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# Environmental and Technological Analysis of the Use of Surplus Wood as an Industrial Fuel

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# ENVIRONMENTAL AND TECHNOLOGICAL ANALYSIS OF THE USE OF SURPLUS WOOD AS AN INDUSTRIAL FUEL

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## DISCLAIMER

## FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents the findings of a research program conducted to evaluate the current status of the technology for burning wood as an industrial fuel. Research and development needed to encourage more extensive use of wood fuel outside the forest products industries is identified. A listing of existing wood-burning installations and summaries of operational experience of selected facilities are included to aid interested companies in developing the capability to burn wood in their own plants. Energy managers in industrial companies as well as R&D planners should find the report of value. For furhter information on the subject please contact the Fuels Technology branch of IERL-Ci.

David G. Stephan
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ABSTRACT

There is widespread interest in the use of surplus wood as an industrial fuel because it is a renewable resource, and because it has a negligible sulfur content. However, the use of wood fuel is still currently limited primarily to the forest products industries.

This research program was conducted to evaluate the current status of wood-burning in industry, to identify research and development activities which are needed to encourage more extensive use of wood fuel in facilities outside the forest products industries, and to evaluate the potential benefits and problems associated with greatly expanded uses of wood fuel.

A listing of 284 domestic and 44 foreign installations of wood-burning equipment was compiled. Information on operational problems was developed through visits to selected facilities and through contact with vendors. Summaries of this information are presented, and research and development programs designed to overcome the most common operational problems are recommended. Non-technical barriers to expanded wood-fuel use are explored.

Estimates for reduction of sulfur-dioxide emissions achieved by burning wood in lieu of coal or oil are presented. Emissions of particulate matter and NOx are not found to be higher from wood-combustion than from coal-combustion.

Industrial fuel requirements are compared with the quantities of unused wood residues available on both regional and national levels as an indication of the level of wood-fuel use which could be supported without endangering long-term forest production.

Ecological impacts of wood residue utilization are explored.

This report was submitted in fulfillment of Grant No. R-805-0-50010, under the partial sponsorhsip of the United States Environmental Protection Agency. This report covers a period from September 1, 1977 to December 31, 1978; work was completed on December 1, 1978.

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TABLES

LIST OF CONVERSION FACTORS

Btu (at 60 F) x $1.055 \times 10^3$ = Joule (J)

$10^6$ Btu x 1.055 = $10^9$ Joule = GJ

feet x 0.3048 = meter (m)

degrees Fahrenheit ($^{o}F$ - 32)/1.8 = degrees Celsius (C)

pound mass (lb) x 0.4536 = Kilogram (kg)

Btu/pound (lb) x $2.326 \times 10^{-3}$ = Mega Joule/kg (MJ/kg)

lb/$10^6$ Btu x 0.4299 = kg/GJ (kg/$10^9$J)

short ton (2000 lb) x 0.907 = metric ton (1000 kg) = k kg

dollars/short ton x 1.102 = dollars/metric ton

dollars/$10^6$ Btu x 0.9479 = dollars/GJ ($/$10^9$ J)

pound force per square inch (psi) x $6.895 \times 10^3$ =
Pascal (Pa) = Newton/$m^2$ (N/$m^2$)

gallon (U.S.) x 3.785 = liter

barrel (42 gallon) x 159.0 = liter

SECTION 1

# INTRODUCTION

In 1975, the United States Environmental Protection Agency asked Battelle Laboratories to evaluate the feasibility of using wood as fuel for a new 50-MW electric power plant in Vermont. In that study, wood was compared with a number of alternative fossil fuels: low-sulfur coal, physically cleaned coal, high-sulfur coal with flue-gas desulfurization, and low-sulfur oil. All of these fuels were compared with respect to: boiler technology; pollutant emissions and pollution-control technology; energy requirements for the acquisition and transportation of the fuels; costs, and ecological impacts. The general conclusions of that 1975 study* were as follows:

- The use of forest surplus wood and waste wood is technically feasible
- Pollutant emissions are controllable
- Net energy balances are favorable
- The cost is competitive
- With proper forest management, there is potentially a net benefit to Vermont's forest ecosystem
- Wood is a renewable resource
- Therefore, a demonstration to advance the concept toward commercial application is recommended.

Since use of wood fuel in small electric power plants (50 MW or less) is feasible in certain areas of the country, its use as fuel in the industrial sector should be investigated. Wood has been used as fuel in the forest products industries for many years; however, very few uses of wood fuel are found in other industries.

The present study was undertaken to clarify the potential benefits and the potential detrimental effects of a greatly expanded use of surplus wood or wood residue for industrial use. Consideration of other sources of wood for fuel was excluded.

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* Hall, E.H., C.M. Allen, D.A. Ball, J.E. Burch, H.N. Conkle, W.T. Lawhon, T.J. Thomas, and G.R. Smithson. 1975. Final Report on Comparison of Fossil and Wood Fuels, to the U.S. Environmental Protection Agency. Battelle Columbus Laboratories, Columbus, Ohio. 238 p.

The objectives of the study were as follows:

1. Summarize the results of recent studies on potential availability of surplus wood.
2. Assess the current state of technology for using surplus wood as a fuel.
3. Describe specific installations where surplus wood residue is being combusted, with emphasis on identification of problems.
4. Identify any technology related research and development needs.
5. Identify non-technical barriers inhibiting wood-waste utilization.
6. Assess the potential for reducing total $SO_2$ emissions by burning wood instead of coal or oil.
7. Evaluate the ecological implications of waste-wood utilization, including the effects that excessive use of wood for fuel might have on the long-range productivity of forests.

## SECTION 2

## CONCLUSIONS

Since the technology for direct combustion of wood is well established, conversion to wood fuel could be readily implemented. Basic firing methods include: stokers, suspension burners, and fluidized beds. Research into new approaches to wood combustion is not needed since very few changes occur in the technology.

Wood-gasification, on the other hand, is not an established technology. When successful processes have been developed, unfavorable economic factors have precluded widespread use. Low-Btu gas produced from wood affords one means for conserving gas and oil, and such a product would provide a relatively simple method of conversion to wood for industries facing curtailment or cutoff of natural gas. Research is needed to clearly identify those aspects of wood-gasification technology which work to its economic disadvantage, and to conceptualize and evaluate technical approaches which improve the relative economics.

Non-technical barriers to the use of surplus wood as an industrial fuel include:

1. The lack of an established supply/market infrastructure. Forest products industries normally have internally generated wood-waste available for use as a fuel. Non-forest products industries would be reluctant to commit capital to conversion to wood fuel without an assured wood supply. Forest products industries could make wood chips available to other industries; however, they are reluctant to invest in additional equipment without an assured market. Some entrepreneurs acting as wood-chip brokers could help to overcome this institutional barrier.
2. Competition among alternative users of wood.
3. Uncertainty concerning the future price of surplus wood.
4. Inconvenience of wood as a fuel, compared with gas or oil.
5. Capital investment required for conversion of facilities to wood fuel.

The use of wood instead of coal or oil can result in decreased emissions of sulfur dioxide ($SO_2$). If 150-million tons* of green wood were burned

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* A table of factors for conversion of English units to metric units is provided on Page viii.

per year, instead of 50-million tons of coal containing three percent sulfur, $SO_2$ emissions would be reduced by 2.85 million tons/year. To achieve equivalent reductions by stack-gas scrubbing would require scrubbers operating at 85 percent removal efficiency to be installed on 1,175 coal-fired boilers averaging 250,000 pounds of steam per hour at 45 percent load factor. If limestone scrubbers were used, more than 18-million tons of scrubber sludge requiring disposal would be produced. Emissions of particulate matter and $NO_x$ would not be increased if wood were burned in place of coal.

Because industrial wood-fuel use is not expected to exceed the supply of unused wood residue, no depletion of forest resources is foreseen. More than half of the total annual fuel requirement of industrial facilities larger than 100-million Btu/hour could be supplied from unused wood residues on a continuing basis. While the extent of industrial wood-fuel utilization cannot be projected exactly, wood-fuel requirements of such magnitude are unlikely.

The long-range significance of nutrient removal associated with utilization of logging residues has not been established.

## SECTION 3

## RECOMMENDATIONS

The following research and development needs were identified in the course of the study.

1. Development of an innovative system for feeding wood-fuel, designed to accommodate various sizes and shapes encountered in the several sources of wood.
2. Development of a cost-effective wood-chip dryer to permit higher overall efficiency in the wood-fuel system.
3. Demonstrations of wood-fuel conversion in plants not associated with the forest products industry. The essential points of the demonstration are: logistics of obtaining wood for fuel, conversion technology, and life-cycle costs for the conversion of such demonstrations. Widespread dissemination of the results would encourage the conversion to wood fuel by industries not familiar with wood-fuel potential.
4. Conceptualization and evaluation of technical and economic approaches to overcome economic disadvantage of wood gasification compared to coal gasification.
5. Development of definitive data on the effects of nutrient removal on long-term forest productivity.

# SECTION 4

# SURPLUS WOOD RESIDUE AVAILABILITY IN THE UNITED STATES

## INTRODUCTION

Rapidly decreasing supplies of fossil fuels are creating a need for alternate or additional sources of energy. Interest in utilizing wood wastes as an energy source is growing because of wood's high Btu content and its relatively clean-burning properties.

In the U.S., approximately 14-billion cubic feet of timber were harvested in 1970 to be processed into lumber, plywood, and pulp (USDA Forest Service, 1973). Large volumes of wood and bark residues are generated by harvesting, processing, and primary manufacturing operations. These by-products, which make up more than 50 percent of a log (Cheremisinoff et al., 1976), include trimmings, sawdust, sander dust, edgings, chips, and bark.

Residue generated at each stage of wood-products processing must be disposed of by sale, burning, landfilling, or use as fuel. Which alternative is exercised depends largely upon (a) availability of residue markets, (b) distance to markets, (c) environmental regulations, and (d) cost and availability of alternative fuels. Most of the easily obtainable residues from milling operations are being or will be utilized for higher-value products such as fiber board and pressed wood products, at least in the near future.

A tremendous volume of wood fiber (1.6 billion cubic feet was reported for 1970; USDA Forest Service 1973), is left in U.S. forests as residue from logging. Only an estimated 50 percent of the above-ground biomass of an individual tree is removed for merchantable sawtimber (Keays, 1975a). Residues from logging operations are typically so scattered as to require a substantial energy cost to collect them. Management methods must be developed for residue collection at initial harvest if the gathering of logging residue is to be profitable. Beyond its potential fuel value, other forces are acting to make forest-residue collection a reality, e.g. in southern pupling forests of short-rotation, plantation design, residuals must be removed prior to seed-bed preparation; in forests in the pacific northwest, massive quantities of forest slash after clearcutting must be removed to reduce the possibility of forest fires.

The border between nonusable and usable wood residues is a dynamic boundary; material previously unused is gaining increasing utility. Treetops, small branches, and foliage, long considered nonusable residues, are now being chipped, transported, and used, e.g. as fuel or pulp feedstock. Such uses encourage whole-tree processing. However, roots, stumps, and unmerchantable trees still remain in the forest, largely as residue.

As new methods and equipment are employed for collecting logging residues, at least some of the material collected will be reclaimed for use in wood products returning more value than if used as fuel. These new methods and equipment affect expansion in wood commodities and in energy use of wood.

FOREST RESOURCES

At present, there are approximately 500-million acres of land in the U.S. classified by the Forest Service as commercial timberland (USDA Forest Service, 1973). By definition, these lands must be capable of producing 20-cubic-feet of timber per acre, per year. These acreages do not include lands withdrawn from harvest, such as areas given wilderness designation. Nearly three-quarters of this commercial timberland is located in the eastern half of the U.S. Approximately 25 percent is concentrated in the Pacific Northwest.

The forests of the U.S. are biologically diverse. There are 40 major forest types and some 60 major tree species. Conifers, such as spruce, pine and Douglas fir, are most fully used for lumber, plywood veneer, and pulp. Hardwoods (oak, maple, hickory) provide materials for solid wood products, paper, and paperboard. Removals of softwood sawtimber were 84 percent of the total removals in 1970. Softwood growing stock growth was 111 percent of the removals. For hardwoods, sawtimber growth was 131 percent of removals; growing stock growth was 179 percent of removals (National Research Council, 1976).

Current annual growth is estimated as 38-cubic-feet per acre, per year (National Research Council, 1976; Spurr and Vaux, 1976). [The mean varied from 65 cubic feet on the Pacific coast to 23 cubic feet in the Rocky Mountain region (National Research Council, 1976).] The latest estimate of net growth is 18.6-billion-cubic-feet per year for the U.S. in 1970.

Current forest statistics from each state are shown in Table 1. Figures reported by the USDA Forest Service (1973) were used in cases where the most recent data for a state were prior to 1970. This table shows 491-million acres of commercial forest land, removals of 232-billion cubic feet and 438-billion cubic feet for hardwoods and softwoods, respectively, and a growth rate of 45-cubic-feet per acre, per year.

Spurr and Vaux (1976) estimate that the commercial forest land base will decrease to 455-million acres by approximately 2020, due to land withdrawals for urban or industrial or other use. (The U.S. Forest Service predicts a decrease to 474 million acres.) Even though available acreage is expected to decrease, Stephens and Heichel (1975) suggest that timber production can be approximately doubled through better, more intensive management. The Pacific states offer the most potential for productivity

## TABLE 1. FOREST STATISTICS FOR THE UNITED STATES BY FOREST REGION[a]

| State | Area of Commercial Forest Land ($10^6$ acres) | Net Volume of Growing Stock ($10^9$ cubic feet) | | Annual Net Growth ($10^6$ cubic feet) | Timber Removals ($10^6$ cubic feet) | Logging Residues ($10^6$ cubic feet) | Date of Survey |
|---|---|---|---|---|---|---|---|
| | | Hardwoods | Softwoods | | | | |
| | | | | **NORTHEASTERN FORESTS** | | | |
| Connecticut | 1.8 | 2.0 | 0.4 | 73.8 | 14.0 | 0.7 | 1972 |
| Delaware | 0.4 | 0.4 | 0.2 | 31.0 | 11.9 | 1.0 | 1970 |
| Maine | 16.9 | 6.5 | 14.8 | 710.8 | 408.7 | 55.8 | 1970 |
| Maryland | 2.9 | 2.5 | 0.5 | 106.5 | 75.6 | 14.8 | 1970 |
| Massachusetts | 2.8 | 2.1 | 1.3 | 130.1 | 34.7 | 3.7 | 1971 |
| New Hampshire | 4.7 | 3.4 | 3.1 | 236.3 | 64.4 | 4.5 | 1973 |
| New Jersey | 1.9 | 1.2 | 0.3 | 24.9 | 16.0 | 0.9 | 1971 |
| New York | 14.5 | 9.2 | 3.3 | 285.9 | 115.0 | 19.7 | 1970 |
| Pennsylvania | 17.5 | 18.7 | 1.6 | 762.8 | 231.8 | 48.2 | 1970 |
| Rhode Island | 0.4 | 0.2 | 0.1 | 14.9 | 3.3 | 0.1 | 1971 |
| Vermont | 4.4 | 3.0 | 1.7 | 106.6 | 47.8 | 6.6 | 1973 |
| West Virginia | 11.5 | 12.7 | 0.8 | 473.5 | 166.1 | 21.2 | 1975 |
| Totals for Region | 79.6[b] | 62.2 | 28.0 | 2,957.0 | 1,189.1 | 177.0 | |
| | | | | **NORTH CENTRAL FORESTS** | | | |
| Illinois | 3.7 | 2.3 | —[c] | 92.5 | 91.1 | 5.4 | 1970 |
| Indiana | 3.8 | 3.5 | 0.1 | 106.5 | 65.7 | 11.2 | 1970 |
| Iowa | 1.5 | 1.0 | —[c] | 48.2 | 25.5 | 1.5 | 1974 |
| Kansas | 1.2 | 0.5 | —[c] | 16.0 | 7.6 | 0.6 | 1970 |
| Kentucky | 11.8 | 7.9 | 0.6 | 319.0 | 141.3 | 19.7 | 1970 |
| Michigan | 18.9 | 12.2 | 4.3 | 605.1 | 213.1 | 15.9 | 1970 |
| Minnesota | 16.9 | 7.8 | 3.9 | 455.6 | 155.2 | 8.1 | 1970 |
| Missouri | 12.4 | 5.4 | 0.3 | 28.7 | 271.7 | 4.6 | 1971 |
| Nebraska | 1.0 | 0.4 | 0.1 | 16.7 | 10.2 | 0.8 | 1970 |
| North Dakota | 0.4 | 0.3 | —[c] | 5.0 | 3.1 | —[c] | 1970 |
| Ohio | 6.4 | 4.1 | 0.1 | 157.7 | 113.1 | 20.7 | 1970 |
| South Dakota | 1.5 | 0.1 | 1.1 | 31.3 | 17.5 | 0.6 | 1970 |
| Wisconsin | 14.5 | 8.7 | 2.7 | 503.7 | 309.0 | 17.0 | 1970 |
| Totals for Region | 94.1 | 54.5 | 13.2 | 2,446.1 | 924.0 | 106.4 | |

TABLE 1. (Continued)

| State | Area of Commercial Forest Land ($10^6$ acres) | Net Volume of Growing Stock ($10^9$ cubic feet) Hardwoods | Net Volume of Growing Stock ($10^9$ cubic feet) Softwoods | Annual Net Growth ($10^6$ cubic feet) | Timber Removals ($10^6$ cubic feet) | Logging Residues ($10^6$ cubic feet) | Date of Survey |
|---|---|---|---|---|---|---|---|
| | | | SOUTHEASTERN FORESTS | | | | |
| Florida | 16.2 | 4.0 | 6.9 | 531.8 | 347.9 | 24.2 | 1970 |
| Georgia | 24.8 | 10.6 | 14.8 | 1,577.2 | 1,017.8 | 79.6 | 1971-1973 |
| North Carolina | 19.5 | 14.4 | 10.4 | 1,124.4 | 750.6 | 116.6 | 1974-1975 |
| South Carolina | 12.4 | 6.3 | 6.4 | 691.4 | 449.0 | 43.6 | 1970 |
| Virginia | 16.0 | 14.1 | 5.5 | 823.2 | 496.0 | 74.3 | 1976-1977 |
| Totals for Region | 89.0 | 49.4 | 43.9 | 4,748.0 | 3,061.2 | 338.3 | |
| | | | SOUTH CENTRAL FORESTS | | | | |
| Alabama | 21.3 | 9.4 | 11.9 | 1,270.5 | 854.7 | 63.0 | 1975 |
| Arkansas | 18.2 | 9.4 | 6.8 | 802.7 | 597.4 | 69.1 | 1975 |
| Louisiana | 14.5 | 7.7 | 9.0 | 928.8 | 601.4 | 64.9 | 1974 |
| Mississippi | 16.9 | 6.7 | 7.2 | 966.3 | 746.0 | 69.2 | 1970 |
| Oklahoma | 4.8 | 0.8 | 0.8 | 70.1 | 52.1 | 4.1 | 1970 |
| Tennessee | 12.8 | 8.6 | 1.8 | 509.1 | 216.4 | 37.9 | 1971 |
| Texas | 12.9 | 3.1 | 7.4 | 566.0 | 461.2 | 36.4 | 1970 |
| Totals for Region | 101.5 | 45.8 | 45.0 | 5,113.4 | 3,529.1 | 344.8 | |
| | | | PACIFIC COAST FORESTS | | | | |
| Alaska (coastal) | 5.6 | 0.3 | 34.5 | 164.7 | 1,079.6 | 39.3 | 1970 |
| California | 16.8 | 3.1 | 51.2 | 630.0 | 927.0 | 105.5 | 1970 |
| Oregon | 25.0 | 6.4 | 77.2 | 1,218.4 | 1,635.1 | 197.3 | 1973 |
| Washington | 18.2 | 5.7 | 58.3 | 1,320.6 | 1,478.9 | 283.3 | 1973 |
| Totals for Region | 65.6 | 15.6 | 221.1 | 3,333.7 | 5,120.6 | 625.4 | |

TABLE 1. (Continued)

| State | Area of Commercial Forest Land ($10^6$ acres) | Net Volume of Growing Stock ($10^9$ cubic feet) Hardwoods | Softwoods | Annual Net Growth ($10^6$ cubic feet) | Timber Removals ($10^6$ cubic feet) | Logging Residues ($10^6$ cubic feet) | Date of Survey |
|---|---|---|---|---|---|---|---|
| | | | NORTHERN ROCKY MOUNTAIN FORESTS | | | | |
| Idaho | 15.9 | 0.2 | 29.3 | 503.0 | 357.3 | 37.2 | 1970 |
| Montana | 16.0 | 0.3 | 28.4 | 443.1 | 324.4 | 44.0 | 1970 |
| Wyoming | 4.2 | 0.2 | 4.5 | 45.8 | 36.2 | 2.5 | 1970 |
| Totals for Region | 36.1 | 0.7 | 62.1 | 991.9 | 717.8 | 83.7 | |
| | | | SOUTHERN ROCKY MOUNTAIN FORESTS | | | | |
| Arizona | 3.7 | 0.2 | 4.6 | 71.3 | 87.7 | 8.6 | 1970 |
| Colorado | 11.6 | 1.9 | 10.3 | 157.3 | 59.0 | 4.8 | 1970 |
| New Mexico | 5.7 | 0.6 | 5.7 | 75.1 | 44.1 | 4.7 | 1970 |
| Nevada | 0.1 | — (c) | 0.3 | 10.4 | 0.1 | — (c) | 1970 |
| Utah | 3.8 | 1.0 | 3.7 | 85.1 | 69.7 | 0.8 | 1970 |
| Totals for Region | 25.0 | 3.8 | 24.6 | 399.2 | 260.0 | 18.9 | |
| Totals for U.S. | 490.9 | 231.9 | 437.9 | 19,989.3 | 14,802.4 | 1,694.6 | |

(a) Sources: U.S. Forest Service Resource Bulletins for appropriate state (see References to Appendix A).

(b) Sums do not equal totals due to rounding.

(c) Negligible amounts present.

increases, with the southern region offering extensive areas for additional production increases.

The increasing demand for forest products is documented, and the continuation of that demand increase is widely forecast. Keays (1975b) has outlined the various sources of increased production potential for the future:

- o Use of unexploited coniferous forests
- o Closer use of underexploited forests
- o Additional conversion of mill wastes
- o More plantation cropping
- o Shorter rotation cycles
- o Advancement of silvicultural practices
- o Increased use of underexploited, unused hardwood species
- o Development of stronger hardwoods
- o Increased pulp yield from the digester
- o Forest loss reduction, i.e., fire, decay.

Projected harvests presented by Howlett and Gamache (1977) (Appendix A, Table A-1) and others reported by the National Research Council (1976) are comparable with estimates prepared by Spurr and Vaux (1976) under the following various production regimes for the year 2000:

- o Biological potential from fully stocked stands.... 29.1 billion cu ft/yr
- o Biological potential under more intensive forest management practices....34.6 billion cu ft/yr
- o Economic potential under intensive forest management practices ....29.4 billion cu ft/yr
- o Economic potential under current institutional constraints ....19.0 billion cu ft/yr.

FOREST RESIDUES

Forest residues comprise the most available component of the by-products of wood production for potential uses. Logging residues, pre-commercial cuttings, understory removal, and annual mortality contribute to the tonnage generated. Today in the U.S., collection and utilization of forest residues is negligible. The material generally has little value, and may be a nuisance to the land/forest owner.

In 1970, the total aboveground forest residual produced was estimated to be 83-million dry-ton equivalents (DTE) (Appendix A, Tables A-2 to A-4) (Inman, 1977).

More recently, volumes of forest residues have increased as timber productivity increased. Improved harvesting techniques facilitate an increase in the amounts of useable lumber and sawtimber which can be obtained. This increased harvest results in an increase in forest residues. The demand for use of these residues has not yet kept pace with the increased production. Inman (1977) projected the amount of forest residues to be generated yearly through 2020 (Table 2). Amounts are expressed in dry-ton equivalents which, on a percentage mix of hardwoods and softwoods, assumes 29-pounds-per-cubic-foot oven-dry weight to green volume (Spurr and Vaux, 1976).

Keays (1975a) gives a conservative estimate that aboveground biomass is equal to or greater than the amount logged. Comprising this biomass (measured for a northern hardwood stand) is the merchantable bark-free bole (50 percent), residual wood (33 percent), bark (13 percent), and foliage (4 percent). These residuals could be made available through full-tree harvesting. In a typical northern hardwood forest, 100-tons-per-acre of biomass would yield 50, 33, 13, and 4-tons-per-acre of merchantable bark-free bole, residual wood, bark, and foliage, respectively, from full-tree harvest. The stump-root system is 20 percent of the merchantable bole for slash pines (Koch, 1974). In complete-tree harvest, 20 percent would be added to full-tree residuals.

TABLE 2. FOREST RESIDUE GENERATION

| | Projection--Millions of DTE* | |
|---|---|---|
| Year | Low | High |
| 1980 | 83 | 110 |
| 2000 | 81 | 148 |
| 2020 | 107 | 195 |

Source: Inman, 1977.
*Dry Ton Equivalent.

Current trends in forest residue utilization are really trends in forest residue reduction. Whole-tree harvest and chipping are growing in acceptability to pulp mills, resulting in a reduction in residue generated at the harvest site and at the mill.

Cost of collecting forest residuals is minimized by processing the residual materials in conjunction with the primary commercial cut of the forest. Particularly in southern forests, where whole-tree harvesting makes use of four-wheel-drive skidders, tops, foliage, non-commercial species, and non-commercial boles can be mechanically chipped at the yarding site. This mixture contains leaves, bark, and wood which, while currently unsuitable for pulping, remains a suitable energy source. This increased utilization of the whole tree contributes in part to a reduced volume of forest residues in the southern states compared to per-acre residues in the Pacific Northwest (Appendix A, Table A-5).

The U.S. Forest Service (1973) estimated that 4.5-billion cubic feet of growing stock volume was lost through natural mortality in 1970 (Appendix A, Table A-6). (Calculated values of mortality in each state presented in Appendix A, Table A-7, were 4.1-billion cubic feet.) This material is widely dispersed and is largely lost to a potential forest-residue market. Concentrated cases of mortality such as those induced by flooding, hurricanes, or insects may be irregularly available.

Bark represents a major component of the available, unused wood residues. Nearly 70 percent of bark residues are unused. Bark comprises twothirds to three quantities of all mill residues. By contrast, bark makes up only 10 to 15 percent of logging residues (Inman, 1977). While no single use of bark is large enough to deplete the vast amounts generated, newly emerging uses, which may compete with energy alternatives, include bark mulches, compressed fireplace logs, hardboard, livestock bedding, charcoal, and alloy smelting.

Another unused (and more difficult to obtain) forest residue is the below-ground residue. Stumps and root systems represent a substantial portion of the total biomass of the living tree. Harvest at or near ground level leaves this material as a residue. An estimated $104 \times 10^3$ DTE of stump-root residues are currently available (Appendix A, Table A-8). Only in the case of limited areas of the southeastern pine forests are stumps being routinely used--in that case for in situ naval store extraction.

Amounts of logging residues generated in the U.S. by wood, bark, top and branches, and stump-root system components are summarized in Table 3.

MILL RESIDUES

The residues from milling are substantial. Mill residues are estimated to account for 59 percent of the dry weight of logs processed in 1970 (Howlett and Gamache, 1977). Inman (1977) reported $86.1 \times 10^6$ DTE of mill residues for the U.S. These residues, however, with the exception of bark, are a largely committed resource, and under current economies are unavailable for fuel purposes (Appendix B, Table B-1).

A brief review of the types and availabilities of mill residues in the U.S. and regionally is given here. In 1970, seventy-five percent of all wood residues from mills were used, including 56 percent for non-energy purposes (mainly pulp production) and 19 percent for fuel at lumber mills. Of all bark residues from mills, 60 percent were used as fuel as or near the mill (Appendix B, Table B-2) (Inman, 1977).

Mitre Corporation, in its 1977 report to the Department of Energy, projected the total residuals output of mills through 2020 (Table 4).

TABLE 4. MILL RESIDUE OUTPUT

| Year | Projection--Millions of DTE* Low | High |
|---|---|---|
| 1980 | 98 | 124 |
| 2000 | 88 | 128 |
| 2020 | 76 | 143 |

Source: Inman, 1977.
*Dry Ton Equivalent.

TABLE 3. SUMMARY OF LOGGING AND MILLING RESIDUES (BY REGION) IN THE U.S. ($10^3$ DTE) -- 1970[a]

| Region[b] | Logging Residues: Wood[c] | Logging Residues: Bark[d] | Logging Residues: Tops and Branches[e] | Logging Residues: Stump-Root System[f] | Logging Residues: Total | Mill Residues (Wood and Bark): Total | Mill Residues (Wood and Bark): Unused | Total Unused Residues |
|---|---|---|---|---|---|---|---|---|
| Northeast | 3,451 | 608 | 5,248 | 9,832 | 19,139 | 6,600 | 2,300 | 21,439 |
| North Central | 2,253 | 397 | 5,550 | 9,554 | 17,754 | 6,400 | 2,100 | 19,854 |
| Southeast | 6,684 | 1,179 | 10,152 | 21,066 | 39,081 | 11,400 | 4,500 | 43,581 |
| South Central | 6,552 | 1,167 | 12,560 | 26,084 | 46,363 | 16,700 | 4,600 | 50,963 |
| Pacific Northwest | 7,249 | 1,279 | 9,833 | 24,467 | 42,828 | 27,800 | 4,200 | 47,028 |
| Pacific Southwest | 1,876 | 331 | 2,730 | 6,729 | 11,666 | 8,800 | 3,300 | 14,966 |
| Northern Rocky Mountain | 1,337 | 236 | 2,027 | 5,125 | 8,725 | 6,600 | 2,100 | 10,825 |
| Southern Rocky Mountain | 351 | 63 | 665 | 1,625 | 2,704 | 1,800 | 1,000 | 3,704 |
| Total U.S. | 29,753 | 5,260 | 48,765 | 104,482 | 188,260 | 86,100 | 24,100 | 212,360 |

(a) Data adapted from Inman, 1977.

(b) Regions are defined as follows: Northeast - Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, Delaware, Maryland, New Jersey, New York, Pennsylvania and West Virginia. North Central - Michigan, Minnesota, North Dakota, South Dakota (East), Wisconsin, Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Nebraska and Ohio. Southeast - North Carolina, South Carolina, Virginia, Florida and Georgia. South Central - Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Okalahoma and Texas. Pacific Northwest - Oregon, Washington and coastal Alaska. Pacific Southwest - California and Hawaii. Northern Rocky Mountain - Idaho, Montana, South Dakota (West) and Wyoming. Southern Rocky Mountain - Arizona, Colorado, Nevada, New Mexico and Utah.

(c) Figures include both growing stock and non-growing stock.

(d) Bark estimated as 15 percent of total weight of wood and bark.

(e) Tops and branches, including foliage, estimated as 15 percent of the sum of: timber harvested (including bark), total residues from growing stock and non-growing stock volume.

(f) Assumes that stump-root systems represent 25 percent of total tree biomass. Includes only stump-root systems of commercial species 5 inches or more in diameter at breast height.

Mitre's projections of a high and low range assume a relative decline in lumber production in favor of plywood and residue-based panel products. Future socioeconomic variables affected the various estimates.

A substantial portion (19 percent) of mill resides in the U.S. is presently going to fuel (Appendix B, Table B-1) (U.S. Forest Service, 1973). In 1972, as much as 37 percent of the energy requirements of the pulp and paper industry were met through combustion of bark and spent pulp liquors (Grantham and Ellis, 1974).

Approximately 30 years ago in the Pacific Northwest, half of the sawmill residue was burned as fuel; 40 percent was dumped or buried; and only 3 percent was used as wood fiber for further processing. Pulp was largely made from roundwood, not from residuals. Today, sawmill residuals are rarely buried or burned for disposal and the pulp business is largely based on residue materials (Appendix B, Table B-2 to B-4). As Christensen, (1976) said: "Yesterday's waste is today's fuel, but may be tomorrow's raw material".

Inman (1977) reports that approximately 24.1 million DTE of wood and bark residues from mill operations in 1970 remained unused. (Appendix B, Table B-3). On a regional basis, percentages of residues unused ranged from 15 percent in the Pacific Northwest to 56 percent in the Southern Rocky Mountain states. Amounts of total and unused milled residues generated in the U.S., by region, are presented in Table 3.

With advancing technology, the residue generated per unit of lumber produced is expected to decline. Projected residues for lumber, plywood, and other industries are presented in Appendix B, Table B-5.

The future uses of mill residues for energy production wil be largely influenced by the future demands for wood products, future timber supplies, technological advances, and the costs of alternative fuels. The largest user of these residues as fuels probably will continue to be the forest-products industry, where mill wastes provide a readily available, constant energy supply.

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SECTION 5

# SURVEY OF WOOD FUEL TECHNOLOGY

## INTRODUCTION

Industrial process heat is derived primarily from the combustion of fossil fuels. The combustion energy is used in the form of direct heat or hot air, or is converted to a form for convenient transfer about the plant as either hot water or steam.

In principle, wood can be substituted for fossil fuels in either of these modes of application. Certainly, a boiler producing hot water or steam can be fired directly with wood. This approach has been used for many years, almost entirely within the forest-products industry. Direct utilization of heat from wood combustion also has been practiced in lumber dry kilns and veneer dryers. However, there is a broad range of heating applications now supplied by fluid fuels, i.e., gas or oil, which cannot be duplicated by direct combustion of wood, e.g., annealing glass, soldering, and drying food products. In these cases, the special characteristics of the flame obtained from a fluid fuel preclude the use of direct firing of wood without a complete process redesign.

## MODES OF WOOD FUEL USE

In the framework of industrial fuels, three different ways of using wood can be identified:

1. Direct combustion
2. Gasification to a low-Btu gas
3. Use as a feedstack to product alcohol or other liquid fuels.

Of the three, direct combustion is the simplest in application. Gasification and liquids-production are directed to meeting the needs of those applications which require a fluid fuel.

### Direct Combustion

The technology for direct combustion of wood was described in detail in the power plant study cited earlier (Hall, 1975). The technology has been employed in the forest-products industries for many years for direct heating, and for steam raising . The steam is used for process heat and, in some cases, for combined electric-power generation and process steam.

If a new boiler is being installed, proven wood combustion technology can be employed. In the case of a retrofit application, a number of factors must be considered. The substitution of wood fuel in an existing boiler designed for coal, would present the fewest problems. If the boiler has a stoker, only a wood-feeding system would have to be added. However, if co-firing of wood and coal is being considered, the combined effect of the wood and coal ash must be carefully analyzed to avoid slagging or clinkering.

Boilers designed for suspension-firing of pulverized coal or heavy oil could be converted to wood fuel. The wood would have to be reduced in size to less than 1/4-inch, and a small grate installed at the base of the unit to permit complete combustion of any wood which did not burn completely in suspension.

A much more difficult problem is encountered in substituting wood fuel in a natural-gas or light-oil boiler. In boilers of this type, no provision is made for ash collection and removal. Further, narrow tube-spacing and the lack of provision for soot blowers would make impossible the burning of wood without extensive boiler modification. This is not a cost-effective substitution.

An alternative approach to the conversion of a natural-gas or light-oil boiler to wood fuel is to construct a separate combustor to burn wood and to conduct the hot combustion gases into the existing boiler. This approach has been employed successfully where clean, dry wood is burned and very little particulate matter is contained in the combustion gases. However, where green wood chips are to be burned, the same problems with narrow tube-spacing in the boiler as noted above will exist.

### Wood Gasification

The problem of substituting wood fuel in a natural-gas or oil-fired boiler would be solved if the wood were gasified and the product gas burned in the existing boiler. Gas derived from wood also could be used in process heat applications which require the flame from a fluid fuel.

Wood can be gasified to produce a low-Btu gas with a typical heating value of 120 to 200 Btu per standard cubic foot. Because of its low Btu content, gas produced from wood would necessitate modification of burners designed for natural gas or oil. These modifications are minor compared with the major structural changes required in a gas-fired boiler to permit direct combustion of wood.

Despite the apparent advantages to be gained from gasifying wood, and despite the fact that there appear to be no technological constraints, gasification of wood remains a relatively untried and unproven practice.

Gasification of wood has been carried out in vertical-shaft, fixed-bed reactors similar to those used in some approaches to coal gasification (Bowen 1978, Mudge 1978, and Williams 1978). These efforts were generally successful with a minimum of technical problems. The major obstacle to the commercial use of wood gasification is its cost, as discussed below.

The wood must be dried to less than 10 percent moisture to achieve stable gasification conditions. More importantly, wood gasification rates of 60-to 90-pounds-per-square-foot of cross section per hour are substantially less than that possible for coal. Since coal has a heating value about 50 percent greater than that of wood, and since the coal does not have to be dried, a wood gasifier would produce substantially less gas than a coal gasifier of the same size. The resultant cost is much higher for the gas produced from wood. This conclusion is supported by the fact that two companies formerly offering wood gasification systems have withdrawn their product; principally because of high cost.

### Wood-Derived Liquid Fuels

Production of alcohol or other liquid fuels from wood provides another approach to substituting wood for petroleum liquids. The technology for making alcohol from wood or other biomass materials is available. The United States Department of Energy is conducting a program of systems analysis and economic evaluation for energy conversion of biomass including the production of alcohol and other liquids.

As with wood gasification, the major constraint on alcohol and other liquid fuel produced from wood is cost; none are competitive with fossil fuels at this stage of development.

## INDUSTRIAL WOOD-FIRED FACILITIES

As a means of identifying uses of wood fuel, a listing of existing industrial wood-burning facilities was compiled. The list, presented in Appendix C, is not intended to be complete, but rather to illustrate applications, the size ranges of units, and the alternative fuels used.

Table C-1 lists domestic facilities and Table C-2 foreign installations. These tables include 284 domestic and 44 foreign installations, give the company name and location, the supplier (if known), type of equipment, capacity, design pressure, temperature, and type of wood fuel. Very few companies outside the forest product industries have entered the wood-fuel market. Boilers are the most common equipment type, with kilns and other dryers accounting for most of the rest.

Hogged fuel, shavings, sawdust, and bark are the principal forms of wood fuel; gas and oil sometimes are available as backup fuels. In a few of the installations coal is co-fired with wood.

## TECHNICAL PROBLEMS IN EXISTING INSTALLATIONS

Visits were made to selected plants to observe current practice and to discuss technical problems encountered. Details of these plant visits appear in Appendix D.

The facilities visited employed three basic types of wood combustors: strokers, vortex (suspension) burners, and fluidized beds. There were several variations in the kind of material burned as well as in the use made of the combustion energy.

As might be expected from the fact that several-hundred facilities are burning wood, no prohibitive problems were reported. However, some difficulties are encountered from time-to-time, as summarized below.

1. The nonuniform nature of wood fuel created intermittent problems with wood-fuel feeding systems. Pelletizing the wood fuel improves feeding; however, that step requires energy and adds to the cost.

2. Wood fuel of different types may exhibit combustion characteristics which can disrupt an otherwise smoothly operating system. Some examples include: a fluidized-bed burner which operated well with hogged wood as the basic fuel, but burned erratically when too many shavings were introduced; in another fluidized-bed burner, the bed hardened into a rather crystalline mass and had to be shut down when veneer trimmings were introduced into the hogged wood and bark fuel.

3. Boiler efficiency is reduced by moisture in the wood. A good, cost-effective method of drying wood before combustion has not been proven.

4. A wood-burning system which included an induced-draft fan showed erosion of the fan blades caused either by wood ash or by sand and dirt associated with wood burning.

## RESEARCH AND DEVELOPMENT NEEDS

### Direct Firing

The technology for direct firing of wood fuel in the forest products industries has developed over many years. Today, no major changes in the basic techniques for burning wood are occuring and no technical breakthroughs are needed. However, research and development in three areas might serve to make wood fuel more attractive and promote its more extensive use:

1. Development of an innovative system for feeding wood fuel, designed to accommodate the varying sizes and shapes encountered in the several sources of wood.

2. Development of a cost-effective wood chip dryer to permit higher overall efficiency in the wood-fuel system.

3. Demonstrations of wood-fuel conversion in plants not directly associated with the forest-products industry, with emphasis on logistics of obtaining wood for fuel, conversion technology, and life-cycle costs for the conversion. Such demonstrations, if successful, could encourage conversion to wood fuel by industries that have no prior knowledge of wood-fuel potential.

## Wood Gasification

At this time, wood gasification is not a viable alternative to oil and gas in industrial boilers and burners. However, as the need to conserve oil and gas increases, the need for wood-gasification technology might also increase. Research is needed to clarify the potential of wood gasification. The research program should encompass the following areas:

1. Technical and economic evaluation of wood gasification to identify aspects of the technology which work to its economic disadvantage.

2. Conceptualization and evaluation of technical approaches to overcome the economic disadvantage.

## FUTURE INDUSTRIAL WOOD-FUEL DEMAND

Predicting the rate of increase of the level of consumption for wood as fuel is difficult. Several approaches to making such predictions were rejected because too many assumptions were needed to yield a credible result; i.e., each decision for or against wood-fuel must be based on trade-offs, and on factors which are both site-specific and dependent upon management goals and philosophy. Some of the variables encountered are the following:

1. Local availability and cost of fossil fuels, local history of gas curtailment, imminence of gas cutoff, management view of the reality of oil and gas shortages over the short or long term.

2. Local availability and cost of wood residues for fuel, management perception of the realiability of supply.

3. Environmental regulations--local, state, federal--history of appropriate authority in granting variances for existing fuel use.

4. Design of existing equipment, retrofit possibilities, availability of space for wood storage and handling facilities.

5. Availability of capital for retrofit conversion, or for new wood-firing facilities.

6. Life-cycle cost of the retrofit conversion or new facilities. This factor, in turn, depends upon management philosophy regarding rate of return, and upon projected trends in the cost of wood relative to the cost of the current fuel.

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SECTION 6

NON-TECHNICAL BARRIERS TO INDUSTRIAL WOOD-FUEL USE

Several existing and potential barriers to the industrial use of wood fuel on a significant scale are considered in this section.

WOOD FUEL AVAILABILITY

Wood fuel is a renewable, but finite, source of energy in the United States. To put the potential supply of wood fuel in perspective: if all of the wood harvested in the United States in 1970, including harvest residues, had been burned as green wood fuel, it would have supplied about 4 quads ($4 \times 10^{15}$Btu) of energy or about 5.6 percent of the U.S. energy consumption for 1970.

Forest Land Resources

The availability of wood for fuel is dependent on the continued availability of harvestable forests. Several factors can influence that availability.

Deforestation. The total area of U.S. forests has been greatly diminished since colonial times. The advent of fossil fuels tended to slow the diminution for a time. The total of U.S. commercial timberlands was reduced by 1.7 percent between 1962 and 1970. As the population increases, there will be continued pressure to convert farm lands to living space and to convert forest lands to farm lands. Deforestation for these purposes creates an immediate supply of wood, but reduces it as a resource for the future. These pressures to reduce timberland areas may be partially offset by better forest management practice and increased tree farming, thereby increasing the productivity of the remaining acreage.

Ownership. Only about 14 percent of U.S. commercial timberlands are owned by companies in the forest industries. The largest fraction, 33 percent, is owned by private owners, including business and professional people, wage and salary workers, housewives, railroads, mining establishments, and other non-farm owners. About 26 percent is owned by farmers and about 1 percent each by the Bureau of Indian Affairs, Bureau of Land Management, and other Federal agencies.

Many representatives of these various classes of ownership are willing to permit timber harvesting on their land holdings. However, in some cases, particularly in the private sector, holdings may be small, necessitating simultaneous agreement with several owners to make harvesting practical.

Depending on the owner's point of view, immediate economic returns may not compensate for future inflationary pressures or the desire to hold onto a tangible resource.

A special case exists in the commercial timberlands held, or formerly held, by the USDA Forest Service. Since 1962, more than 3-million acres of National Forest area formerly classified as commercial timberlands were selected for potential inclusion in the wilderness system. When included in the system, this acreage will not be available for harvesting; fortunately however, it amounts to only about 0.5 percent of the total commercial timberlands area in the United States. Furthermore, most of this potential wilderness acreage in the contiguous states is located in the Rocky Mountains, where timber harvesting is difficult and costly.

## Alternative Uses of Wood

Some conventional uses of wood contribute to the supply of wood wastes and other uses compete with fuel use for that waste supply.

Roundwood. The harvesting of roundwood for sawtimber, poles, piles, posts, and mine props leaves a significant quantity of waste cellulosic material in the forest. With selective cutting, this waste material includes tops, branches, and leaves of harvested growing-stock trees, smaller trees inadvertently felled, and possibly bark and residues from rough and rotten trees. When clear cutting, the residues will include saplings and cull trees. All of these materials are potential sources of fuel.

Wood Products. The generation of wood wastes generally continues after the roundwood has been removed from the forest. The production of lumber, plywood, veneer, and a wide variety of finished wood products results in the generation of bark, slabs, sawdust, shavings, and scraps, all of which are potential sources of fuel. Any subsequent treatment of roundwood for use as poles, piles, posts, and mine props generates little wood waste other than bark.

Competing Uses. The harvesting of wood for use in pulp mills was not mentioned in the preceding section on roundwood. Pulpwood was formerly harvested exclusively as roundwood and was debarked and chipped at the mill, leaving significant harvesting residues in the forest. There is now a strong trend, however, toward chipping the harvest residues in the forest and hauling the chips to the pulp mill. In some cases, this trend has extended to chipping in the forest for wood pulp uses the residues of other timber-harvesting operations. The ultimate trend in this direction is whole-tree chipping in the forest. This pulpwood application for harvesting wastes, and even whole trees, offers the greatest current and anticipated competition for the use of green wood as a fuel. The production of particleboard (hardboard, fiberboard, and chipboard) also competes with fuel use for wood chips.

Sawdust, wood shavings, and other wastes from the manufacture of finished wood products are very suitable materials for use as fuel. However, much of this material already finds use as agricultural mulch (along with shredded bark), bedding for animals, and in the production of charcoal. These uses tend to reduce the availability of wood wastes for fuel use.

## COST OF WOOD

The elements that contribute to the cost of wood fuel include harvesting costs for green wood fuel, collection costs for wood-industry plant wastes, transportation costs, and competition with other fuels.

### Harvesting Green Wood Fuel

The wood-fuel industry is small. In 1970, about 3.6 percent of the volume of wood harvested in the United States was sold as fuelwood cut from roundwood. This fuelwood was used almost exclusively for domestic heating and cooking. Because of small and scattered demand for such fuel, most operators in this business are quite small.

Only a very few operators have established a business of chipping green wood in the forest for use as fuel. The operator must have access to wood, must invest in one or more portable chippers and in wood-moving equipment, must have adequate and reliable manpower, and must be assured that he can sell the product at a profit. He may also need to arrange transportation of the wood fuel to the customer. Seldom does the wood harvester also own and operate transportation facilities; establishing a small business under these conditions is difficult. A bank loan would be difficult to secure without orders for purchase of wood fuel. Conversely, a potential customer would be reluctant to place orders without assurances that the supplier had access to wood-fuel supplies.

The concentration of wood to be harvested for fuel is a very important economic consideration. Although chippers are portable, time and money expended to move them could better be used in chipping. The highest concentration of harvestable wood fuel occurs when a stand of timber is clear-cut for a whole-tree chipping. The concentration of harvest residues would also be high when a stand is clear-cut for primary harvest of roundwood. As harvesting becomes more selective, the concentration of wood for fuel use decreases.

The nature of the terrain may also be an important factor in wood fuel harvesting costs. Setting up and operating a chipper on a hillside and moving chips out is more difficult than moving logs from the same hillside. Some southern pine is harvested in swampy or marshy areas where harvesting of residues would be difficult. Obviously, harvesting of wood fuel in certain locations would be difficult and expensive, if not impossible.

Adverse weather conditions may contribute to the cost of harvesting green wood fuel. In geographic areas where the number of working days is limited by weather, the investment in equipment may be prohibitive. Labor costs in such conditions may also affect productivity.

## Collecting Plant Wastes

Wood residues from primary wood-processing plants (sawmills, veneer mills, for example) amounted to 3,806-million cubic feet in 1970. (USDA Forest Service, 1973). Of this total, 2,086-million cubic feet was used for pulp and other products, 726-million cubic feet was used as fuel, and 994-million cubic feet was unused. Statistics are not available for secondary wood-manufacturing establishments (producers of millwork, hardwood dimension lumber and flooring, prefabricated structures, pallets, and other products). However, the U.S. Forest Service estimated that in 1970 such firms produced about 900 million cubic feet of plant by-products, of which about 270-million cubic feet was for fuel use, and about 300-million cubic feet was burned or dumped as waste.

Wood waste at primary plants may be in the chippable forms of bark, slabs, edging, or scraps, or in the fine form of sawdust. Chipping and loading facilities may be available at larger plants, facilitating the loading of full truckloads of material more-or-less ready for fuel use. At smaller plants, chippers are not likely to be available, loading facilities are likely to be primitive, and quantities of waste wood limited.

Wood waste at secondary plants is largely sawdust and shavings, with limited quantities of larger, chippable material. Many such establishments are small, where segregation of fine and coarse wood wastes is not practiced. Loading facilities for the waste material are likely to be primitive, and collection of wastes from several secondary plants may be required to obtain a truckload.

## Transportation

Transportation costs for wood fuel can be a large fraction of the total cost of the fuel. Commercial forests and major sawmills may be located far from industrial centers, which are the greatest market for wood fuel. Wood chips are bulky relative to their energy content, and may contain up to 50 percent water.

Transportation of green wood chips by truck for 100 miles at $0.05 per ton-mile would add about $0.42 per million Btu to the fuel cost. Transportation for longer distances could be accomplished economically only by railroad or barge; trucks would also be required to deliver fuel to central storage and loading facilities. The shortage of railroad cars, with at least a 12-month delivery time on new cars, (Business Week, 1978), is another negative economic point.

Hauling distances might not be so great for wood fuel procured from secondary wood-processing plants, which are frequently located close to industrial centers. However, the quantity of wood waste produced by such plants is small compared to that of primary plants, and a collection route to several plants might be required to fill a truck. As a somewhat compensating factor, waste wood from secondary plants, if it is protected from weather, should be somewhat drier than waste wood from primary plants, and, therefore, should have a higher energy content per ton. This factor would tend to reduce the transportation cost per million Btu.

### Competition with Other Fuels

Unless the United States adopts extremely effective energy-conservation measures or major breakthroughs are achieved in harnessing non-fuel sources of energy, the prices of all fossil fuels will increase at a rate exceeding the rate of inflation. Despite these price increases, the availability of domestic petroleum and natural gas in the foreseeable future will decrease more or less rapidly, depending on the funds available to the energy companies for exploration and development. The demand for wood fuel under such conditions should cause its price to rise to levels competitive with other fuels. This use, in turn, would tend to increase the price of wood for competitive uses, particularly in the lumber and paper industries.

## CONSUMER BARRIERS

There are several reasons why industrial firms might be reluctant to use wood fuel. These reasons are usually related to convenience or investment.

### Inconvenience

Use of wood fuel is less convenient than fossil fuels, particularly natural-gas and liquid-petroleum fuels. Flames can be much more readily initiated and turned down with natural gas and the liquid fuels than with coal or wood fuels. Control of particulates in the flue gas is more of a problem with wood fuel than with natural gas or distillate fuels, but will create less of a control problem than coal. Sulfur dioxide emissions are not generally a problem with natural gas and distillate fuels, nor should they be a problem with wood fuel; the problem is more or less severe with coal, coke, and residual fuel oils, depending on the sulfulr content of the fuel.

Storage of fuel and the associated reliability of supply offer more problems with wood fuel than do the fossil fuels. With natural gas, a user is not required to provide storage facilities, although some users operating on an interruptible basis might provide storage facilities. Users of liquid-petroleum fuels normally have fuel tanks which occupy relatively smaller space and can be filled from tank trucks, tank cars, or pipelines. Coal is normally stored in large piles exposed to weather. Although coal may occasionally freeze, it does not absorb water. A much larger pile of wood fuel would be required to provide the same heat energy as a coal pile because of the low density and low bulk density of wood chips. Wood fuel must be protected from weather to prevent absorption of water and the necessity to evaporate the water and heat the steam thus formed with the resultant lower heating value. Also, the susceptibility of wet wood to biological attack further diminishes its heating value and may cause undesirable odors.

Provisions must be made for a receiving and storage system. For coal, receiving facilities may include roadways and parking space, railroad lines and sidings, and suitable unloading equipment. Receiving facilities for wood fuel would be comparable. However, to satisfy the same energy requirement, wood's greater bulk would require more vehicles and more storage space.

Transporting fuel from storage and feeding it to the combustion device would likewise require more equipment to handle wood's greater bulk; however, wood does not require as much ash removal equipment as coal.

Investment

The investment in new facilities to burn wood fuel would be comparable to the investment in new facilities to burn coal. Greater storage and handling facilities would be required for wood fuel, but significant ash-handling facilities would be required for coal. More space would be required for receiving and storage of wood fuel, and the storage space should be covered. Equipment for drying the wood fuel prior to combustion would be needed. Facilities for drying the wood fuel and protecting it from weather would increase the capital investment while also increasing energy-yield from the fuel.

The technical problems of retrofitting a wood-fuel system to an existing natural-gas or liquid-fuel combustion system would be costly. Significant investments in additional equipment will be required, and a considerable amount of extra space, which may or may not be available, will be needed. In some cases, conversion to wood fuel may be impossible.

Even when wood fuel is shown to be technically and economically feasible, the switch from a fossil fuel may still be difficult for the user to make because he is not sure that suppliers of wood fuel can assure the long-term deliveries to justify his investment. Should wood fuel become a popular source of energy, its availability will diminish at some time in the foreseeable future, and its cost will escalate.

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# SECTION 7

## ENVIRONMENTAL ASSESSMENT

Although the combustion of any fuel to produce steam or direct heat for industrial processes is accompanied by emissions to the atmosphere, wood is a comparatively clean-burning fuel. Because wood, unlike coal or oil, has a negligible quantity of sulfur, essentially no sulfur dioxide is emitted when it burns. The ash content of wood is lower than that of coal, as is the nitrogen content.

The pollutant emissions and control technology aspects of burning wood were treated in detail in the powerplant study cited previously (Hall, 1975). With that generalized background, this study was designed to obtain information on particulate control techniques as applied to existing facilities, and to evaluate the potential of wood fuel in reducing $SO_2$ emissions through substitution of wood for coal or residual oil.

### APPLIED PARTICULATE CONTROL TECHNOLOGY

Information regarding particulate control techniques was obtained through discussions with vendors of wood-fired equipment, and through visits to operating facilities.

The most common particulate collection system encountered was a mechanical system of the multiclone type. In one case, the multiclone was followed by a wet scrubber, and in another plant an electrostatic precipitator was placed in series with the multiclone. Another plant used a bag house collector.

In each case, the firms were able to meet State and Federal particulate emission regulations, although at one plant, using multiclones, high opacity readings were observed when fuel with very high moisture content was burned. The only operational problem reported was plugging in the wet scrubbers which were not operational at the time of the visit.

At most facilities collected fly ash was landfilled with no problems being reported. Some of the plants can sell the ash for mulch and for fertilizer because of its potassium content.

## IMPACT OF WOOD FUEL ON POLLUTANT EMISSIONS

### $SO_2$ Emissions

The major advantage of wood over coal or oil with respect to pollutant emissions is the negligible sulfur content of wood. The use of wood in place of coal or oil, either by conversion of existing facilities or in the choice of fuel for new facilities, will result in a reduction of $SO_2$ emissions. The purpose of this portion of the study is to estimate the possible magnitude of this reduction.

Model Plant Analysis. A simple comparison of fuel requirements and $SO_2$ emissions for two model plants will illustrate wood fuel's potential for reduction of $SO_2$ emissions. The comparison is made for an industrial steam boiler producing 250,000 pounds of steam per hour and operating with a 45-percent load factor. The basic assumptions which define each plant are as follows:

1. Coal-Fired Boilers

   Fuel - Eastern coal with 3 percent sulfur content and a heating value of $24 \times 10^6$ Btu per ton.

   Boiler efficiency - 82 percent

   Emissions - 95 percent of input sulfur is emitted from the stack, or 114 lb $SO_2$/ton coal.

2. Wood-Fired Boiler

   Fuel - Wood with negligible sulfur content, 45 percent moisture (wet basis), and $17 \times 10^6$ Btu per ton of bone dry wood (9.35 x 106 Btu per ton of green wood as received).

   Boiler efficiency - 68.4 percent

   Emissions - Negligible $SO_2$ emissions.

The reduced efficiency of the wood-fired boiler was calculated by considering the following sources of heat loss: dry stack gases, water in the wood, water formed from hydrogen in the wood, incomplete combustion, and radiation.

With these basic assumptions the following comparisons may be made.

| Factor | Coal-Fired Plant | Wood-Fired Plant |
|---|---|---|
| Heat Input, $10^6$ Btu/Hour | 305 | 365 |
| Heat Input, $10^{12}$ Btu/Year | 1.20 | 1.44 |
| Fuel Input, Tons/Year | 50,000 | 84,700 (dry) |
| Fuel Input, Tons/Year | - | 154,000 (green) |
| $SO_2$ Emissions, Tons/Year | 2,850 | Neg. |

These simple comparisons show that the use of wood to fuel one 250,000 lb/hr boiler would reduce $SO_2$ emissions by 2,850 tons per year over the use of coal under the assumed conditions. Extension of this result to a wood fuel use equivalent to, say, 1000 model plants yields the following:

Wood required = 84.7 million tons of dry wood/year
= 154 million tons of green wood/year
Coal supplanted = 50 million tons/year
$SO_2$ reduction = 2.85 million tons/year

To achieve a reduction of 2.85 million tons per year of sulfur dioxide emissions by scrubbing, the equivalent of 1175 coal-fired boilers of the model plant size would have to use scrubbers operating at 85 percent sulfur-removal efficiency. If limestone-type scrubbers were used, more than 18-million tons of scrubber sludge would be produced which would require disposal. Of course, the wood-fired plants would produce no sludge.

If wood fuel were substituted for residual oil, similar results would be obtained. The sulfur content of residual oil ranges from 0.7 to 3.5 percent. Since the heating value per unit weight of oil is higher than that for coal, the quantity of $SO_2$ emitted from a model plant, burning residual oil containing 3 percent sulfur, would be about 65 percent of that emitted from a coal-fired plant. Thus, the decrease in $SO_2$ emissions resulting from the substitution of wood fuel for residual fuel oil would be about one third less than that for coal.

These comparisons show that significant reductions in $SO_2$ emissions will be achieved when wood is burned instead of coal or oil. The total magnitude of this benefit depends, of course, on the amount of wood fuel burned. As noted in a preceding section, there are a number of tradeoffs to be considered regarding the use of wood fuel. To accurately predict the actual use of wood fuel is impossible; however, in general, the decrease in $SO_2$ emissions from wood fuel is such that the promotion of wood fuel as one element of an overall $SO_2$ control strategy is merited.

## Other Pollutant Emissions

Particulate emissions from wood-fired facilities can be controlled to meet existing State and Federal regulations. Since the same particulate matter emission limits apply to wood fuel and fossil fuel, the use of wood fuel would not increase the quantity of particulate matter emitted over that associated with the use of any fossil fuel.

Although only limited data are available regarding emissions of $NO_x$ from wood-fired facilities, a recent study of measured emissions from a boiler firing coal and various mixtures of coal and wood (Midwest Research Institute, 1977) showed no significant variation in $NO_x$ emissions. From this limited information we can expect that $NO_x$ emissions would not be increased on substitution of wood for coal.

## COMPARISON OF INDUSTRIAL FOSSIL FUEL USE WITH AVAILABILITY OF WOOD WASTES

In view of several favorable aspects in the use of wood fuel in industrial facilities, a significantly increased use of wood for fuel will probably occur. This anticipated use raises questions about ultimate depletions of our forests. Beacuse of the variation in regional distribution of our forest resources, an evaluation of possible depletion of these resources should be conducted on a regional basis.

Although projections of actual wood-fuel use by industry are difficult to make until better estimates are available from industries outside the forest-products industries, some tentative projections can be made by comparing industrial fossil-fuel use with the quantities of wood residues available in various regions.

Data on the quantities of various fossil fuels used by industry were taken from a survey conducted by the Federal Energy Administration (FEA, now incorporated in the Department of Energy). The data base includes the quantities of fuel used in "boilers, burners, or other combustors" having a fuel input of 100-million-Btu per hour or greater. Data were reported for 1973 and 1974.

The quantities of fuel used were agregated by State and then by regions, corresponding to those employed by the U.S. Forest Service. The results are given in Table 5. The first four columns show the totals in each region for individual fossil fuels, and the total of all fuels is given in the fifth column. For comparison, the quantities of unused wood residues previously presented in Table 3 are given in millions of tons per year of dry wood in Column 6, and in trillions of Btu per year in Column 7. The reader should note that the wood residue quantities tabulated are associated with normal logging and milling activities, thus, they are on an annual basis, not on a one-time-only basis. However, these quantities include the stump-root system that is not normally harvested.

Considering first the entire United States, the total annual fossil fuel use in industrial facilities larger than 100-million-Btu/hr is 6,290 x $10^{12}$ Btu, or 6.29 quad ($10^{15}$ Btu). The total of unused wood (including the stump-root system) in 1970 was 3.61 quad, or 57 percent of the fossil fuel total. Thus, more than half of the fuel requirement could be supplied from unused residues on a continuing basis.

## TABLE 5. COMPARISON OF INDUSTRIAL FOSSIL FUEL USE AND QUANTITY OF UNUSED WOOD RESIDUES

| Region[c] | 1974 Fossil Fuel Use, $10^{12}$ Btu/Year[a] | | | | | Total Unused Wood Residues[b] | |
|---|---|---|---|---|---|---|---|
| | Coal | Residual Fuel Oil | Distillate Fuel Oil | Natural Gas | Total Fossil Fuel | $10^6$ DTE[d] | $10^{12}$ Btu/yr[e] |
| Northeast | 461.4 | 430.2 | 29.2 | 241.1 | 1,162 | 21.4 | 364.5 |
| North Central | 740.3 | 201.4 | 62.5 | 696.4 | 1,701 | 19.9 | 337.5 |
| Southeast | 124.8 | 240.8 | 17.6 | 108.2 | 491 | 43.6 | 740.9 |
| South Central | 184.5 | 168.1 | 14.5 | 1,795.3 | 2,162 | 51.0 | 866.4 |
| Pacific Northwest | 16.5 | 39.0 | 1.0 | 113.0 | 170 | 47.0 | 799.5 |
| Pacific Southwest | 2.7 | 58.8 | 3.3 | 250.2 | 315 | 15.0 | 254.4 |
| So. Rocky Mountain | 16.5 | 17.1 | 1.3 | 55.2 | 90 | 10.8 | 184.0 |
| No. Rocky Mountain | 66.4 | 26.0 | 6.6 | 99.8 | 199 | 3.7 | 63.0 |
| U.S. TOTALS | 1,613.0 | 1,181.4 | 135.9 | 3,359.2 | 6290 | 212.4 | 3610 |

(a) Source: Major Fuel Burning Installation Coal Conversion Report, FEA C-602-5-0. Reported data apply to boilers, burners, or other combustors with 100 x $10^6$ Btu/hour, or greater, fuel input.

(b) From Table 3. These totals include the stump-root system. U.S. totals excluding these residues would be 107.9 x $10^6$ dry tons equivalent (DTE) and 1776 x $10^{12}$ Btu/year.

(c) Regions are defined in footnote to Table 3.

(d) DTE = Dry Tons Equivalent.

(e) Conversion factor = 8500 Btu/dry pound, or 17 x $10^6$ Btu/DTE.

On a regional basis, the Northeast, North Central, South Central, Southern Rocky Mountains, and Pacific Southwest Regions use fossil fuel in quantities greater than the unused wood residue quantities. In the other regions, wood residues are available in substantially greater amounts than the fossil fuel required by the industries in the region. The North Central region show the greatest fossil fuel use in comparison to the unused wood residue quantity, with a ratio of about 5 to 1. If accelerated wood-fuel use by industry were ever to pose a threat to long-term forest resources, it would probably occur first in the North Central region. However, even in this region, excessive use of wood for fuel is not likely to occur. Coal is the fossil fuel most likely to be displaced by wood in existing units. In Table 5, the total of unused residues shown for the North Central region is 46 percent of the coal use, and a wood-fuel penetration of that magnitude would not be expected. The unused wood residue quantities listed in Tables 3 and 5 do not include noncommercial species, a source which could add substantially to the wood residue totals.

Wood-fuel use is unlikely to expand rapidly enough to jeopardize the long-term productivity of our forests. Wood residue quantities are expected to increase in the future, thus providing a further margin of safety.

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## SECTION 8

## ECOLOGICAL IMPACTS OF WOOD RESIDUE USE

The use of wood residues as fuels will create ecological impact from logging operations. Logging operations and associated activities, such as construction of roads and use of heavy equipment, impact physical and chemical components of terrestrial and aquatic ecosystems associated with the forested area.

### SOIL NUTRIENTS

Extensive reviews exist which evaluate soil-nutrient removal from logged areas (Hall et al., 1975; McElroy et al., 1973; Bell et al., 1974). Data are often not comparable and are sometimes conflicting. Nutrient losses reported in the Hubbard Brook Forest ecosystem studies were substantial (Liken et al., 1970); however, regeneration of the clearcut area studied was prevented for two years by applications of herbicides. Other data imply that when natural regeneration is allowed, soil-nutrient loss is neglibible (Patric and Smith, 1975).

Forests remove definable amounts of nutrient materials from the soil each year. Table 6 presents the annual nutrient uptake and components which have been found to vary with species, age, and soil. Table 7 presents the findings of several researchers in studies of the nutrient contents of tree components representative of some of the major forest areas of the United States. Removal of logging residues would deplete nutrient supplies in amounts similar to those presented in Table 7.

Sixty-eight percent of the nutrients utilized for annual growth in a spruce forest association were found to be returned to the soil with leaffall (Sloboda, 1975). In an oak-aspen forest (Boiko et al., 1977), 50 percent of absorbed nutrients were returned with leaffall. Additional nutrient recycling occurs in cut-over areas with the decay of bark, branches, twigs, and roots. Removal of these materials could result in soil-nutrient depletion. Whole-tree harvest of a 16-year-old stand of loblolly pine would remove 12 percent of the total nitrogen, 8 percent of extractable phosphorous and 31 percent of extractable potassium of the entire site (Hall et al., 1975).

The probability of nutrient deficiency increases not only with complete utilization of residuals, but also with shorter rotation times (Patric and Smith, 1975; Hall et al., 1975). Both are forest management techniques designed to increase productivity. The type of harvesting method is also

TABLE 6. ANNUAL NUTRIENT UPTAKE AND RETURN BY THREE REPRESENTATIVE SPECIES

| | Nutrient kg/ha | | | | |
|---|---|---|---|---|---|
| | Ca | K | P | N | Reference |
| Scotch pine | | | | | |
| Uptake | 30 | 7 | 4 | 44 | Wilde, 1958 |
| Retention | 10 | 2 | 1 | 10 | |
| Return | 19 | 4 | 3 | 36 | |
| Beech | | | | | |
| Uptake | 95 | 14 | 12 | 50 | |
| Retention | 13 | 4 | 2 | 10 | |
| Return | 81 | 10 | 10 | 40 | |
| Oak-Hickory | | | | | |
| Uptake | 82 | 29 | 6 | 54 | Rochow, 1975 |
| Return | 56 | 4 | 3 | 28 | |

# TABLE 7. NUTRIENT CONTENT OF TREE COMPONENTS

| Tree Species or Component | Nutrient kg/ha Ca | K | P | N | Age Of Stand | Location | Reference |
|---|---|---|---|---|---|---|---|
| Deciduous Hardwoods | | | | | | | |
| Roots | 169 | 43 | 10 | | 100 yr | Europe | (Spurr & Barnes, 1973) |
| Stems | 257 | 121 | 20 | | | | |
| Bark | 590 | 57 | 15 | | | | |
| Branches | 204 | 47 | 17 | | | | |
| Foliage | 64 | 32 | 8 | | | | |
| Whole Tree | 1283 | 320 | 70 | | | | |
| Conifers Other Than Pines | | | | | | | |
| Roots | 89 | 49 | 8 | | | | |
| Stems | 129 | 102 | 10 | | | | |
| Bark | 214 | 84 | 18 | | | | |
| Branches | 143 | 74 | 14 | | | | |
| Foliage | 101 | 64 | 20 | | | | |
| Whole Tree | 676 | 375 | 70 | | | | |
| Pines | | | | | | | |
| Roots | 37 | 17 | 2 | | | | |
| Stems | 84 | 45 | 8 | | | | |
| Bark | 72 | 17 | 5 | | | | |
| Branches | 51 | 20 | 5 | | | | |
| Foliage | 39 | 39 | 10 | | | | |
| Whole Tree | 283 | 138 | 30 | | | | |
| Douglas Fir | | | | | | | |
| Trees | 333 | 220 | 66 | 320 | 36 yr | Seattle, WA | (Turner et al., 1976) |

TABLE 7. (Continued)

| Tree Species or Component | Nutrient kg/ha Ca | K | P | N | Age Of Stand | Location | Reference |
|---|---|---|---|---|---|---|---|
| Red Alder | | | | | | | |
| Roots | 123 | 7 | 4 | 176 | 34 yrs | | |
| Trunk Wood | 51 | 27 | 16 | 128 | | | |
| Trunk Bark | 69 | 18 | 10 | 165 | | | |
| Branches | 77 | 4 | 2 | 20 | | | |
| Leaves | 42 | 43 | 5 | 100 | | | |
| Total | 299 | 99 | 37 | 589 | | | |
| Northern Hardwoods | | | | | | | |
| Aboveground | 383 | 155 | 34 | 351 | | Vermont | (Likens et al., 1977) |
| Belowground | 101 | 63 | 53 | 181 | | | |
| Pacific Fir | | | | | | | |
| Tree Wood | 61 | 421 | 29 | 141 | 175 yrs | Seattle, WA | (Turner & Singer, 1976) |
| Bark | 574 | 225 | 8 | 13 | | | |
| Branch | 119 | 120 | 9 | 18 | | | |
| Foliage | 259 | 190 | 17 | 173 | | | |
| Total Aboveground Tree | 1013 | 956 | 63 | 345 | | | |

directly related to the amount of nutrient leaching. Losses of calcium and nitrogen approximately doubled with whole-tree harvest as compared with stem-only harvest (Hornbeck, 1977). Usually, when any of these methods are employed, nutrients must be added in the form of fertilizers to lessen the effects of nutrient loss and to make regeneration possible.

## OTHER SOIL PROPERTIES

Soil properties can be altered by certain other logging operations besides removal of tree biomass. Clearcutting decreases soil mositure, changes soil texture, bulk density, and permeability (Bell et al., 1974). Filling and yarding influence soil compaction and create soil disturbance. Road construction, hauling, felling, and yarding increase erosion and runoff.

Clearcutting has considerable influence on soil temperature, air temperature, wind speed and light regime in the cut-over area. Increased soil temperatures due to increased solar radiation can be detrimental to regeneration. Removal of residues formerly allowed to decay will not only increase solar radiation in the soil, but will also reduce the humic content of the soil.

Physical damage can occur to regenerating species from logging and skidding operations (Gottfried and Jones, 1975). Host (1972) reported damage to regeneration ranging from 11 to 35 percent for various skidding methods. Loss was heaviest for larger specimens. By removing residuals, damage to new growth will be more costly because regeneration time will be longer.

## WILDLIFE

Wildlife is indirectly affected by logging operations. Tree-removal eliminates local habitats for nesting species which may cause them to evacuate the area. On the other hand, openings in the forest caused by clearcutting provide an increased food supply and more favorable habitat for many animals. Small species make use of residuals for both food supply and protection. Removal of slash materials will prolong the time required for establishment of these populations.

Timing of logging operations can also influence wildlife behavior. Areas are more conducive to rehabitation after vegetation has leafed out, and the available food source serves as an attractant.

Regrowth in a clearcut area provides browse for larger game species. Deer use of a cut-over area was found to peak shortly after logging. As regeneration proceeded, use declined (Black, 1974). However, over-use of a clearcut area by deer, hare, and mountain beaver can cause failure in regeneration.

## WATER QUALITY

Soil sediments are transported to streams by the erosive action of rainwater runoff and snowmelt. In the case of heavily deforested areas, large amounts of nutrients in the form of metal ions and organic debris (green vegetative matter and decomposed humic material) increase the loading to the aquatic system (Likens et al., 1970; McElroy et al., 1973; Snyder et al., 1975). Increased amounts of nutrients can produce eutrophic conditions in the receiving water body.

Acidity of streams in logged areas may increase due to nitrification of the forest floor caused by tree removal and to the absence of the neutralization of acid precipitation by the canopy. The resultant pH may be directly toxic to certain aquatic life forms and may slow rates of decomposition (Likens et al., 1978). Use of logging residues would prolong the time of regeneration, and therefore, of nitrate leaching.

Logging, road construction, and use are major sources of increased turbidity and sedimentation in forest watersheds. High levels of turbidity are unsuitable for most gill-breathing organisms. Associated sedimentation destroys habitats, renders spawning and rearing beds unsuitable, smothers invertebrates, fish food organisms, and fish eggs. Location of logging roads is critical in reducing impacts from sedimentation.

Filter strips of undistrubed vegetation and forest floor can greatly reduce or eliminate increased sedimentation due to logging roads. The width of such strips depends on the slope and type of terrain (Packer, 1967; Bell et al., 1974). For land with 0 percent slope, the filtration strip should be, in general, a minimum of 25-feet wide; and at least 50-feet wide in watersheds supplying municipalities (Trimble and Sartz, 1957).

Canopy-removal and cutting of forest vegetation increases the amount of runoff which reaches streams (Hall et al., 1975 ; Likens et al., 1970; Douglass and Swank, 1972). Amounts of throughfall, snow storage, and water yield increase with cutting intensity, resulting in increased streamflow (Bell et al., 1974). Removal of residuals would further increase the runoff. Manipulating forest vegetation can alter the quality and quantity of water appearing in the form of wetlands, bogs, marshes, and springs (Hornbeck, 1977). Soil-compaction and loss of permeability due to logging operations and the absence of growing vegetation utilizing soil moisture contribute to a higher water table. These increases can have serious impacts on sensitive areas such as marshes.

Canopy-removal along stream banks increases the area of stream exposed to direct solar radiation, causing rises in stream temperature and larger than normal daily fluctuations in temperature (Likens et al., 1970; McElroy et al., 1973; Snyder et al., 1975; Hall et al., 1975). Such temperature changes are unsuitable for certain species of fish and other aquatic life.

Buffer strips protecting streamside vegetation moderate or eliminate stream temperature fluctuations, reduce bank scouring, maintain stability, and provide a natural food source to the acquatic system (Brown, 1974; Snyder et al., 1975).

Some accumulation of residues in stream channels occurs naturally. Residues may triple after logging operations (Brown, 1974). Large debris may be yarded out of the channel, but fine particles remain at higher levels than before logging. Both types of residues can detrimentally affect aquatic habitats. Biological degradation of fine residues reduces dissolved oxygen. Accumulation of these residues can also interfere with circulation of water. Large residues alter stream hydraulics, affect bank stability, and can block fish migration. Large debris-dams may also cause flooding.

Use of residuals would eliminate stream damage caused by larger residues. Fine residuals too small for efficient removal or use would remain in the cutover area and could potentially enter stream channels in runoff. Effects of both fine and larger residuals in streams could be mitigated by the preservation of buffer strips on both sides of the stream bed.

The extent of water-quality impacts resulting from the use of logging residues will be strongly influenced by prevailing environmental conditions such as climate, precipitation, soil type, land use, forest type, temperature, and humidity. The following paragraphs briefly characterize sections of the United States, and indicate areas of greatest potential impact on water quality from the use of logging residues.

Northeast

The terrain of the northeastern regions of the United States is typified by low, open mountains, high hills, and hilly plains.

Mean daily temperatures range between 10° and 85° F. Mean annual rainfall is approximately 40 inches. The climate is humid, maintaining water surpluses even during periods of less-than-average precipitation.

Predominant soils in the New England states are cool, moist types with a mean annual soil temperature lower than 47° F. While these soils are protected from leaching in the winter by freezing, they are more likely to lose nitrate in the summer than soils in other parts of the U. S. The New England soils absorb little nitrate, and evaporation losses are lower in summer (Engelstad, 1970). These soils occur on gently-sloping and steep terrain and are suited for woodland.

Major forest types are red-white-jack pine, spruce-fir, and oak-hickory. Approximately 55 percent (31 million acres) of the region's land use is forest and woodland.

The humid conditions in this region facilitate rapid decay of logging residues and rapid return of nutrients which offsets losses due to natural leaching during the summer. Removal of residues coupled with the leaching would hasten nutrient depletion of these soils.

Based on figures presented by Likens et al. (1977) for nutrient contents of northeastern deciduous hardwood forests, removal of logging residues would decrease available nutrients in the following amounts: 351 kg/ha nitrogen, 34 kg/ha phosphorus, 155 kg/ha potassium, and 383 kg/ha calcium.

Mid-Atlantic

Soils of the middle Atlantic states are warm and moist. Those used primarily for cropland and grazing have weakly differentiated soil horizons. Areas used for forestry and woodland have soils low in bases (base saturation at pH 8.2), and organic matter with subsurface horizons of clay accumulation.

Vegetation types grade from northern hardwoods in New York to Appalachian oak forests in Pennsylvania and New Jersey to mixed mesophytic forests in Maryland, Delaware, and West Virginia. Major forest types are oak-hickory and maple-beech-birch.

Climate is humid with mean annual precipitation of approximately 40 inches. Mean daily temperatures range between 20° and 90° F.

Impacts on water quality would be similar to those for the New England states above.

Southeast

The coasts of the southeastern U. S. are characterized by flat plains. Georgia, North Carolina, and South Carolina have some irregular plains and low mountains. Coastal soils are warm and wet. Rolling plains soils are low in organic matter in subsurface horizons and are used for general farming and woodland.

The coastal climate is warm and humid. Growing season varies from 7 to nearly 12 months. Annual rainfall is 40 or more inches, evenly distributed, although drought can occur in winter. Low elevation and pressence of impervious clay sediments impede drainage on many soils. Less fertile lands support longleaf, shortleaf loblolly and slash pine. Productive soils produce oaks, hickories, ash and beech. Primary land use is for forestry (65 percent).

Mean daily high and low temperatures range from 30° to 90° F. Based on the combination of rainfall, evaportranspiration, soil water holding capacity, and temperature, leaching of nutrients, particularly nitrogen is more likely to occur in the winter in the Southeast (Engelstad, 1970).

Again, the humid climate contributes to the rapid decay of logging residues and the return of nutrients to soils subject to nutrient leaching. In addition, the slope of the land coupled with the type of soils in northeastern North Carolina, South Carolina, and Georgia produce a high erosion potential for deforested areas. Logging residues left in place would provide slope stability and help prevent erosion. Nutrient losses from use of logging residues are approximated for pine and oak-hickory forest in Table 6.

South Central

The bulk of the south central terrain is flat irregular plains and open hills. Some low, mountainous areas are found in Arkansas and Louisiana.

Soils of Tennessee, Mississippi, Alabama, Arkansas, and Louisiana are predominantly warm, moist types which are low in bases with subsurface horizons of clay accumulation. These soils are low in organic matter in subsurface horizons and are used for general farming, woodland, and pasture. Along the Mississippi River, soils have weakly differentiated horizons; materials have been altered or removed but have not accumulated. These soils are seasonally wet with an organic surface horizon. Undrained lands are used for woodland and pasture. Approximately 55 percent of the land use in these states is for forestry.

Predominant forest types are loblolly-shortleaf pine, longleaf-slash pine, and along the Mississippi River, oak-gum-cypress forests.

The climate of these states is generally warm and humid with an annual precipitation of 56 inches, mean daily low and high temperatures are between 40° and 95° F.

Nutrient leaching from soils in Tennessee and Alabama would again be offset by rapid decay of logging residues.

Texas and Oklahoma fall into a marginal region which is subject to long and short-term droughts. Mean annual precipitation is between 16 and 32 inches. Mean daily temperatures are between 20 and 95° F. Soils are warm dry types; some are organic-rich; most are high in bases with subsurface horizons of salt and carbonate accumulations characteristic of semiarid climates. These lands are used predominantly for grazing, pasture, and small grain crops.

North Central

The topography of the north central section of the United States is characterized by flat, open plains and open low hills.

Soils in Iowa, Illinois, Nebraska, and Kansas are rich in organic matter, high in bases, black in color, warm and moist. The primary use of these soils is for corn, soybeans, small grains, and pasture.

Large areas of Ohio, Indiana, Missouri, and Kentucky have soils medium to high in bases with gray to brown surface horizons and clay accumulation in subsurface horizons. These soils are usually moist but may become dry in some horizons during warm seasons. Primary use is for row crops, small grain, and pasture.

The Great Lakes area receives abundant sunshine in summer, high daytime temperatures, and infrequent but heavy rainfall (32-40 inches mean annual precipitation). Surface geology reflects various aspects of glaciation: table-like plains of glacial outwash, ridges of terminal and recessional moraines, plateaus of ground moraines, "sheep backs", and aeolian sands interspersed with thousands of lakes.

Over half the forest land for the north central region is found in Michigan, Wisconsin, and Minnesota (50 million acres). Forest types are dominated by red pine, jack pine, hard maple, beech, birch, slippery elm, rock elm, white pine, hemlock, white spruce, and trembling aspen.

North and South Dakota are somewhat dissimilar from other states in this region. Their topographical features include smooth, flat plains in the eastern portions of the states grading to open, low hills in the western sections. Soils of North Dakota are largely cool and moist, with black organic-rich surface horizons used primarily for small grain, hay, and pasture. South Dakota soils are also black and organic-rich, but are semiarid. During warm seasons, these soils are intermittently dry. Salts or carbonates have accumulated in subsurface horizons. Use is for wheat or small grains. Land use is approximately 50 percent cropland, 35 percent grazing. Less than 5 percent is used for forestry or woodland. Mean annual precipitation varies from 16 to 24 inches. The Dakotas are in a marginal region where they are vulnerable to both long- and short-term droughts. Mean daily temperatures range from 0° to 90° F.

Impacts from the removal of logging residues in most states of the Midwest would be most pronounced along waterways where erosion of soils is most likely to occur. Nutrient losses, at worst, would be very localized due to the limited area of commercial forest land.

Rocky Mountain

The Rocky Mountains extend from the northern to the southern border of the North American continent. They range in elevation from sea level to about 15,000 feet. The system is geologically young and exhibits a wide range of soil groups and formations delineated by deserts at the foothills and alpine meadows or skeletal barrens at the mountain tops.

The north-south orientation of the mountain ranges serves as a barrier to moisture-laden winds from the Pacific Ocean. Drastic differences in climate are encountered within a distance of several miles in either a vertical or an east-west direction. The effect of the climatic factors differentiates both the vegetation and soils into distinct climatic-zonal groups. Forest associations are of several types. Dry woodland species--scrub oaks, mountain mahogany, juneberry--occur in areas of low elevation and annual rainfall of less than 20 inches. These species have little commercial value except as a source of fuel, but are important for watershed protection. Pinyon-juniper types cover large areas at higher elevations and are a source of fuel, posts, and mine timber. The ponderosa pine type borders dry woodland zones and extends in the southern Rockies to an elevation of 8,000 feet. Annual rain fall is between 20 and 25 inches. Stands are widely distributed and trees are of good size and form. The value of the wood and the comparative ease of logging, give the ponderosa pine forest a high commercial importance.

Above the ponderosa pine belt, extending occasionally to elevations of 10,000 feet is the Douglas fir forest type. Precipitation, much of which occurs in the form of snow, varies between 25 and 30 inches. Extended periods of drought occur in spring and fall. Soils are usually well supplied with nutrients, but often are shallow and have a low water-retaining capacity.

The lodgepole pine type has a wide ecological range, tolerating extreme temperatures, drought, and low nutrients. This forest type usually forms pioneer cover and is eventually replaced by Douglas fir or Engelmann spruce. Lodgepole pine cones open by fire resulting in dense even-aged pioneer stands in burned-over areas.

Spruce-fir is the timber-line type, extending to elevations of 12,000 feet. Annual precipitation is approximately 30 inches. The growing season is about 3 months, with an average temperature during that time of about 50° F. Forest stands are uneven-aged and well-stocked with mature trees reaching a diameter of 30 inches.

Soils in the northern Rocky Mountain elevations are cool and moist, high in bases, and used for woodland, pasture, and small grains. Remaining soil types are warm and dry and used primarily for range and small grain crops. Primary land use is for grazing and pasture.

The region receives 16 to 32 inches of precipitation per year. Much of the area is arid, subject to periods of long and shrot term droughts. Mean monthly temperatures range between 10° and 85° F.

Soils of the southern Rocky Mountains are predominantly warm and dry. Much of the region falls within an arid section of the country subject to drought. Soils are suitable for wheat, range, and irrigated crops. Some of the mountain soils are cool and moist, medium-to-high in bases, with a subsurface clay accumulation. These soils are used for woodland, supporting hardwood, pinyon-juniper, and fir-spruce forest types.

The major land use is for pasture and grazing. Mean annual precipitation is between 8 and 20 inches. Mean daily temperatures fall between 20° and 105° F.

In the arid climate of the West, logging residues decompose slowly. In spite of the low amount of rainfall, there is evidence of nutrient loss, particularly nitrates, in soils due to leaching (Engelstad, 1970). Removal of residues could result in a decrease in available nitrogen as well as other nutrients.

Pacific Northwest Coast

The terrain in Oregon and Washington is punctuated by mountains and plateaus. Soils in the western portions are warm and moist types, low in bases, high in organic content, and are used for woodland and range. Soils of the central plateau region are cool and moist, low in bases and typical of soils found in tundra. Primary use is for woodland. The eastern portions of both states are warm and dry. Soils have an organic-rich surface layer and are used mainly for wheat range and irrigated crops.

Major forest types are as previously described for the Rocky Mountains. Approximately 40 percent of the land use is for forestry. Monthly average temperatures are between 20° and 55° F. Mean annual precipitation on the western coastal areas is approximately 96 to 128 inches. In the central and eastern portions, mean annual precipitation decreases sharply to 8 to 24 inches.

Terrain in northern California is mountainous, grading to flat central plains and southern hilly plains. Northern coastal soils are organic rich and low in bases with subsurface clay accumulations. These areas are used primarily for woodland and pasture. Temperatures and precipitation are similar to western Oregon and Washington as are forest types.

Central and southern California soils are warm, dry types, low in organic matter, subject to long and short term droughts and are used primarily for range and small grain crops. Rainfall is between 8 and 24 inches per year.

Climatic conditions are such that the Pacific Northwest is one of the major forest areas of the U.S., supplying almost 35 percent of the nation's lumber. Approximately 242-million cubic feet of logging residue remain in Washington, Oregon, and northern California forests. Complete use of residuals could result in removal of as much as 1,000 kg/ha of nutrients from the system. The periodically high rainfall increases probability of nutrient loss due to leaching. Steep slopes increase the likelihood of erosion. Selective use of residuals and residual components would be essential to avoid detrimental impact.

The land mass of Alaska has various relief. The central portion is typified by open, high mountains; the southern coastal regions are plains and flatlands; northern coastal regions are high and low mountains. Predominant soils are cool and wet with organic surface horizons used for vegetable crops, woodland, and pasture. Alaska also has large barren areas of mainly rock and ice which do not support crops. Approximately 30 percent of the land use in Alaska is for forestry. Over 50 percent of the land area was unused as of 1967. The major forest type is hemlock-Sitka spruce along the coast. The interior region supports mostly spruce-hardwood forests of medium to poor quality and of noncommercial use. Commercial harvest of Alaskan forests yielded approximately 1,100-million cubic feet of timber in 1970; 40-million cubic feet remain as residue.

## CONCLUSIONS

Of forest harvest techniques, the clearcutting method produces the most profound ecological effects as well as the largest volume of residuals. Impacts were considered on this worst-case basis. Clearcutting is a method likely to be employed when large residual volume recovery is attempted.

Increased use of logging residuals is not likely to produce many beneficial ecological impacts. Removal of slash materials does reduce raw material for forest fires, and may provide esthetically more pleasing landscaping; however, by preventing natural recycling of materials, soil nutrients could be seriously depleted. Various tree components absorb different amounts of nutrients. Selective use of residual components is essential to avoid or alleviate soil nutrient depletion.

Slash materials hasten regeneration of clear cut areas. New growth, as well as leafed-out tree residues, provide browse and cover for many wildlife species.

Negative impacts of large residues in stream channels can be avoided by simple preventative measures (filter strips). Negative impacts associated with slash removal, however, are more costly to prevent (fertilization, lengthened natural regeneration time).

Severity of impacts from the use of logging residuals will vary with regional geological and climatological conditions. Impacts would not be as extensive in areas of the country where forestry is not a major land use. Removal of residuals will have most pronounced effects in areas where such materials are necessary to maintain soil nutrient levels (areas subject to leaching) and prevent erosion (areas of moderate or steep slope, heavy precipitation, shallow soil depth, or river bank and floodplain areas).

Increased use of mill residues currently being wasted will alleviate problems of inconvenience and cost associated with disposal of these materials and reduce soil disturbance and leaching impacts caused by burning and burial. The most efficient use of mill wastes is as boiler fuel in the mill itself.

## RECOMMENDATIONS

Biomass, wood, and wood residues will continue to be an important source of fuels, fibers, and chemical feedstocks. In the short-term (0-50 years) we anticipate that there will be a great demand to utilize wood and wood residues for fuels. The long term use will be more oriented toward fiber and chemical feedstocks. Irrespective of the uses, trends suggest that the forests of today must supply the materials and feedstocks necessary to maintain our current lifestyles.

Whether or not our forest lands can be managed to successfully supply needed materials depends on the fundamental issue of long term forest productivity as it relates to particular wood/wood residue utilization scenarios. This issue must be addressed by means of a definitive experimental program.

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**TABLE A-1. PROJECTED U.S. TIMBER HARVESTS, BY TYPE AND GEOGRAPHICAL SECTION - 1980, 2000 AND 2020**

| Type and Section[a] | Estimated 1970 Harvest ($10^6$ cubic feet) | Projected Timber Harvests ($10^6$ cubic feet) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1980 | | 2000 | | 2020 | |
| | | Low[b] | High | Low[b] | High | Low[b] | High |
| **Softwoods** | | | | | | | |
| North | 509 | 740 | 945 | 874 | 1,440 | 905 | 1,762 |
| South | 3,745 | 3,494 | 5,441 | 4,546 | 7,488 | 4,706 | 9,164 |
| Rocky Mtn. | 853 | 796 | 1,229 | 1,005 | 1,655 | 1,001 | 1,949 |
| Pacific Coast | 3,805 | 3,550 | 4,287 | 2,626 | 4,325 | 2,839 | 5,512 |
| Total Softwoods | 8,912 | 8,580 | 11,902 | 9,051 | 14,908 | 9,451 | 18,387 |
| **Hardwoods** | | | | | | | |
| North | 1,410 | 1,610 | 1,960 | 1,638 | 3,342 | 2,694 | 4,559 |
| South | 1,668 | 1,758 | 2,140 | 1,417 | 2,892 | 2,422 | 4,100 |
| Rocky Mtn. | 11 | 31 | 37 | 38 | 77 | 63 | 107 |
| Pacific Coast | 85 | 54 | 66 | 45 | 91 | 81 | 137 |
| Total Hardwoods | 3,174 | 3,453 | 4,203 | 3,138 | 6,402 | 5,260 | 8,903 |
| Total Softwoods and Hardwoods | 12,086 | 12,033 | 16,105 | 12,189 | 21,310 | 14,711 | 27,290 |

Footnotes appear on the following page.

FOOTNOTES FOR TABLE A-1

(a) Sections defined as follows: North - Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, Delaware, Maryland, New Jersey, New York, Pennsylvania, West Virginia, Michigan, Minnesota, North Dakota, South Dakota (east), Wisconsin, Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Nebraska and Ohio. South - North Carolina, South Carolina, Virginia, Florida, Georgia, Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma, and Texas. Rocky Mountain - Idaho, Montana, South Dakota (west), Wyoming, Arizona, Colorado, New Mexico, Nevada, and Utah. Pacific Coast - Alaska (coastal), Oregon, Washington, California, and Hawaii.

(b) Assumes a relatively low level of basic demand factors such as population growth and disposable income, accompanied by rising relative prices for primary forest products, the latter reflecting relatively tight timber supply conditions.

Source: Howlett and Gamache, 1977.

TABLE A-2. TOTAL LOGGING RESIDUES BY REGION, 1970

| Region[1] | Residues from Growing Stock Volume[2] ($10^3$ DTE) | Total Residues[3] ($10^3$ DTE) |
|---|---|---|
| New England | 1,408 | 3,976 |
| Middle Atlantic | 2,259 | 5,331 |
| Lake States | 865 | 3,670 |
| Central States | 1,405 | 4,530 |
| South Atlantic | 4,935 | 11,813 |
| East Gulf | 2,074 | 5,622 |
| Central Gulf | 3,465 | 10,585 |
| West Gulf | 3,471 | 9,694 |
| Pacific Northwest | 7,715 | 18,361 |
| Pacific Southwest | 1,970 | 4,937 |
| Northern Rocky Mtn. | 1,535 | 3,600 |
| Southern Rocky Mtn. | 345 | 1,079 |
| Total U.S. | 31,447 | 83,198 |

Source: Inman, 1977.

[1]Regions defined as follows:

New England - Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island
Middle Atlantic - Delaware, Maryland, New Jersey, New York, Pennsylvania, West Virginia
Lake States - Michigan, Minnesota, North Dakota, South Dakota (east), Wisconsin
Central States - Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Nebraska, Ohio
South Atlantic - North Carolina, South Carolina, Virginia
East Gulf - Florida, Georgia
Central Gulf - Alabama, Mississippi, Tennessee
West Gulf - Arkansas, Louisiana, Oklahoma, Texas
Pacific Northwest - Alaska (coastal), Oregon, Washington
Pacific Southwest - California, Hawaii
Northern Rocky Mountain - Idaho, Montana, South Dakota (west), Wyoming
Southern Rocky Mountain - Arizona, Colorado, New Mexico, Nevada, Utah

[2]"Growing stock" includes live trees of commercial species qualifying as desirable or acceptable trees. "Growing stock volume" is the net volume of the stems of growing stock trees 5 inches or more in diameter at breast height (4-1/2 feet above ground level), from a 12-inch high stump to a minimum 4-inch top diameter.

[3]Total residues include residues from growing stock volume, residues from non-growing stock volume and tops and branches. Not included are trees and shrubs of non-commercial species, regardless of size, trees of commercial species less than 5 inches in diameter at breast height, and stump-root systems.

TABLE A-3. ESTIMATES OF SOFTWOOD LOGGING RESIDUES, BY REGION - 1970 ($10^3$ DTE)[6]

| Region[8] | Softwood Timber Harvest ($10^6$ cu. ft.) | Residues from Growing Stock Volume[1] | | | Residues from Harvested Non-Growing Stock Volume[2] | | | Tops and Branches[3] | Total Residues[4] | Residue Coefficient[5] (DTE/$10^3$ cu. ft.) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Wood | Bark[7] | Total | Wood | Bark[7] | Total | | | |
| New England | 337 | 628 | 111 | 739 | 127 | 22 | 149 | 1,054 | 1,942 | 5.87 |
| Middle Atlantic | 88 | 185 | 33 | 218 | 23 | 4 | 27 | 277 | 522 | 5.93 |
| Lake States | 138 | 122 | 22 | 144 | 6 | 1 | 7 | 400 | 551 | 3.99 |
| Central States | 17 | 13 | 2 | 15 | 1 | * | 1 | 49 | 65 | 3.82 |
| Southern Atlantic | 789 | 732 | 129 | 861 | 50 | 9 | 59 | 2,296 | 3,216 | 4.08 |
| East Gulf | 897 | 814 | 143 | 957 | 57 | 10 | 67 | 2,606 | 3,630[9] | 3.40 |
| Central Gulf | 978 | 1,039 | 183 | 1,222 | 37 | 7 | 44 | 2,866 | 4,132 | 4.22 |
| West Gulf | 1,081 | 1,487 | 262 | 1,749 | 37 | 7 | 44 | 3,224 | 5,017 | 4.64 |
| Pacific Northwest | 2,978 | 6,260 | 1,104 | 7,364 | 672 | 119 | 791 | 9,369 | 17,524 | 5.88 |
| Pacific Southwest | 828 | 1,426 | 251 | 1,677 | 85 | 15 | 100 | 2,530 | 4,307 | 5.20 |
| Northern Rocky Mtn. | 654 | 1,305 | 230 | 1,535 | 31 | 6 | 37 | 2,025 | 3,597 | 5.50 |
| Southern Rocky Mtn. | 199 | 289 | 51 | 340 | 36 | 7 | 43 | 601 | 984 | 4.94 |
| TOTAL U. S. | 8,984 | 14,300 | 2,521 | 16,821 | 1,162 | 207 | 1,369 | 27,297 | 45,487[9] | 5.00 |

Source: Inman, 1977
*negligible
Additional Footnotes appear on the following page.

FOOTNOTES FOR TABLE A-3

[1]See Footnote 2, Table A-2.

[2]"Non-growing stock" as defined here includes trees of commercial species which do not qualify as growing stock because they are classified as "rough", "rotten", or "salvable dead". "Non-growing stock volume" is the volume of the stems of non-growing stock trees 5 inches or more in diameter at breast height, from a 12-inch high stump to a minimum 4-inch top diameter. Estimates of residues for non-growing stock volume are based on the ratio of this material to total timber inventory in each region.

[3]Tops and branches, including foliage, estimated as 15% of the sum of: timber harvested (including bark), total residues from growing stock volume, and total residues from non-growing stock volume.

[4]See Footnote 3, Table A-2.

[5]The residue coefficient is the weight of residues generated per unit volume of timber harvested.

[6]Assumed softwood specific gravity of .49, based on dry weight and green volume.

[7]Bark estimated as 15% of total weight of wood and bark.

[8]See Footnote 1, Table A-2.

[9]Corrected value; error in Inman's data as presented.

TABLE A-4. ESTIMATES OF HARDWOOD LOGGING RESIDUE, BY REGION - 1970 ($10^3$ DTE)[6]

| Region[8] | Hardwood Timber Harvest ($10^6$ cu. ft.) | Residues from Growing Stock Volume[1] | | | Residues from Harvested Non-Growing Stock Volume[2] | | | Tops and Branches[3] | Total Residues[4] | Residue Coefficient[5] (DTE/$10^3$ cu. ft.) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Wood | Bark[7] | Total | Wood | Bark[7] | Total | | | |
| New England | 200 | 569 | 100 | 669 | 76 | 13 | 89 | 1,276 | 2,034 | 10.2 |
| Middle Atlantic | 386 | 1,735 | 306 | 2,041 | 108 | 19 | 127 | 2,641 | 4,809 | 12.5 |
| Lake States | 394 | 613 | 108 | 721 | 50 | 9 | 59 | 2,339 | 3,119 | 7.9 |
| Central States | 430 | 1,182 | 208 | 1,390 | 266 | 47 | 313 | 2,762 | 4,465 | 10.4 |
| Southern Atlantic | 516 | 3,463 | 611 | 4,074 | 476 | 84 | 560 | 3,963 | 8,597 | 16.7 |
| East Gulf | 178 | 949 | 168 | 1,117 | 143 | 25 | 168 | 1,287 | 2,572 | 14.5 |
| Central Gulf | 579 | 1,907 | 336 | 2,243 | 340 | 60 | 400 | 3,810 | 6,453 | 11.2 |
| West Gulf | 396 | 1,454 | 268 | 1,722 | 251 | 44 | 295 | 2,660 | 4,677 | 11.8 |
| Pacific Northwest | 68 | 298 | 53 | 351 | 19 | 3 | 22 | 464 | 837 | 12.3 |
| Pacific Southwest | 17 | 249 | 44 | 293 | 116 | 21 | 137 | 200 | 630 | 37.1 |
| Northern Rocky Mtn. | ** | * | * | * | 1 | * | 1 | 2 | 3 | 10.7 |
| Southern Rocky Mtn. | 10 | 4 | 1 | 5 | 22 | 4 | 26 | 64 | 95 | 9.5 |
| TOTAL U. S. | 3,174 | 12,423 | 2,203 | 14,626 | 1,868 | 329 | 2,197 | 21,468 | 38,291 | 12.1 |

* negligible

** less than 500,000 cubic feet

Footnotes appear on the following page.

FOOTNOTES FOR TABLE A-4

[1]See Footnote 2, Table A-2.

[2]See Footnote 2, Table A-3.

[3]Tops and branches, including foliage, estimated as 25% of the sum of: timber harvested (including bark), total residues from growing stock volume, and total residues from non-growing stock volume.

[4]See Footnote 3, Table A-2.

[5]See Footnote 5, Table A-3.

[6]Assumed hardwood specific gravity of .59, based on dry weight and green volume.

[7]See Footnote 7, Table A-3.

[8]See Footnote 8, Table A-2.

TABLE A-5. ESTIMATES OF LOGGING RESIDUES PER ACRE HARVESTED, BY REGION

| Region[1] | Average per Acre Harvest Volume[2] (cubic feet/acre) | Average Residues per Acre Harvested: Above-Ground (DTE/acre) | Average Residues per Acre Harvested: Stump-Root Systems (DTE/acre) |
|---|---|---|---|
| New England | 1,076 | 8.3 | 9.8 |
| Middle Atlantic | 949 | 11.0 | 10.3 |
| Lake States | 776 | 5.4 | 7.1 |
| Central States | 607 | 6.2 | 6.3 |
| South Atlantic | 916 | 10.3 | 9.5 |
| East Gulf | 705 | 5.6 | 6.4 |
| Central Gulf | 779 | 6.4 | 7.3 |
| West Gulf | 817 | 6.7 | 7.6 |
| Pacific Northwest | 3,395 | 24.0 | 27.8 |
| Pacific Southwest | 2,698 | 17.3 | 22.1 |
| Northern Rocky Mtn. | 1,709 | 9.5 | 13.5 |
| Southern Rocky Mtn. | 1,193 | 6.8 | 9.7 |
| Total U.S. | 1,236 | 9.1 | 10.9 |

[1]See Footnote 8, Table A-2.

[2]Estimates based on average timber inventories per acre (growing stock plus non-growing stock) in 1970, and average proportions of inventories harvested in 1970.

Source: Inman, 1977.

TABLE A-6. ANNUAL MORTALITY OF GROWING STOCK VOLUME, BY REGION, 1970

| Region | Mortality: Amount ($10^6$ cubic feet) | Mortality: Percent of Total Growing Stock Volume |
|---|---|---|
| Northeast | 564.8 | 0.6 |
| North Central | 691.8 | 0.8 |
| Southeast | 616.2 | 0.8 |
| South Central | 554.3 | 0.7 |
| Pacific Northwest - Douglas fir | 700.4 | 0.6 |
| Pacific Northwest - Ponderosa pine | 248.6 | 0.6 |
| Coastal Alaska | 167.1 | 0.5 |
| Pacific Southwest | 349.4 | 0.6 |
| Northern Rocky Mtn. | 392.1 | 0.6 |
| Southern Rocky Mtn. | 220.7 | 0.8 |
| Total U.S. | 4,505.4 | 0.7 |

Source: Inman, 1977.

TABLE A-7. CALCULATED[a] ANNUAL MORTALITY OF GROWING STOCK IN UNITED STATES' FORESTS

NORTHEASTERN FORESTS

| State | $10^6$ cubic feet |
|---|---|
| Connecticut | 15.2[b] |
| Delaware | 3.2 |
| Kentucky | 44.6 |
| Maine | 111.8 |
| Maryland | 15.8 |
| Massachusetts | 16.8[b] |
| New Hampshire | 13.6[b] |
| New Jersey | 11.6[b] |
| New York | 65.6 |
| Ohio | 22.0 |
| Pennsylvania | 106.6 |
| Rhode Island | 1.3[b] |
| Vermont | 30.1[b] |
| West Virginia | 70.9 |
| Total Mortality for Region | 529.1 |

NORTH CENTRAL FORESTS

| State | $10^6$ cubic feet |
|---|---|
| Illinois | 13.7 |
| Indiana | 21.5 |
| Iowa | 6.9[b] |
| Michigan | 98.3 |
| Minnesota | 69.7 |
| Missouri | 13.0[b] |
| Wisconsin | 67.9 |
| Total Mortality for Region | 291.0 |

ROCKY MOUNTAIN FORESTS

| State | $10^6$ cubic feet |
|---|---|
| Arizona | 33.1 |
| Colorado | 84.2 |
| Kansas | 3.5 |
| Nebraska | 3.5 |
| New Mexico | 43.5 |
| North Dakota | 2.1 |
| South Dakota | 14.5 |
| Wyoming | 32.4 |
| Total Mortality for Region | 216.8 |

SOUTHEASTERN FORESTS

| State | $10^6$ cubic feet |
|---|---|
| Florida | 65.0 |
| Georgia | 155.6[b] |
| North Carolina | 140.5[b] |
| South Carolina | 75.7 |
| Virginia | 119.5[b] |
| Total Mortality for Region | 556.3 |

SOUTHERN FORESTS

| State | $10^6$ cubic feet |
|---|---|
| Alabama | 103.5[b] |
| Arkansas | 85.1 |
| Louisiana | 108.7[b] |
| Mississippi | 72.6 |
| Oklahoma | 8.0 |
| Tennessee | 43.3[b] |
| Texas | 54.9 |
| Total Mortality for Region | 476.1 |

INTERMOUNTAIN FORESTS

| State | $10^6$ cubic feet |
|---|---|
| Idaho | 203.6 |
| Montana | 198.0 |
| Nevada | 2.1 |
| Utah | 32.4 |
| Total Mortality for Region | 436.1 |

PACIFIC COAST FORESTS

| State | $10^6$ cubic feet |
|---|---|
| Alaska (coastal) | 240.1 |
| California | 374.7 |
| Oregon | 576.8 |
| Washington | 441.6 |
| Total Mortality for Region | 1,633.2 |

Total Mortality for U.S. = 4,138.6 x $10^6$ cubic feet.

(a) Mean percentage mortality of growing stock calculated from reported values.

(b) Reported values in appropriate state Forest Resource Bulletin (see References at the end of this appendix).

# TABLE A-8. STUMP-ROOT SYSTEM RESIDUES, 1970

| Region[1] | Softwood Amount[2] ($10^3$ DTE) | Softwood Residue Coefficient[3] (DTE/$10^3$ cubic feet) | Hardwood Amount[2] ($10^3$ DTE) | Hardwood Residue Coefficient[3] (DTE/$10^3$ cubic feet) | Total Amount ($10^3$ DTE) |
|---|---|---|---|---|---|
| New England | 2,665 | 7.9 | 2,107 | 10.5 | 4,772 |
| Middle Atlantic | 701 | 8.0 | 4,359 | 11.3 | 5,060 |
| Lake States | 1,014 | 7.4 | 3,860 | 9.8 | 4,874 |
| Central States | 122 | 7.2 | 4,558 | 10.6 | 4,680 |
| South Atlantic | 5,809 | 7.4 | 6,539 | 12.7 | 12,348 |
| East Gulf | 6,594 | 7.4 | 2,124 | 11.9 | 8,718 |
| Central Gulf | 7,251 | 7.4 | 6,286 | 10.9 | 13,537 |
| West Gulf | 8,158 | 7.6 | 4,389 | 11.1 | 12,547 |
| Pacific Northwest | 23,702 | 8.0 | 765 | 11.3 | 24,467 |
| Pacific Southwest | 6,401 | 7.7 | 328 | 19.3 | 6,729 |
| Northern Rocky Mtn. | 5,122 | 7.8 | 3 | 10.7 | 5,125 |
| Southern Rocky Mtn. | 1,519 | 7.6 | 106 | 10.6 | 1,625 |
| Total U.S. | 69,058 | 7.7 | 35,424 | 11.2 | 104,482 |

[1]See Footnote 8, Table A-2.

[2]Assumes that stump-root systems represent 25% of total tree biomass, as per Young, 1974. Includes only stump-root systems of trees of commercial species 5 inches or more in diameter at breast height.

[3]Residue coefficient is the weight of stump-root systems left as residue per unit volume of timber harvested.

Source: Inman, 1977.

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APPENDIX B

MILL RESIDUES

TABLE B-1. USES OF WOOD AND BARK RESIDUES PRODUCED BY PRIMARY WOOD PROCESSING PLANTS IN THE UNITED STATES, 1970[a]

| | Percent |
|---|---|
| Uses of wood residues | |
| Pulp | 47 |
| Fuel | 19 |
| Other products (particle board, etc.) | 8 |
| Unused | 26 |
| | 100 |
| Uses of bark residues | |
| Industrial fuel and charcoal | 23 |
| Domestic fuel | 4 |
| Fiber products | 1 |
| Miscellaneous products and uses | 3 |
| Unused (burned or dumped) | 69 |
| | 100 |

(a) U.S. Forest Service, 1973.

TABLE B-2. ESTIMATED MILL RESIDUE VOLUMES, BY TYPE - 1970

| | Lumber Industry ($10^6$ DTE) | | Plywood Industry ($10^6$ DTE) | | Miscellaneous ($10^6$ DTE) | | Total ($10^6$ DTE) | |
|---|---|---|---|---|---|---|---|---|
| Coarse wood residues | | | | | | | | |
| Used | 32.3 | 85% | 9.0 | 93% | 3.0 | 90% | 44.3 | 87% |
| Unused | 5.7 | 15% | 0.7 | 7% | 0.3 | 10% | 6.7 | 13% |
| Total | 38.0 | 100% | 9.7 | 100% | 3.3 | 100% | 51.0 | 100% |
| Fine wood residues | | | | | | | | |
| Used | 5.3 | 38% | 0.4 | 80% | 0.6 | 45% | 6.3 | 40% |
| Unused | 8.8 | 62% | 0.1 | 20% | 0.7 | 55% | 9.6 | 60% |
| Total | 14.1 | 100% | 0.5 | 100% | 1.3 | 100% | 15.9 | 100% |
| Bark residues | | | | | | | | |
| Used | 8.8 | 60% | 1.7 | 60% | 1.1 | 60% | 11.6 | 60% |
| Unused | 6.0 | 40% | 1.1 | 40% | 0.7 | 40% | 7.8 | 40% |
| Total | 14.8 | 100% | 2.8 | 100% | 1.8 | 100% | 19.4 | 100% |

Source: Inman, 1977

TABLE B-3. 1970 REGIONAL MILL RESIDUES (WOOD AND BARK)

| Region[1] | Total Residues Generated | Residues Used | | Residues Unused | |
|---|---|---|---|---|---|
| | | Amount | % of Total | Amount | % of Total |
| | ($10^6$ DTE) | ($10^6$ DTE) | | ($10^6$ DTE) | |
| Northeast | 6.6 | 4.3 | 65 | 2.3 | 35 |
| North Central | 6.4 | 4.3 | 67 | 2.1 | 33 |
| Southeast | 11.4 | 6.9 | 61 | 4.5 | 39 |
| South Central | 16.7 | 12.1 | 72 | 4.6 | 28 |
| Pacific Northwest | 27.8 | 23.6 | 85 | 4.2 | 15 |
| Pacific Southwest | 8.8 | 5.5 | 63 | 3.3 | 37 |
| Northern Rocky Mountain | 6.6 | 4.5 | 68 | 2.1 | 32 |
| Southern Rocky Mountain | 1.8 | 0.8 | 44 | 1.0 | 56 |
| Total | 86.1 | 62.0 | 72 | 24.1 | 28 |

Source: Inman, 1977
Footnotes appear on the following page

## FOOTNOTES FOR TABLE B-3

[1]Regions are defined as follows:

Northeast - Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, Delaware, Maryland, New Jersey, New York, Pennsylvania, West Virginia

North Central - Michigan, Minnesota, North Dakota, South Dakota (East), Wisconsin, Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Nebraska, Ohio.

Southeast - North Carolina, South Carolina, Virginia, Florida, Georgia.

South Central - Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma, Texas.

Pacific Northwest - Oregon, Washington, Coastal Alaska.

Pacific Southwest - California, Hawaii.

Northern Rocky Mountain - Idaho, Montana, South Dakota (West), Wyoming.

Southern Rocky Mountain - Arizona, Colorado, Nevada, New Mexico, Utah.

## TABLE B-4. MILL RESIDUES IN 1970 BY INDUSTRY

| | Lumber | | Plywood | | Miscellaneous[1] | | Total | |
|---|---|---|---|---|---|---|---|---|
| | ($10^6$ DTE) | Percent | ($10^6$ DTE) | Percent | ($10^6$ DTE) | Percent | ($10^6$ DTE) | Percent |
| Timber consumed, including bark | 113.4 | 100 | 20.9 | 100 | 13.4 | 100 | 147.7 | 100 |
| Primary product | 46.5 | 41 | 7.9 | 38 | 7.2 | 53 | 61.6 | 42 |
| Total residues | 66.9 | 59 | 13.0 | 62 | 6.3 | 47 | 86.2 | 58 |
| Wood residues used | 37.6 | 33 | 9.5 | 45 | 3.5 | 26 | 50.6 | 34 |
| Wood residues unused | 14.6 | 13 | 0.8 | 4 | 1.0 | 8 | 16.4 | 11 |
| Total wood residues | 52.2 | 46 | 10.3 | 49 | 4.5 | 34 | 67.0 | 45 |
| Bark residues used | 8.8 | 8 | 1.7 | 8 | 1.1 | 8 | 11.6 | 8 |
| Bark residues unused | 6.0 | 5 | 1.1 | 5 | 0.7 | 5 | 7.8 | 5 |
| Total bark residues | 14.8 | 13 | 2.8 | 13 | 1.8 | 13 | 19.4 | 13 |

Assumptions - Average specific gravity, softwoods, of .50.
- Average specific gravity, hardwoods, of .59.
- 60 Percent of bark residue used, as estimated by Ellis, 1975.

Includes cooperage, piling, poles, mine timbers, shingles and other minor industries.

Source: Inman, 1977, after U.S. Forest Service, 1973.

TABLE B-5. ESTIMATED RESIDUE GENERATION IN THE LUMBER, PLYWOOD AND MISCELLANEOUS WOOD PRODUCTS INDUSTRIES - 1970, 1980, 2000 AND 2020

| Industry and Year | Coarse Residues $10^6$ DTE) | Fine Residues ($10^6$ DTE) | Bark Residues ($10^6$ DTE) | Total Residues ($10^6$ DTE) |
|---|---|---|---|---|
| Lumber | | | | |
| 1970 (actual) | 38.0 | 14.1 | 14.8 | 66.9 |
| 1980 - Low | 41.4 | 15.4 | 16.1 | 72.9 |
| - High | 54.7 | 20.3 | 21.3 | 96.3 |
| 2000 - Low | 36.3 | 11.8 | 14.0 | 62.1 |
| - High | 55.1 | 17.9 | 21.3 | 94.3 |
| 2020 - Low | 29.7 | 8.2 | 11.4 | 49.3 |
| - High | 61.7 | 16.9 | 23.8 | 102.4 |
| Plywood | | | | |
| 1970 (actual) | 9.7 | 0.6 | 2.8 | 13.1 |
| 1980 - Low | 12.9 | 0.8 | 3.6 | 17.3 |
| - High | 15.2 | 0.9 | 4.3 | 20.4 |
| 2000 - Low | 13.9 | 0.8 | 4.0 | 18.7 |
| - High | 19.6 | 1.1 | 5.6 | 26.3 |
| 2020 - Low | 14.1 | 0.8 | 4.0 | 18.9 |
| - High | 25.0 | 1.4 | 7.2 | 33.6 |
| Miscellaneous Wood Products | | | | |
| 1970 (actual) | 3.3 | 1.2 | 1.8 | 6.3 |
| 1980, 2000, and 2020 | 3.9 | 1.4 | 2.1 | 7.4 |
| Total | | | | |
| 1970 (actual) | 51.0 | 15.9 | 19.4 | 86.3 |
| 1980 - Low | 58.2 | 17.6 | 21.8 | 97.6 |
| - High | 73.8 | 22.6 | 27.7 | 124.1 |
| 2000 - Low | 54.1 | 14.0 | 20.1 | 88.2 |
| - High | 78.6 | 20.4 | 29.0 | 128.0 |
| 2020 - Low | 47.7 | 10.4 | 17.5 | 75.6 |
| - High | 90.6 | 19.7 | 33.1 | 143.4 |

Source: Howlett and Gamache, 1977.

# APPENDIX C

## PARTIAL LIST OF INDUSTRIAL WOOD-FIRED FACILITIES

### TABLE C-1. WOOD-REFUSE-BURNING INSTALLATIONS, UNITED STATES

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **Alabama** | | | | |
| American Can Company | Naheola | Riley Stoker Corp. | Grate stoker boiler | 300,000 | 975 | 825 | Unlogged bark, coal and gas |
| International Paper Company | Mobile | Foster Wheeler Energy Corp. | C.A.D. grate boiler | 450,000 | 1,275 | 900 | Wood/oil |
| Delta Industries, Inc. | Livingston | Energy Products of Idaho | FB-180 with boiler and direct fired veneer dryers | 27,600 | 300 | -- | Wood wastes |
| Russell Corporation | Alexander City | -- | Boiler | 120,000 | -- | -- | 500 tpd wood wastes |
| Hammermill Paper Company | Selma | Zurn Industries | Boiler to be in 1979 | 160,000 | 600 | -- | Waste bark |
| Kimberly-Clark Corporation | Coasa Pines | -- | Boiler | -- | -- | -- | Coal/bark |
| Allied Paper, Inc. | Jackson | -- | Boiler | -- | -- | -- | Gas/oil/bark |
| Union Camp Corp. | Montgomery | -- | Power boiler | 460,000 | 800 | -- | Oil/gas/bark |
| MacMillan Bloedel, Inc. | Pine Hill | Combustion Engineering | Power boiler | 900,000 | 850 | -- | Gas/oil/bark |
| Lee Timber Products | Opelika | Energy Limited | Direct fired drying kiln | $26 \times 10^6$ Btu | -- | -- | Wood waste |
| | | | **Alaska** | | | | |
| Ketchikan Spruce Mills | Ketchikan | Ultrasystems, Inc. | PSMD stoker boiler | 34,500 | -- | -- | Wood waste |
| Alaska Lumber & Pulp Co., Inc. | Sitka | -- | Power boilers | -- | -- | -- | Oil/bark |
| | | | **Arizona** | | | | |
| Western Pine Industries | Snowflake | Ultrasystems, Inc. | HRT stoker boiler | 15,000 | -- | -- | Wood |
| | | | **Arkansas** | | | | |
| Potlach Corp. | Warren | Ultrasystems, Inc. | Keeler CP boiler dry plywood | 32,000 | -- | -- | Wood |
| International Paper Co. | Gurdan | -- | Boiler, startup 1979 | -- | -- | -- | Shavings, dust chips and bark |
| Nekoosa Edwards Paper Co., Inc. | Ashdown | -- | Power boiler | -- | -- | -- | Gas/oil/bark |
| Georgia-Pacific Corp. | Crossett | -- | Power boilers | -- | -- | -- | Gas/oil/bark |
| Permaneer | Hope | Energex Limited | Rotary drier | $27 \times 10^6$ Btu | -- | -- | Wood wastes |

## TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | California | | | | |
| Lindsay Olive Growers | Lindsay | Energy Products of Idaho | FB-75 with boiler | 10,000 | 150 | -- | Wood wastes |
| Roddis Plywood Corp. | Arcata | Riley Stoker Corp. | Boiler | 50,800 | 225 | 397 | Logged wood waste |
| Simpson Plywood | Arcata | Ultrasystems, Inc. | Union iron works boiler | 50,000 | -- | -- | Waste wood |
| California Cedar Products Co. | Stockton | Ultrasystems, Inc. | Keeler stoker MKB boiler | 34,000 | -- | -- | Waste wood |
| Union Lumber Company | Fort Bragg | Riley Stoker Corp. | Boiler | 105,000 | 400 | 700 | Logged wood |
| Diamond National Corp. | Red Bluff | Riley Stoker Corp. | Boiler | 60,000 | 300 | sat. | Wood refuse & Gas |
| Diamond National Corp. | Red Bluff | Riley Stoker Corp. | Boiler | 60,000 | 325 | sat. | Logged refuse wood |
| Georgia Pacific Corp. | Samoa | Riley Stoker Corp. | Boiler | 125,000 | 620 | 750 | Wood and oil |
| Placerville Lumber Co. | Placerville | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| Commander Industries | Elk Creek | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| Erickson Lumber Co. | Marysville | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark, sawdust, trim |
| Plumas Lumber Co. | Crescent Miles | Wellons, Inc. | Boiler | -- | -- | -- | Shavings |
| Paul Bunyan Lumber Co. | Anderson | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| American Forest Products | Foresthill | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| American Forest Products | North Fork | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| Commander Industries | Red Bluff | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| Sierra-Pacific Industries | Happy Camp | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust & shavings |
| Sierra-Pacific Industries | Inyokern | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| Wetsel-Oviatt Lumber Co. | Elderado Hills | Wellons, Inc. | Boiler | -- | -- | -- | General waste, sawdust and bark fines |
| American Forest Products | Foresthill | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| Coin Lumber Co. | Susanville | Wellons, Inc. | Boiler | -- | -- | -- | Bark and wet sawdust |
| Masonite Corp. | Cloverdale | Wellons, Inc. | Boiler | 14,000 | 15 | -- | Green redwood planer shavings |
| Sierra-Pacific Industries | Susanville | Wellons, Inc. | Boiler | -- | -- | -- | Bark and wet sawdust |
| Pine Mountain Lumber Co. | Yreka | Wellons, Inc. | Boiler | 24,000 | 250 | -- | Bark and wet sawdust |
| Simonson Lumber Co. | Smith River | Wellons, Inc. | Boiler | -- | -- | -- | Bark and wet sawdust |
| Hambro Forest Products | Crescent City | Wellons, Inc. | Boiler | -- | -- | -- | Logged wood & plywood trim |

TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | California (Continued) | | | | |
| Pickering Lumber Co. | Standard | Wellons, Inc. | Boiler | -- | -- | -- | Bark and wet sawdust |
| Sierra-Pacific Industries | Central Valley | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| Sierra-Pacific Industries | Arcata | Wellons, Inc. | Boiler | -- | -- | -- | Logged wood & bark |
| Little Lake Industries | Willits | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark |
| Schniedbauer Lumber Co. | Eureka | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark |
| Anderson Lumber Industries | Redding | Wellons, Inc. | Boiler | -- | -- | -- | Planer shavings |
| Arcata Redwood Co. | Arcata | Wellons, Inc. | Boiler | -- | -- | -- | Sawdust & shavings |
| Masonite Corp. | Ukiah | Foster Wheeler | 1-SF boiler inclined grate | 150,000 | 950 | -- | Hogged redwood bark |
| California Cedar Products Co. | Stockton | Ultrasystems, Inc. | Keeler MKB boiler | 34,000 | -- | -- | Wood waste |
| Wicks Forest Industries | Chawchilla | Ultrasystems, Inc. | Rotary dryer | 25,000 | -- | -- | Sander dust |
| Diamond Sunsweet, Inc. | Stockton | -- | Boiler | -- | -- | -- | Walnut shells |
| Humboldt Flakeboard | Arcata | Energex Limited | 2 Rotary Dryers | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Humboldt Flakeboard | Arcata | Energex Limited | 1 Stationary and flash dryer | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Crauen Simpson Pulp Co. | Eureka | -- | Power boilers | -- | -- | -- | Oil/log waste |
| Louisiana-Pacific Corp. | Samoa | -- | Power boiler | 530,000 | 875 | -- | Log waste |
| | | | Colorado | | | | |
| Michigan River Timber Co. | Walden | Wellons, Inc. | Boiler | -- | -- | -- | Shavings |
| Kremmling Timber Co. | Kremmling | Wellons, Inc. | Boiler | -- | -- | -- | Shavings |
| | | | Florida | | | | |
| Southern Plywood Corp. | Cantonment | Riley Stoker Corp. | Boiler | 25,000 | 150 | sat. | Bark |
| St. Regis Paper Co. | Pensacola | Riley Stoker Corp. | Boiler | 250,000 | 450 | 650 | Bark/gas |
| Duval Lumber & Supply Co. | Jacksonville | Energex Limited | 2 Boilers drying kilns | $15 \times 10^6$ Btu | -- | -- | Planer shavings |
| Procter & Gamble Co. (Buckeye Cellulose Corp.) | Perry | -- | -- | -- | -- | -- | Bark, dust |
| ITT Rayanier, Inc. | Fernandia Beach | -- | Power boilers | -- | -- | -- | Waste wood |

## TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | Florida (Continued) | | | | |
| Container Corp. of America | Fernandia Beach | -- | Power boilers | -- | -- | -- | Bark/oil |
| Alton Box Beard Co. | Jacksonville | -- | Power boilers | -- | -- | -- | Oil/bark |
| St. Regis Paper Co. | Jacksonville | -- | Power boilers | -- | -- | -- | Oil/bark |
| Hudson Pulp & Paper Co. | Palatka | -- | Power boilers | -- | -- | -- | Oil/bark |
| | | | Georgia | | | | |
| St. Mary's Kraft Corp. | St. Marys | Riley Stoker | Boiler | 160,000 | 675 | 750 | Unlogged bark & oil |
| Great Northern Paper Co. | Cedar Springs | Babcock & Wilcox | -- | -- | -- | -- | Bark |
| Union Camp Corp. (Operate by 1980) | Savannah | Combustion Engineering | Boiler and generator | 350,000 | 15,000 | -- | Waste wood, oil & coal |
| Weyerhaeuser Co. | Adel | -- | 2 direct fired drying kilns | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Continental Can Company, Inc. | Augusta | -- | Power boilers | -- | -- | -- | Oil/gas/bark |
| Brunswick Pulp & Paper Co. | Brunswick | -- | Power boilers | -- | -- | -- | Oil and bark |
| ITT Rayonier, Inc. | Jesup | Combustion Engineering | 4 power boilers | -- | -- | -- | Coal/bark |
| Continental Can Co., Inc. | Port Wentworth | -- | Power boiler | -- | -- | -- | Gas/oil/bark |
| Owens-Illinois, Inc. | Valdosta | -- | Power boiler | -- | -- | -- | Oil/gas/bark |
| | | | Hawaii | | | | |
| Hawaiian Commercial & Sugar Co. | Puunene | Foster Wheeler | 1-FW C.A.D. grate boiler | 319,000 | 425 | 740 | Bagasse |
| Hawaiian Commercial & Sugar Co. | Puunene | Foster Wheeler | 1-FW C.A.D. grate boiler | 290,000 | 425 | 740 | Bagasse & #6 oil |
| Honokaa Sugar Company | Haina | Foster Wheeler | 1-FW Pinhole grate | 288,000 | 610 | 800 | Bagasse/oil |
| C. Crewer & Company Ltd. | Naaleha | Ultrasystems, Inc. | Beglow boiler stoker | 125,000 | -- | -- | Bagase and oil |
| | | | Idaho | | | | |
| Potlach Forest, Inc. | Jaype | Riley Stoker Corp. | Boiler | 180,000 | 325 | sat. | Wood waste |
| Potlach Forest, Inc. | Lewiston | Riley Stoker Corp. | Boiler | 180,000 | 300 | sat. | Wood refuse |

## TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **Idaho (Continued)** | | | | |
| St. Maries Veneer & Plywood | St. Maries | Riley Stoker Corp. | Boiler | 80,000 | 250 | sat. | Wood waste |
| Bennett Lumber Company | Princeton | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| Idaho Stud Mill | St. Anthony | Wellons, Inc. | Boiler | -- | -- | -- | Shavings |
| Konkolville Lumber Company | Orafino | Wellons, Inc. | Boiler | -- | -- | -- | General waste |
| Idaho Veneer Company | Post Falls | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark |
| Idaho Forest Industries | Coeur d'Alene | Energy Products of Idaho | FB-140 boiler | 40,000 | 150 | -- | Wood waste |
| Merritt Bros. Lumber Co. | Priest River | Energy Products of Idaho | FB-100 boiler | 20,000 | 150 | -- | Wood waste |
| Boise Cascade Company | Emmett | Energy Products of Idaho | FB-160 Boiler & direct fired dryer | 26,000 | 150 | -- | Wood waste |
| Boise Cascade Company | Boise | -- | Boiler | -- | -- | -- | Logged bark |
| DeArmond Stud Mill | Colur d'Alene | Energy Products of Idaho | FB-140 boiler | 40,000 | 150 | -- | Log fuel |
| American Greetings Corp. | Payson | (Being built) | Boiler | -- | -- | -- | Wood waste |
| | | | **Indiana** | | | | |
| Allis Chalmers Mfg. Co. | LaPorte | Riley Stoker Corp. | Boiler | 60,000 | 200 | 440 | Bark & coal, unhogged wood |
| DeKalb Corp. | Crawfordsville | Energy Limited | Flash dryer | $15 \times 10^6$ Btu | -- | -- | Wood waste |
| | | | **Iowa** | | | | |
| Midwest Walnut Company | Council Bluffs | Wellons, Inc. | Boiler | -- | -- | -- | Hardwood, sawdust and Logged bark |
| | | | **Kansas** | | | | |
| American Walnut Company | Kansas City | Wellons, Inc. | Boiler | -- | -- | -- | Logged wood & bark, wet sawdust |
| Hammermill Paper Company (Frank Purcell Walnut Lumber Co.) | Kansas City | Wellons, Inc. | Boiler | -- | -- | -- | Logged wood & Bark, wet sawdust |
| Hallmark Card Company | Leavenworth | -- | Boiler | -- | -- | -- | Waste paraffin |

## TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **Kentucky** | | | | |
| Westvaco Corp. | Wickliffe | Foster Wheeler | C.A.D. grate stoker boiler | 300,000 | 625 | 750 | Wood hog |
| Westvaco Corp. | Wickliffe | Foster Wheeler | C.A.D. grate stoker boiler | 450,000 | 625 | 750 | Log fuel/oil |
| Wood Mosaic | Louisville | Wellons, Inc. | Boiler | -- | -- | -- | Wood waste |
| Wescor Corp. | Hawesville | Riley Stoker Corp. | VO boiler | -- | -- | -- | Wood waste and oil |
| | | | **Louisiana** | | | | |
| Gaylord Container Corp. | Bogalusa | Riley Stoker Corp. | Boiler | 250,000 | 1,000 | 830 | Unlogged wood bark and coal |
| Crown Zellerbach Corp. | Bogalusa | (Operate Nov., 1978) | Boiler | 350,000 | -- | -- | Log fuel |
| Joe Miles Lumber Co. | Bogalusa | Energex Limited | Drying kiln | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Anthony Forest Products | Plain Dealing | Energex Limited | 2 drying kilns | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Anthony Forest Products | Plain Dealing | Energex Limited | Rotary dryer | $15 \times 10^6$ Btu | -- | -- | Wood waste |
| Leesville Lumber Company | Leesville | Energex Limited | Drying kiln | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Boise Southern Co. | Deridder | -- | Power boilers | -- | -- | -- | Gas/bark |
| Calcasiew Paper Co. | Elizabeth | -- | Power boilers | -- | -- | -- | Gas/bark |
| Continental Can Co., Inc. | Hodge | -- | Power boilers | -- | -- | -- | Gas/bark |
| Pineville Kraft Corp. | Pineville | 1-Combustion Engineering 1-Erie City | Power boilers | -- | -- | -- | Gas/bark |
| Georgia-Pacific Corp. | Port Hudson | Babcock & Wilcox | Power boilers | 525,000 | 850 | -- | Gas/oil/bark |
| OlinKraft, Inc. | West Monroe | -- | Power boilers | -- | -- | -- | Gas/oil/bark |
| | | | **Massachusetts** | | | | |
| Kelly Enterprises | Pittsfield | Energy Products of Idaho | FB-75 boiler | 10,000 | 15 | -- | Log fuel |

TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **Maine** | | | | |
| Boise-Cascade Company | Rumford | Zurn Industries | Paper dryer boiler | 170,000 | -- | -- | Wood waste |
| Great Northern Paper Company | Millinockette | Combustion Engineering | Boiler | -- | -- | -- | Wood |
| Blier Cedar Company | Van Buren | Energy Products of Idaho | FB-100 boiler | 20,000 | -- | -- | Wood refuse |
| Georgia-Pacific Company | Woodland | -- | Boiler to generate electricity | -- | -- | -- | Log fuel, bark, chips |
| Old Town Pulp Products, Inc. | Old Town | -- | Power boilers | -- | -- | -- | Oil/bark |
| Oxford Paper Company | Rumford | -- | Power boilers, 4-oil, 1 bark | 170,000 | 700 | -- | Bark |
| Scott Paper Co. | Winslow | -- | Power boilers | -- | -- | -- | Oil/bark |
| | | | **Michigan** | | | | |
| Conway Corporation | Grand Rapids | Ultrasystems, Inc. | Keeler CP Stoker boiler | 32,000 | -- | -- | Wood |
| Hoerner Waldorf Corp. | Ontonagon | Riley Stoker Corp. | Boiler | 250,000 | 1,500 | 900 | Bark |
| Cody High School | Detroit | -- | Boiler | -- | -- | -- | Wood chips |
| U.S. Plywood Corp. | Gaylord | Energex Limited | 2 rotary dryers | $27 \times 10^6$ Btu | -- | -- | Wood refuse |
| Abitibi Corp. | Alpena | -- | Power boilers | -- | -- | -- | Cool/wood waste |
| Escanaba Paper Co. | Escanaba | -- | Power boilers | -- | -- | -- | Oil/gas/bark |
| | | | **Minnesota** | | | | |
| St. Regis Paper Co. | Sartell | -- | Power boilers | -- | -- | -- | Gas/coal/logged waste |
| Anderson Corp. | Bauport | -- | Boiler | -- | -- | -- | Sawdust and shavings |
| | | | **Mississippi** | | | | |
| U.S. Plywood Corp. | Oxford | Riley Stoker Corp. | Boiler | 70,000 | 235 | sat. | Bark & powder dust |
| Koppers Company, Inc. | Grenada | Wellons, Inc. | Boiler | -- | -- | -- | Wet logged wood |
| International Paper Co. | Natchez | Foster Wheeler | C.A.D. grate boiler | 300,000 | 1,275 | 900 | Wood log |

TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **Mississippi (Continued)** | | | | |
| Madison Furniture | Canton | Energex Limited | Drying kiln | $6 \times 10^6$ Btu | -- | -- | Waste wood |
| St. Regis Paper Co. | Monticello | -- | Power boilers | -- | -- | -- | Gas/bark |
| | | | **Missouri** | | | | |
| Walnut Products, Inc. | St. Joseph | Energy Products of Idaho | FB-75 Boiler | 10,000 | 150 | -- | Log fuel |
| Iowa-Missouri Walnut Co. | St. Joseph | Energy Products of Idaho | FB-75 Boiler | 6,900 | 150 | -- | Log fuel |
| Midwest Walnut Company | Willow Springs | Willons, Inc. | Boiler | -- | -- | -- | Hardwood saw dust and log bark |
| | | | **Montana** | | | | |
| Plum Creek Lumber | Columbia Falls | Riley Stoker Corp. | Boiler | 120,000 | 325 | sat. | Wood |
| Yellowstone Pine Lume Co. | Belgrade | Wellons, Inc. | Boiler | -- | -- | -- | Shavings |
| C&C Plywood Corp. | Kalispell | Wellons, Inc. | Boiler | -- | -- | -- | General waste |
| American Timber Co. | Olney | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark |
| Pyramid Mtn. Lumber Co. | Geeley Lake | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark |
| Louisiana Pacific Corp. | Trout Creek | Wellons, Inc. | Boiler | -- | -- | -- | Sawdust and bark |
| Eastmont Forest Products | Ashland | Energy Products of Idaho | FB-100 Boiler | 20,000 | 15 | -- | Log fuel |
| Plum Creek Lumber Co. | Columbia Falls | Enerex Limited | 2 flash dryers | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Montana-Pacific | Roundup | Energex Limited | Boiler | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| | | | **New Mexico** | | | | |
| Amalia Lumber Co. | Amalia | Foster Wheeler | Pinhole grate Boiler | 40,000 | 250 | sat. | Wood |
| Navajo Forest Products | Navajo | Energex Limited | Rotary dryer | $15 \times 10^6$ Btu | -- | -- | Wood waste |

TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **New York** | | | | |
| Hooker Chemical Company | Niagara Falls | Foster Wheeler | 2 C.A.D. grate boilers | 300,000 | 1,200 | 750 | Municipal refuse |
| Celotex Corp. | Deposet | -- | Power Boiler | 30,000 | 150 | -- | Gas/logged waste |
| | | | **North Carolina** | | | | |
| Weyerhaeuser Company | Plymouth | Foster Wheeler | C.A.D. grate Boiler | 400,000 | 1,300 | 925 | Wood log |
| Weyerhaeuser Company | Plymouth | Foster Wheeler | C.A.D. grate Boiler | 550,000 | 875 | 825 | Wood/oil |
| H&B Lumber Company | Marion | Energy Products of Idaho | FB-100 Boiler | 120,000 | 100 | -- | Log fuel |
| Atlantic Veneer Corp. | Beaufort | Energy Products of Idaho | FB-75 Boiler | 34,500 | 200 | -- | Log fuel |
| Boise Cascade Corp. | Mancure | Energy Products of Idaho | FB-160 boiler & veneer dryers | 26,500 | 150 | -- | Log fuel |
| The Champion Paper & Fiber Co. | Canton | Riley Stoker Corp. | Boiler | 200,000 | 500 | 750 | Unlogged wood, bark and coal |
| Rishel Furniture Industries | Louisburg | -- | Boiler | -- | -- | -- | Wood chips |
| Genwave Furniture Industries | Indian Trial | -- | Boiler | -- | -- | -- | Veneer scrap, bark, boards |
| Jordan Lumber Co. | Mt. Gilead | Energex Limited | Drying kiln | $15 \times 10^6$ Btu | -- | -- | Wood waste |
| Weyerhaeuser Company | Plymouth | Energex Limited | Hot logs | $15 \times 10^6$ Btu | -- | -- | Wood waste |
| Federal Paper Board Co. | Riegelwood | -- | Power boilers | -- | -- | -- | Coal/oil/gas/bark |
| Albermarle Paper Co. | Roanoke Rapids | -- | Power boiler | 750,000 | -- | -- | Oil/coal/bark |
| | | | **Oregon** | | | | |
| Little River Box Company | Glide | Foster Wheeler | Pinhole grate boiler | 35,000 | 150 | sat. | Wood and oil |
| Lane Plywood | Eugene | Energex Limited | Veneer dryer | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Carolina-Pacific | Grants Pass | Energex Limited | 2-veneer dryer | $27 \times 10^6$ Btu | -- | -- | Wood waste |

TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | Oregon (Continued) | | | | |
| Dillard Lumber Company | Dillard | Wellons, Inc. | Boiler | -- | -- | -- | Wood chavings |
| Eugene Beirrell Lumber Co. | White City | Wellons, Inc. | Boiler | 15,000 | 15 | -- | Wood bark |
| Spalding & Sons, Inc. | Grants Pass | Wellons, Inc. | Boiler | -- | -- | -- | Bark and sawdust |
| Cane Lumber Company | Gashen | Wellons, Inc. | Boiler | -- | -- | -- | Wet sawdust |
| Western Wood Mfg. Co. | Lake Oswego | Wellons, Inc. | Boiler | -- | -- | -- | Shavings & sander dust |
| Agnew Timber Products | Brookings | Wellons, Inc. | Boiler | -- | -- | -- | Bark |
| Stuckart Lumber Co. | Lyons | Wellons, Inc. | Boiler | -- | -- | -- | Bark |
| Superior Lumber Co. | Glendale | Wellons, Inc. | Boiler | -- | -- | -- | Bark |
| Murphy Veneer Co. | Florence | Wellons, Inc. | Boiler | -- | -- | -- | Bark |
| Taylor Lumber Sales | Sheridan | Wellons, Inc. | Boiler | 24,000 | 150 | -- | Bark & sawdust |
| Jeld-Wen, Inc. | Klamath Falls | Wellons, Inc. | Boiler | -- | -- | -- | Combination bark & wet sawdust |
| Louisiana Pacific Corp. | Lakeview | Wellons, Inc. | Boiler | 24,000 | 150 | -- | Combination bark & wet sawdust |
| Round Prairie Lumber Co. | Dillard | Wellons, Inc. | Boiler | -- | -- | -- | Combination bark & wet sawdust |
| Tomco, Inc. | Sweet Home | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark |
| Warrenton Lumber Co. | Warrenton | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark |
| Boise Cascade Corp. | Williamina | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark |
| Fort Hill Lumber Co. | Grande Ronde | Wellons, Inc. | Boiler | -- | -- | -- | Planer shavings & wet sawdust |
| Eugene Water & Elec. Board | Eugene | Riley Stoker | Boiler | 175,000 | 725 | 835 | Logged firewood, coal & oil |
| Hanel Lumber Co. | Hood River | -- | Boiler | -- | -- | -- | Wood |
| Olson-Lawyer Lumber, Inc. | Medford | Herreschoff | Boiler | -- | -- | -- | Bark |
| Boise Cascade | Sweet Home | Energex Limited | Veneer Dryer | $6 \times 10^6$ Btu | -- | -- | Wood waste |
| Leading Plywood | Corvallis | Energex Limited | Veneer dryer | 15 mm Btu | -- | -- | Wood waste |
| SWF Plywood | Grants Pass | Energex Limited | 2 Veneer dryers | 27 mm Btu | -- | -- | Wood waste |
| SWF Plywood | Albany | Energex Limited | 2 Veneer dryers | 27 mm Btu | -- | -- | Wood waste |
| Linnton Plywood | Portland | Energex Limited | Veneer dryer | 27 mm Btu | -- | -- | Wood waste |
| Kinzua Corp. | Kinzua | Energex Limited | Veneer dryer | 45 mm Btu | -- | -- | Wood waste |

TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **Oregon (Continued)** | | | | |
| Weyerhaeuser Co. | North Bend | Energex Limited | Rotary dryer | 27 mm Btu | -- | -- | Wood waste |
| Weyerhaeuser Co. | Springfield | Energex Limited | Rotary dryer | 45 mm Btu | -- | -- | Wood waste |
| Permaneer | Dillard | Energex Limited | Rotary dryer | 27 mm Btu | -- | -- | Wood waste |
| Georgia-Pacific Corp. | Coos Bay | -- | Power boilers | -- | 200 | -- | Log wood |
| Weyerhaeuser Co. | Klamath Falls | -- | Power boilers | 30,000 | -- | -- | Wood waste |
| Crown Zellerbach Corp. | Lebanan | -- | Power boilers | -- | -- | -- | Oil/gas/logged waste |
| Menasha Corp. | North Bend | -- | Power boilers | -- | -- | -- | Logged wood/oil |
| Crown Zellerbach Corp. | West Linn | -- | 6 Power boilers | -- | -- | -- | Oil/gas/logged waste |
| Grenco, Inc. | Portland | -- | Boiler | -- | -- | -- | Wood/paper refuse |
| Ricikini Lumber Co. | Cottage Grove | Ultrasystems, Inc. | 2 Boilers Erie City Stokers | -- | -- | -- | Wood waste |
| Western States Plywood Corp. | Portland | Ultrasystems, Inc. | 2-Keeler CP Stoker boiler | 20,000 | -- | -- | Wood waste |
| | | | **Oklahoma** | | | | |
| Weyerhaeuser Co. | Craig | Energex Limited | Flash dryer | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| | | | **Pennsylvania** | | | | |
| Masonite Corp. | Towanda | -- | Power boilers | -- | -- | -- | Gas/wood |
| Hammermill Paper Co. | Erie | Riley Stoker Corp. | Boiler | 200,000 | 759 | 675 | Unlogged wood and coal |
| The Proctor & Gamble Co. | Mehoopany | Riley Stoker Corp. | Boiler | 50,000 | 600 | 550 | Unlogged wood, coal & oil |
| P. H. Glatfelter Co. | Springs Grove | Riley Stoker Corp. | Boiler | 200,000 | 850 | 800 | Bark & coal |
| York-Shipley, Inc. | York | Energy Products of Idaho | FB-50 Boiler | 3,800 | 15 | -- | Various |
| Kane Hardwood Division of Collins Pine Co. | Kane | Wellons, Inc. | Boiler | -- | -- | -- | Hemlock |
| Robert Mallery Lumber Co. | Emporium | Perry Smith Co. | Boiler | -- | -- | -- | Logged wood |
| True Temper Corp. | Union City | -- | Boiler | -- | -- | -- | Dry shavings |
| Catawissa Lumber & Specialty Co. | Catawissa | -- | Boiler | -- | -- | -- | Wood waste |

TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **South Carolina** | | | | |
| Sonoco Products Co. | Hartsville | Riley Stoker Corp. | Boiler | 275,000 | 1,400 | 950 | Unlogged wood, gas/oil & coal |
| Bowaters Carolina Corp. | Catawaba | -- | 2 Boilers | -- | -- | -- | Gas/oil/bark |
| Westvaco Corp. | Charleston | -- | 5 Power boilers | -- | -- | -- | Gas/oil/bark |
| South Carolina Industries, Inc. | Florence | -- | 2 Power boilers direct fired | -- | -- | -- | Bark/oil/gas |
| Ingram Lumber Co. | Florence | Energex Limited | Drying kilns | $15 \times 10^6$ Btu | -- | -- | Wood waste |
| | | | **South Dakota** | | | | |
| Homestake Forest Products | Splarfish | Wellons, Inc. | Boiler | 15,000 | 15 | 150 | Bark and wet sawdust |
| | | | **Tennessee** | | | | |
| Tibbals Flooring Company | Oneda | -- | Boiler | -- | -- | -- | Wood waste |
| Bowaters Southern Paper Corp. | Calhoun | -- | 5 Power boilers | -- | -- | -- | Gas/oil/bark |
| | | | **Texas** | | | | |
| TEX-O-Cal Hardwoods, Inc. | Temple | Wellons, Inc. | Boiler | -- | -- | -- | Dry shavings |
| Eastex, Inc. | Evadale | -- | 3 Power boilers | -- | -- | -- | Gas/bark |
| Southland Paper Mills, Inc. | Houston | Babcock & Wilcox | 2 Power boilers | -- | -- | -- | Gas/oil/bark |
| Southland Paper Mills, Inc. | Lufkin | -- | 7 Power boilers | -- | -- | -- | Gas/bark |
| Owens-Illinois, Inc. | Orange | -- | 2 Power boilers | -- | -- | -- | Gas/bark |
| Champion Papers Division | Pasadena | -- | 7 Power boilers | -- | -- | -- | Gas/bark |
| | | | **Vermont** | | | | |
| Burlington Electric Dept. | Burlington | Conversion | Wicks water tube Power boiler | 10 mw | -- | -- | 75% wood/25% oil |
| Burlington Electric Dept. | Burlington | In planning stage | Power boiler | 50 mw | -- | -- | Wood waste |
| Vermont State Hospital | Waterbury | Energy Products of Idaho | FB-75 Boiler | 10,000 | -- | 150 | Log fuel |

## TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **Virginia** | | | | |
| Continental Can Co. | Hopewell | Riley Stoker Corp. | Boiler | 135,000 | 490 | 650 | Logged wood |
| Union Camp Corp. | Franklin | Babcock & Wilcox | Boiler | -- | -- | -- | Wood |
| St. Regis Paper Co. | Franklin | Babcock & Wilcox | Boiler | -- | -- | -- | Wood |
| Westvaco Corp. | Covington | -- | 5 Power boilers | -- | -- | -- | Gas/coal/bark |
| Chesapeake Corp. of Virginia | West Point | -- | 3 Power boilers | -- | -- | -- | Oil/bark/coal |
| Gray Lumber Co. | Waverly | Energex Limited | Direct fired dry kiln | $15 \times 10^6$ Btu | -- | -- | Wood waste |
| Masonite Corp. | Waverly | Energex Limited | Rotary dryer | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| | | | **Washington** | | | | |
| Crown Zellerbach Corp. | Camas | -- | 9 Power boilers | -- | -- | -- | Gas/oil/bark |
| Scott Paper Co. | Everett | -- | 9 Power boilers | -- | -- | -- | Gas/bark |
| Longview Fibre Co. | Longview | -- | 4 Power boilers | -- | -- | -- | Oil/gas/log waste |
| Inland Empire Paper Co. | Millwood | -- | 2 Power boilers<br>1 gas<br>1 waste | 1,750 | 200 | -- | Log waste |
| Crown Zellerbach Corp. | Port Angeles | -- | 8 Power boilers | 103,000 | -- | -- | Oil/bark |
| Boise Cascade Corp. | Steilacoom | -- | 3 Power boilers | -- | -- | -- | Oil/gas/bark |
| St. Regis Paper Co. | Tacoma | -- | 6 Power boilers<br>2 Erie City-oil<br>4 Logged waste | 230,000 | 425 | -- | Logged waste |
| | | | **Washington** | | | | |
| M&R Lumber Co. | Port Angeles | Ultrasystems, Inc. | Boiler (Deltak) | 36,000 | -- | -- | Wood waste |
| Buffelin Woodworking Co. | Tacoma | Ultrasystems, Inc. | 2 Stoker boilers | 30,000 | -- | -- | Wood waste |
| Kerns Furniture Co. | Oakwood | Ultrasystems, Inc. | 2 Stoker boilers | 10,000 | -- | -- | Wood waste |
| Crown Zellerbach Corp. | Port Townsend | -- | Boilers | 200,000 | -- | -- | Log fuel |
| ITT Rayanier, Inc. | Port Angeles | -- | Boiler | -- | -- | -- | Waste wood |
| Boise Cascade Corp. | Spokane | Energex Limited | Veneer dryer | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Boise Cascade Corp. | Kettle Falls | Energex Limited | Veneer dryer | 27 mm Btu | -- | -- | Wood waste |
| Crown Zellerbach Corp. Bico Div. | Omak | Energex Limited | Veneer dryer | 45 mm Btu | -- | -- | Wood waste |

TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **Washington (Continued)** | | | | |
| Weyerhaeuser Co. | Cosmopolis | Energex Limited | 2 Rotary dryers | 27 X $10^6$ Btu | -- | -- | Wood waste |
| Broughton Lumber Co. | Underwood | Wellons, Inc. | Boiler | -- | -- | -- | Planer shavings |
| Layman Lumber Co. | Naches | Wellons, Inc. | Boiler | -- | -- | -- | Bark and sawdust |
| Bingen Plywood Co. | Bingen | Wellons, Inc. | Boiler | -- | -- | -- | Logged plywood trim & sander dust |
| Arden Lumber Co. | Colville | Wellons, Inc. | Boiler | -- | -- | -- | General waste |
| Vaagen Bros. Lumber Co. | Colville | Wellons, Inc. | Boiler | -- | -- | -- | Bark & wet sawdust |
| Pacific Wood Treating Corp. | Ridgefield | Wellons, Inc. | Boiler | -- | -- | -- | Wood, bark, wet & dry sawdust |
| Allen Logging Company | Forks | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark & wet sawdust |
| Boise Cascade Corp. | Goldendale | Wellons, Inc. | Boiler | -- | -- | -- | Logged bark & wet sawdust |
| Weyerhaeuser Co. | Raymond | Energy Products of Idaho | FB-180 Boiler | 60,000 | 150 | -- | Log fuel |
| Weyerhaeuser Co. | Longview | Foster Wheeler | C.A.D. Grate boiler | 550,000 | 1,250 | 950 | Wood log |
| Weyerhaeuser Co. | Tacoma | Foster Wheeler | C.A.D. Great boiler | 400,000 | 1,250 | 950 | Log fuel |
| Coast Sash & Door Co. | Tacoma | Ultrasystems, Inc. | H.R.T. Stoker boiler | -- | -- | -- | Wood |
| Tyee Lumber Co. | Seattle | Ultrasystems, Inc. | H.R.T. Boiler | 15,000 | -- | -- | Wood |
| | | | **Wisconsin** | | | | |
| Webster Lumber Co. | Bangar | Energy Products of Idaho | FB-120 Boiler | 26,000 | 150 | -- | Log fuel |
| Boise Cascade Corp. | Phillips | Energy Products of Idaho | FB-120 boiler & Direct fired fiber dryer | 20,000 | 250 | -- | Log fuel |
| Nagel Lumber Co., Inc. | Land O'Lakes | Energy Products of Idaho | FB-140 Boiler | 20,700 | 175 | -- | Log fuel |
| Continental Forest Products, Co. | Ashland | Foster Wheeler | Pinhole grate boiler | 35,000 | 150 | sat. | Wood & #6 oil |

TABLE C-1. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | Wisconsin (Continued) | | | | |
| Superior Fibre Products | Superior | Foster Wheeler | Pinhole Greate boiler | 44,000 | 300 | sat. | Wood |
| International Paper Co. | Fond du Lac | Babcock & Wilcox | Boiler | -- | -- | -- | Wood waste |
| Scott Paper Co. | Oconto Falls | -- | 3-power boilers | -- | -- | -- | Gas/bark/oil waste liquor |
| Badger Paper Mills, Inc. | Peshtigo | -- | 3-power boilers | -- | -- | -- | Gas/oil/bark |
| Weyerhaeuser Co. | Rothschild | -- | 6-power boilers | -- | -- | -- | Coal/oil/bark |
| Owens-Illinois, Inc. | Tomahawk | -- | Power boilers | -- | -- | -- | Coal/bark |
| Weyerhaeuser Co. | Marshfield | Energex Limited | Rotary dryer | $27 \times 10^6$ Btu | -- | -- | Wood waste |
| Richardson Brothers Co. | Sheboygan | -- | Boiler | 400 hp | -- | -- | Wood scraps & sawdust |
| | | | Wyoming | | | | |
| Hines Lumber Co. | Saratoga | Wellons, Inc. | Boiler | -- | -- | -- | Shavings |
| Brandt & Wicklund Forest Products | Fox Park | Wellons, Inc. | Boiler | -- | -- | -- | Bark & wet sawdust |
| Cambria Forest Industries, Inc. | New Castle | Wellons, Inc. | Boiler | -- | -- | -- | Bark & wet sawdust |
| Neiman Sawmill, Inc. | Hulett | Wellons, Inc. | Boiler | -- | -- | -- | Bark & wet sawdust |

## TABLE C-2. WOOD-REFUSE-BURNING INSTALLATIONS, FOREIGN

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | British Columbia, Canada | | | | |
| Pasta Industries, Ltd. | Grand Forks | -- | -- | -- | -- | -- | Wood waste |
| Northwood Pulp (Mead) | Prince George | Foster Wheeler | Pinhole grate boiler | 250,000 | 625 | 750 | Wood log |
| Tahsis Company, Ltd. (International Paper) | Gold River | Foster Wheeler | Pinhole Boiler | 230,000 | 625 | 750 | Wood log |
| Intercontinental Pulp (Reed Paper) | Prince George | Foster Wheeler | Pinhole Boiler | 145,000 | 600 | 700 | Wood log |
| Kamloops Pulp & Paper Co. (Weyerhaeuser) | Kamloops | Foster Wheeler | C.A.D. 2 grate boilers | 350,000 | 625 | 750 | Wood bark, gas or oil |
| Cariboo Pulp & Paper (Weldwood & Daishawa Maruheui) | Quesnel | Foster Wheeler | C.A.D. grate boiler | 480,000 | 600 | 750 | Wood log, gas or oil |
| B. C. Forest Products | Crofton | Foster Wheeler | C.A.D. grate boiler | 400,000 | 625 | 750 | Wood log |
| Prince George Pulp & Paper, Ltd. | Prince George | Foster Wheeler | Inclined grate boiler | 250,000 | 600 | 700 | Bark & wood/gas |
| Tahsis Company, Ltd. | Gold River | Foster Wheeler | Pinhole grate boiler | 525,000 | 625 | 625 | Logged wood |
| International Paper Co., Ltd. | Prince George | Foster Wheeler | Pinhole grate boiler | 450,000 | 600 | 700 | Oil/logged wood |
| Van Isle Moulding | Victoria | Energex Limited | Direct fired dry kiln | $45 \times 10^6$ Btu | -- | -- | Wood waste |
| MacMillan Bloedel, Ltd. | Vancouver | Energex Limited | 2 rotary dryers | 27 mm Btu | -- | -- | Wood waste |
| MacMillan Bloedel, Ltd. | Powell River | Energex Limited | 2 rotary dryers | 27 mm Btu | -- | -- | Wood waste |
| ITT Rayonier, Inc. | Port Alice | -- | Boiler | -- | -- | -- | Waste wood |
| Canadian Forest Products | New Westminister | Foster Wheeler | Inclined grate boiler | 250,000 | 850 | 850 | Log fuel/oil |
| ITT Rayonier, Inc. | Port Carter | -- | Boiler | -- | -- | -- | Waste wood |
| Consolidated Bathurst, Ltd. (Laurentide Div.) | Grand'Mere | Foster Wheeler | Inclined grate boiler | 215,000 | 150 | sat. | Bark & wood, coal |
| Consolidated Bathurst, Ltd. (Portage DuFort) | Pontiac County | Foster Wheeler | Boiler | 400,000 | 600 | 750 | Wood/oil |
| Gaspesia Pulp | Chandler | Foster Wheeler | Boiler | 110,000 | 600 | 735 | Wood/oil |
| J. H. Normick, Inc. | LaSarre | Energex Limited | Direct fired 2 dry kilns | $15 \times 10^6$ Btu | -- | -- | Wood waste |
| Maibec Industries | St. Pamphile | Energy Products of Idaho | FB-75 for direct fired kiln | 10,000 | -- | -- | Log fuel |

TABLE C-2. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | **Ontario, Canada** | | | | |
| Dominian Electrohome Inds. | Kitchener | Foster Wheeler | Grate boiler | 10,000 | 125 | sat. | Wood refuse/oil |
| Canadian Splint & Lumber Co., Ltd. | Pembroke | Foster Wheeler | Grate boiler | 25,000 | 140 | sat. | Wood refuse/gas |
| Chapleau Lumber Co. | Chapleau | Energy Products of Idaho | FB-140 Boiler | 20,000 | 15 | -- | Log fuel |
| Boise Cascade Corp. | Kenora | Energy Products of Idaho | FB-180 Boiler | 45,000 | 250 | -- | Bark & Sludge |
| Great Lakes Paper Co. | Thunder Bay | -- | Boiler | -- | -- | -- | Wood waste |
| | | | **Manitoba, Canada** | | | | |
| M.P. Industrial Mills, Ltd. | The Pas | Foster Wheeler | Grate boiler | 275,000 | 775 | 825 | Wood refuse/oil |
| Manitoba Forestry Resources, Ltd. | The Pas | Foster Wheeler | Grate boiler | 275,000 | 775 | 825 | Log fuel/oil |
| | | | **New Brunswick, Canada** | | | | |
| New Brunswick International Paper Co., Ltd. | Dalhousie | Foster Wheeler | Grate boiler | 120,000 | 450 | 650 | Wood/bark/oil |
| Fraser Companies | Edmundston | Foster Wheeler | Boiler | 150,000 | 650 | 750 | Wood/chips/shavings/oil |
| | | | **Alberta, Canada** | | | | |
| Bissell Bros. Lumber, Ltd. | Eirela | -- | Boiler | -- | -- | -- | Wood waste |
| | | | **Philippines** | | | | |
| San Carlos Milling Co., Inc. | San Carlos City | Foster Wheeler | HS Boiler | 90,000 | 160 | 420 | Bagasse |
| Central Azucarera | Don Pedro | Foster Wheeler | SF-X Boiler | 300,000 | 400 | 500 | Bagasse/oil |
| | | | **Peru** | | | | |
| W. R. Grace | Paramonga | Foster Wheeler | Boiler | 200,000 | 450 | 700 | Bagasse/oil |
| Negociacion Azucarera Laredo, Ltda. | Lima | Foster Wheeler | Pinhole grate boiler | 88,000 | 370 | 662 | Bagasse/oil |

## TABLE C-2. (Continued)

| Company | Location | Supplier | Type of Equipment | Capacity lbs, hr | Design Pressure | Temperature, F | Fuel |
|---|---|---|---|---|---|---|---|
| | | | Peru (Continued) | | | | |
| Negociacion Azucarera Nepena, S.A. | Hacienda San Jacinto | Foster Wheeler | Grate boiler | 110,000 | 600 | 700 | Bagasse/oil |
| C.A.P. San Jacinto, Ltda. | Chimbote | Foster Wheeler | Grate boiler | 110,000 | 600 | 700 | Bagasse.oil |
| | | | Columbia | | | | |
| Ingenio San Carlos, Ltda. | Tulua | Foster Wheeler | Pinhole Grate boiler | 30,000 | 150 | 470 | Bagasse |
| | | | Ecuadar | | | | |
| Compania Azucarera Valdez, S.A. | Guayaqiul | Foster Wheeler | HS-OB boiler | 70,000 | 300 | 465 | Bagasse/oil |
| Compania Azucarera Valdez, S.A. | Guayaquil | Foster Wheeler | Harshal furnace boiler | 70,000 | 300 | 465 | Bagasse/oil |
| Compania Azucarera Valdez, S.A. | Guayaquil | Foster Wheeler | Horseshoe furnace boiler | 120,000 | 300 | 465 | Bagasse/oil |
| | | | Kingston, West Indies | | | | |
| J. Wray & Nephew, Ltd. | Appleton Estate | Foster Wheeler | Inclined grate boiler | 70,000 | 300 | 530 | Bagasse/oil |
| | | | Iran | | | | |
| Stadler Hurter, Ltd. for Gilan Forest Prod. Complex | Tehran | Foster Wheeler | Inclined grate Boiler | 352,800 | 853 | 833 | Wood/oil |
| Seka-Akdeniz Mill | Silifke-Heysm | Foster Wheeler | C.A.D. grate boiler | 330,690 | 896 | 842 | Log fuel/oil |

APPENDIX D

CONCISE REPORTS OF SITE VISITS

Plant A

The Wellons unit was put in almost 3 years ago and works very well. Burn hogged bark, chips, and sawdust. All hardwood-maple, beech, cherry, oak, and hemlock. Sometimes do custom planning of pine and burn the chips. Wood waste may contain up to 55 percent water, but usually is below 50 percent.

The hogged waste from the mill is conveyed to a silo, which is agitated to deliver the waste to screw conveyor that dumps it in a surge bin. Feed from this bin is automatically fed to the combustor depending on steam demand. Both gasification and combustion occur in the "fuel cell". The feed drops about 10 ft. to the water cooled grates, allowing gasification during fall and combustion on the grates. Off-gases go to the boiler to generate steam. The boiler is rated at 25,000 lb/hr, 155 lb pressure, with saturated steam. Steam goes to run the log turner, kicker, carriage, stop and loader, and to the drying kiln.

The unit has no auxiliary fuel. To restart after shutdowns, they simply pile some chips and sawdust on the grate, add a small quantity of oil and ignite.

Ash removal is simple. They open the access door, pull out the ash, and restart. Presently they are putting the ash in a ravine at the back of the property. No complaints so far.

Multiclones are used to remove particulates and can meet EPA regulations. Particulates are being piled up now but someone want them for mulch and fertilizer.

Plant runs 2-10 hour shifts, 4 day/week. Dry about 45,000 board feet/ shift or 90,000 board feet/day. All lumber goes for furniture manufacture.

The unit is quite dependable, and most problems are people errors. Sometimes the fireman lets the water level in boiler get too low. This causes trouble with the sequential automatic system. When the waste fuel is not burning hot enough a lot of particulates collect on the boiler tubes.

Plant A is located fairly high on top of a knob. The stack is too short and during a high wind the exit gases are blown back to the boiler. Would like another way to drive the agitator in the silo. The universal joint now used is immersed in fuel and gets fouled up occasionally and has to be cleaned, so they shut down for several hours. Also, they can't keep the universal joint greased.

Would like to have another, short conveyor to deliver fuel to the combustor thus bypassing the silo. Would speed things up if required. Would like to put "wrappers" on the silo walls to jar the fuel and make it flow better.

Originally the silo had an open top, they put one on and installed heaters for use in winter time. Also, they made a winter cover for the conveyor to the silo.

Burns about 5 units of wood/hr in the winter, and 3 units of wood/hr in the summer. According to Wellons, one unit is 200 cu. ft. Operating 5 kilns now and expect to put in 5 more later this year. This will require a new boiler and will recommend another Wellons unit. The Wellons unit cost about $350,000 originally.

Plant B

Plant B is installing an Ultrasystems unit with a Keeler boiler. The unit was scheduled to be in operation last month and now appears it will be operating about mid-June. The boiler is rated at 35,000 lb steam/hr, 150 lb pressure, 250-300° temp. The steam will be used for drying kilns and a minor amount for space heating during cold weather.

This plant produces only hardwood lumber. Over 70 percent is red oak, the remainder is maple, cherry, walnut and ash. The wood fuel will be a mixture of sawdust, planer shavings, and hogged wood--all dry. May try to burn some wet sawdust.

Have an old Johnson wood fired boiler, 100 lb pressure, at the lumber yard operation which is hand controlled. Works well on fairly dry wood waste, but can't handle wet bark. Plant B is setting up to sell bark as mulch.

The plant runs 2 shifts on the mill and 3 shifts on the kilns. The cycle in the kilns varies depending on the wood being dried and the moisture content. The variation is from 2-3 days for light lumber to 2 months for heavy green stock. Figures the average per charge is 1 month. Have 32 drying kilns and produce $15 \times 10^6$ ft. dried lumber per year.

Selected the Ultrasystems units because thinks it is the best one and cheaper than some others. Has seen Ultrasystems, Wellons, Energex, and Energy Products of Idaho units in operation as well as some of the big units made by B&W, Riley, FW, and CE. Stated that the Wellans unit is more expensive because of the firebrick lined fuel cell combustor. Also, the Ultrasystems unit does not require auxiliary fuel.

The wood fuels will be mixed in 2 large silos and feed into the combustion chamber as triggered by the steam demand. Likes the automatic operation.

Has 2 Carter Day baghouse units for particulate control. The baghouse is continuously cleaned by forced air and the particulates blown back to the feed silo.

The unit will burn 3 tons of wood/hr during startup, then drop to 2T/hr for remainder of drying cycle. Have been burning oil and sometimes gas. Will save money when burning wood waste, oil is 45¢/gal now and now have to pay to dispose of the waste. Figures a ton of wood waste equals 91 gal. of oil or 12.7 x $10^6$ Btu.

| | | |
|---|---|---|
| 91 gal @ 0.45 | = | $40.95 |
| 1T wood | = | 13.50 |
| | | $27.45 savings |

Total cost for the entire new system is about $850,000.

Talked briefly about ash disposal. Assumes 3 percent ash in the wood and burn 2T/hr.

4000 lbs x 0.03 x 24 hrs = 2880 lbs = 1.44T/day ash

Is trying to find someone to haul the ash away either for free or to pay him for the K content.

Woodex Co., Woodburn, Oregon's President Rudolph Gunnerman makes entruded wood waste pellets but is being sued by three men who claim Woodex stole their process.

Lawyer is close to Morbark in Wynn, Michigan and says they are really pushing to set up central stations for chipping wood within a radius of 25-39 miles. Says Morbark has been out talking to loggers trying to sign them up.

American Fyrefeeder is preparing a proposal to install pyrolysis unit at Plant B. This would replace the old Johnson boiler.

Plant C

Plant C has a Riley stoker, traveling belt and turntable that spreads the fuel on the grate. Coal and bark in a ratio of 60-40 are used normally, sometimes 50-50. The bark contains about 36 percent moisture. The boiler is rated at 200,000 lb per hour, 425 lb pressure and operates at 750 F. Installed in 1954.

Normally uses mainly unhogged bark, wood and coal, but also buys sawdust and bark from sawmills to save money. Burns 500 T/day.

A dependable operation with very few problems. Occasionally the hopper screw gets plugged up if the wood is really wet. Have also experienced visible emissions of unburned, unhogged wood upon occasion.

Use 2 multiclone collectors and Zurn wet scrubbers. Can meet State and Federal EPA emissions specs, claim to be one of the best in the country. Primary collector does most of the work, while the secondary collector often plugs up due to bad design and presently is not working. Are considering putting in a baghouse.

Do not reinject the ash because it plugs up the system. The ash and particulates recovered to to an approved landfill, no problesm. Have sold some char from boiler as mulch to commercial growers.

The stack gas has pH 2.3 so maintain the scrubber at pH 7.0. Use NaOH from own chlorine-caustic operation.

The plant produces 1370 T pulp and 1450 T paper and board per day. Whole tree chipping is done haere as it cleans up the forest. However, can only load 10 percent of whole tree chips to the pulpers because too much dirt gets into the system.

Estimates that wood has 8300-8500 Btu/lb on a dry basis. Figures that theoretically 2 tons wood = 1 ton coal. Plant C has its own coal mine and the plant pays $30/T delivered. Can buy 3 tons of wood for $30, or $10/T. Doesn't like the coal they are presently getting because of 25 percent ash.

Overall has few problems and can handle any found.

Plant D

York-Shipley installed the Energy Products of Idaho boiler system for lumber drying kilns in July, 1974. Had 6 kilns and put in 5 more recently, may put in more. Dry about 400,000 bd/ft lumber per week. Hogged wood is the fuel.

The system is described as "beautiful" all automatic, and no real problems. Have to be careful in adding too many shavings because they burn at the top of the combustor and create too much heat. The plant works 3 shifts, 350 days, with 2 weeks off at Christmas.

Close down one 8 hour shift every 5-6 months to replace the olivine inert bed. Throw this into a landfill. The plant is 11 miles "up the holler" and no one is living very close to the plant.

Use Zurn Industries Multiclone collectors and were recently checked OK by EPA.

Burns 4 cu yds/hr now and estimates a saving of $1400 in oil per month. Use a small quantity of oil to heat the bed occasionally when it has been shut down. The bed is heated to 700 F, the oil shut off, and wood fuel does the job from then on.

Can't see any need for R&D on this system. Have an oversupply of chips and sells them.

Plant E

Have a Riley stoker boiler, 275,000 lb/hr, 1250 lb pressure, 950 F. Use unhogged wood, gas, oil, and coal as fuels. This is an older boiler that works satisfactorily.

Most talk centered around a Weiss boiler (Germany) that was installed 2 years ago, and numerous changes have been made since then. Boiler rated at 55,000 lb/hr, 400 lb pressure, and 650 F. Burns 8 T of hogged hardwood bark containing 50 percent moisture per hour. The bark is fed in at the top and is all burned when it gets to the bottom. The boiler output is used to drive a turbogenerator and for turbo drives in the plant.

Improper grate design and feeder slope incline were bad at first but have been corrected. Turnage says its working fine now. The grate affords a drying zone as the wood enters at the top and progressively burns as it goes to the bottom.

The plant makes 200-300 T/day of pulp and 500-550 T/day of paper products.

A German design multiclone system is used for air emissions, meets State limits easily. Thinks particulates are <0.2 lbs/million Btu. EPA regulations are too severe and difficult to meet. Ringelman opacity test is bad when burning very wet bark. Ash from the boiler goes to a landfill. Certain growers have asked to buy the ash because of its K content to use as a fertilizer.

Burned 1100 tons of other waste in March using own bark. May purchase bark in the future, figure 4500 Btu/lb. Estimate saved $2 million spent for oil annually.

Only R&D needed is on lowering $H_2O$ in bark. Usually stored in a concrete silo and can get wet during a hard rain. Could the flue gas be used to dry bark? Is there a practical heat trasfer technique that would not require too much horsepower?

The Weiss system is the best (since problems taken care of). The system is cheaper than American built and Weiss offers to design for the specific wood fuel to be burned. A number of other company representatives have visited this plant. All could find problems with American equipment and like the Weiss system.

Weiss also makes a real neat sawdust burner. One is at High Point, North Carolina.

Mentioned the Woodex Process for pelletizing wood or cellulose wastes. The advantage offered is ease of handling and transportation. Pellets appear to be well suited to a Riley spreader or traveling grate stoker as they cascade better than hogged wood. Burning them doesn't require an ESP as multiclone will handle emissions. But require power to make pellets. Thinks the company is located in Northwest Oregon.

Plant F

Energex Limited combustor for a direct fired drying kiln. Burn ground planing mill shavings all passing 1/8 in. screen.

A silo, containing 3 days supply of wood, feeds the wood into a fine grinder, then to a hopper, then to the combustion unit. Small system but works great. The burner fires the wood and the heated off gases go directly to the drying kilns. Burner capacity is 15 million Btu/hr.

A drying kiln holds 120,000 bd. ft. of rough lumber and 18 tons of wood (less than 15 percent $H_2O$) per charge are burned. The cycle is 32 hours for drying, temperature rises from ambient to 230°, use maximum feed to the burner to raise temperature at the start (8-10 hrs) and gradually lower until the last 8-10 hrs. are only fueled to maintain desired temperature. Actually, the heat required for drying is only a small part of the total energy used in the plant. The majority is electricity for equipment such as saws, planers, grinding, etc.

Plant F changed from oil to wood fuel for the kilns to save money.

Their estimates are:

#2 oil = 140,000 Btu/gal
wood with 10 percent $H_2O$ = 8000 Btu/lb
1 gal oil = 17 1/2 lbs wood

| | |
|---|---|
| 2500 gal oil/charge = 2500 x $0.40 = | $1000 |
| 20 tons wood at $10 = | 200 |
| | $ 800 |

deduct $50 for grinding and storing wood = $750 saved.

Presently operate kilns 7 da/24 hrs. The system is cleaned every 10-15 charges to remove the ash solids. The amount of ash is small, but apparently larger than they expected from discussions with others. They are putting in another Energex system that should be fired for test this week. When the second unit is on stream will go to a 5 da/3 shift operation thus cutting shift premium pay. Also afraid of a fire that would put them out of business for at least 4 months. This is costly.

Have had no real problems with present unit. Major complaint is that a vortex system is dirty because there is no smoke stack and there are particulates in the hot gases that deposit on the lumber. Of course they dress lumber and remove the ash. When clean rough lumber is needed you must use steam for drying. The ash particulates on the lumber also create more dust in the dressing operation and is bad for the operators of the planers. Would like to clean this up.

Overall thinks it is a very good system, else wouldn't install another.

The Energex Limited unit used only on drying kilns was installed in June, 1975. Have had no real problems. Burn pine sawdust (10 percent $H_2O$) and ground pine shavings. The rating is 15 million Btu/hr. The plant operates 6 da/3 shifts, cycle time in the kiln is 24 hrs., 100,000 bd ft/day, at 235 F. Essentially operate same as others, maximum feed and temperature for 8 hrs., gradual decrease, then 8 hrs. of just maintenance heat.

Have had no EPA violations, either State or Federal. The system cost $200,000.

Burn about 18 tons of wood waste a day. Clean the system once a week and remove about 3-5 gallon buckets of ash that is dumped in pot holes in the yard. Used 2000 gal/da oil prior to the wood burning system. Oil costs 43¢/gal now. Figures wood waste at $10/ton so are saving about $650-$700 per day in fuel cost.

Are now installing a second system, somewhat larger to dry 130,000 bd ft/da. It is interesting that McConnell Industries of Birmingham, Alabama installed the original Energex unit. The second unit is similar to the Energex one, but made entirely by McConnell.

Plant H

Energy Products of Idaho (York-Shipley) fluidized bed system rated at 30,000#/hr., 150# psi, 360 F, was installed in October, 1977. Normally burn hogged hardwood and pine bark with 45-50 percent $H_2O$. Have tried to burn dried veneer trimmings and have problems. The plant runs 3 shifts/day the year around. Close 8 hrs. a week on Saturday, PM for maintenance.

The hot gases go first to a boiler and the resultant steam to the dryers. Steam is also used to steam the wood blocks before peeling and to drive the hot press operation. Takes 4-5 hrs. to steam the blocks and 9 minutes to dry veneer. Hot air from the boiler and the kiln is recycled to the burner. Use multiclones and a Joy precipitator for emission control.

A number of problems have risen. The major ones are as follows:

1. Feeding arrangement plugs up, primarily from foreign matter such as stones and it is not big nor heavy enough.

2. There is an induced draft on the boiler. Particulate matter from the burner chews up the fan blades. Plans to put a dust cyclone ahead of the fan.

3. Particulates also carry over into the dryer. The jet tubes appear to plug up worse than do longitudinal tubes. Have to hose out every 3 weeks. Probably the new cyclone will help.

4. Occasionally the fluid bed hardens into a rather crystalline mass. This happens when they burn veneer scraps along with hogged wood. Thinks the resin is to blame.

5. Is sure that some part of the fluid bed is being carried out of the burner, because the bed depth decreases. Was not sure what the bed material is except it is crystalline and maybe a silicate.

6. Feels the fuel handling system is not large enough for an all out operation of the burner. Wants one twice as big.

Prior to installation of this unit oil was used for the boiler and natural gas for the veneer dryers. Still have an oil burner for emergencies. Natural gas contract was terminated January 1, 1978. Have a propane system to preheat the bed when needed. Propane has been used entirely for the dryers when the wood burner is out of commission.

Alan Mejac of the Coe Manufacturing Company, Painesville, Ohio was at the plant and introduced to me. Coe had done the actual installation for Energy Products and are trying to help Porter work out the bugs. Mejac admitted he was stumped as to why the unit was down except for the extremely wet fuel being used. He volunteered to talk with me if I had any questions.

## TECHNICAL REPORT DATA
*(Please read Instructions on the reverse before completing)*

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15. SUPPLEMENTARY NOTES
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16. ABSTRACT

The report examines the technology and the environmental aspects of the use of surplus wood as an industrial fuel. It includes a review of various wood-burning technologies and a listing of existing facilities. Information on operational problems obtained through site visits is summarized. Estimates are presented of the reduction of sulfur dioxide emissions achieved by burning wood instead of coal or oil. Industrial fuel requirements are compared with the quantities of unused wood residues available on both regional and national levels. Ecological impacts of wood residue utilization and non-technical barriers to the use of wood fuel are explored.

17. KEY WORDS AND DOCUMENT ANALYSIS

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|---|---|---|
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