as does the avoidance of costly cooling towers when exhaust steam is applied to processing.

Although a few wood industry plants operating residue-fueled power facilities have fuel available to produce more than enough power for their own needs, there is little opportunity for these plants to sell surplus power to utilities because its availability seldom coincides with peak electrical demand. However, current shortages of electricity are causing utilities to place greater value on electricity from wood industry plants. Several wood industry plants now have short-term arrangements to furnish power to utilities.

In the previous quarter century, many pulpmills converted from hogged fuel to gas- or oil-fired powerplants. Only recently has the trend been reversed as some plants have installed modern equipment to burn residue (mostly bark) for power in a manner consistent with current and anticipated air quality standards.

Combining Wood Residue and Municipal Refuse

When wood residue, especially mill residue, can be burned with municipal refuse for power generation, even relatively small generating plants offer favorable possibilities if alternative means of disposal cost more. The technical problems of burning mixtures of refuse and wood are surmountable, and trade offs between landfill, incineration, and power generation will influence the decision of a particular municipality.

Together, wood residue and other solid organic wastes (both municipal and agricultural) represent a significant energy source. The possibility that wood residue will improve the practicality of burning municipal refuse for electric power generation was investigated. Such dual firing might also offer a more promising outlet for residue than use as fuel in a conventional generating plant.

Although wood residue could assist in burning refuse for power, generally these wastes do not appear likely to be used for electrical power generation unless they present a serious disposal problem. Both the wood and refuse are bulky and scattered, and economics of dual-fired generating plants are still uncertain.

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[8] ~ o Eh Whitman. Generation of energy from forest residues. Unpublished report to the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 34 p., 1972.

[9] For thermodynamic reasons and under typical boiler conditions, 1 kWh of thermal energy yields about one-third kWh of electrical energy.

Cohan et al. have estimated a fuel value for refuse (based on costs and heat values of fossil fuel) and suggest that delivered cost of refuse as a replacement for fossil fuels should not exceed $2.46 per ton (about $3.50 per dry ton). [10] Gross heating value of refuse with an average moisture content of about 30 percent (wet basis) was estimated to be 4,500 Btu per pound. Table 7 shows that many western wood and bark materials have a gross heating value about 1.4 times that of refuse. Roughly, this suggests a maximum equivalent replacement fuel cost of about $4.90 per dry ton of delivered wood residue. This may be compared with the price range of $2 to $4 per dry ton of mixed mill-generated hogged fuel.

Costs of delivery and preparation of either wood residue or refuse for firing must also be considered. Wood residue requires only hammer milling (hogging) to make it suitable for clean burning, whereas municipal refuse requires shredding and magnetic separation before burning in suspension (see footnote 10). In a theoretical installation, Cohan and his coworkers calculated that transportation and preparation of refuse for firing would cost $5 per ton and have a fuel value (as delivered) of only $2.46 per ton. In the same example, however, they calculated that the $2.54 cost to burn refuse for power was still advantageous and a preferred alternative to the estimated cost ($6.22 per ton) for hauling the refuse to a landfill site and burying it.

Calculated equivalent fuel value for delivered wood residue would have to be reduced similarly to recognize transportation and preparation costs. If these are estimated on the same distance basis (25 miles one way), bulk hauling and hogging of a portion of the wood fuel amount to $5.35 per dry ton, slightly more than the rough estimate of equivalent fuel value of $4.90 per dry ton. There is no surplus to apply against any initial fuel cost or longer hauling distances, 100-percent hogging, and other costs for yarding and loading that would be incurred in using logging residue with municipal refuse. Obviously, available supplies of mill residue would cost less for dual-fired generation of electric power than would logging residue.

Capital and operating costs for generating plants burning wood residue and municipal refuse mixtures may be similar to costs shown in table 9, but smaller power revenues may result in larger negative fuel values (fig. 4) for wood residue. Even if this should be the case, an energy outlet for mill residue might be available if local mills were able to offset such a "dump charge" by avoiding equal or higher costs for alternative forrns of disposal.

Other Wood-to-Energy Conversion Methods

Most existing power boilers are designed to be fueled with oil, gas, or pulverized coal. Substantial modification in boiler design would be necessary to accommodate wood as the sole fuel or in combination with conventional fuel (see footnote 10). Furthermore, because of the lower carbon content, the potential for fly ash emission is greater when wood is burned unless the boiler is equipped with adequate air pollution control equipment. [11]

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[10] L. J. Cohan, J. W. Regan, and R. C. Shenk. Study of the advantages of burning wood residues in mixture with municipal waste to generate power. Unpublished report to Pacific Northwest Forest and Range Experiment Station by Combustion Engineering Company, Windsor, Connecticut, 75 p., 1972.

[11] L. G. Desmon. On particulate emissions using wood as fuel. Paper presented at Air Pollution Control Authority meeting, Eugene, Oregon, November 15-17, 1972.

(see footnote 10). Consequently, there is considerable interest in converting wood residue to an oil or gas and burning it in conventional power boilers. For this purpose, no distinction need be made among species or between wood and bark.

Anaerobic digestion of organic wastes by certain micro-organisms can convert these wastes to methane gas (natural gas). It is estimated that 10,000 cubic feet of methane could be produced from each dry ton of solid waste. Development is only beginning, but because of the texture of wood residue, rate of formation of gas from wood by this process is believed to be prohibitively slow.

The Bureau of Mines became interested in such conversions because of the huge accumulating quantities of municipal and agricultural wastes with high cellulosic content.[12/] In one catalytic procedure, an oil is obtained with a fuel value of 17,000 Btu per pound. Because of the energy required to carry out the conversion, however, net yield of oil is 300 pounds from 1 dry ton of residue with a net fuel value of 4 million Btu. Conversely, when burned as green hogged fuel, the the equivalent of 1 dry ton yields about 12 million Btu. Thus only one-third of the energy obtained by direct combustion is made available by conversion to oil. Furthermore, because of high operating temperatures and pressures, capital equipment costs would be high--although further work is necessary to quantify these. A small pilot plant demonstration unit has been planned but has not been built.

In a second process involving pyrolysis by *indirect* heating, the Bureau of Mines is also studying the gasification of organic wastes. From 1 dry ton of bark, 200,000 cubic feet of gas is obtained with 40-50 percent of the fuel value of natural gas and a high carbon monoxide content. This gas cannot be used for conventional municipal or residential purposes, since State laws limit the maximum carbon monoxide content in fuel gas. Furthermore, gasification is not complete; about 30 percent of the initial substance weight is converted to char. More seriously, about half the gas is required to carry out the reaction.

Such a conversion process would be more attractive if gasification was complete, with no production of char, as in a more recent proposal by Johanson and Sarkanen involving *direct* heating of residues in a fluidized bed reactor.[13/] In proper sequence, the char formed in pyrolysis is gasified by means of the water-gas reaction. A portion of the emerging low-energy fuel gas (200-300 Btu per cubic foot) is withdrawn from the main stream and recycled to the chamber for combustion, drying, and pyrolyzing of the residues. The main portion of the gas stream after purification is then used to operate both a gas turbine and a steampower generator. A combined theoretical power of 29 MW is claimed from such direct-heat pyrolysis of 20 dry tons per hour.

Although this is about the same as the power produced by directly burning 20 dry tons of wood residue, the fly

[12/] H. R. Appell, Y. C. Fu, Sam Friedman, P. M. Yovorsky, and Irving Wenders. Converting organic waste to oil, a replenishable energy source. Report of Investigation R. I. 7560, U.S. Department of the Interior Bureau of Mines, 1971.

[13/] L. N. Johanson and K. V. Sarkanen. Means of converting wood residues to energy other than through direct conversion to steam. Unpublished report to Pacific Northwest Forest and Range Experiment Station, 40 p., 1972.

ash problems are considerably minimized. The low-energy-content gas just described is an ideal propellant for a gas turbine. Johanson and Sarkanen (see footnote 13) note that the nature of residues and their scattered source of supply suggest a gasification process using *direct heating* to produce low Btu content fuel. They point out that it is difficult, however, to justify large scale (> 80 MW) power facilities based on wood residues. A reasonable size range would utilize 100-1,000 tons per day; this would provide units of 30- to 75-MW capacity. Considerable research and development are still necessary, however, to evaluate the fluidized bed reactor section of the proposed complete power facility; and it has not been possible to arrive at an adequately precise fuel value to make direct comparisons with other processes.

Additional processes for converting wood residue to energy may be forthcoming, as in new home heating units; but at this time these are insufficiently proven.

Although technical and economic feasibility of these wood-to-energy conversion systems is not yet well understood, these systems are promising avenues for which wood residue may be well suited.

Home furnaces burning sawdust or hogged fuel were in use in the Portland and Seattle areas in the 1930's and 1940's but have been displaced due to unavailability of clean mill residue as a fuel supply, collapse of the distribution system, changing architectural styles that provide no space for dry fuel storage or handling, and a changing life style toward more convenient heating systems. If the energy shortage continues to grow more severe, there could be renewed interest in wood-burning home furnaces, or those with a dual use--fired with wood and oil, gas, or coal depending on availability of fuel.

Today, the threat of fuel shortages has prompted many families to lay in a supply of firewood, partly as a reserve for emergencies, but also to reduce their use of other fuels. Demand has increased for Franklin-type stoves, for freestanding fireplaces, and for fuel logs of compressed wood residue. Thus, the home market for firewood might well be reevaluated, particularly in areas where wood supplies are close by, where smoke release is not a problem, and where use of wood for cooking and heating is more in harmony with the life style than in the cities. New home designs which provide for a wood stove in a family room or kitchen area, for both esthetic and practical reasons, could encourage domestic use of fuelwood.

Currently, there is increased demand for firewood from National Forests and Bureau of Land Management forest lands. This has helped reduce forest residue in some local areas, but the total effect and total potential are probably still small in relation to the total forest residue problem.

RAW MATERIAL FROM LOGGING RESIDUE

Wise use of mill residue as raw material for a variety of products has demonstrated the potential of wood residue in general. Similar use of logging residue is logical as utilization standards change with increased raw material demand and economic adjustments.

The possible raw material uses of logging residue represent a wide range of products and values. The highest value use available is usually preferred and sought. Ideally, the sounder segments of long cull or utility grade logs might be bucked for lumber or plywood production. Other portions containing sound fiber suitable for chips could be used for domestic production of pulp, paper, or building boards or for export chips. The remaining material would be available as fuel for steam or electric power generation.

Pulp Chips

In 1971, pulp chips in west coast and Japanese markets averaged about $18 per dry ton delivered to the pulpmill or export point. With a value many times that of hogged fuel, pulp chips appear to offer the best immediate use for logging residue — where there are markets for chips--except for those logs or log segments that can be economically sorted out for lumber or veneer production.

More than two-thirds of the logging residue now left in the woods is estimated to be sound chippable wood (table 2), and the remainder is usable as fuel. A 5-percent growth in pulp production on the Pacific coast would require yearly an additional 650,000 tons of mill and logging residue for fiber, plus additional energy equivalent to that obtainable from 1 million tons of residue. Unfortunately, the pulp industry seems more likely to expand in the South where residue provides only 20 percent of the industry's raw material, rather than in the West where mill residue supplies nearly 80 percent of the raw material and a large volume of logging residue is available for expanded production.

It is estimated that the Japanese pulp industry could use as much as 3.5 million dry tons of Western United States softwood chips by 1975 compared with 1.8 million tons in 1971. To supply this growing market for export chips, new chip handling facilities have recently been built at several Pacific coast ports. Export of pulp chips from logging residues is attractive but requires either a complementary outlet or alternative means of disposal for the bark, screenings, and other material rejected in chip manufacture. On the plus side, chip export requires relatively small capital investment, contributes little to pollution from processing, and has a favorable though small effect on the Nation's balance of payments.

Chips for Building Board Manufacture

Another major product area with potential for absorbing large volumes of logging residue raw material are the building boards--insulation board, hardboard, and particle board. This industry's history of rapid growth and projections for demand for building boards indicate a sustained high rate of growth. Particle board, currently derived primarily from mill residue, is especially in demand. A result of this demand and competition with the pulp industry for coarse residue[14/]

[14/] Suitable for chipping; includes slabs, edgings, and veneer cores and clippings.

is that available and suitable mill residue is becoming scarce in many areas. As suitable mill residue becomes scarcer, logging residue will become more attractive as a raw material source. Current prices for particle board raw materials are considerably less than the costs estimated for supplying logging residue for this use. In **1971,** mill residue shavings used for particle board sold for about **$6.50** per dry ton. This is less than pulp chips at $18 per ton but more than the estimated value for fuel.

As with pulp chips, complementary uses or alternative disposal means will be needed for the nonacceptable logging residue fractions that are developed in making chips or other wood particles for building boards. Inability to use all of a ton of logging residue as raw material means that selling prices mentioned for chips are for net volumes of sound, salable material, not' per ton of unprocessed logging residue.

PUBLIC BENEFITS OF WOOD RESIDUE USE

The authors of this report share a common belief: Benefits that will accrue to the public from wood residue use are significant and far reaching, and public sharing of residue utilization costs will be required if environmental goals related to forest resources, wood products, and energy are to be achieved. In the democratic process, the cost of environmental controls (and thus wood residue utilization) will be balanced by the desire for benefits. Numerous professional and nonprofessional and technical and nontechnical groups are attempting to increase the public's awareness of the conflicting and interacting forces involved. Of prime importance is the need to determine costs and benefits of residue use or disposal.

The public benefits from wood residue use include greater environmental protection with less need for broadcast burning of logging slash, a cleaner appearance of the forest after logging, better on-the-ground access for reforestation and intensive land management, an addition to employment and gross national product, and a net addition to the Nation's energy and raw material supplies.

High costs of collecting and transporting logging residue and the capital investment necessary for new electric generating plants or new wood processing facilities are major deterrents to residue use. The benefits of utilization are believed to be great enough to justify public absorption of some of the associated extra costs, at least for logging residue from publicly owned lands. In short, public benefits can offset high residue removal costs and can make utilization more feasible.

This is by no means a new concept nor original with the authors. In **1964,** a Pacific Northwest consulting firm emphasized a similar concern about air pollution from disposal of mill residues by burning.[15] The firm's report pointed out the contribution that electric power generation could make to the national economy with an accompanying reduction in **air** pollution from mill refuse burners. They further recommended that these positive effects be recognized as justification of accelerated depreciation schedules for necessary installations. Various

[15] Cornell, Howland, Hayes, and Merryfield, Inc. Power or pollution—a study of the economics **of** power generation as a solution to the **waste** disposal problem in the forest industries. Corvallis, Oregon, 37 p., April **1964.**

legislation to encourage this kind of action has been considered, but specific measures have not been enacted.

Better alternatives for treating logging residue are basic to the effort covered by this report. Utilization is a preferred treatment, but deterrents to increased use must be overcome. Logging residue is normally treated by various means to reduce conflagration hazards and to facilitate reforestation. In table 10, estimated costs are compared for alternative logging residue treatments, including removal for use, a partial measure--varying amounts of residue left on the site may require further measures before the logging residue treatment is complete. Present standards for residue treatment do not universally require the costly practice of yarding unutilized material (YUM) into large piles for subsequent burning, but when required the cost comes close to that estimated for removing the largest size class of residue and of treating the remainder.

If removal of residue resulting from timber harvest were required, the cost of such removal could be made a part of the stumpage appraisal in any given timber sale, as are estimated YUM costs. This removal cost could be treated either as a deposit for future payment to a contractor specializing in such removal work, or as a regular cost for work required in the original timber sale. The report of the President's Advisory Panel on Timber and the Environment [16/] suggests that compensation for required removal of small or defective material without economic value could readily be expressed as a purchaser credit against stumpage payments due. If an assured logging residue supply is needed to amortize a long-term plant investment, the deposit procedure could also be made to apply to a reserve account. This reserve could be used to pay incentives for removal over a period of years to an electric utility or to a processor holding a long-term contract for residues.

With special attention to the potential for power from wood residue, a recapitulation of some pros and cons of such use is included in the appendix. This is by no means an exhaustive listing but does include many significant factors favoring or disfavoring development of wood-to-energy conversion facilities in the Pacific Coast States.

With the expectation that some public sharing of extra costs will have to be a part of any significant program to use wood residues for energy, four possibilities are suggested for the public to absorb part of the extra costs of power generation using logging residue from public lands: (1) required removal, making these extra costs part of the total cost of logging an entire timber sale area, (2) sharing in capital plant investment through a nonrepayable grant, (3) special provision for accelerated depreciation for income purposes, and (4) indirectly through a general price increase for electric power from all sources.

A combination of possibilities would seem most suitable. For example, in combining possibilities 1 and 4, an estimated $15 per thousand board feet reduction on stumpage value spread over an entire timber sale could make the total cost of power generation (including fuel but no profit) about 6 mills per kWh for a 25-MW plant financed by public grant, or about 13 mills if the plant were privately financed. These rates are higher than current Pacific Northwest power

[16/] Report of the President's Advisory Panel on Timber and the Environment, 541 p., April 1973.

Table 10.--*Logging residue treatment costs*[1]

Treatment	Cost of removal to point of use[2]	Postremoval site treatment cost	Total residue treatment cost	
Burning in place	--	--	193	5
YUM[3] and burning	--	--	625	16
Removing for utilization all residue to minimum size:[4]				
A. 4-inch diameter, 4-foot length	1,241	41	1,282	32
B. 8-inch diameter, 8-foot length	793	60	853	21
C. 12-inch diameter, 8-foot length	574	141	715	18

1/ Based on an area typical of the western slope of the Cascade Range with a 40,000 board feet per acre net timber harvest.

2/ Estimated yarding, loading, and transport costs plus 20-percent margin for profit and risk (no preprocessing included).

3/ Yarding unutilized material into central piles.

4/ Quantities of residue removed, size classes A, B, and C respectively, 37, 28, and 22 dry tons per acre.

costs to utilities from conventional sources, but they may compare favorably with the costs for additional power from new sources.

Averaging small amounts of high-cost wood-generated power with very large amounts of low-cost hydro and other conventional power for a slightly increased overall cost for a larger power supply might be acceptable to environmentally concerned consumers. Moreover, lowering the overall stumpage return from a timber sale as suggested above may be justified in recognition of the indirect public costs and benefits involved.

RESEARCH AND DEVELOPMENT NEEDS

Research and development needs identified in this preliminary investigation appear to have an important bearing upon significant gains in wood residue utilization, especially from logging. Additional funding of public and private research and development programs could speed completion of work underway, but this requires awareness of the benefits from use of residues.

Marketing Procedures for Logging Residue

Wood uses that accommodate large volumes of residue usually require that available mill residue supplies be supplemented by logging residue. New marketing procedures are needed for competitive proposals to remove and use logging residue from public lands, especially where assurance of long-term availability of residue is required to justify capital expenditures for a powerplant or a wood processing facility. These marketing arrangements, some of which could require new legislation, must be developed and field tested.

"Service-type" contracts which require the forest land being left in a specified manner may be part of the answer; the contractor could be required to leave the land in a specified condition ready for reforestation, thus requiring removal of all sound and unsound material to a specified level. Payment for costs of such "service" could be provided by the appraised value of the timber to be removed. Potential contractors could compete for such a job on a bid basis, paying to get the contract, or if timber values were considered insufficient, offering to undertake the job for payment to them of a bid amount. An important facet of this procedure is that it places emphasis on the performance of cultural measures and services supplied to the public landowner (see footnote 16) rather than on timber volume sold and removed.

Other measures being considered include more rapid closeout of timber sale contracts, with the result that title to residue not removed reverts more quickly to the public landowner, allowing residue to be competitively reoffered for sale. For species subject to rapid deterioration, salvage must be prompt or it is of little value. Also, potential saw-log quality material may be stained and checked, so that it is suitable only for chips if salvage is delayed one or more seasons.

Materials Handling

Far more than by marketing arrangements and product technology, use of logging residue is limited by prohibitive costs incurred in use of current equipment and methods to collect, load, and transport the highly variable and dispersed residue from forest areas. This is a challenge to wood residue users for which solutions must be found. Innovative preprocessing measures also are needed to minimize costs of handling residue materials in subsequent operations. Typical are systems to progressively debark, sort for highest value use, and preprocess the residue at an optimum point between the place of collection in the forest and the place of use. A related development and pilot test need is for complementary outlets to facilitate disposition of rejects from a wood preprocessing point (e. g., bark and rot at a pulp chip preprocessing site).

Fortunately, various aspects of residue materials handling are receiving attention. Forest engineering research and development in improved skyline systems will have significant applicability to residue reduction in steep terrain of the Pacific coast (Lysons and Twito 1973). Both private and public agencies are engaged in developing and testing equipment, sometimes cooperatively as in woods chipping trials in Wyoming (Gardner and Hann 1972).

Process and Product Technology

Process and product technology advances require more research and development. For example, potential methods for producing power from wood, coal, or municipal refuse include direct pyrolysis in a fluidized bed to obtain a low energy gas for operating a gas turbine or a combination of gas and steam turbines for electric power generation. These processes could provide improved efficiency and improved particulate control in residue burning. Several processes are reviewed by Johanson and Sarkanen (see footnote **13**) and others (Anonymous 1972b).

The potential for logging residue use can be significantlyincreased by use of bark fiber in more grades of paper and board. Investigators are pursuing improvements in removing bark from small irregular-shaped pieces of wood and in separating the wood and bark components of rough chips. However, the wider use of bark in products offers greater promise for expanding residue use (Horn and Auchter 1972).

Development, demonstration, and acceptance of a weather-resistant particle board with strength characteristics similar to those of construction plywood would improve the building board industry's ability to pay for delivery and use of large volumes of logging residue as raw material. Public agencies and private firms are developing a structural particle board, working together on some aspects of the overall program. Although boards with structural properties are being introduced, these are considered of an intermediate nature, with the full potential for boards with advanced structural properties yet to be realized.

Market Evaluation

Additional utilization of wood residue is more than a matter of cost comparison with competing materials. It is also a matter of convenience, dependability, market demand, and environmental effects. Market studies can be especially useful in guiding development of any major effort toward increased residue use either in domestic heating or in industrial applications.

LOCAL FEASIBILITY EVALUATIONS

This broad preliminary investigation has identified possibilities for utilization of wood residue which must be carefully evaluated for conditions found in a local area. Only through a localized evaluation of feasibility can a "go" situation be confirmed for an energy or raw material use of available mill or logging residue.

General conclusions reached in this preliminary investigation about feasibility of a particular energy or raw material use may be unrealistic for a local area with special needs or special opportunities. Overall, the opportunity to use wood residue for power generation in forest industry plants appears more favorable than in central generating plants. However, there may be communities in the Pacific Coast States that could use residue for energy. A microarea might have forest industry plants needing both residue disposal and process steam. Such an area might also have unfulfilled consumer power needs and need an improved method for disposing of municipal refuse. Ability to burn wood residue (perhaps in combination with municipal refuse) for process steam and electric power could make wood-to-energy conversion economically feasible. Another area with a different condition of residue availability or environmental need could reach a "no go" decision. Only a local evaluation can determine this. Some guidelines to determine the local availability of residue are given in the appendix.

The concept of feasibility must take into account the growing pressures from society and land managers to cleanup after logging and to prepare the land for reforestation and improved productivity. The public is demanding changes, but costs of making these changes must be recognized and accepted. Economic costs must be traded for benefits to society. Local analyses aided by increased efforts in research and development should establish which utilization alternative (or combination of alternatives) will provide the most acceptable solution for a given situation.

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APPENDIX

Units of Measure for Wood Residue

Cubic foot.--Cubic volume may be expressed in solid cubic feet as with logs or chunks or in bulk volume as with a 200 cubic-foot unit of chips. Solid cubic volume may be expressed in gross cubic feet (total volume) or net cubic feet (the volume considered usable). The difference is the volume considered unusable because of small size or an advanced degree of defectiveness.

Tons (wet).--Residue includes moisture and is expressed as tons (wet). The wet weight of wood residue may be made up of roughly half wood and half water. Residue weight is often estimated by applying a conversion factor to the measured solid cubic content. In this report, the conversion factor for wet (or green) round material is 50 pounds per cubic foot of wood and bark.

Tons (dry).--The bone dry weight of wood and bark is a basic unit for measuring wood residue of varying densities and moisture contents. For the mix of softwood species occurring in the wood residue of the Pacific Coast States, a conversion factor of 25 pounds per cubic foot (bone dry) is used in this report. Dry and green weights of wood and bark of some western species may be found in figure 6.

Unit.--The unit applied in the bulk measurement of fine wood residue such as sawdust, hogged fuel, or chips is the quantity occupying 200 cubic feet of bulk volume. The amount of solid wood and the weight of residue contained in one unit will vary with compaction, moisture content, and species. The solid cubic content of wood in one unit may vary from as little as 30 cubic feet of wood in the form of planer shavings to as much as 90 cubic feet of wood in compacted pulp chips (fig. 7). For this report, one unit of wood residue is considered equivalent to 80 cubic feet of solid wood and bark with a wet weight of 4,000 pounds and a dry weight of 2,000 pounds.

Cunit.--A measure originally based on a stack of 5-foot long wood, 4 feet high and 8 feet long (160 cubic feet in bulk) or its equivalent--now taken to be 100 cubic feet of solid wood, in log or bolt form.

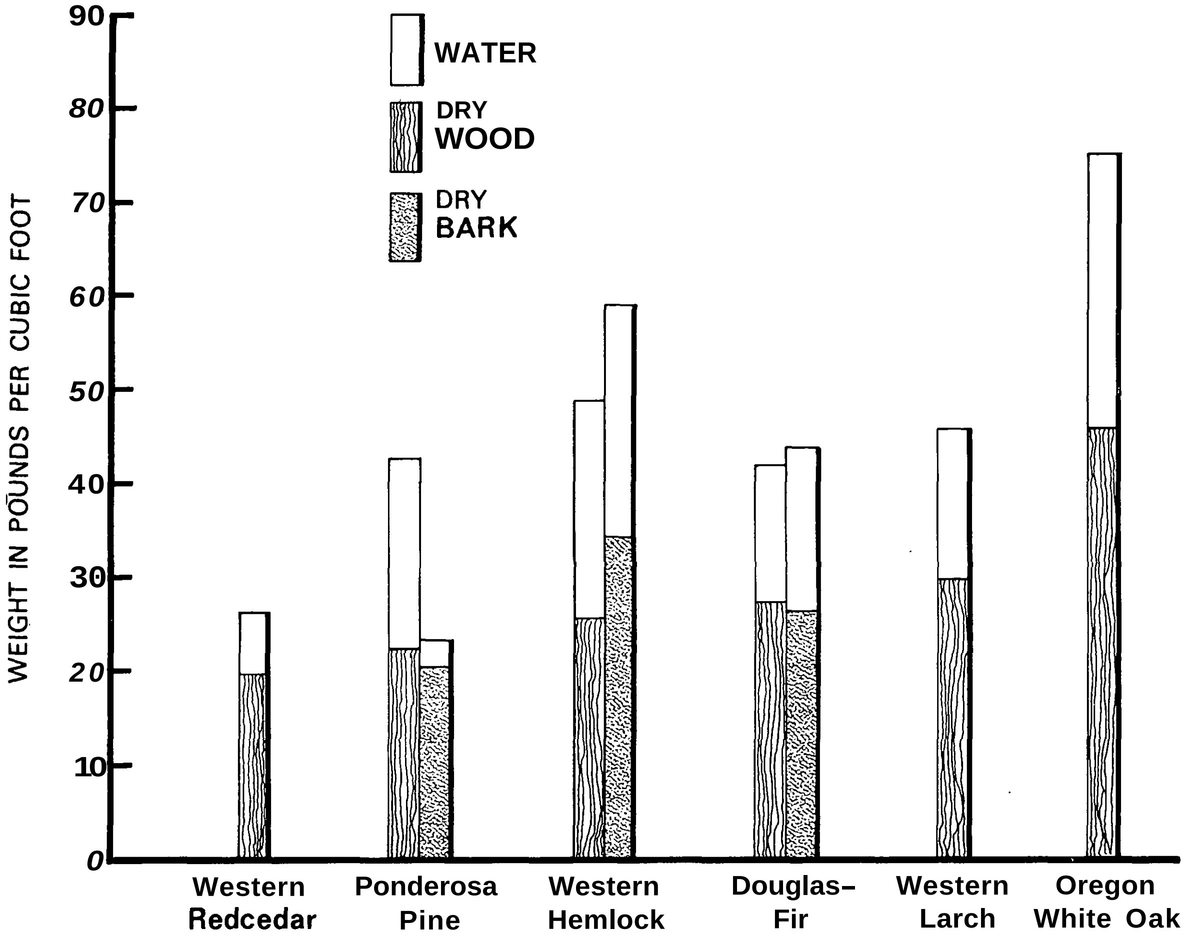

Figure 6.--Bone dry (shaded) and green weights (including water) of some western woods and barks.

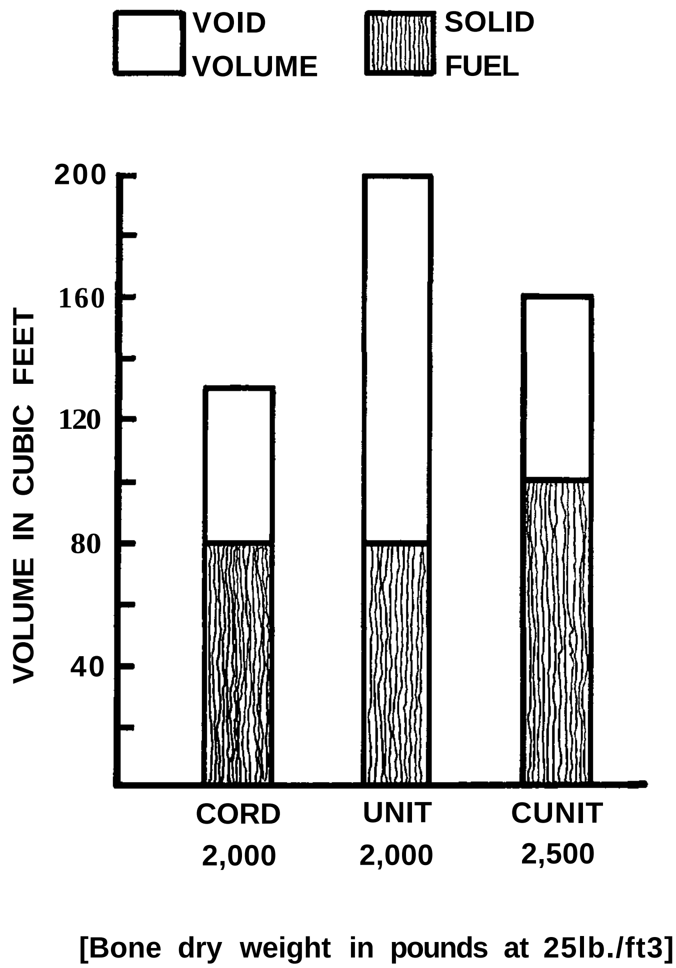

Figure 7.—Average volumes and weights of some common units of measurement for wood residue fuels.

Guide to Estimating Residue Availability in a Specific Location

1. Anticipated logging residue

   Allowable annual cut on all National Forest lands tributary to the location X appropriate factor from table 2 or table 3 ______

   Allowable annual cut on other tributary public lands X appropriate factor from table **2** or use National Forest factor from table **3** ______

   Estimated annual acreage of private land to be cut in the area X the appropriate factor from table 2 ______

   Add 10 percent for bark volume available ______

2. Unused mill residue*

   Determine local lumber production and apply the residue factor from page **3** ______

   Determine local veneer or plywood production and apply the appropriate factor of 0.4 dry ton or **0.5** ton per thousand square feet (3/8-inch thickness) of green veneer or plywood, respectively ______

*Factors for mill residue include bark.

Some Pros and Cons of Power Generation From Wood Residue

Pro	Con
1. Wood residue can supply some of the critical energy needs in the Pacific Coast States, especially as costs and problems of availability of other fuels increase,	1. Volume of mill residue may be insufficient without use of high-cost logging residue.
2. Wood-to-energy conversion at modern central plants can lessen the undesirable. environmental effects of wood residue disposal in the forest and at individual mill sites.	2. Uncertainties of cost and availability of logging residue on a long-term basis are discouraging.
3. Public opinion generally favors putting residue to use, rather than being wasted by burning or land filling.	3. Technology of an efficient, economical, and environmentally acceptable wood residue-fueled electric generating plant is not completely worked out and demonstrated.
4. Power generation in wood industry plants can have the dual benefit of providing both electricity and process steam needed in such plants.	4. Fly ash and boiler tube erosion are generally greater with wood fuels than with fossil fuels.
5. Lead time required for wood residue-fueled electric generating plants is less than for nuclear plants or hydro facilities.	5. Wood residue-fueled plants of 25- to 50-MW capacity are less economical than the 200- to 1,000-MW size fossil or nuclear plants on which the power industry usually bases its plans.
6. Combinations of wood residue and municipal refuse can be burned together to provide power and solve disposal problems at the same time.	6. Raw material demands cause logging and mill residue volumes to vary, with long-term trend of increased use of residue for products.
7. Wood residue can substitute for fuels in short supply, releasing current supplies for other use.	7. The capital cost of a wood residue-fueled plant is about double the cost of a nuclear plant of equivalent capacity.
8. Dependence upon foreign sources of fuels can be reduced when drastic cutbacks are in prospect.	
9. Use of wood residue for power generation saves disposal costs that would otherwise be necessary.	
10. Wood-to-energy conversion does not produce undesirable sulfur and nitrogen compounds.	
11. Modern wood- or bark-fired boilers can substitute for obsolete reserve plants now in use.	

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

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