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GENERATING ELECTRICITY WITH WOOD AND SOLID WASTES IN SOUTHERN OREGON

D. A. PERRY, PRINCIPAL INVESTIGATOR

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Note:

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Research Laboratory
(Research bulletin.)

(Cop 2)

OVERVIEW

And pluck till time
  and times are done

. . .

The golden apples of
  the sun.

-- The Song of the Wandering Aengus
William Butler Yeats (1899)

INTRODUCTION

David Perry
Department of Forest Science
Oregon State University

Use of wood fuels to harvest renewable energy from the sun has aroused great interest in the Pacific Northwest. A recent report by the Pacific Northwest Utilities Conference Committee[1] estimated that 2.5 million ovendry tons of forest residue and 0.3 million ovendry tons of unused mill residue were available annually in the Northwest (Oregon, Washington, Idaho, western Montana). Potential electrical generation from those residues is about 425 megawatts (MWe). Electrical generation with wood represents not only a more efficient use of renewable natural resources and an easing of our dependence on fossil fuels, but a stable economic base for a segment of the wood products industry. Ratke[2] estimates that 90 people would be employed in yarding and hauling residue to, and the operation of, a wood-fueled power plant. Our own estimates suggest this figure may be closer to 200.

The existence of wood and other fuels, however, does not guarantee that they can be recovered economically. Because of small piece size and low volumes per acre, the yarding and loading of logging residue may be two to three times more expensive than the handling of an equal volume of logs. Furthermore, the feasibility of any large generation plant must be evaluated, not only economically, but in light of its environmental impacts. Particulate emissions, increased traffic, and impacts on forest site and stream quality are environmental costs that must be quantified and evaluated in relation to those of electrical generation by other means.

This report on the potential for electrical generation with wood and municipal waste in the Southern Oregon Coastal Zone was funded jointly by the Bonneville Power Administration and the Oregon Department of Energy, with Regional Biomass funding from the U.S. Department of Energy and the National Oceanic and Atmospheric Administration (NOAA), Office of Coastal Zone Management. Our objectives were to:

a. Estimate the amount of biomass fuels potentially available to an electrical generating plant at either Powers or Gold Beach, Oregon.

b. Identify harvest, yarding, and transportation costs for the various fuel types and the two potential plant sites.

c. Assess environmental impacts of operating such a plant, including air pollution, soil and nutrient loss associated with timber harvest, and traffic congestion.

Our economic analysis deals with plant sizes ranging from 10 to 50 MWe. Other sections of the report discuss only 30- and 50-MWe plants, the sizes most likely to be built.

The report is structured as follows. In the section titled Summary and Final Economic Model, we summarize our findings on availability and costs of the various fuel sources, and integrate these into a model which gives a range of costs of fuel delivered to the two plant sites, Powers and Gold Beach. In this section we also briefly discuss potential employment associated with harvest and transportation of fuels, and summarize our findings with regard to air pollution, soil and nutrient loss, and traffic congestion. Following the Summary and Analysis Section are the detailed reports of the various investigators: first, those dealing with objectives (a) and (b), fuel availability and acquisition costs, and secondly, those addressing objective (c), the various aspects of environmental cost.

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[1] Pacific Northwest Utilities Conference Committee and Wood and Biomass Subcommittee of the Alternative Resources Committee. Wood residue energy report. April 1982. PNUCC Systems Planning Office. 520 SW 6th Ave. Portland, Oregon 97204. 40 p.

[2] Ratke, Hans D. 1980. Potential employment effects related to logging residue utilization in the South Coast-Curry Area. U.S. Bureau of Land Management, Portland, Oregon.

SUMMARY AND FINAL ECONOMIC MODEL

David Perry
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Oregon State University

AVAILABILITY OF BIOMASS FUELS

There are four potential biomass fuels in the study area: noncommercial hardwoods, logging residues, mill residues, and municipal solid waste. If one assumes that (a) standing hardwoods are harvested over a 20-year period and (b) *all* of the above fuels are potentially available (see, however, below), estimated yearly tonnages[3] from each source are:

	Available per year (wet tons x 10^6)	Average Btu per ovendry pound	Equivalent generating capacity (MWe)
Standing hardwoods	1	8,100	71.4
Mill residue	.12	9,700	10.2
Logging residue	1	8,800	77.6
Municipal solid waste	.09	6,800	5.4

Faster or slower rates of hardwood harvest will change the amount available on a yearly basis.

The fact that a given amount of fuel is present within the study area does not mean that it is physically or economically available. We estimate that, for both economic and environmental reasons, only about 70 percent of logging residues can be considered "available." Further, we feel that roughly 40 percent of hardwood volumes should be considered unavailable until factors such as road networks and owner marketing desires are better understood. Even with these constraints, we estimate that biomass fuels in the study area could support over 100 MWe generating capacity for 20 years. As we will discuss in detail later, however, costs rise sharply as the proportion of logging residue in the fuel mix increases. Following are more detailed descriptions of each potential fuel.

Hardwoods

We estimate that there are slightly over 993 million ft^3, or 20 million wet tons, of noncommercial hardwoods in the study area (Fig. 1). This estimate does not include stands (a) with less than 50 percent (by volume) hardwoods, (b) within reserved areas (e.g., wilderness), or (c) within large private ownerships that expressed no interest in selling their hardwoods. Details of our estimation procedure are given in the chapter on "Standing Hardwoods."

The hardwood resource is comprised primarily of five species. In Curry County, the southern part of the zone, tanoak predominates, but there is also a significant component of canyon live oak and madrone. These species comprise about 40 percent of the total hardwood resource in the study area and may occur either in extensive pure stands or mixed with conifers. North of Powers, in Coos and Douglas Counties, tanoak and madrone give way to red alder and bigleaf maple; these species comprise about 60 percent of the study area's hardwoods and occur either mixed with conifers or in pure stands. Thirty-six percent of the hardwoods are on public lands; by far the largest proportion of these are tanoak stands occurring on the Chetco and Gold Beach Districts of the Siskiyou National Forest. Thirty-eight percent are on private industrial lands and 26 percent on nonindustrial lands. About 40 percent of private hardwoods are in the tanoak type.

Higher heating value of red alder wood is 8,000 Btu per dry pound. Btu values derived for tanoak in the study area (no published values exist) ranged from 8,041 to 8,242 per dry pound. This report uses an average of 8,100 Btu for all hardwoods.

Logging residue

We estimate that slightly over 1,000,000 tons of logging residue greater than 3 inches in diameter and 12 inches long are generated each year in the study area, about two-thirds of them on public lands. This figure is conservative, reflecting the current depression in the lumber industry, and would be expected to rise with increased harvesting. Roughly

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[3] Except where otherwise noted, all weights within the report are at 40 percent moisture content. Use of a single moisture value throughout the report is necessary for simplicity and consistency. We chose 40 percent because our information suggested it as a reasonable "average" value for all fuels and seasons.

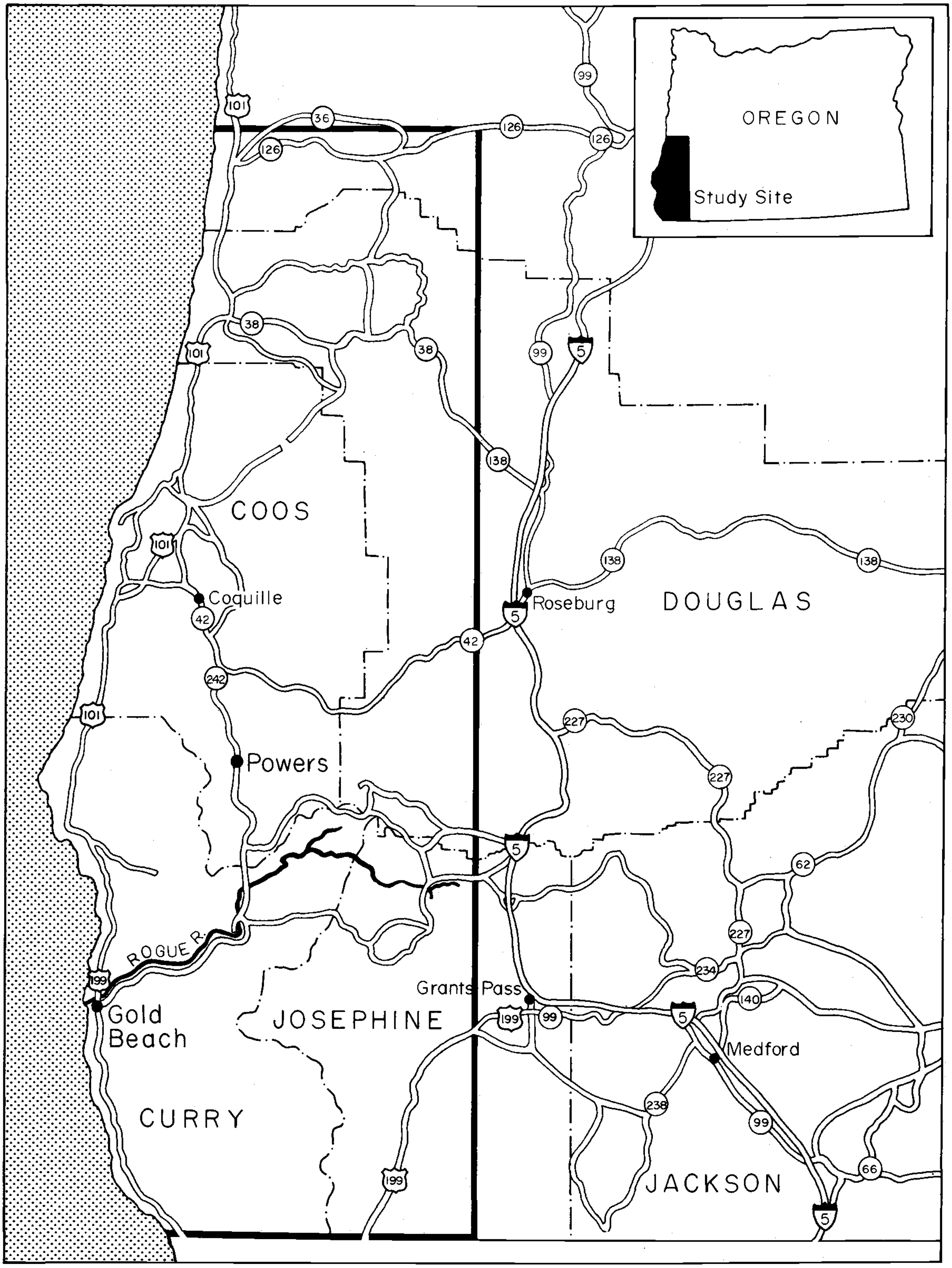

FIGURE 1

THE STUDY AREA (WITHIN THE BLACK BOUNDARY).

80 percent of the tonnage is 8 inches or greater in diameter and at least 8 feet long, and 70 percent is at least 12 inches in diameter and 8 feet long. As we will discuss later in this Summary, the cost of harvesting rises sharply when material smaller than 12 inches in diameter is included. A high proportion of logging residues are coniferous; therefore, we assume 8,800 Btu per ovendry pound for this material.

Mill residue

Although a large amount of mill residue is generated in the study area, only 119,000 tons per year are unused. Over 80 percent of the unused tonnage is Douglas-fir bark, which averages to 9,400 to 10,100 Btu per ovendry pound.

Municipal solid waste

Twenty-three thousand tons of municipal solid waste (MSW) are generated yearly in Coos County, 6,200 tons in Curry County, and 59,000 tons in Douglas County. Average Btu value of this material is one-half that of wood-bark fuels. We estimate that both Douglas and Coos County MSW could be economically delivered to Powers, and could comprise 10 percent of the total fuel requirements of a 50-MWe plant. Both Coos and Curry County wastes could be utilized at Gold Beach, and would contribute 4 percent of a 50-MWe plant's fuel needs.

FUEL COST COMPONENTS

There are three components to fuel cost: purchase, harvest (felling, yarding, chipping), and transportation.

Purchase

Purchase price may vary considerably, depending on demand for the particular fuel and objectives of the owner. For the most part, public agencies and private industrial owners of noncommercial hardwoods wish to convert these lands to conifers. Therefore, we might expect the cost of hardwood stumpage to be quite low. Increased demand, however, may well alter this trend. We have assumed a stumpage price of $3.80 per ton.[4] In the current market this price is high; in future markets it may be low. We have assumed no purchase cost for either logging residue or municipal solid waste. On the basis of contact with mills, we assumed mill residue would cost $23 per ton.

Harvest

Harvesting costs are dependent on both wood volume per acre and how this volume is distributed among pieces. Low volumes per acre are uneconomical to harvest, and high volumes consisting of many small pieces may also be uneconomical. Detailed stand examinations on the Chetco District of the Siskiyou National Forest allow an estimation of the structure of hardwood stands in the study area. On the Chetco District, 35 percent of the hardwood acres and 11 percent of the total hardwood volume consist of stands that have less than 2,000 ft^3 per acre, a volume that we feel cannot be economically logged. Size distribution of trees in the remaining stands will be shown in the chapter on "Costs of Harvesting Hardwoods." On the average, there are 1,134 trees per acre below, and 292 above, 7 inches in diameter. However, 80 percent of the volume is contained in the higher diameter classes. Figure 2 shows the effect of level of diameter utilization on total harvesting costs. These figures will of course vary with the type of operation (size of equipment, number of employees, etc.), but they are reasonably consistent with the costs of logging operations currently underway in hardwood stands of the study area. Our economic analysis assumes an average harvest cost per ton of slightly over $20, equivalent to a minimum harvested diameter of 7 inches. Because volumes are relatively low and large pieces are scattered and often partially rotten, yarding and chipping of logging residue is considerably more expensive than harvesting standing hardwoods. Figure 3 shows that yarding and loading costs rise sharply for pieces less than 10 to 12 inches in diameter. Our analysis assumes a cost of $42 per ton, equivalent to a lower utilization limit of 11 inches.

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[4] Except where noted otherwise, costs are given in 1985 dollars, assuming an 8 percent inflation rate (personal communication from Dave White, Oregon Department of Energy).

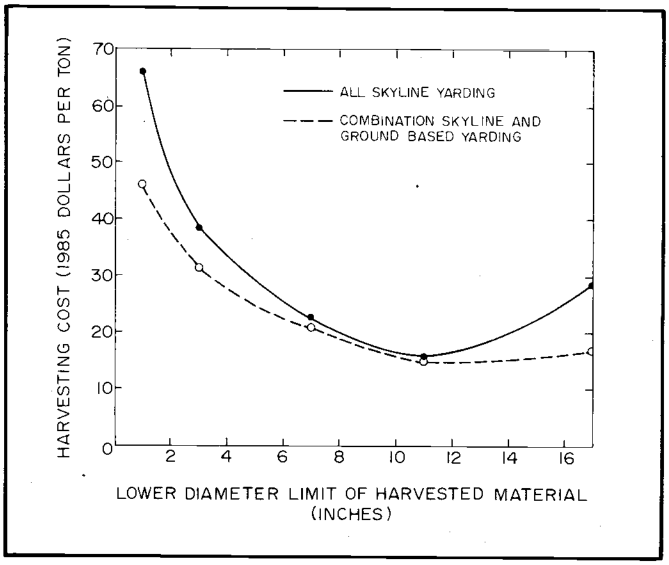

FIGURE 2

EFFECT OF LEVEL OF UTILIZATION ON COST OF HARVESTING HARDWOODS.

Transportation

To compute transportation costs, we had to estimate where the various resources were located. To do so, we used the township as the basic unit, apportioning hardwood and residue volumes according to the proportion of the various ownership classes in each township. Details of the procedure are given in the body of the report. A mapbook[5] shows estimated hardwood and residue volumes by township.

Transportation distances are based on measurements from the center of each township to the place of consumption (Powers or Gold Beach). Actual road miles rather than air miles were measured. Costs are computed on the basis of travel time rather than distance for two reasons: first, trucking companies quote off-highway rates by the hour rather than by the minute; second, where a given route contains both on- and off-highway components, travel time rather than travel distance gives a more realistic cost figure. Our cost estimates were off-highway--$0.84 per minute, highway--$1.57 per minute.

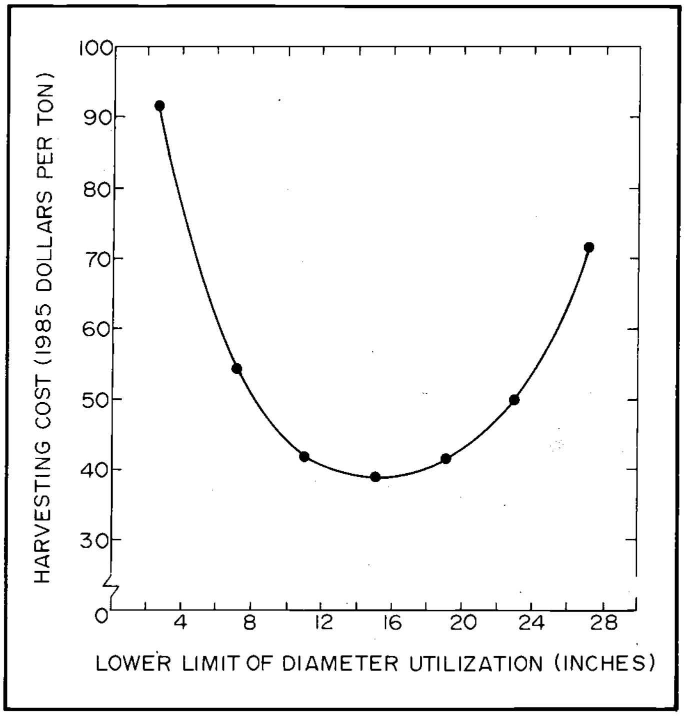

FIGURE 3

EFFECT OF UTILIZATION LEVEL ON COST OF YARDING, LOADING, AND CHIPPING RESIDUE. ASSUMPTIONS USED TO DERIVE THIS FIGURE ARE AS FOLLOWS:

1. WESTERN OREGON CLEARCUTS ONLY ON NATIONAL FOREST LAND.
2. VOLUMES WERE USED FOR MATERIAL ON SLOPES GREATER THAN 35 PERCENT AND YARDING DISTANCES OF LESS THAN 1,001 FEET.
3. AVERAGE YARDING DISTANCE IS 667 FEET.
4. AVERAGE LATERAL DISTANCE IS 60 FEET ON EACH SIDE OF THE SKYLINE.
5. TOTAL COST PER DAY FOR YARDING AND LOADING IS $3,150.
6. ROAD CHANGE TIME = 30 MINUTES PER ROAD.
7. NET VOLUME PER DIAMETER CLASS VARIES FROM GROSS VOLUME. LARGE PIECES ARE ASSUMED TO BE LESS SOUND THAN SMALLER ONES. THE AVERAGE NET VOLUME INCREASES AS THE DIAMETER LIMITS ARE LOWERED.
8. THIS FIGURE IS BASED ON MANY OTHER ASSUMPTIONS AND CONDITIONS. A WORKED-OUT, STEP-BY-STEP APPROACH IS QUITE LENGTHY AND IS AVAILABLE TO INTERESTED PERSONS.

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[5] A limited number of mapbooks are available on a loan basis from Richard Durham, Oregon Department of Energy; Pat Fox, Bonneville Power Administration; or David Perry, Department of Forest Science, Oregon State University.

SOURCES OF ERROR

In evaluating this report, the reader must remember that many of our figures are of necessity rough estimates. There are several sources of error. First, the data from which we derived hardwood and residue volumes are based on a limited sample and are therefore uncertain. Second, the method used to locate resources spatially, though the best approach we could take in the given time constraints, was very crude. Third, we cannot judge how much of the estimated hardwood volume may be physically unavailable--either inaccessible by road or in ownership that does not wish to make it available. Fourth, harvesting costs vary greatly according to such factors as piece size distribution and equipment type, which are essentially unmeasurable in a report such as this.

To partially account for these uncertainties, we have, in the following economic analyses, dealt with an array of possible situations.

ECONOMIC ANALYSIS: THE COST OF DELIVERED FUELS

Figure 4 shows our estimated costs for delivered fuel (1985 dollars per kilowatt-hour) at three levels of availability. These costs were derived by summing expenses for purchase, harvest, and transportation. The case labeled "probable" assumes that our estimates of residue availability and standing hardwood volumes are correct but that only 60 percent of the hardwoods will be available for harvest (with the balance unavailable because of size, accessibility, or owner-related factors). The "best case" assumes residue production at 120 percent of our estimate (feasible if the lumber market improves) and hardwood volumes at 150 percent of our estimate, with all of the hardwoods eventually available. The "worst case" assumes residue production at 50 percent of our estimate and available hardwood volumes at 30 percent of our estimate. The various cases share three common assumptions: hardwood volumes are harvested over a 20-year period; municipal solid waste is burned first at no cost;[6] after municipal waste is burned, available fuels are taken in order of their delivered cost.

Two important points are not obvious from Figure 4. First, even in the "worst case" there is sufficient biomass available to fuel a 50-MWe plant at either Powers or Gold Beach (680,000 wet tons per year for material averaging 8100 Btu per dry pound). Second, logging residue, because of its high harvest cost, is not used at all except in the "worst case," where it comprises about 45 percent of the total fuels for a 50-MWe plant at either location.

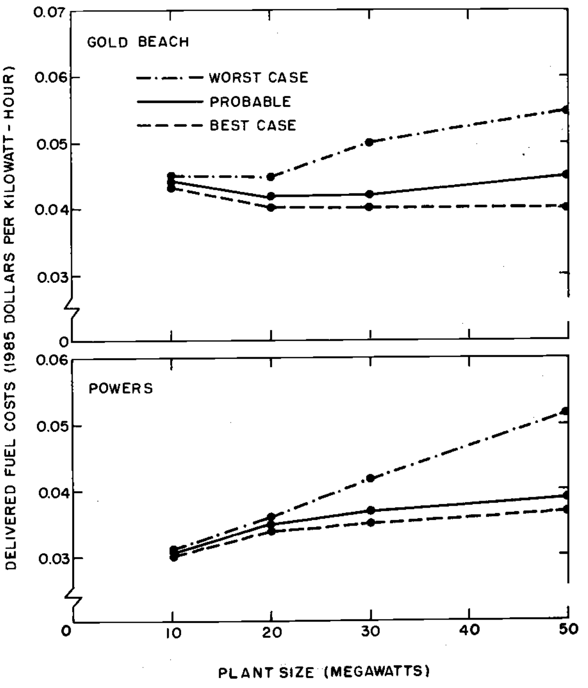

FIGURE 4

DELIVERED FUEL COSTS EXPRESSED IN 1985 DOLLARS PER KILOWATT-HOUR, BY PLANT SIZE, FOR TWO POTENTIAL PLANT SITES (POWERS AND GOLD BEACH) AND THREE FUEL-AVAILABILITY LEVELS. (SEE TEXT FOR DESCRIPTION.)

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[6] Most Curry County waste is generated in Gold Beach (the potential plant site), and Coos County waste is, under current plans, to be delivered to Powers (the other potential plant site) for incineration. Thus, no additional costs are incurred in delivery to Powers as a fuel. We have assumed that no additional expense would be incurred by trucking Coos County waste to Gold Beach rather than Powers, or by trucking Douglas County waste (primarily from Roseburg) to Powers rather than the current disposal site.

For the larger plants at either site, fuel costs per kilowatt-hour rise sharply when the "worst case" is in effect. This rise is due to the increased use of logging residues, which are relatively expensive to harvest. Figure 5 shows the components of cost for the "probable" fuel availability. For the larger plants at both sites, harvest costs comprise about 65 percent of the total, purchase about 20 percent, and transportation 15 percent. This cost structure explains why larger amounts of available hardwood make little difference in price of delivered fuel. Transportation costs are a small component of the total; therefore, variation in the radius of acquisition has a relatively small effect on fuel cost. Because logging residues are expensive to yard, their proportion in the fuel mix is the most important determinant of final cost. Thus, if our "worst case" turns out to be correct, it could be more economical to transport hardwoods from outside of the study area (e.g., from northern California) than to utilize large amounts of logging residue. Other factors, however, may act to lower the costs of logging residues. Many logging contracts on federal lands require that unmerchantable material above a certain size be yarded to the landing. The cost of this operation (called "yumming") is usually reflected in lower bid prices for the merchantable timber. Presumably the logger, having yarding costs in effect subsidized (through the lower price he pays for the merchantable stumpage), would sell this "yummed" material for fuels at a price which is competitive with that of hardwoods. This would have a minor effect on cost of delivered fuel in our scenario for "probable" fuel availability. However, in our "worst case" it would have a dramatic effect, lowering total delivered costs by 15 percent at both plant sites. Thus, if significant amounts of yummed material are indeed available, we might expect costs of delivered fuel to be relatively insensitive, within limits, to our estimates of supply.

Figure 5 can be used to further test the sensitivity of our cost estimates to variations in the cost of the various components. For example, if hardwood harvest turns out to be 20 percent more expensive than we have estimated, total costs would be 13 percent higher or, for a 50-MWe plant at Powers, $.044 per kilowatt-hour rather than $.039. If the hardwoods are obtained without stumpage fee, as may well happen, total costs will drop by nearly $.01 per kilowatt-hour.

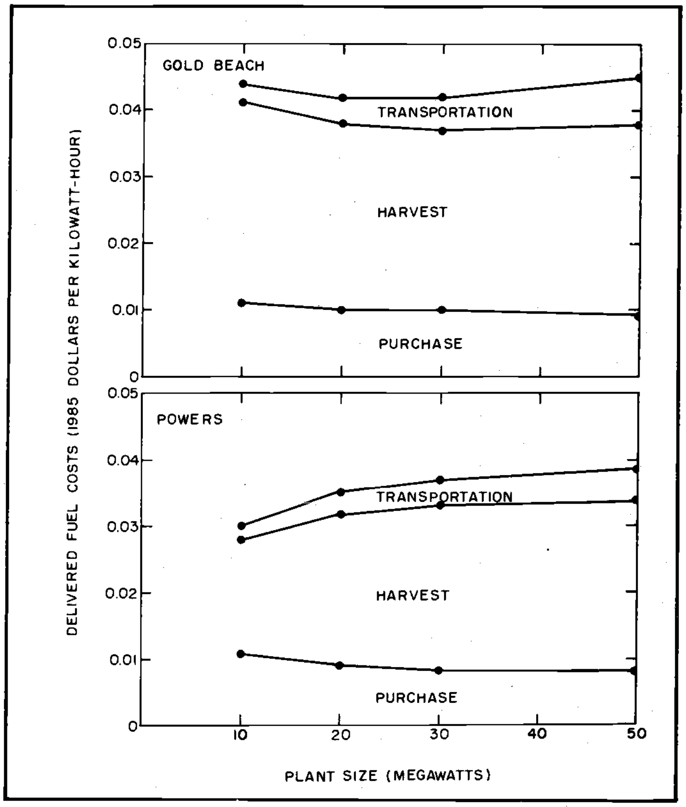

FIGURE 5

COMPONENTS OF FUEL COST, BY PLANT SIZE, FOR POWERS AND GOLD BEACH: "PROBABLE" FUEL-AVAILABILITY LEVEL.

COMPARISONS OF FUEL COSTS AT POWERS AND GOLD BEACH

Our analysis shows that fuel costs are less at Powers than at Gold Beach, regardless of plant size or fuel availability level. The differential is greatest for a 10-MWe plant, with fuel costs at Powers 68 percent of those at Gold Beach; and least for a 50-MWe plant operating under "worst case" fuel availability, with only a 5 percent cost differential between the two sites. For a 50-MWe plant operating under "probable" fuel availability, fuel costs at Powers are 13 percent less than those at Gold Beach.

There are three reasons for the difference in fuel costs between the two sites. First, we have assumed that the relatively large amount of municipal solid waste generated in Douglas County would be available to a plant at Powers, but not to one at Gold Beach. Second, there are more mill residues available near Powers. Third, Powers is centrally located inland, so that transportation costs are less than at Gold Beach.

COMPARISON TO COST OF COAL

According to our estimates, the cost of biomass fuel delivered to plant sites in the study area is only slightly greater per Btu than that of coal. Mr. Bill Shockley of American Coal Company in Coos Bay, Oregon, quotes a current price of $35 to $40 (1982 dollars) per ton for delivered coal averaging 10,500 Btu per pound; or $1.67 to $1.90 per million Btu. We estimate biomass fuels delivered to the Powers site will average 4,860 Btu per wet pound and cost $19.50 per wet ton (1982 dollars), or $2.00 per million Btu.

EMPLOYMENT OPPORTUNITIES

The examples of hardwood harvest operations given by Avery in "Costs of Harvesting Hardwoods" show that productivity generally ranges from 12 to 17 tons per person-day (including truck drivers). If we assume a 7-month logging season, then a 50-MWe plant at Powers consuming 544,000 tons of hardwoods per year (80 percent of the total fuel requirement) would employ 150 to 200 persons in harvesting and transportation activities alone. If it were necessary to harvest logging residues as well as hardwoods, this figure would increase substantially, because productivity (tons per person-day) from residue harvest is about half that of hardwood harvest. For example, in our "worst case" in which logging residue comprises about 45 percent of the fuels for a 50-MWe plant, roughly 290 persons would be employed in harvesting and transportation. Again, these figures are based on 7-month rather than full-year harvesting.

THE POTENTIAL FOR BIOMASS PLANTATIONS

It is unlikely that a large electrical generation plant can be operated in the study area much beyond the year 2010 with the current hardwood resource and logging residue. In order to produce power at competitive rates, the proportion of logging residue burned will have to be kept below about 30 percent, which means current hardwood stands must be liquidated in 20 to 30 years. Once hardwoods are gone, the economics of power may be such that residue can be used, but by this time the timber industry will be logging second-growth coniferous stands, which produce much less unusable wood than the old-growth stands currently being harvested. Therefore, residues may not be available to replace declining hardwood volumes in the fuel mix. These facts suggest that, if biomass power is to become a stable, long-term component of the energy economy in the study area (and in the region), serious consideration must be given to growing trees for energy.

Biomass plantations hold great promise. Joe Dula, of Canby, Oregon, is currently producing hybrid cottonwood at rates exceeding 15 to 20 dry tons per acre per year. Work by Reinhardt Stettler of the University of Washington indicates that considerable gains in productivity of hardwoods can be made through genetic selection. If we assume that an average productivity of 20 dry tons per acre per year can be sustained over large areas (this would require irrigation and fertilization), 20,000 acres would supply fuel for a 50-MWe plant.

Gross income per acre of energy plantation would compare reasonably well with common agricultural crops of western Oregon. In 1981, wheat in Benton County yielded an average gross revenue of $214.50 per acre, and annual ryegrass seed yielded $272 per acre (actual 1981, not 1985, dollars). Biomass priced to compete with coal (on a Btu basis) could bring $20 to $25 in 1981 dollars per dry ton, or $400 to $500 in 1981 dollars per acre (gross). Trees grown on a coppice system (resprouting from roots following harvest) would require a minimum of pre-harvest tending; and if grown on reasonably level ground, costs of harvest would be considerably lower than those we have calculated for the hardwood stands, which are growing wild in the area. Therefore, net, as well as gross, income from energy plantations is likely to be at least as good as, and possibly better than, that from cereal grains and grass seed.

ENVIRONMENTAL IMPACTS

Background: Some plant characteristics

A 50-MWe biomass-fueled power plant would require about 680,000 tons of fuel per year (assuming 8,100 Btu per dry pound). If fuel were delivered to the plant during a 7-month harvesting period, 133 truckloads would be required per day. Storage of a 5-month wood supply would require about 14 million cubic feet, or roughly 10 acres of hog fuel piled 60 feet high. The plant would have to dispose of 41 tons of ash per day. In contrast, a coal-fired plant of the same size would require only 34 truckloads per day (assuming coal could be delivered year-round) and could store one month's fuel supply in less than one-tenth of the area required for a 5-month supply of biomass fuels. The coal plant would have to dispose of 79 tons of ash per day.

Air pollution

Emission characteristics of 30- and 50-MWe plants fueled by coal and biomass are

Emissions[a]	Biomass 30-MWe	Biomass 50-MWe	Coal 30-MWe	Coal 50-MWe
	- tons/yr -		- tons/yr -	
Particulates	207	330	170	271
Gas				
CO	540	900	446	712
SO_2	24	14	1,020	1,627
Fuel-based NO_2	1,030	1,723	2,668	4,257

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[a] See chapter on "Air Pollution" for assumptions used in these calculations.

Any plant emitting a pollutant at a rate exceeding 250 tons per year is considered a "major stationary source" of pollutants. A 50-MWe plant, whether fueled by biomass or coal, exceeds 250 tons per year in all relevant emission categories, while a 30-MWe plant exceeds that figure in gaseous emissions only.

Environmental Protection Agency (EPA) regulations require extensive mathematical modeling of particulate dispersion from a "major stationary source." Such modeling may in turn require meteorological modeling and measurements prior to plant construction. A variety of technologies exist for controlling particulate emissions. These are discussed in the chapter on "Air Pollution."

Emissions of carbon monoxide (CO) are not likely to be controlled by either the EPA or the State of Oregon unless modeling shows that the plume will have an impact on the Eugene-Springfield area. Because of very real concerns over the worldwide impact of acid rain, emissions of sulphur dioxide (SO_2) and the various nitrous oxides (NO_x) would be viewed much more seriously. It is unlikely that a plant would be permitted to operate on 100 percent coal without devices to control SO_2 emissions. Note that a biomass-fueled plant emits less than half the NO_2, and only 1 percent of the SO_2, of a coal-fired plant. The importance of this point cannot be overemphasized. High levels of atmospheric SO_2 and nitrous oxides, produced primarily by burning fossil fuels, have been closely linked to decreased crop and forest growth in Eastern North America. Acid precipitation, once confined to the eastern portions of the continent, is now appearing in the West, raising the possibility that prime agricultural regions may be affected. In Central Europe, where emissions are essentially uncontrolled, vast acreages of forests are dead or dying. If similarly dramatic effects appear in the United States, it is likely that emission controls will be tightened.

Nutrient and soil loss after harvest

Well-stocked tanoak stands have nutrient contents similar to those of coniferous stands. Harvesting practices recommended by Avery (this report) as most economical--7-inch lower diameter limit for utilization, whole-tree removal of trees in the 7- to 11-inch diameter class--would remove about 380 pounds of nitrogen per acre in the average tanoak stand. If trees in all diameter classes were topped (branches and leaves left on site) before yarding, nitrogen removal would drop to about 180 pounds/acre. Nitrogen, the most limiting element on these sites, is added at very low rates by natural processes. Therefore, in order to prevent deterioration in site quality, especially where whole trees are harvested, sites should be fertilized. Because transportation costs are relatively low, it may be more economical to forego whole-tree logging and make up lost tonnages by traveling further. We estimate that the radius of acquisition could be extended up to 100 miles for the same cost that would be incurred by replacing nitrogen lost in whole-tree harvest. Because production of nitrogen fertilizer requires large amounts of fossil fuels, its use to replace nitrogen lost in foliage and small branches may be poor energy-economics; i.e., in terms of net Btu yield, it may be preferable to leave the smaller biomass components on site, rather than removing them and then spending relatively large amounts of energy to replace the lost nitrogen.

Whole-tree harvest also removes large amounts of organic material which, if left on site, would eventually become an important structural component of the forest soil. Soil organic material is as important in fertility as soil nutrients; however, unlike nitrogen and other nutrients, it cannot be directly replaced by fertilization. Because of this constraint and because of the energy cost of using commercial nitrogen fertilizer, we recommend that (a) branches and foliage be left on site, unburned (burning volatilizes carbon and nitrogen and thus defeats the purpose of leaving the material); (b) where feasible, nitrogen-fixing plants such as legumes and alders be used to fertilize sites, thereby putting energy-cheap nitrogen and organic material back into soils.

Most soils in the study area are moderately to highly resistant to erosion and landslide. There are exceptions, however, which will require special precautions during logging. Soils formed from the Days Creek and Otter Point geologic formations are unstable. Such soils comprise only a small percentage of the study area, but they are located close to potential plant sites and thus are likely to be logged heavily. In order to mitigate soil loss, ground disturbance should be minimized and as much vegetation kept on site as possible. These measures will provide rooting strength and prevent soils from becoming water-saturated, a condition that can lead to landslides. In addition, rapid revegetation should be encouraged. On any soils in the study area, slopes greater than 65 percent are unstable and should be treated with the same precautions.

Impact on transportation

The effect of additional truck traffic on highway capacity and level of service (e.g., freedom to maneuver and pass) was determined for all of the study zone's highway sections now heavily used and projected to be traveled by trucks hauling fuelwood. No significant impact was found.

AVAILABILITY AND COSTS OF FUELS

STANDING HARDWOODS

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Within the study area, approximately 993 million ft^3 or 20.4 million wet tons (40 percent moisture content) of wood occur within stands composed predominantly of hardwoods with an average diameter greater than 4 inches. Species composition is as follows:

	Volume (10^6 ft^3)	Percent of total
Red alder	522	53
Maple	44	5
Tanoak	259	26
Madrone	78	8
Chinkapin	12	1
Laurel	53	5
White oak	13	1
Miscellaneous hardwoods	13	1

Distribution of hardwoods by location and ownership is given in Table 1. Hardwoods within restricted areas such as wilderness and those on ownerships unlikely to make them available for harvest are not included. If we assume an average higher heating value of 8,100 Btu per dry pound (see chapter on "Fuel and Plant Characteristics") and 5 percent total volume harvested yearly, then hardwoods in the study area provide slightly more than 71 MWe of generating capacity per year. It is unlikely that this total can be realized in practice, however. Avery's analysis of the "Costs of Harvesting Hardwoods" suggests that roughly 30 percent of the total volume cannot be economically harvested. Though road networks are generally good, some stands may well be inaccessible.

The procedures by which the volumes in Table 1 were estimated are given below. Detailed information on the characteristics of tanoak stands are given by Avery.

U.S. FOREST SERVICE

Hardwood inventory data for the two national forests in the southern coastal zone were obtained from the U. S. Forest Service's Regional Office in Portland, Oregon, and from individual Ranger Districts. The Chetco District of the Siskiyou National Forest provided the most complete data (75 percent of the hardwood land base cruised in the district). From its records of stand examinations, a 20 percent sample was made and three linear regression models developed for predicting the cubic foot volume per acre on the basis of stand density. Each model predicts volume from tree density within a certain diameter range. From these models, hardwood volumes were calculated for all cruised stands within the Chetco District. The uncruised hardwood stands in the district have low volumes, are in inaccessible areas, and generally occur on poor sites. Consequently, these stands are unuseable as fuels for the proposed generating plant.

The land base of the Chetco District, like all national forest districts in the southern coastal zone, is divided into management compartments. Compartment boundaries are irregular and often extend through several townships. Hardwood resources in a particular compartment were allocated to a township on the basis of the proportion of the compartment within that township. This procedure was used for all districts on both the Siskiyou and the Siuslaw National Forests.

The current inventory of hardwood stands in the Gold Beach District of the Siskiyou National Forest was not as complete as that of the Chetco District. Records of recent stand examinations within Gold Beach showed significantly less volume than was reported in the 1968 inventory of the Siskiyou National Forest. The data from the 1968 inventory were considered more accurate by Earl Suherd of the Gold Beach Ranger District and were used to determine the hardwood resource of the District. Ten percent of the District's hardwood land base is classified as either Wilderness or Scenic River and was not included in the assessment. Seventy-five percent of the available hardwood acreage is estimated to be accessible and useable for fuel.

The Powers and Galice Districts of the Siskiyou National Forest have little or no inventory data based on timber cruises. The cruise data that existed were used to formulate assumptions about the cubic foot volume per acre for hardwood stands in the area:

1. Mature stands composed mainly of hardwoods were assumed to have an average volume of 5,000 ft^3/acre.

2. Immature stands with a major component of hardwoods were assumed to have an average volume of 1,500 ft^3/acre.

These assumptions were applied to the acreages of the various cover types as computed from aerial photographs.

Records of stand examinations were provided for the Mapleton District by the Supervisor's Office of the Siuslaw National Forest. These

TABLE 1
HARDWOOD VOLUME AVAILABLE IN VARIOUS OWNERSHIPS IN THE SOUTHERN COASTAL ZONE.

Ownership and location	Volume	Weight
	Ft^3	Tons[a]
Siuslaw National Forest		
Mapleton District	28,468,160	479,020
Siskiyou National Forest		
Chetco District	34,143,145	1,020,530
Galice District	1,564,840	38,074
Gold Beach District	195,650,000	4,915,820
Powers District	6,335,075	145,200
Bureau of Land Management		
Coos Bay District		
Unit 2	298,236	5,184
Unit 3	309,183	6,505
Unit 4	6,206,562	130,582
Unit 5	3,163,930	66,567
Unit 6	6,870,462	144,550
Roseburg District		
Unit 1	556,671	11,712
Medford District		
Unit 7	453,626	9,544
Private industrial		
Coos County	149,783,906	2,782,930
Curry County	109,201,218	2,406,650
Douglas County	128,228,484	2,382,437
Josephine County	4,560,840	104,600
Private nonindustrial		
Coos County	128,336,300	2,203,703
Curry County	116,376,496	2,272,793
Douglas County	45,971,152	789,385
Josephine County	10,918,400	213,245
Elliott State Forest	15,901,781	277,906
Total	993,298,467	20,406,946

[a] Volume data for each ownership converted to weight at 40 percent moisture content. Weight-density conversion factors by species are given in Appendix I.

examinations indicated that the species diversity of hardwoods on this District is less than on the Siskiyou National Forest. Therefore, an average cubic footage per acre was calculated for red alder and bigleaf maple, the two most common hardwoods on the District. This average volume was applied to the District's hardwood acreage within the southern coastal zone.

BUREAU OF LAND MANAGEMENT

Hardwood data for the BLM came from its operations inventory, which classifies the type of stand and the management class for all hardwood acreage. Because harvesting is often prohibited in stands with restricted management, such stands were not evaluated. The inventory specialist from the Coos Bay District supplied data on average volumes per acre for the four size classes of timber. The inventory was reported in acres of timber type, and the average volume was applied for each type. Because the operations inventory was already broken down by township, geographic distribution of the resource was easy to determine. Similar data were obtained for the Medford and Roseburg Districts of the BLM and were used in the same manner.

PRIVATE LANDS

The private sector's hardwood resource was determined from 1977 data provided by the U.S. Forest Service's Pacific Northwest Forest and Range Experiment Station in Portland, Oregon. From these data, the average volume per acre was calculated separately for private industrial and private non-industrial owners within Coos, Curry, and Josephine Counties. Private holdings within the southern coastal zone of Douglas County were assumed to have per-acre volumes similar to those in neighboring Coos County. Because of necessarily limited sampling and high variability in hardwood stands within the southern coastal zone, volumes developed from Forest Service data should be regarded as estimates only. Significantly more or less volume may actually exist.

ELLIOTT STATE FOREST

Hardwood data for Elliott State Forest were derived from estimated acreages in the various hardwood cover types. An average volume per acre was supplied by the Unit Forester in charge of each of the three management units. All data were broken down by township. The hardwood harvest level was obtained from proposed sales for fiscal year 1982. These volumes were assigned to their proper township after being converted to tonnages by the previously described method.

The hardwood resources of each owner type within each township were summed to determine the tonnages present, and it was assumed that all hardwood stands would be available for harvest. This figure was then equally proportioned over a 20-year cutting cycle, which is assumed to be the minimum liquidation period.

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LOGGING RESIDUES

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Approximately 1 million tons (40 percent moisture content) of logging residues greater than 3 inches in diameter and 12 inches long are generated each year in the study area. However, only 700,000 tons are in size classes which can be economically logged (greater than 12 inches in diameter and 8 feet long). If we assume 8,800 Btu per dry pound (see "Fuel and Plant Characteristics"), then the latter tonnage represents slightly more than 54 MWe per year. Thirty-two percent of residues occur on Bureau of Land Management lands, 37 percent on private lands, 26 percent on national forest lands, and 5 percent on the Elliott State Forest (Table 2).

Residue prediction is based on ratios of softwood harvest volumes to residue produced. These ratios have been developed by Howard (1981a) and convert thousand board feet (MBF) of harvested volume to cubic feet of net residue. The conversion ratios are applied according to harvest method and ownership category:

National forest, clearcut--47 ft^3/MBF
Other public, clearcut--52 ft^3/MBF
Private, clearcut--40 ft^3/MBF

The resulting cubic foot volume for each category and harvest method is converted to a tonnage value. Douglas-fir is assumed to be the major species harvested, and the number of cubic feet required to make one ton of residue is based on the density of Douglas-fir at a 40 percent moisture content. Residues of both solid wood and bark are included in the calculations. A factor for converting cubic feet of residues to tons of net residues is computed on the basis of Howard's (1981b) data on the percentage of wood to bark in residues. This conversion factor is then applied to predicted cubic foot volumes in order to determine the amount of net residue in tons for each owner class. Net residues calculated by this method consist of materials greater than 3 inches in diameter inside bark (DIB) and greater than 12 inches long. Percentage distribution by piece size is shown in the chapter on "Costs of Residue Recovery." Actual per-acre volumes, by piece size and owner class, are given in Appendix II. As Avery will show later in this report, the lower size limit for economical yarding is about 12 inches in diameter.

Table 2 presents a summary of logging residue for each of the five owner types in the supply zone as predicted from harvest data. Residue for the private and the private industrial classes is determined from county harvest data in 1976. Although more recent data are available, the data selected represent the smallest harvest in the past 5 years and thus may more closely approximate harvest levels in the near future.

Data for the Siskiyou National Forest are based on softwood sales in fiscal year 1982 from the four ranger districts within the zone. Expected harvest volumes of these sales are used to determine residue availability. Total harvest volume for the forest equals its annual allowable cut (AAC), which is apportioned over all districts on the forest.

The Siuslaw National Forest provided 1980 harvest data for the Mapleton Ranger District, 54 percent of which lies within the supply zone. This percentage was used to estimate the amount of harvest within the zone. The ratio for converting harvest volumes to net residues on national forest clearcuts was applied to the harvest volume. Residue was then allocated over the south half of the district (54 percent of the landbase) on the basis of the average tonnage of net residue per acre.

The Bureau of Land Management (BLM) provided actual harvest volumes for 1980. These softwood data are representative of the AAC over the previous 5 years. The appropriate ratios for clearcuts and partial cuts were used to convert harvest volumes to net residues. Three BLM districts are within the zone and have been divided into seven units. Unit No. 1 is the Roseburg District; Units 2 through 6 belong to the Coos Bay District; Unit 7 is the Medford District. The distribution of residues was determined by multiplying each unit's average tonnage of residue per acre by the BLM acreage in each township within a particular unit. Because data on the Roseburg and Medford units were lacking, these units were assumed to generate the same amount of residue as Unit 6 of the Coos Bay

TABLE 2.

ANNUAL LOGGING RESIDUES GENERATED BY VARIOUS OWNERSHIPS IN THE SUPPLY ZONE.

Owner	Harvest volume		Predicted residue		Weight of residue by size		
	Clear-cut	Partial cut	Clear-cut	Partial cut	>3-in. diam. and >12 in. long	>8-in. diam. and >8 ft long	>12-in. diam. and >8 ft long
	Thousand board ft		Thousand ft^3		- - - Tons - - -		
Bureau of Land Management							
Roseburg District							
Unit 1	28,608	3,585	1,488	333	35,566	26,674	22,196
Coos Bay District							
Unit 2	38,976	187	2,066	17	40,684	30,513	25,390
Unit 3	38,206	527	1,987	49	39,766	29,824	24,817
Unit 4	41,557	3,186	2,161	296	47,988	35,911	29,948
Unit 5	42,000	90	2,184	8	42,812	32,109	26,718
Unit 6	63,648	916	3,310	85	66,309	49,732	41,382
Medford District							
Unit 7	14,498	17,096	754	1,590	45,781	34,336	28,571
Private industry							
Coos County	266,556	0	10,662	0	207,518	161,864	144,270
Curry County	46,862	0	1,874	0	36,424	28,411	25,323
Douglas County[a]		0		0	122,151	95,278	84,922
Josephine County[b]		0		0	1,589	1,239	1,105
Private nonindustrial							
Coos County	19,178	0	767	0	17,895	13,958	12,441
Curry County	22,789	0	912	0	19,371	15,109	13,467
Douglas County[a]		0		0	75,551	58,930	52,524
Josephine County[b]		0		0	1,673	1,305	1,163
Siuslaw National Forest							
Mapleton District (south half)	38,757	109	1,821	15	66,225	49,006	43,046
Siskiyou National Forest							
Chetco District	33,000	0	1,551	0	30,293	22,417	19,690
Galice District	31,000	0	1,457	0	28,457	21,058	18,497
Gold Beach District	48,000	2,600	2,256	354	50,969	35,378	31,075
Powers District	48,400	500	2,275	68	45,758	33,861	29,743
Elliott State Forest							
Ten Mile Unit	12,100	0	629	0	12,289	9,217	7,669
Millicoma Unit	15,600	0	811	0	15,844	11,883	9,888
Umpqua Unit	19,800	0	1,029	0	20,109	15,082	12,550
Total	869,535	28,796	39,994	2,815	1,071,022	813,095	706,395

[a] Forest lands in this ownership were assumed to provide similar amounts and sizes of residue as those in Coos County. Therefore, the average tonnage of net residue per acre was applied to acres in Douglas County within the zone.

[b] Josephine County ownerships were assumed to resemble Curry County ownerships, and the application of residue tonnages was made accordingly.

District, which was nearby. The same approach was applied to private industrial and private nonindustrial owners in these two BLM units. For both of these ownerships, the average residue per acre from the county closest to the landholding was used to predict the amount of residue for each tract.

The Elliott State Forest is divided into three units, and residue predictions are based on the average AAC for each unit. The total residue was apportioned over the land base of each unit and then summarized by township. For scattered parcels of State land, the average residue produced per acre was assumed to be similar to that of the nearest public agency, which was the BLM.

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MUNICIPAL SOLID WASTES

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Estimated annual tonnage of municipal solid wastes (MSW) available to each of the proposed plant sites is as follows (Btu content is approximately one-half that of dry hardwoods):[7]

Contributing county	Gold Beach (tons MSW)		Powers (tons MSW)	
Coos	23,397	(19,887)	23,397	(19,887)
Curry	6,205	(5,274)	--	--
Douglas	--	--	59,004	(50,153)
Total	29,602	(25,161)	82,401	(70,040)

Note: Figures in parentheses are the tonnages of MSW at a higher heating value equivalent to that of wood/bark fuels at a 40 percent moisture content. The converted totals have been subtracted from the yearly fuel requirement for each plant site as listed elsewhere in this report.

At Gold Beach, estimated annual tonnage of MSW available is 4 percent of the total requirement for a 50-MWe plant and 6 percent of the requirement for a 30-MWe plant. At Powers, available MSW is 10 percent of the requirement for a 50-MWe plant and 16 percent of the requirement for a 30-MWe plant.

MSW in Lane and Josephine counties has been excluded from consideration. The points of collection in these two counties are so far from the potential plant sites that transportation would be prohibitively expensive. Similarly, the movement of Curry County's MSW to a generator in Powers would seem uneconomical in light of the haul distances. Curry County's MSW, therefore, was excluded from the fuel supply for the Powers plant but was included for Gold Beach.

Coos County's MSW is disposed of at a site 7 miles north of Bandon, where it is subjected to nodular combustion before burial in a sanitary landfill. Estimated cost to complete this task is $20 per ton. However, this figure varies according to the operating conditions of the disposal system.

The disposal facilities for both Coos and Curry Counties have an unrealized potential for steam generation. Portions of Coos County's MSW are currently either burned at a site near Powers or transported to Florence (Reedsport). The MSW generated by these areas has been included as a fuel supply for both the Gold Beach and Powers sites. In addition, Douglas County can annually supply a considerable amount of MSW to the Powers facility. Currently, Douglas County's MSW is being buried in three landfills near Roseburg. One or more compaction facilities might reduce the cost of transporting such material.

Use of a system for fuel upgrading and waste recycling at the proposed plant could increase the Btu output of the fuel and reduce its ash content. A study of such a system by the University of Oregon indicated that ash content was reduced by 23 to 25 percent. Furthermore, an increase in Btu output might be realized by sorting. Sorting can be done mechanically in several ways, but a system with low energy requirements would be most suitable. Recycling of useable products could be done at the same time, thereby improving the efficiency of such a facility.

Although recycling has not been included in calculating the yearly fuel supply for the proposed plants or the fuel's higher heating values, the following survey of the typical composition of MSW indicates that glass and metal, those components which are partially recyclable, make up about 18 percent of the total:

Component		% by weight	% by volume
Glass	Partially recyclable	8.4	2.0
Metal		9.8	10.3
Paper		47.8	59.1
Plastics and miscellaneous		7.5	17.3
Textiles		2.5	2.1
Wood		1.9	2.0
Food waste		16.9	5.2
Garden waste		1.0	0.9
Remaining inerts		4.2	1.1
		100.0	100.0

Derived from: CH2M Hill, Energy recovery from solid wastes for the Oregon South Coast Region, Corvallis, Oregon (1974).

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[7] Information concerning amount, composition, and heating value of MSW was provided by Tim Davison of the Oregon Department of Environmental Quality and Gary Liss of Gershman, Brickner, and Bratton Inc., Fresno, California.

MILL RESIDUES

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Unused residues from forest products mills represent a potential fuel for wood-burning generating plants. This chapter will discuss both the availability and the characteristics of such residues. Topics to be covered include potential availability and distances from sites at Powers and Gold Beach, potential competing markets, expected monthly and annual variations in availability, and physical and chemical characteristics of the residue.

POTENTIAL ANNUAL SUPPLY

Most forest products mills in the study area are near either the Pacific Ocean or Interstate 5. It was determined that the mills near Interstate 5 would not be identified as potential sources because there are currently many residue users in that area and more are expected within the next several years. Various studies have determined that the long-distance hauls involved would be uneconomical for fuelwood (McMahon 1976, Howard 1979); however, our own economic analysis suggests that transportation costs would not be an important factor (see "Summary and Final Economic Model").

Table 3 summarizes the quantities of wood and bark residue generated in the supply zone. It also identifies how much of the residue is presently being utilized and for what purposes. These quantities are available during a "normal" year; expected variations will be discussed later. Note that in a normal year 1,406,600 dry tons of residue are generated, of which about 79 percent is wood residue. However, only about 5 percent of the total generated is presently unused. Bark comprises almost 93 percent of this unused residue. Paper and board mills are the largest users of wood residue, while energy production accounts for most of the bark.

The geographic distribution of unused mill residues around Powers, Oregon, is shown in Table 4. As can be seen, no unused residue is available within 10 air miles of Powers, but all of the unused residue in the supply zone is within 70 air miles. Almost 55 percent of it is available within a distance of 40 air miles. Both wet and dry weights are given because residues are usually reported on a dry weight basis at the mills but are hauled on a wet weight basis.

Table 5 reports the distribution of unused mill residue around Gold Beach, Oregon. Again, both dry and wet weights are given. Because the data for Powers and Gold Beach are both based on the same supply zone, the totals in Tables 4 and 5 are identical. Note that the largest portion of the unused mill residue is closer to Powers than to Gold Beach, mainly because many of the mills are located in the Coos Bay and Reedsport areas.

TABLE 3

QUANTITY AND DISPOSITION OF MILL RESIDUES IN THE SUPPLY ZONE OF SOUTHERN OREGON IN A NORMAL YEAR.

Residue type	Total generated	Used for paper and board	Used for fuel	Used in other ways	Unused
	- - - - - Tons, dry weight (percent of total mill residues) - - - - -				
Wood	1,106,919 (78.69)	789,454 (56.12)	131,030 (9.32)	181,153 (12.88)	5,282 (0.37)
Bark	299,681 (21.31)	545 (0.04)	211,955 (15.07)	20,992 (1.49)	66,189 (4.71)
Total	1,406,600 (100)	--	--	--	71,471 (5.08)

TABLE 4

DISTANCES FROM POWERS, OREGON, TO SOURCES OF UNUSED MILL RESIDUES WITHIN THE SUPPLY ZONE.

Air miles from Powers	Dry weight basis			Wet weight basis[a]		
	Unused wood residue	Unused bark residue	Total	Unused wood residue	Unused bark residue	Total
	- - - - - - - -		- Tons/year -	- - - - - - - -		
0-10	--	--	--	--	--	--
10-20	--	5,821	5,821	--	9,702	9,702
20-30	458	24,023	24,481	654	40,038	40,692
30-40	936	8,013	8,949	1,337	13,355	14,692
40-50	--	--	--	--	--	--
50-60	3,888	8,875	12,763	5,554	14,792	20,346
60-70	--	19,457	19,457	--	32,428	32,428
Total	5,282	66,189	71,471	7,545	110,315	117,860
Percent of total	7.39	92.61	100.00	7.39	92.61	100.00

[a]Wet weight is based on the assumption that wood is at 30 percent moisture content and bark is at 40 percent moisture content (Corder 1976). Wood is taken at 30 percent rather than the 40 percent used elsewhere because, as mill residue, it is likely to be drier than more recently harvested hog fuels.

TABLE 5

DISTANCES FROM GOLD BEACH, OREGON, TO SOURCES OF UNUSED MILL RESIDUES WITHIN THE SUPPLY ZONE.

Air miles from Powers	Dry weight basis			Wet weight basis[a]		
	Unused wood residue	Unused bark residue	Total	Unused wood residue	Unused bark residue	Total
	- - - - - - - -		- Tons/year -	- - - - - - - -		
0-10	17	11	28	24	18	42
10-20	--	--	--	--	--	--
20-30	138	19,786	19,924	197	32,976	33,173
30-40	--	--	--	--	--	--
40-50	--	--	--	--	--	--
50-60	320	29,515	29,835	457	49,192	49,649
60-70	919	8,002	8,921	1,313	13,337	14,650
70-80	--	--	--	--	--	--
80-90	3,888	4,644	8,532	5,554	7,740	13,294
90-100	--	4,231	4,231	--	7,052	7,052
Total	5,282	66,189	71,471	7,545	110,315	117,860
Percent of total	7.39	92.61	100.00	7.39	92.61	100.00

[a]Wet weight is based on the assumption that wood is at 30 percent moisture content and bark is at 40 percent moisture content (Corder 1976).

SUPPLY VARIATIONS

We have been discussing quantities of residue for a "normal" year. In reality, however, the supply will vary greatly. Recent trends in the industry indicate that the amount of unused residues available from Oregon mills will decrease in coming years (Table 6). As Howard and Hiserote (1978) have pointed out, the forest products industry is itself the largest consumer of mill residue, especially bark, for fuel. In addition, there is expected to be a continued heavy demand for wood chips by the paper and board industries and by the export chip market.

Because most residues in this zone of Oregon are generated by the lumber, veneer, and plywood industries, annual variations in the production of these industries will greatly affect residue availability. Figure 6 shows recent rates of lumber and plywood production from mills in Oregon, which ranks first among states in the production of lumber (20 percent of national total) and plywood (40 percent of national total) (Ruderman 1980). The fluctuations in production result from similar fluctuations in the housing industry, which is closely tied to the wood products industry. This same relationship will also cause monthly supply variations within each year. The housing industry typically peaks in mid-summer and ebbs during January or February.

PHYSICAL AND CHEMICAL CHARACTERISTICS

Over 90 percent of the mill residue generated in the supply zone is Douglas-fir. The remainder is made up of small quantities of hemlock, true firs, spruces, lodgepole pine, ponderosa pine, western red cedar, and a few other minor softwood and hardwood species (Howard and Hiserote 1978). Residues from these species vary greatly in moisture content. For instance, sander dust is very low in moisture, while green material varies according to storage time and conditions. However, because over 90 percent of the potential supply is Douglas-fir and over 92 percent is bark, it seems reasonable to apply Corder's (1976) value of 40 percent moisture content (wet weight basis) to all residues.

Table 7 lists representative values for key chemical and physical characteristics of some of the species expected to be grown or utilized in the supply zone (Corder 1973, Corder 1976, Mingle and Boubel 1968, Pingrey 1976, Smith and Kozak 1971, U.S. Forest Products Laboratory 1974).

SUMMARY

The annual quantity of unused mill residue in the southwest Oregon coastal zone is 71,471 dry tons. Over 90 percent of that material is Douglas-fir, and over 92 percent of it is bark. There is a higher percentage of residue close to Powers than to Gold Beach.

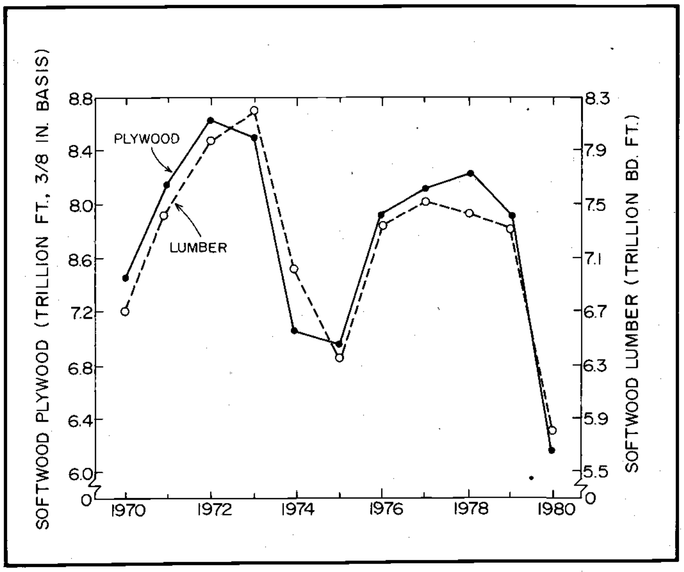

FIGURE 6

ANNUAL PRODUCTION OF SOFTWOOD LUMBER AND PLYWOOD IN OREGON.

TABLE 6

DISPOSITION OF OREGON MILL RESIDUES FROM 1968 TO 1976.[a]

	Wood			Bark		
Use	1968	1972	1976	1968	1972	1976
	- - - - - -	- Percent	- - -	- - -	- -	-
Paper and board	61.6	69.5	73.1	--	1.1	0.6
Fuel	20.0	19.5	15.6	49.8	61.5	75.7
Miscellaneous	5.3	6.1	9.2	7.4	14.9	15.2
Unused	13.1	4.9	2.1	42.8	22.5	8.5

[a]From Howard and Hiserote (1978).

TABLE 7

CHEMICAL AND PHYSICAL CHARACTERISTICS OF WOOD AND BARK OF SPECIES LIKELY TO SERVE AS FUEL IN THE SUPPLY ZONE.

Species and category	Ultimate analysis (Dry weight basis) Carbon	Hydrogen	Oxygen	Sulfur	Nitrogen	Ash	Higher heating value	Specific gravity (Green vol, O.D. wt)
	- - - - - -	- Percent		- - -	- -	-	Btu/lb	
Douglas-fir								
Wood	52.3	6.3	40.5	--	0.1	0.3-0.8	8,800-9,200	0.45
Bark	53.0	6.2	39.3	--	--	1.2-2.2	9,400-10,100	0.436
Western hemlock								
Wood	50.4	5.8	41.4	--	0.1	0.2-2.2	8,000-8,620	0.42
Bark	51.2	5.8	39.2	--	0.1	1.7-3.7	8,900-9,800	0.502
Engelmann spruce								
Wood	51.8	5.7	38.4	0.1	0.2	2.5-3.8	8,740	0.33
Bark	--	--	--	--	--	--	8,424-8,846	0.480
Lodgepole pine								
Wood	--	--	--	--	--	--	8,600	0.38
Bark	--	--	--	--	--	2.0	10,260-10,794	0.456
Western redcedar								
Wood	--	--	--	--	--	2.0	9,700	0.31
Bark	--	--	--	--	--	0.2	8,700	0.376
White fir								
Wood	--	--	--	--	--	0.5	8,000	0.37
Bark	--	--	--	--	--	2.6	--	0.649
Ponderosa pine								
Wood	--	--	--	--	--	0.2	9,100	0.38
Bark	--	--	--	--	--	0.7	9,100	0.346
Sitka spruce								
Wood	--	--	--	--	--	--	8,100	0.37
Bark	--	--	--	--	--	--	--	0.538

continued

TABLE 7 (continued)

Species and category	Ultimate analysis (Dry weight basis) Car- bon	Hydro- gen	Oxy- gen	Sul- fur	Nitro- gen	Ash	Higher heating value	Specific gravity (Green vol, O.D. wt)
	- - - - - - Percent					- - - - - -	Btu/lb	
White oak								
Wood	50.44	6.59	42.73	--	--	0.24	8,110-8,810	0.60
Bark	49.7	5.4	39.3	0.1	0.2	5.3	7,074-8,370	--
Red alder								
Wood	--	--	--	--	--	0.6	8,000	0.37
Bark	--	--	--	--	--	2.4-3.1	8,406	0.562
Black cottonwood								
Wood	--	--	--	--	--	--	8,800	0.31
Bark	--	--	--	--	--	--	9,000	0.423
Quaking aspen								
Wood	--	--	--	--	--	--	--	0.35
Bark	--	--	--	--	--	2.8	8,924	0.478
Bigleaf maple								
Wood	--	--	--	--	--	--	8,400	0.44
Bark	--	--	--	--	--	--	--	0.592

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COSTS OF HARVESTING HARDWOODS

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HARDWOOD CHARACTERISTICS

In order to derive harvesting costs, it is necessary to specify stand structural characteristics, particularly number and size distribution of trees. Representative data on available hardwoods within the zone were obtained from the records of 39 stand examinations conducted by the Chetco Ranger District of the Siskiyou National Forest. These data consisted of numbers of trees per acre within six broad diameter classes and the acreages involved. Volumes per acre for each of the 39 stands were determined from a table of tanoak volumes broken down by diameter class (MacDonald 1978, pp. 101-103). Stands with more than 2,000 ft^3 of volume per acre for all diameter classes were considered to be of good quality. Findings about the stands can be summarized as follows:

> Total acreage for all 39 stands was 2,829 acres.
>
> About 65 percent of this total acreage was composed of stands with volumes greater than 2,000 ft^3 per acre.
>
> Eleven percent of the total volume for all stands was in stands of poor quality (i.e., less than 2,000 ft^3 per acre).
>
> Stocking of trees greater than 3.9 inches d.b.h. averaged 700 per acre in good stands and 310 per acre in poor ones.
>
> Volume per stem for all trees larger than 3.9 inches d.b.h. averaged 5.2 ft^3 in good stands and 3.0 ft^3 in poor ones.
>
> Total volume per acre for all stems larger than 3.9 inches d.b.h. averaged 3,660 ft^3 in good stands and 915 ft^3 in poor ones.
>
> In both poor and good stands, tanoak comprised approximately 75 percent of the total number of stems per acre in each diameter class.
>
> Pacific madrone was the next largest component within the stand, varying from 10 to 25 percent of the total number of stems per acre.

Percentages of total volume in the various diameter classes are shown for the good stands in Figure 7. Table 8 shows the number of stems per acre, volume per stem, and volume per acre for each of the six diameter classes. Note that while about 80 percent of the stems are less than 7 inches in diameter, 80 percent of the volume is in trees 7 inches or greater in diameter.

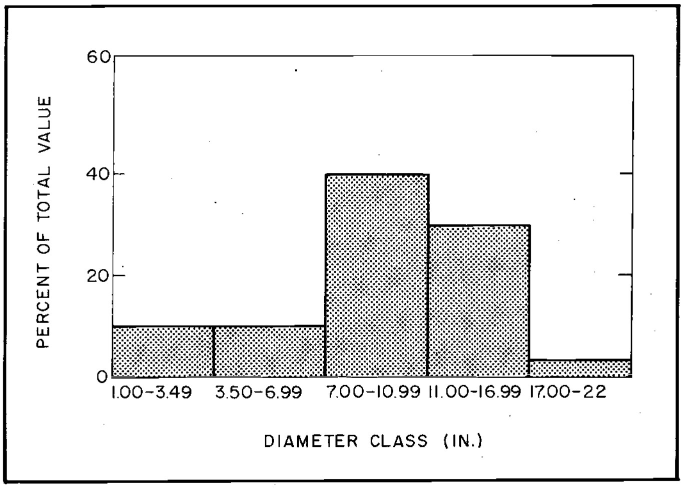

FIGURE 7

WEIGHTED AVERAGE PERCENT OF TOTAL VOLUME PER ACRE IN EACH OF SIX DIAMETER CLASSES FOR TANOAK STANDS WITH MORE THAN 2000 FT^3 PER ACRE. TOTAL VOLUME PER ACRE FOR ALL STEMS IS 4,023.1 FT^3. DATA PROVIDED BY THE CHETCO RANGER DISTRICT, SISKIYOU NATIONAL FOREST.

HARVESTING COSTS

The cost of yarding tanoak and madrone is difficult to determine. Forest Service appraisers on the Siskiyou National Forest do not have a separate appraisal procedure for dealing with hardwood only. The small piece size and differences in handling requirements prevent the use of the cost factors used for determining conifer harvesting costs. Usually, a fixed cost per thousand board feet for yarding unmerchantable material is assumed without considering piece size, yarding distance, or slope. Moreover, the appraisal estimates provided a cost per thousand board feet only; no reference to production per hour or representative types of equipment were given. Therefore, it was decided to use a more empirical approach to determine harvesting costs.

Kramer (1978) has demonstrated that small yarders can be successfully used with hardwoods. For example, his data show that small equipment yarding uphill in 40-year-old mixed stands of alder and maple with an average piece size of 16.48 ft^3 can theoretically yard up to approximately 3,170 ft^3 per 8-hour shift with a 3-man crew.

In an effort to obtain data on costs as well as productivity, loggers currently yarding hardwoods in the area were contacted. Their estimates of gross production per day and costs per unit of production were verified at local mills and elsewhere. Three of these operations plus two hypothetical ones are summarized below (for proprietary reasons, real operations are not identified). Costs are given in 1985 dollars, and an 8 percent yearly inflation rate is assumed.

TABLE 8.

WEIGHTED AVERAGE NUMBER OF STEMS PER ACRE, VOLUME PER STEM, AND VOLUME PER ACRE BY DIAMETER CLASS FOR TANOAK STANDS WITH MORE THAN 2,000 FT^3 OF VOLUME PER ACRE. DATA FROM CHETCO RANGER DISTRICT.

Diameter class (inches)	Stems/ acre	Volume/ stem[a]	Volume/ acre
	No.	Ft^3	Ft^3
1-3.49	722.25	0.50[b]	361.1
3.50-6.99	412.09	1.1	453.3
7.0-10.99	233.99	7.5	1,754.9
11.0-16.99	55.05	23.1	1,271.7
17.0-22.99	3.13	55.0	172.2
23.0-28.99	.096	103.1	9.9
Total, all classes	1,426.6	--	4,023.1
Total, excluding 1- to 3-inch	704.4	--	3,662.0

[a] From MacDonald (1978).

[b] Estimated.

Operation No. 1

Equipment	Small yarder, less than 80 hp 2 saws Loading subcontracted to self-loading trucks
Crew size	4 (1 yarder operator, 1 to 2 choker setters, 1 to 2 fellers)
Operation	Yarding alder, whole-tree. External yarding distance, up to 650 feet. Lateral yarding distance, 40 to 50 feet. Trees bucked at landing for chipping at mill site. Average payload, between 1,500 and 2,000 lb/turn. Average log size, 10 to 15 ft^3. Minimum diameter yarded, 7.5 inches d.b.h.
Production/day	2.5 to 3 loads per day. One load ≅ 22 tons.
Cost/day	$882 (very low costs for equipment, overhead, and labor)
Cost/ton	$13.67 to $16.38/ton excluding hauling and chipping

Operation No. 2

Equipment	Truck-mounted tower, 60 feet high 4 saws 1 small skidder Small chipper leased from chip buyer

Crew size	8 to 10 (5 to 6 yarding, 1 chipping, 2 to 4 felling)
Operation	Yarding in extremely dense tanoak stands. External yarding distance, up to 1,200 feet but averaging 1,000 feet. Trees limbed in woods except those smaller than 10 inches d.b.h. Small trees chipped whole at landing. Trees smaller than 6 inches d.b.h. not yarded, but all trees less than 6 inches d.b.h. felled and left on site. Stems also brought to landing by skidder (1 to 2 loads/day).
Production/day	4 to 6 loads, winter (includes skidder) 6 to 8 loads, summer (includes skidder) One load ≅ 22.0 tons.
Cost/day	$2,646 (chipper leased, very low depreciation and overhead, labor rates assumed to be $12.00 to $14.00/hr including fringe benefits and overhead).
Cost/ton	$17.64 to $23.06/ton including skidder and hauling.

Operation No. 3

Equipment	2 portable chippers FMC (skidder with low ground pressure) 175-hp rubber-tired skidder 2 saws, 1 pickup truck Small helicopter, leased All hauling subcontracted
Crew size	10 excluding pilot (4 choker setters, 2 chipper operators, 2 skidder drivers, 2 fellers)
Operation	Clearcut. Helicopter yarding small alder (whole-tree). Skidder yarding some Douglas-fir. FMC swinging alder to chipper. External yarding distance, 1,800 feet. 2 sets of 2 choker setters, preset chokers. Average piece size, 10 ft^3. Turn weight, 2,500 to 3,000 pounds. Turns/hour, 35 to 40. Hauling approximately 30 miles one way.
Production/day	16 to 20 loads/day (including skidder) One load = 22 tons Production = 376 to 470 tons/8-hr day
Costs/day (yarding, chipping)	$10,520 day Helicopter Chippers, $125/hr Labor, $175/hr including fellers Skidder FMC } $350/day
Cost/ton	$26.84 to $32.38/ton including hauling at $4.41/ton.

Operation No. 4

Equipment	1 small, industry-built swing yarder, less than 350 hp 1 small skidder, 130 hp 2 saws, 1 pickup truck Chipper leased from chip buyer
Crew size	7 (5 yarding, 1 chipping, 1 skidder operator)

Operation	Cable yarding dense stands of tanoak and madrone. External yarding distance, up to 1,000 feet. Skidder also bringing in trees. Presetting chokers (2 sets of 5). Average piece size, 12 ft^3. Average pieces/turn, 4.25. Turn weight (average), 3,060 lb. Stems less than 8.0 inches d.b.h. not yarded. Trees larger than 12 inches d.b.h. limbed in woods except those on very steep slopes, which were limbed at the landing. Decks assembled before chipping to ensure steady supply of material. Skidder used to swing material to chipper when necessary.
Production/day	5.5 to 7.0 loads/day at 22 tons/load Production = 4,400 to 5,600 ft^3/9-hr day (including skidding)
Cost/day	$2,730 ($630, yarder; $500, chipper; $1,400, labor; $200, skidder)
Cost/ton	$17.70 to $22.56/ton excluding felling and hauling.

Operation No. 5

Equipment	Medium-size swing yarder, 450 hp Portable chipper 175-hp skidder 3 saws, 2 pickup trucks
Crew size	7 (5 yarding, 1 chipper operator, 1 skidder operator)
Operation	Working in thick stand of alder. External yarding distance, up to 1,000 feet. Presetting chokers (2 sets of 5). Average piece size, 12.5 ft^3. Average pieces/turn, 4.5. Stems less than 8 inches d.b.h. not yarded. Trees yarded whole except for those greater than 14 inches d.b.h., which were limbed. Trees decked before chipping to ensure steady supply of material. Average turn weight, 3,000 to 3,500 lb. Stems also brought to deck by skidder.
Production/day	5.5 to 7.5 loads/day at 22 tons/load (including skidding) Production = 6,600 to 9,000 ft^3/9-hr day.
Cost/day	$3,120 ($1,400, labor; $950, yarder; $570, chipper; $200, skidder)
Cost/ton	$20.30 to $25.80/ton excluding felling and hauling.

FELLING COSTS

The same loggers also provided data on the cost and rate of felling tanoak and madrone. Rates predicted by regression equations were far short of actual rates achieved by professional fellers in crowded hardwood stands.

The main variables affecting felling of small hardwoods are:

Tree diameter and length.

Density and length of crown, especially if tree must be limbed.

Spacing between trees--affects travel time and hangups in the crowns of neighboring trees.

Slope and roughness of ground--affects cutters' mobility in limbing and topping and percentage of breakage.

Number of non-merchantable trees per acre--large numbers of them decrease productive time per day and increase costs per unit of volume.

Amount of underbrush--affects travel time and mobility.

Tree species--hardwoods require more felling time than conifers, especially in the larger diameters.

The loggers agreed that non-productive felling time can be minimized by not cutting trees less than 3 inches d.b.h. unless necessary. They usually employ a single slanting cut to sever the bole of trees less than 9 inches d.b.h. They further agreed that they seldom limbed hardwood trees less than 8 to 12 inches d.b.h. because these could be fed whole into a portable chipper.

Felling rates were calculated from the loggers' data on loads per day or cost per bone-dry unit. For example, working from one logger's records of 4 loads produced per day by one feller and assuming an average volume per tree of 11 ft^3 and 22 tons per load, we can calculate an average felling rate of about 279 trees/day. Similarly, from another logger's costs of $6.60 per bone-dry unit (2,400 pounds) and $24.60 per hour (1985 dollars) for a cutter and saw, we can calculate an average felling rate of 288 trees/day. A third logger's records of acreage in 8- to 12-inch alder harvested indicate a felling rate of 250 trees/day. The average of these three felling rates is about 272 trees/day.

With this average, we can estimate an average felling time per tree and per acre for each diameter class (Appendix II, Tables II-A and II-B). In turn, these averages can be used to estimate costs per acre and per ton by diameter class (Table 9). Note that the cost per ton increases as smaller diameter classes are harvested.

TABLE 9.

WEIGHTED AVERAGE FELLING COSTS FOR DIFFERENT LEVELS OF HARDWOOD UTILIZATION (1985 DOLLARS). EACH TOTAL IN THE TABLE IS FOR THE INDICATED DIAMETER CLASS PLUS ALL LARGER CLASSES.

D.b.h. class (inches)	Cumulative tons/ acre[a]	Cumulative time/ acre[b]	Cumulative cost/ acre[c]	Cost/ ton[d,e]
		Scheduled min.	$	$
1-3.49	120.69	712.5	291.70	2.42
3.50-6.99	109.88	611.35	250.36	2.28
7.0 -10.99	96.30	530.75	217.35	2.25
11.0-16.99	43.623	203.17	83.16	1.90
17.0-22.99	5.463	18.2	7.43	1.36
23.0-28.99	.2969	.672	.386	1.30

[a] Average cubic feet/tree (from Appendix II, Table II-C) x 60 lb/ft^3 ÷ 2,000.

[b] Productive time/acre (from Appendix II, Table II-B) x 1.67 = scheduled minutes.

[c] Minutes/acre ÷ 60 minutes/hr x $24.57/hr felling cost.

[d] Column 4 ÷ column 2.

[e] Gross tonnage assumes a 40 percent moisture content.

YARDING COSTS

Yarding is generally the most expensive harvesting operation because of the men and equipment required. The chief variables affecting yarding cost are:

Average yarding distance--the average distance the carriage must travel to reach the choker setters; for fan-shaped settings, two-thirds the longest distance; for rectangular settings, half the total length.

Volume per turn.

Number of pieces per turn.

Number of choker setters.

Lateral yarding distance--distance on either side of the skyline that a mainline or skidding line is pulled by the choker setters to reach the logs.

Slope and roughness of terrain--influences the amount of cable tension that can be used to lift logs and bring them to the landing.

Brushiness of ground--limits mobility.

Time per road change--time required to reposition the yarder for the next corridor.

An optimal balance between all these factors is necessary to achieve the highest productivity. Decisions must be made about corridor length and width, minimum piece size, number of pieces per turn, and many other factors, while nonproductive time must be kept to a minimum. Regression equations may be used in the analysis, but their use requires thousands of iterations for the various combinations of the above variables and is best left to a high-speed computer. An example based on typical conditions for yarding hardwoods in the southern coastal zone may serve to demonstrate the calculations required. Let us begin with the following assumptions, which are partially based on the time estimates of Gabrielli (1980), Dykstra (1975, 1976), Folkema (1977), and Gardner (1980):

1. Fan-shaped setting. Long corner distance = 1,000 ft. Lateral distance = 60 ft each side. Therefore, number of acres =

$$\frac{1{,}000 \text{ ft} \times 60 \text{ ft} \times 2}{43{,}560 \text{ ft}^2/\text{acre}} = 2.755 \text{ acres.}$$

2. Crew size--2 choker setters, 1 chaser, 1 yarder operator, 1 rigging slinger.
3. Equipment characteristics--average outhaul speed = 666 ft/minute.
   --lateral inhaul speed = 110 ft/minute.
   --inhaul speed = 550 ft/minute.
   --able to yard heaviest stem in setting.
4. Assume choker setters can pull line out at the rate of 100 ft/minute.
5. The actual number of turns required per acre will depend on the stand diameter distributions and the lower limit of utilization. For the representative tanoak stand of Table 8, the relation between lower diameter limit of utilization and number of turns per acre is

Lower utilization limit (D.b.h. class) (inches)	Stems/acre (cumulative)	Turns/acre (cumulative)
1.0 up	1,426.61	222.04
3.5 up	704.36	131.76
7.0 up	292.27	68.38
11.0 up	58.28	21.58
17.0 up	3.23	3.23
23.0 up	.096	.096

6. Road change time between corridors averages 30 minutes.
7. Chokers are preset--that is, while one turn is on its way to the landing, the second turn is being readied.
8. The average time for attaching a choker to a stem is 0.50 minute. This operation is assumed to be completed while the carriage is in transit to and from the deck.
9. The time required to attach the chokers to the mainline or skidding line is 0.30 minute for each stem.
10. Unhooking time is 0.10 minute per stem.

With these assumptions, we can proceed to calculate yarding cost per ton. The calculations can be done in nine steps, as follows:

Step 1.--Calculate number of stems per corridor for each diameter class. The number of stems per corridor is equal to the number of stems per acre multiplied by the number of acres in the corridor; in this case, 2.755:

D.b.h. (inches)	Stems/acre[a]	Stems/corridor[a]
1-3.49	722.25	1,989.80
3.50-6.99	412.09	1,135.31
7.0-10.99	233.99	644.64
11.0-16.99	55.05	151.66
17.0-22.99	3.13	8.62
23.0-28.99	.096	.264

[a] From Table 8.

Step 2.--Calculate the number of turns per corridor as the diameter limits are lowered. This is done by summing the cumulative number of stems per corridor and dividing by the average number of stems/turn:

D.b.h. (inches)	Stems/corridor for indicated diameter classes	Stems/corridor for indicated and all higher classes	Average stems/turn	Turns/corridor[a]
1-3.49	1,989.80	3,930.29	6.4	614.11
3.50-6.99	1,135.31	1,940.49	5.3	366.13
7.0-10.99	644.64	805.18	4.3	187.25
11.0-16.99	151.66	160.54	2.7	59.46
17.0-22.99	8.62	8.88	1.0	8.88
23.0-28.99	.264	.264	1.0	.264

[a] Column 3 ÷ column 4.

Step 3.--Calculate average turn time. As mentioned in the assumptions, attachment of the chokers to the mainline takes 0.3 minute per piece, and unhooking at the deck takes 0.1 minute per piece. Outhaul, lateral, and inhaul times are assumed to be the same regardless of diameter class:

D.b.h. class (inches)	Average pieces/turn for indicated and all higher classes	Outhaul[a]	Lateral[b]	Process[c]	Inhaul[d]	Total for indicated and all higher classes[e]
		minutes	minutes	minutes	minutes	minutes
1-3.49	6.4	1.0	0.76	2.56	1.21	5.53
3.50-6.99	5.3	1.0	.76	2.12	1.21	5.09
7.0-10.99	4.3	1.0	.76	1.72	1.21	4.69
11.0-16.99	2.7	1.0	.76	1.08	1.21	4.05
17.0-22.99	1.0	1.0	.76	.40	1.21	3.37
23.0-28.99	1.0	1.0	.76	.40	1.21	3.37

---

[a] Outhaul time $= \frac{1,000 \text{ ft} \times 2/3}{667 \text{ ft/min}} = 1.0$ minute

[b] Outhaul lateral $= \frac{60 \text{ ft} \times 2/3}{100 \text{ ft/min}} = 0.40$ minute

Inhaul lateral $= \frac{60 \text{ ft} \times 2/3}{110 \text{ ft/min}} = 0.36$ minute

0.76 minute total.

[c] Process time = 0.4 minute per piece x number of pieces per turn

[d] Inhaul time $= \frac{1,000 \text{ ft} \times 2/3}{550 \text{ ft/min}} = 1.21$ minutes

[e] Total time = sum of outhaul, lateral, process, and inhaul times. Productive minutes only are shown here.

Step 4.--Calculate time per corridor. Time per corridor is the product of total turn time and number of turns per corridor when each is calculated for the indicated diameter class and higher classes:

D.b.h. (inches)	Cumulative turns/corridor	Productive time/turn	Productive time/corridor	Productive time/corridor
		minutes	minutes	hours
1-3.49 up	614.11	5.53	3,396.03	56.60
3.50-6.99 up	366.13	5.09	1,863.60	31.06
7.0-10.99 up	187.25	4.69	878.20	14.64
11.0-16.99 up	59.46	4.05	240.81	4.01
17.0-22.99 up	8.88	3.37	29.93	.50
23.0-28.99 up	.264	3.37	.89	.015

Step 5.--Calculate volume per corridor. Volume per corridor is the product of stems per corridor and volume per stem when each is calculated for the indicated diameter class and all higher classes:

D.b.h. (inches)	Stems/corridor	Average volume/stem	Cumulative volume/corridor	Cumulative volume/corridor[a]
		ft^3	ft^3	tons
1-3.49 up	3,930.29	2.82	11,083.4	332.50
3.50-6.99 up	1,940.49	5.20	10,090.5	302.72
7.0-10.99 up	805.18	10.98	8,840.9	265.23
11.0-16.99 up	160.54	24.95	4,005.5	120.16
17.0-22.99 up	8.88	56.38	500.7	15.0
23.0-28.99 up	.264	103.10	27.2	.82

---

[a] Assumes 60 lb/ft^3 (tanoak and madrone) with 50 percent moisture content.

Step 6.--Calculate a production rate in corridors per day. Initial assumptions are as follows:

8-hr day x 60 minutes/hr = 480 minutes/day.
Time for breaks, delays, and mechanical failures is 80 minutes/day.
Road changes take 30 minutes and are begun immediately after a corridor is completely yarded (zero minutes is assumed for setting up the initial corridor).

Then the total time required to yard one corridor and change roads one time, together with the number of corridors yarded per day, is as follows:

D.b.h. class (inches)	Time/corridor	Time needed for road changes	Total time	Corridors/day[a]
	minutes	minutes	minutes	
1-3.49 up	3,396.03	30	3,426.03	0.1168
3.50-6.99 up	1,863.60	30	1,893.60	.2112
7.0-10.99 up	878.20	30	908.20	.4404
11.0-16.99 up	240.81	30	270.81	1.4771
17.0-22.99 up	29.93	30	59.93	6.6745
23.0-28.99 up	.89	30	30.89	12.9492

---

[a] Calculated by dividing total time by the number of minutes in one day (400).

Step 7.--Calculate a production rate in tons/day. Tons/day = corridors/day x tons/corridor. Therefore:

D.b.h. class (inches)	Corridors/day	Tons/corridor	Tons/day	Loads/day[a]
1-3.49 up	0.1168	332.50	38.836	1.765
3.50-6.99 up	.2112	302.72	63.934	2.906
7.0-10.99 up	.4404	265.23	116.807	5.309
11.0-16.99 up	1.4771	120.16	177.488	8.068
17.0-22.99 up	6.6745	15.0	100.117	4.551
23.0-28.99 up	12.9492	.82	10.618	.483

---

[a] 1 truckload ≅ 22.0 tons.

Thus, these calculations indicate that the lower diameter limit should be about 12 inches if daily production is to be maximized. Such a limit, however, is not definitive, for the following reasons:

Only gross volumes have been given. Larger trees are more likely to have rot than are small ones.

The numbers apply to this example only and have not been verified over a range of examples.

Landowners would probably want trees removed at least to the 7- to 10-inch level to reduce fuel loadings.

Contrary to the assumptions of this analysis, yarding may be delayed while the choker setters attempt to find suitable material to yard.

Most of the loggers contacted in the coastal zone were yarding material 8 inches and up, and one was yarding material 6 inches and up.

In addition to loads brought in daily by the yarder, almost all the operators contacted also used a small skidder to bring logs to the landing. The number of truckloads per day varied between one and two. For material 7.0 inches and larger, about 75 stems are required to make one load.

Step 8.--Determine the cost per day. To determine daily costs, let us assume the following:

Total cost of operating a yarder including operator, fuel, oil, repair and maintenance, supplies and expenses, license, insurance, taxes, and depreciation is $126/hr (this and following costs in 1985 dollars). This number is higher than the rates quoted by some loggers, but their assumptions on depreciation and overhead were very low.

Labor rates for 5 people (2 choker setters, 1 chaser, 1 rigging slinger, 1 skidder operator) at $20.80/hr including fringe benefits and overhead = $830.00/day.

Skidder costs equal $22/hr without operator.

Other costs related to moving the equipment and miscellaneous expenses equal $190/day.

Therefore, total costs per 8-hr day = $2,200/day. While this cost may seem low, one operator who is currently harvesting hardwood in the area gave a rate of $2,270/day *including* a chipper and felling costs. Presumably, his labor rates were between $12.60 and $15.12 per hr including overhead.

Step 9.--Determine the cost/ton. Cost/ton is calculated by dividing costs/day into tons/day:

D.b.h. class (inches)	Cost/day[a] without skidding	Tons/day without skidding	Cost/ton without skidding	Cost/ton[b] with skidding
	$		$	$
1-3.49 up	2,030	38.836	52.24	29.46
3.50-6.99 up	2,030	63.934	31.73	22.06
7.0-10.99 up	2,030	116.807	17.36	14.43
11.0-16.99 up	2,030	177.488	11.43	10.33
17.0-22.99 up	2,030	100.117	20.26	16.20
23.0-28.99 up	2,030	10.618	191.05	47.30

---

[a] $2,200 - $170 for skidder.

[b] Assumes skidder is bringing in 1.5 truckloads of material 7 inches and up at 24 tons/load and that cost/day is $2,200.

In this example, whole-tree yarding has been assumed for all stems less than 11.0 inches d.b.h. in order to retain as much volume as possible on the smaller trees. In practice, yarding will cause some breakage of the smaller trees and limbs, which will be scattered over the corridor. Furthermore, if the stems smaller than 7.0 inches are not yarded, then approximately 25 tons per acre will be left behind.

While the skidder is assumed to be adding 1.5 truckloads per day to the total tonnage, the actual figure will vary from 0 to 2 loads. Ground skidding will not be feasible in all areas.

The costs shown assume a very low overhead and do not include a replacement depreciation for the equipment used. They should be expected to vary upward by as much as 100 percent if more expensive equipment is used.

CHIPPING COSTS

Calculation of the costs of chipping hardwood trees on the landing is based on the following assumptions:

There is adequate room on or near the landing to position the chipper and allow chip vans to maneuver.

Part of the material to be chipped is decked ahead of the chipper, and part is brought to it by a skidder.

The chipper used is a Morbark Model 22 Chiparvestor with a debris chute for removing leaves, twigs, dirt, and some bark.

The chipper is mechanically available for 6 hours during an 8-hour day, with 2 hours needed for repair, maintenance, and changing knives.

Hourly costs for a Model 22 Chiparvestor, as based on data from three operators, range between \$50 and \$65.

Calculated cost per hour is

$$\text{Depreciation} = \frac{\$328{,}000 - 15\text{ percent salvage}}{8\text{ yr} \times 180\text{ days/yr} \times 8\text{ hr/day}} = \$24.20/\text{hr}$$

Fuel--8.0 gallons/hour x \$1.00/gallon	10.00/hr
Oil, lubrication, and filters (estimated)	1.60/hr
Repair and maintenance--100 percent of depreciation	24.20/hr
Operator wage (includes overhead)	20.80/hr
Total	\$56.60/hr

Daily cost is rounded off at \$500. If equipment is leased, assume a daily cost of \$400.

Hourly production for a Morbark Chiparvestor is reported in the literature to range from 26.5 tons (Chisholm and Van Raalte 1980) to 32 tons per scheduled hour (Resource Management, Inc., and Sverdrup/Sverdrup Technology, Inc. 1981).

Hourly production for this chipper is reported by local loggers as 18.5 and 23.5 tons per scheduled hour for material 6 inches and up and 23.5 and 30.11 tons per hour for material 8 inches and up.

Because the chipper is assumed to be partially waiting on the yarder and skidder for wood, its daily production rate is fixed at that of those two machines when working with material 7 inches and larger:

Yarding	115 to 120 tons/day
Skidding	0 to 36 tons/day
	115 to 156 tons/day

Thus, because the chipper costs $500/day to operate, chipping cost is

$500/day ÷ 115 tons/day = $4.35/ton
$500/day ÷ 156 tons/day = $3.21/ton

If material 3.5 inches and larger is chipped, production would be

Yarding = 64 to 84 tons/day
Skidding = 0 to 36 tons/day
64 to 120 tons/day

And chipping cost would be

$500/day ÷ 64 tons/day = $7.81/ton
$500/day ÷ 120 tons/day = $4.17/ton

Average cost ≅ $6.00/ton

If the chipper were leased from a mill at an assumed cost of $400 per day, then the cost per ton for chipping material 7 inches and larger would be

$400/day ÷ 115 tons/day = $3.48/ton
$400/day ÷ 156 tons/day = $2.56/ton

Because it is impossible to predict whether loggers will use leased machines, chipping costs per ton with and without leasing will be averaged. Daily costs are calculated as follows:

$$\frac{\$400/\text{day} + \$500/\text{day}}{2} = \$450/\text{day}$$

For material 7 inches d.b.h. and larger, the cost/ton is:

$450 ÷ 115 tons/day = $3.91/ton
$450 ÷ 156 tons/day = $2.88/ton

Average cost ≅ $3.40/ton

TOTAL COST PER TON

Total cost per green ton (1985 dollars) is derived by adding the cost per ton for felling, yarding, and chipping. On a daily basis, total yarding and skidding cost is $2,200, felling costs are $400 for two fellers with saws, and average chipping cost is $450. Thus, the total cost per day for all operations is $3,050. The costs per green ton for each level of diameter utilization is shown in the following tabulation, which summarizes the earlier sections of this chapter and allows for a range of yarding distances and road change times:

D.b.h. class (inches)	Felling cost/ton	Yarding cost/ton		Chipping cost[a]	Total cost/ton	
		Without skidding	With skidding		Without skidding[b]	With skidding[c]
	- - - - - - - -	- - - -	- - - -	1985 dollars	- - - -	- - - -
1-3.49 up	2.40	48.40	28.20	12.00	62.80	42.60
3.50-6.99 up	2.30	29.10	20.80	6.00	37.40	29.10
7.0-10.99 up	3.00[d]	15.90	13.50	3.40	22.30	19.90
11.0-16.99 up	1.90	10.70	9.70	2.75	15.35	14.35
17.0-22.99 up	1.40	23.90	17.90	2.50	27.80	21.80
23.0-28.99 up	1.25	274.90	50.40	--	276.15	51.65

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[a] Only the second and third members in this column were shown earlier in this chapter; the rest are derived values. Note that stems in the 23-inch and up class are too large to be chipped in the woods.

[b] Total of columns 2, 3, and 5.

[c] Total of columns 2, 4, and 5.

[d] Assumes material smaller than 7.0 inches d.b.h. is felled only and not yarded.

The $42.60 at the top of column 7 is the estimated cost per ton for felling, yarding, skidding, and chipping all material 1.0 inch and greater. It assumes the skidder is also bringing in 36 tons per day of material 7.0 inches d.b.h. and larger. The $62.80 at the top of column 6 is the cost per ton without skidding. As stated earlier, the lowest cost occurs at 11 inches d.b.h. and larger, but if the interest is in reducing fuel loading per acre, then the next lower diameter class should be the lower limit. Recall that these costs are in 1985 dollars and assume an 8 percent inflation rate.

Although this analysis was based on the representative size distribution in tanoak stands, it would apply to the removal of other hardwood species in the southern coastal zone as well. Regardless of tree species, there are undoubtedly large variations in stocking density and size distributions of stands. Thus, although these cost figures are reasonably accurate for "average" stand conditions, substantial deviations can occur. Costs would also be lowered slightly if commercial conifers are harvested as well as hardwoods on the same setting. The true average cost for all operations excluding hauling and additional cost is expected to lie within ± 20 percent of the costs shown.

It should be noted that while the costs shown include an allowance for overhead, they do not include a full allowance for road maintenance, slash disposal, construction of fire lines, profit and risk, or the hauling of the material to the generating plant. Arriving at a final cost per ton will require a negotiated agreement between buyer and seller. If material 8.0 inches and larger were to be utilized, then the expected cost per ton would be approximately 5 to 10 percent less than the costs indicated for the material 7.0 inches and larger.

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COSTS OF RESIDUE RECOVERY

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BACKGROUND

Information on the costs of recovering residues in the supply zone came from published reports, from maps and background material supplied by public agencies that manage timber within the zone, and from loggers and woods managers familiar with logging residues and the costs involved. Because of time constraints, no field studies were conducted. Only cable logging was considered because most of the ground in the zone is sloped more than 35 percent. Only removal from clearcuts was considered.

RESIDUE CHARACTERISTICS

Howard (1981b) has determined the volume and size distribution of residue on western Oregon clearcuts, an essential first step in determining yarding costs. The percentage of total residue volume found within various diameter and length classes is shown in Table 10 and, on a cumulative basis, in Figure 8. Note that 92 percent of the gross volume consists of pieces 8 feet long or more and 7 inches or greater in diameter. Cubic foot

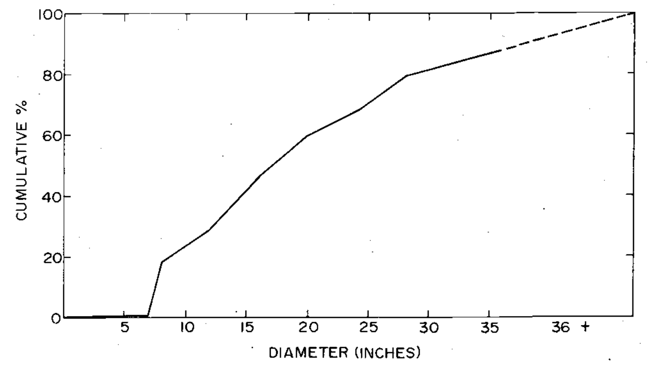

FIGURE 8

CUMULATIVE PERCENTAGE OF TOTAL AVERAGE GROSS VOLUME OF RESIDUES PER ACRE BY DIAMETER CLASS. DATA ARE FOR PUBLIC AND PRIVATE CLEARCUTS IN WESTERN OREGON ONLY.

TABLE 10

PERCENT OF TOTAL GROSS VOLUME OF RESIDUE PER ACRE[a] WITHIN VARIOUS DIAMETER AND LENGTH CLASSES (HOWARD 1981).

Diameter	Length (feet)						
(inches)	1.0-3.9	4.0-5.9	6.0-7.9	8.0-15.9	16.0-31.9	32+	Total
	- - - - Percent of total residue volume - - - -						
3.1-3.9	0.02	0.08	0.13	--	--	--	0.23
4.0-4.9	.10	.16	.16	--	--	--	.42
5.0-5.9	.00	.06	.08	--	--	--	.14
6.0-6.9	.09	.23	.24	--	--	--	.56
7.0-7.9	.00	.04	.04	3.78	7.19	5.62	16.67
8.0-11.9	.19	.53	.69	3.35	4.21	2.18	11.15
12.0-15.9	.29	.62	.74	3.71	5.09	7.31	17.76
16.0-19.9	--	--	1.07	2.91	4.39	4.39	12.76
20.0-23.9	--	--	.55	2.00	4.55	2.11	9.21
24.0-27.9	--	--	.25	2.09	4.48	3.75	10.57
28.0-35.9	--	--	.40	1.55	3.50	3.56	9.01
36.0+	--	--	.44	.48	7.45	3.12	11.49
Total	.69	1.72	4.79	19.87	40.86	32.04	99.97

[a] Based on average total residue volume of 3,111 ft^3/acre (average of clearcut data on national forests and other public and private ownerships in western Oregon). Does not include residue in large piles.

volume by diameter and length class is shown in Appendix II, Table II-D. An average of 65 percent of the total volume is on slopes greater than 35 percent and would thus have to be skyline yarded. (Because of generally steep terrain, this proportion is likely to be higher in the study area.) Of that amount, 92 percent is within 1,000 feet of a road and is thus accessible to logging and hauling equipment (Appendix II, Table II-E).

Public lands have the highest gross volume of residue per acre, probably because they contain the largest amount of old-growth timber, but this volume will undoubtedly drop as these lands are cut over and restocked.

Industrial lands have lower volumes of residue because they have a preponderance of second-growth stands (Appendix II, Table II-E). Of the total residue volumes, the proportion that is 8 feet long or more, less than 1,000 feet from a road, and on slopes exceeding 35 percent is 49 percent on national forests, 70 percent on other public lands, and 46 percent on private lands (Appendix II, Tables II-E through II-H). In terms of total number of residue pieces per acre, a relatively large percentage is found in the lower diameter classes on all these ownerships (Appendix II, Tables II-I through II-K).

YARDER PRODUCTIVITY

As we have seen, the general pattern for residues is that of large numbers of small pieces scattered among a small number of large pieces. Loggers generally leave small pieces because they do not provide much volume. For example, about 170 pieces 3 to 8 inches in diameter and less than 8 feet long are required to make 100 ft^3 of gross volume, whereas only 1 to 6 pieces 16 to 20 inches in diameter and more than 8 feet long are required for the same volume (Appendix II, Tables II-L through II-N). Thus, with big pieces much more volume can be yarded in a single turn (the amount brought to the landing at one time).

For small, light pieces, the number of chokers is the limiting factor in production, whereas for larger, heavier material, weight of pieces is also important in determining volume yarded per turn. Thus, if there are six chokers and each can carry one piece, then one turn of wood in the 16- to 20-inch diameter class brings out between 20 and 100 ft^3. But with wood in smaller diameter classes, one turn may bring out only 3 ft^3. (For smaller average piece size, more chokers may be flown, up to the weight limits of the particular yarder in use.)

In one of the few published assessments of yarder productivity during residue harvesting, Adams (1980) calculated that highlead logging (in which the cable is suspended from a tower to lift the logs) resulted in 7.14 ovendry tons of residue being yarded per machine hour on the Wind River Experimental Forest near Carson, Washington, from 1975 through 1977. When only the material larger than 9 inches was considered, the production rate was 8.9 ovendry tons per machine hour. Weight of residues over 3 inches in diameter was 64 ovendry tons per acre, of which 51 tons were over 9 inches in diameter. Yarding costs were estimated at $11.99 per ovendry ton for pieces 3 inches and larger in diameter and $10.69 per ovendry ton for pieces 9 inches and larger (1976 dollars). Although highlead systems are not well-suited to yarding residues, these figures do provide a rough index of productivities and costs over a sustained period.

What machine characteristics are necessary for yarding residues? First, because overall productivity depends on piece size and volume per acre, the machine must be capable of handling the largest piece likely to be encountered. Note, however, that the frequency with which large pieces are encountered helps determine the class of equipment used, and Howard's (1981) assessment of residues in this area points to a low frequency of large pieces. Second, the yarder must be capable of being quickly set up and taken down and of being transported over logging roads. Third, it must be capable of being rigged in a variety of cable configurations in order to take advantage of existing topography. Fourth, if residues are to be yarded directly to an existing road with no intermediate landing, then a swing-type yarder that can position the pieces beside the machine will be mandatory. (To date, swing-type yarding has not been widely used for residues.)

Operating procedures will also be especially important in yarding residues. A necessary first step will be to pinpoint bottlenecks in production. In harvesting logging residues, the bottleneck will probably be the yarder. The solution is to minimize delays and downtime of the yarder while maximizing production. The first measure usually taken is to set up corridors ahead of the yarding crew. Another measure will be to adopt techniques that partially compensate for the pieces being small and widely scattered. Two such techniques are the presetting of chokers and the prebunching of pieces. In presetting, two sets of chokers are used; while one turn of pieces is on its way to the landing, the next turn is being readied. Prebunching is accomplished by a small winch that bunches the pieces close to the skyline corridor, thereby both reducing time and increasing payload per turn.

In selecting the proper yarder for harvesting residues, the logger must bear these machine characteristics and operating procedures in mind. Small machines of less than 80 horsepower such as the Koller, the Igland Jones Trailer Alp, and the Pee Wee Yarder are easily transportable and can be operated for less than $1,300 a day, but they cannot handle large pieces. Consequently, even though daily operating costs with small yarders would be low, the cost per unit of product would be high. For high productivity, larger yarders such as the Madill 071, West Coast Tower, Skagit SJ Series, GT-3 or GT-4, or Washington 78 SL or 118 would be more effective. Some of those machines have already been used for yarding residues in the area, and data on costs and productivity will be available in the near future.

CHIPPING RESIDUES

Residues could be chipped at the landing with a portable machine such as the Morbark Model 22 Chiparvestor, which can handle material up to 18 inches in diameter. Such chipping requires a steady supply of fairly uniform material, a large area in which the chipper can work, ample room in which the chip vans can turn, and synchronized scheduling of the chip vans. With residues, however, the piece size distributions indicate a relatively low number of long, uniform pieces available, and the space at most landings would be limited. Furthermore, chip vans would be difficult to maneuver around the sharply curved roads sometimes found on forest lands. Thus, residue chipping may not be economically feasible at the landing.

A more cost-effective plan might be to establish a centralized location to which trucks could bring the yarded residues and in which the chipper and chip vans could move. Pieces too large for the Morbark Chipper could be split or chipped at the plant site. Such an arrangement would ensure that the chipper is not underutilized by being forced to work on material of irregular lengths without ample room to maneuver--an important consideration with machines that were recently estimated to cost $80/hour to operate (Chisholm 1979).

COSTS AND ESTIMATED PRODUCTIVITIES

The rise in cost of logging equipment and supplies has outpaced the general rate of inflation. Thus, because the value of delivered logs has not risen proportionally, profit margins are tighter. These relationships will inevitably affect the harvesting of residues in the southern coastal zone. For example, operating costs on suitable machinery such as a used Skagit SY 717 yarder, a used log loader, a used Caterpillar D6, plus a crew of 7 would amount to about $2,700 per 9-hour day, and adding the costs of operating a chipper, a trailer, and trucks would boost the daily total to over $3,300. A few loggers who have yarded residues in the area quoted their daily costs as being between $1,500 and $2,000, but their production rates were low. The small yarders mentioned earlier could easily be operated at even lower costs, but they are unsuitable for yarding residues.

Despite the lack of studies on residue yarding in the southern coastal zone, we can estimate daily production with various types of equipment by making a series of assumptions. First, let us assume that the following productivities will result from the enumerated costs of yarding and loading (all costs are in 1985 dollars at an assumed inflation rate of 8 percent):

Cost/day $	Average production/day pieces
1,900*	120-150*
2,200	140-170
2,500*	160-200*
2,800	190-240
3,100	225-275
3,500	275-325
3,800*	300-325*
4,100	300-350
4,400*	325-350*

*Estimated value. Other values were quoted by loggers in the area and would vary according to site. One day equals 9 hours.

Let us further assume that:

Average volumes/acre and piece sizes are as developed earlier.

Weight of green wood is 40 lb/ft^3 at a 40 percent moisture content.

Average *net* volume of residue pieces is 60 percent of gross volume, with much of the loss incurred as breakage, decay, and otherwise unsuitable material (limbs, tops, etc.). [Howard (1981) reported an average net volume of 55 percent. The higher rate used here allows for inclusion of bark and some variation in weight per cubic foot.]

Average volume of residue pieces varies from 25.0 to 40 ft^3 per piece (gross). This range was calculated separately as being economically optimal for yarding.

On the basis of these assumptions, estimated daily production and operating costs for logging residue are as in Table 11. Note that yarding and loading costs per green ton range between $24.00 and $43.50 (1985 dollars). The average would be about $34.00, which is probably high unless piece size were small. A better estimate would be $25 to $32.

Other factors must also be considered in computing the cost of a ton of residue. An estimated additional 25 percent is needed to cover costs of slash disposal, fire line construction, road maintenance, moving in and out, additional personnel, equipment and rigging; this increase would bring the total to $31.50 to $39.40. Chipping the residues would cost between $4 and $6 per green ton, bringing the total to $35.50 to $45.40. At least 5 percent should be added to reflect the current uncertainty about prices for wood and wood products; this increase would bring the costs to $37.27 to $57.20. Such costs do not include hauling to the plant nor profit and risk. In terms of bone-dry tons, average costs should range between $49 and $63. These figures might drop slightly (less than 15 percent) if the operator were able to collect a significant portion of the residues with a skidder instead of a yarder. This course will not be feasible on a large scale, however.

The above estimates assume that the logging operation is recovering only residues. There may, however, be an economic advantage in yarding residues along with sound merchantable wood. Doing so would allow the higher cost per ton of yarding the residues to be averaged with the lower cost of harvesting a greater volume of merchantable material. Efficiency could be increased by yarding several pieces of residue concurrently with each run of merchantable material. The additional time required to attach the residue to the current load of logs destined for the landing would be very small, and the fixed costs of the operation would be amortized over a greater volume of material. Such an operation presupposes adequate room at the landing to sort and merchandise the residues. Additional delay could be expected in handling the residues. And, of course, the operation would require a larger, more expensive yarder with higher operating costs than would the recovery of residues alone.

Brown (1981) recently studied the economics of harvesting resiudes with merchantable material near Blue River, Oregon. His study showed that the cost of yarding residues was higher than that of merchantable material. Of the total tonnage of wood recovered, 72.6 percent was merchantable and accounted for 68.3 percent of the total yarding costs. Slightly over 25 percent of the total tonnage recovered was large residues suitable for hog fuel and pulp chips, and the rest was suitable for firewood. Delivered prices for

TABLE 11

ESTIMATED COSTS PER TON (1985 DOLLARS) AND GROSS TONNAGE PER DAY FOR LOGGING RESIDUE BY AVERAGE PIECE SIZE. WEIGHTS ARE AT 40 PERCENT MOISTURE CONTENT. (SEE ALSO FIGURE 3.)

Yarding and loading cost per day ($)	Average piece size in ft^3						
	25.0	27.5	30.0	32.5	35.0	37.5	40.0
	- - - Cost per ton in $ (gross tonnage per day) - - -						
1,900	46.67 (40.50)	42.45 (44.55)	38.88 (48.60)	35.90 (52.65)	33.34 (56.70)	31.11 (60.75)	29.17 (64.80)
2,200	47.41 (46.50)	43.10 (51.15)	39.51 (55.80)	36.48 (60.45)	33.87 (65.10)	31.61 (69.75)	29.64 (74.40)
2,500	46.67 (54.00)	42.42 (59.40)	38.88 (64.80)	35.90 (70.20)	33.34 (75.60)	31.11 (81.00)	29.17 (86.40)
2,800	43.95 (64.50)	39.96 (70.95)	36.63 (77.40)	33.81 (83.85)	31.40 (90.30)	29.31 (96.78)	27.47 (103.20)
3,100	42.00 (75.00)	38.18 (82.50)	35.00 (90.00)	32.31 (97.50)	30.00 (105.00)	28.00 (112.50)	26.25 (120.00)
3,500	38.51 (90.00)	35.00 (99.00)	32.08 (108.00)	29.61 (117.00)	27.51 (126.00)	25.67 (135.00)	24.07 (144.00)
3,800	40.32 (93.75)	36.65 (103.13)	33.60 (112.50)	31.02 (121.88)	28.80 (131.25)	26.88 (140.62)	25.20 (150.00)
4,100	42.00 (97.50)	38.18 (107.25)	35.00 (117.00)	32.31 (126.75)	30.00 (136.50)	28.00 (146.25)	26.25 (156.00)
4,400	43.46 (101.25)	39.50 (111.38)	36.21 (121.50)	33.43 (131.63)	31.04 (141.75)	28.97 (151.88)	27.16 (162.00)

Net tonnage equals 60 percent of gross volume.

this material ranged between $23 and $32 per ton (1985 dollars, based on an inflation rate of 8 percent).

A readily available source of residues is the piles of unmerchantable material that must be removed from the forest floor. These are usually piled near the landing and either sold for firewood or burned. Yarding costs for this material will have already been paid; thus, its utilization would incur only a loading and a hauling cost. Because this material is of random sizes, however, a log truck could not hold as much of it as of merchantable material. Estimated costs for loading and hauling this material would be between $10.50 and $13.00 per green ton, excluding profit and risk.

The energy-effectiveness of acquiring logging residue is usually shown as a ratio of fuel retrieved to fuel expended. It is more revealing, however, to add in the cost of retrieving the residue and convert the total to a fuel value in Btu's. If we compare the Btu content of 1 ton of green residues with that of the Btu's that could be purchased by investing the same amount in diesel fuel, the energy ratio of wood to fuel is 2.4:1. Thus, we can obtain 2.4 times more Btu's by logging residues than by reinvesting in diesel fuel. Therefore, at a 1985 cost of $1.25 per gallon for fuel, we can spend up to $123.50 per green ton in harvesting and delivering to the power plant without a negative energy expenditure.

RECOMMENDATIONS

Field studies on the costs of cable-yarding residues are critically needed if predictions are to be based on more than assumptions and extrapolation from dissimilar data.

Current work on designing equipment for steep slopes is several years from completion and should be accelerated as much as possible.

Field studies on the prebunching of residues before yarding are needed and would not be time-consuming or expensive.

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FUEL AND PLANT CHARACTERISTICS

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FUEL CHARACTERISTICS

As a starting point, it was necessary to determine the characteristics of the alternative fuels, coal and wood. No ultimate analysis of tanoak was recorded in the literature. A report by Leonard (1979) provided an ultimate analysis of black oak, as follows:

Constituent	Sample 1 (dry)	Sample 2 (dry)	Sample 3 (dry)	Sample 4 (wet)
	- - - - -	percent	- - - - -	
Carbon	48.78	48.85	46.90	23.45
Oxygen	44.98	45.05	43.25	21.62
Hydrogen	6.09	6.10	5.86	2.93
Nitrogen	0	0	0	0
Sulfur	0	0	0	0
Ash	0.15	0	4.00	2.00
Water	0	0	0	50.00
	100.00	100.00	100.00	100.00

With the exception of nitrogen concentration, the ultimate analysis of sample 4, above, was used in this report. It is doubtful that the above nitrogen analysis is correct. Rodin and Bazilivich's (1967) compilation of nutrient contents in several hardwood species shows nitrogen concentration in wood ranging from 0.14 to 0.36 percent. Nitrogen content in red alder wood, which comprises 53 percent of the total volume in the study area, averages 1.3 percent on an ovendry basis (Kermit Cromack, unpublished data). The analysis of tanoak leaves and twigs in "Impact of Biomass Harvest on Soil and Nutrient Loss" indicates that the nitrogen content of tanoak is very close to that of Douglas-fir, which has roughly 0.1 percent nitrogen (ovendry basis) in wood. There could be small amounts of sulfur in some of the wood burned in the study area. Rodin and Bazilivich (1967) show sulfur in wood of several hardwood species varying from traces to 0.04 percent. However, Mingle and Boubel (1968) found no sulfur in either birch or maple. For purposes of calculating emissions, we assume that nitrogen averages 0.12 percent (dry weight basis) and that there is no sulfur in hardwoods in the study area.

Our analysis of tanoak indicated that it has an average moisture content of 47.6 percent. However, because our samples were taken in winter whereas most logging will be in summer when wood moisture is lower, we used 40.0 percent throughout this analysis (with some exceptions, which are noted). Moisture content of red alder and other hardwood species in the area should be similar. Energy content of the two major hardwood species in the study area is similar and lower than the average for wood. Red alder is reported in the literature as having 8,000 Btu's per dry pound (Willey 1942). No published values exist for the Btu content of tanoak. Mike Hoag of the Department of Forest Products, Oregon State University, in tests performed for this study, found that tanoak trees from a variety of sites in the study area contained from 8,041 to 8,242 Btu per dry pound. We have assumed an average Btu content of 8,100 per dry pound for all hardwoods in the study area. Residues, being largely conifers, will likely have higher Btu values, ranging from 8,800 to 9,200 per dry pound of wood and from 9,600 to 10,000 per dry pound of bark.

The characteristics of the coal were taken from several sources. Telephone contact with Mr. Mike Whitty, a Coos Bay attorney who is working with Can-Asia (a corporation interested in exporting coal from Coos Bay), provided some information on the characteristics of two coal deposits in the area. The information provided is shown below:

Characteristics	Eden Ridge Sample 1	Eden Ridge Sample 2
Higher heating value (Btu/wet lb)	8,350	6,900
Moisture content (percent)	4.6	2.7
Ash content (percent)	32.6	40.5
Volatile content (percent)	35.7	31.3
Fixed carbon (percent)	31.7	28.2
Sulfur (percent)	1.9	1.4
Density (lb/ft^3)	87.0	99.0

	Beaver Hill	
Characteristics	Sample 1	Sample 2
Higher heating value (Btu/wet lb)	9,690	10,080
Moisture content (percent)	16.4	10.1
Ash content (percent)	8.5	16.0
Volatile content (percent)	35.1	36.1
Fixed carbon (percent)	40.0	37.8
Sulfur (percent)	0.4	N.A.
Density (lb/ft^3)	N.A.	N.A.

The coal from the larger of the two deposits (Beaver Hill) is similar to two coals identified at Nos. 15 and 16 in *Steam, Its Generation and Use* (Babcock and Wilcox Co. 1975). Values for these two coals were averaged to obtain the following ultimate analysis of the Beaver Hill coal:

Constituent	Volatile components	As burned
	- - percent	- -
Carbon	75.00	55.875
Oxygen	18.0	13.410
Hydrogen	5.30	3.949
Nitrogen	1.30	0.949
Sulfur	0.40	0.298
Ash	0	12.250
Water	0	13.250
	100.00	100.000

The Beaver Hill deposit was selected as the representative coal for the proposed plant because

> The deposit is substantially larger than that at Eden Ridge and would provide a more stable, long-term coal supply.
>
> It has a lower sulfur content than the deposit at Eden Ridge and would require less cleanup of stack gases to meet state and federal standards on sulfur dioxide emissions.
>
> Because its ash content is much lower than that at Eden Ridge, less difficulties would be encountered in burning the coal, removing the ash from the boiler, and disposing of the ash in a land fill.

THERMAL EFFICIENCY

The above-listed characteristics of wood and coal fuels were used in combustion calculations for determining the thermal efficiency of boilers in the proposed steam plant. Operating variables in the steam plant were assumed to be as follows:

Variable	Value
Maximum steam pressure	880 P.s.i., abs
Steam temperature	750 F
Feedwater temperature	352 F
Turbine bleed pressure for process heat steam	150 P.s.i., abs
Turbine exhaust pressure	3 inches Hg
Excess air: Wood/bark	50 percent
Coal	40 percent
Combustion air temperature	450 F
Boiler exhaust gas temperature	400 F
Higher heating value of dry fuels: Wood/bark	8,800 Btu/lb
Coal	11,438 Btu/lb
Percent of fuel carbon converted to CO_2	99.7 percent
Percent of fuel carbon converted to CO	0.2 percent
Percent of fuel carbon unburned	0.1 percent
Boiler drum blowdown rate	3 percent
Radiation and convection losses from boiler	4 percent
Allowable particulate emission rate	0.1 lb/million Btu

Calculations were carried out with a software package designed for boiler evaluations. Two preliminary runs were made to determine the boiler's thermal efficiency under the assumptions listed above. The results indicated that thermal efficiency was 74.2 percent with wood and bark fuels and 90.5 percent with coal.

These calculated values are higher than those typically encountered with wood and bark fuels. However, it was assumed that a power plant constructed and operated by a utility company would be equipped with well-designed and operated boiler components, auxiliaries, and controls and that the staff operating the boiler would be well trained. Given these assumptions, the calculated efficiency levels are achievable.

The software package for calculating combustion efficiency is available through the Energy Research and Development Institute of Oregon State University. It was developed for use with a Hewlett-Packard 41-CV hand-held calculator equipped with card reader and printer.

STEAM GENERATION RATE CALCULATIONS

Steam generation rates required for the two plant capacities proposed were calculated on the basis of the operating variables listed above. A software package entitled COGEN was used for the calculations. (COGEN is described in Appendix III.) The following data were input to COGEN:

Variable		Value
1	Feed water enthalpy	323.9 Btu/lb
2	Maximum steam enthalpy	1,369.2 Btu/lb
3	Bleed steam enthalpy (high pressure steam)	1,194.1 Btu/lb
4	Turbine exhaust steam enthalpy	935.0 Btu/lb
5	Boiler thermal efficiency with wood/bark	74.2 percent
6	Higher heating value of dry wood/bark fuel	8,100.0 Btu/lb
7	Non-combustible ash content of dry wood/bark	4.0 percent
8	Density of wood/bark fuel "as received"	22.0 lb/ft^3
9	Moisture content of wood/bark fuel "as burned"	40.0 percent
10	Boiler thermal efficiency with coal	90.5 percent
11	Higher heating value of dry coal	11,438.0 Btu/lb
12	Non-combustible ash content of dry coal	12.25 percent
13	Density of coal "as received"	45.0 lb/ft^3
14	Moisture content of wet coal "as burned"	13.25 percent
15	Process heat steam load at plant site	60,000.0 lb/hr
16	Maximum electric power generation capability	30.0 MWe 50.0 MWe
17	Percent of energy which is supplied by wood/bark	100.0 percent 0.0 percent

Note that the first 14 variables in the above list are fixed. Variables 15, 16, and 17 are input as follows:

Run no.	Process heat load lb/hr	Generating capacity MWe	Fuel type	Maximum steam rate lb/hr
1	60,000	30	Wood/bark	335,637
2	60,000	30	Coal	335,637
3	60,000	50	Wood/bark	535,526
4	60,000	50	Coal	535,526

As expected, the calculated rates of maximum steam generation are independent of the fuel.

FUEL USE RATE

From the input data, COGEN calculated data on rates of fuel use and ash produced:

Run no.	Generating capacity MWe	Wood use rates lb/hr	tons/yr	units/mo	trucks/day
1	30	97,291	426,000	15,920	53
2	30	0	0	0	0
3	50	155,232	680,000	25,402	85
4	50	0	0	0	0
		Coal use rates			
1	30	0	0	0	0
2	30	39,070	171,185	3,126	21
3	50	0	0	0	0
4	50	52,338	273,020	4,987	34
			Ash tons/day		
1	30		26		
2	30		50		
3	50		45		
4	50		79		

ENVIRONMENTAL IMPACTS

AIR POLLUTION

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EMISSION RATES

The computer program used for evaluating boilers by combustion analysis (Appendix III) also calculates the emission rates for particulate, carbon monoxide, sulfur dioxide, and fuel-based oxides of nitrogen. The calculations are based on the following assumptions:

1. The particulate emission rate is input in terms of allowable pounds of particulate per million Btu of heat input from the fuel. It was assumed that the allowable emission rate for particulate would be 0.10 lb/million Btu. Department of Environmental Quality rule 340-21-020 gives the allowable emission rates for particulate in units of allowable grains per standard calculated in dry cubic feet of exhaust gas corrected to 12 percent CO_2 (approximately 50 percent excess air). The emission rate of 0.10 lb/million Btu corresponds to 0.05 grains/SDCF at 12 percent CO_2. It is assumed that actual emission rate equals the maximum allowable particulate emission rate.

2. It was assumed that 0.20 percent of all the carbon in the fuel forms CO. For each of the four combinations of plant capacity and fuel, this percentage results in CO concentrations in the dry exhaust gases of 300 parts per million (0.03 percent). This is a typical value expected for well-controlled combustion in a boiler of the size anticipated.

3. It was assumed that woody materials comprise 95 percent of total fuels in the biomass plant and that they contain 0.12 percent nitrogen on a dry weight basis and no sulfur (see "Fuel and Plant Characteristics"). It was further assumed that all of the nitrogen in the fuel is converted to NO_2.

4. It was assumed that municipal solid wastes constitute 5 percent of total fuels and that their combustion releases 150 tons/year NO_2, 24 tons/year SO_2, and 60 tons/year CO for the 50-MWe plant (60 percent of these values for the 30-MWe plant).

5. It was assumed that there is no atmospheric nitrogen fixation contributing to the emissions of oxides of nitrogen. In fact, small amounts of nitrous oxides will be fixed atmospherically.

Given these assumptions, the calculated emission rates for the four combinations of plant capacity and fuel are as follows:

Run. No.	Fuel	Plant capacity	Particulate emission rate	
		MWe	lb/hr	tons/yr
1	Wood	30	47.3	207
2	Wood	50	75.4	330
3	Coal	30	38.8	170
4	Coal	50	61.8	271

			Gaseous emission rate		
			CO	SO_2	Fuel based NO_2
			tons/yr	tons/yr	tons/yr
1	Wood	30	540	14	1,030
2	Wood	50	900	24	1,723
3	Coal	30	446	1,020	2,668
4	Coal	50	712	1,627	4,257

By definition, any plant with the potential of emitting any criteria pollutant at a rate exceeding 250 tons per year is classified as a "major stationary source." Note that both plants with a 50-MWe capacity exceed the yearly limit for both particulate and gaseous pollutants but that plants with a 30-MWe capacity exceed the limit only for gaseous pollutants.

EMISSION CONTROLS

Particulate emissions are regulated by the Environmental Protection Agency's regulations on Prevention of Significant Deterioration of Air Quality and by its New Source Review Process. Those regulations stipulate that dispersion of particulate pollutants be modeled mathematically. Adequate controls must be applied at the plant so that specified ground-level concentrations of particulate pollutants will not be exceeded. The regulations are complex, and extensive meteorological modelling and measurements may be required in the area prior to construction.

There are several proven techniques for limiting the emission of particulate to the atmosphere. The four devices currently used with large boilers burning wood or coal are electrostatic precipitators, baghouses, electro-dry scrubbers, and wet scrubbers. The first three are most common, and of these, electrostatic precipitators (ESP) are probably the most effective for plants burning both wood and coal. Although proven effective, ESP's are considered to be costly. For example, complete installation of an ESP costs approximately $32 per actual cubic foot of exhaust treated per minute. In the case of a 50-MWe plant burning wood, the exhaust gas flow rate is 363,116 ft^3 per minute; thus, installation of an ESP for such a plant would cost $11,620,000 (1985 dollars).

Because of the inherent fire hazard, as of June 1981, only seven baghouses had been installed nationwide on wood-fired boilers. Nevertheless, these devices are effective in limiting pollutant emissions to very low levels, although they do require regular maintenance and costly bag replacement.

Use of electro-dry scrubbers on wood-fired boilers is fairly new, and it is not known if they are presently used on coal-fired boilers. They are effective in controlling particulate emissions but have high maintenance costs.

Other devices for controlling pollution by controlling either combustion or emissions are in use by utility companies. Many of these devices are quite expensive and contribute significantly to the overall cost of the plant. Information on these devices can be found in publications of the Electric Power Research Institute.

ENVIRONMENTAL IMPACTS

The environmental impacts of gaseous pollutants from the proposed generating plant are difficult to assess. Emissions of CO are unlikely to be regulated by either the State of Oregon or the EPA unless the mathematical modelling indicates that the plume from the plant will have an impact on the air shed of Eugene and Springfield, which constitute a "non-attainment area" for CO. There is no demonstrated emission control for CO from wood-fired boilers. Rather, combustion control is the most effective means of limiting the formation of this gaseous pollutant.

The U.S. Environmental Protection Agency regulates allowable emissions of SO_2. If the proposed plant is designed to burn coal, the flue gas may have to be desulfurized or the coal refined so that $S0_2$ emissions are minimized. With the present worldwide concern over acid rain, it is unlikely that the plant will be permitted to operate only on coal without some device to curtail SO_2 emission.

Emissions of oxides of nitrogen are less of a problem with wood combustion than they are with coal combustion. There is enough nitrogen in coal to result in $N0_x$ emissions of major magnitude, regardless of plant capacity. Furthermore, with coal combustion, some oxides of nitrogen will probably form from fixation of atmospheric nitrogen whenever furnace temperatures exceed 2,800°F. Such fixation is particularly likely if combustion air is preheated to 450°F to improve the overall thermal efficiency of the boiler system. Oxides of nitrogen have never been considered a problem in the Oregon coastal zone, and the EPA through its regulations on Prevention of Significant Deterioration of Air Quality would undoubtedly act to ensure that they did not become a problem through construction of the proposed generation plant.

IMPACT OF BIOMASS HARVEST ON SOIL AND NUTRIENT LOSS

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Large-scale utilization of biomass for energy is a relatively recent notion and a still uncommon practice. Consequently, little information exists about its impact on future site productivity. This question has elicited much speculation--several symposia in the past few years have dealt with the topic--but few hard facts. One major impact is removal of nutrients, including carbon. However, although the magnitude of nutrient loss associated with various degrees of utilization can be calculated with reasonable accuracy, there is a lack of quantitative data on the relation between nutrient loss and subsequent tree growth.

Adding to the problem of long-term evaluation is the fact that, accompanying the direct effects of biomass removal (nutrient loss) are sometimes subtle, indirect effects which may also influence site productivity (either positively or negatively). These include loss of carbon, which is a critical structural component of soils and an energy source for microorganisms, and shifts in the composition of the soil microbial community, which is essential to the growth of higher plants.

In this report we will discuss:

(a) the nutrient contents in forests of the study area; how many nutrients would be removed by various levels of utilization; how quickly they would be replaced by natural processes (e.g., rainfall); and possible impacts of nutrient removal on subsequent tree growth,

(b) the geology of the study area and the susceptibility of various substrate types to erosion following timber harvest or residue removal,

(c) effects of biomass utilization on soil biology and, in turn, on tree growth.

Because they are expensive to harvest, residues are unlikely to comprise a significant proportion of the fuel for a biomass-fueled generating plant in the area (see "Summary and Final Economic Model"). Therefore, we focus primarily on hardwood utilization, particularly whole-tree harvest.

It is appropriate to define clearly the context within which we evaluate, in this report, the significance of nutrient losses from forested sites. As an analogy, if the driver of a car uses 10 gallons of gasoline a week but only adds 5 gallons back, he will eventually run out of gas. If his car has a large gas tank, this will take longer than if it has a small tank, but he *will* run out. Similarly, if we remove more nutrients from a site than are replaced, either naturally or by fertilization, site productivity will eventually decrease. Fertile sites with large nutrient storage capacity will take longer to "run out" than less fertile sites, but there is no disputing that they eventually will. Thus, our analysis focuses on how many nutrients are removed, and whether or not they are replaced in a reasonable period. Within this context, knowing how many nutrients are present on site at any one time is irrelevant except to the extent that it helps us predict the magnitude of nutrient removal in biomass. In other words, we are interested in preventing the car from running out of gas, not predicting when it will.

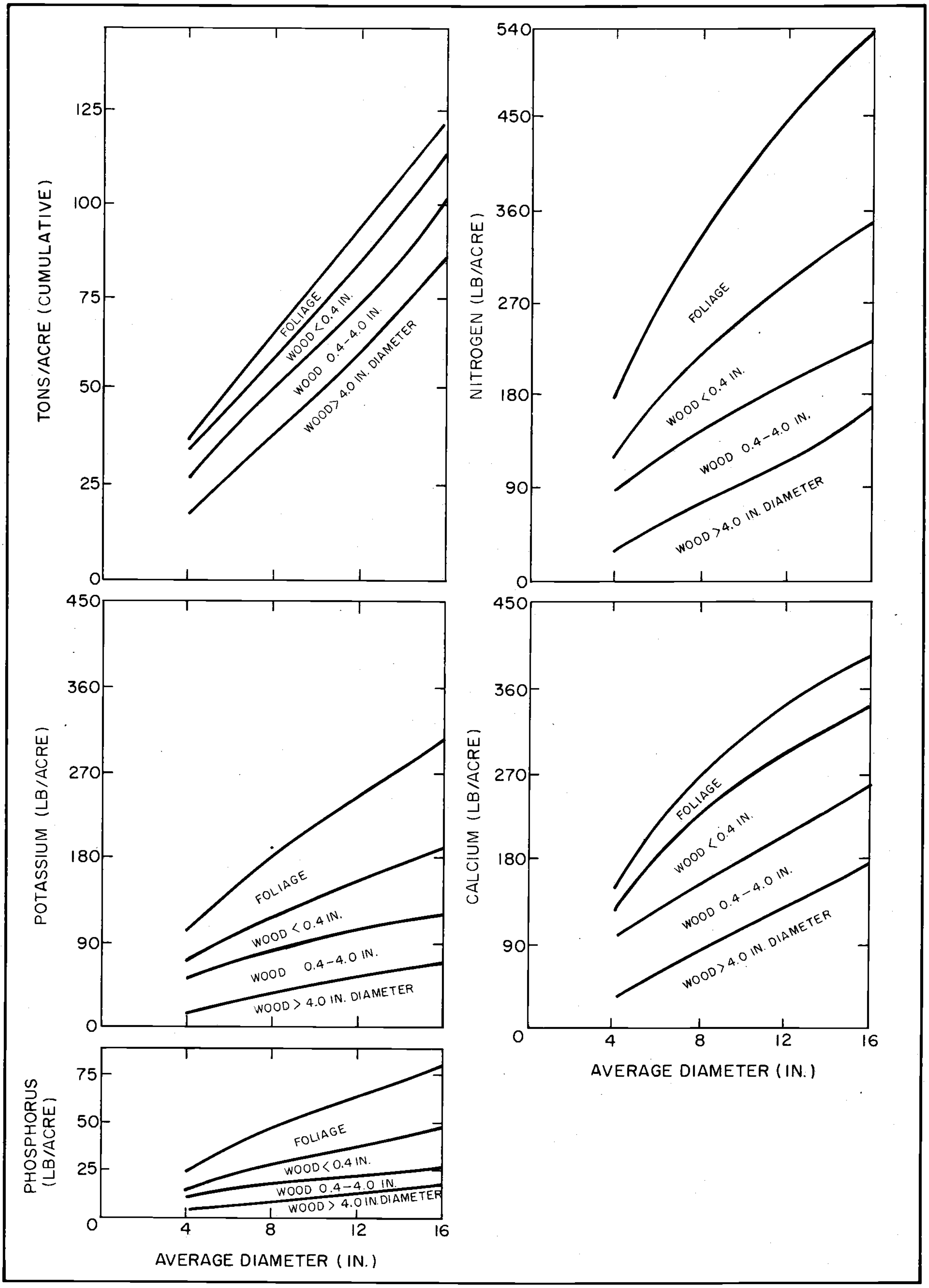
NUTRIENT REMOVAL IN BIOMASS

Nutrient concentration is about 10 times higher in foliage, and 3 times higher in branches, than in stemwood. It is also considerably greater in bark than in wood. Thus, whole-tree harvesting in which foliage and small branches are removed has a disproportionate effect on the nutrient status of a site.

Figure 9 shows the biomass and nutrients contained in foliage and three size classes of coniferous wood (see Appendix IV for details of the calculation). These values are estimates and will vary with species, site, and stocking density (number of trees per acre). Note that cumulative values are given.

FIGURE 9

CUMULATIVE WEIGHT AND NUTRIENT CONTENT PER ACRE OF VARIOUS TREE COMPONENTS, AS A FUNCTION OF AVERAGE STAND DIAMETER: CONIFEROUS STAND.


TONS/ACRE (CUMULATIVE)
125
100
75
50
25
0
FOLIAGE
WOOD < 0.4 IN.
WOOD 0.4–4.0 IN.
WOOD > 4.0 IN. DIAMETER
NITROGEN (LB/ACRE)
540
450
360
270
180
90
0
FOLIAGE
WOOD < 0.4 IN.
WOOD 0.4–4.0 IN.
WOOD > 4.0 IN. DIAMETER
POTASSIUM (LB/ACRE)
450
360
270
180
90
0
FOLIAGE
WOOD < 0.4 IN.
WOOD 0.4–4.0 IN.
WOOD > 4.0 IN. DIAMETER
CALCIUM (LB/ACRE)
450
360
270
180
90
0
FOLIAGE
WOOD < 0.4 IN.
WOOD 0.4–4.0 IN.
WOOD > 4.0 IN. DIAMETER
4
8
12
16
AVERAGE DIAMETER (IN.)
PHOSPHORUS (LB/ACRE)
75
50
25
0
FOLIAGE
WOOD < 0.4 IN.
WOOD 0.4–4.0 IN.
WOOD > 4.0 IN. DIAMETER
4
8
12
16
AVERAGE DIAMETER (IN.)

For a coniferous forest with an 8-inch average diameter, utilization of wood greater than 4 inches in diameter removes about 50 percent of the total site biomass but only 25 percent of the nutrients in the living biomass. Whole-tree harvest could potentially double biomass yields but could quadruple nutrient removals. (In practice, losses of this magnitude would probably not occur, because some foliage and small branches would be broken off and left on site during harvesting.)

How would whole-tree harvest affect nutrients in tanoak stands? We found N concentration of tanoak to be 0.8 percent in leaves and 0.3 percent in small twigs on an ovendry basis--values similar to those of coniferous species. On the assumption that concentrations of other nutrients were also close to those of coniferous species, we calculated the nutrients contained in individual tanoaks of various diameters (Fig. 10). Because stocking density of hardwoods varies over wide ranges, assessing nutrient contents on

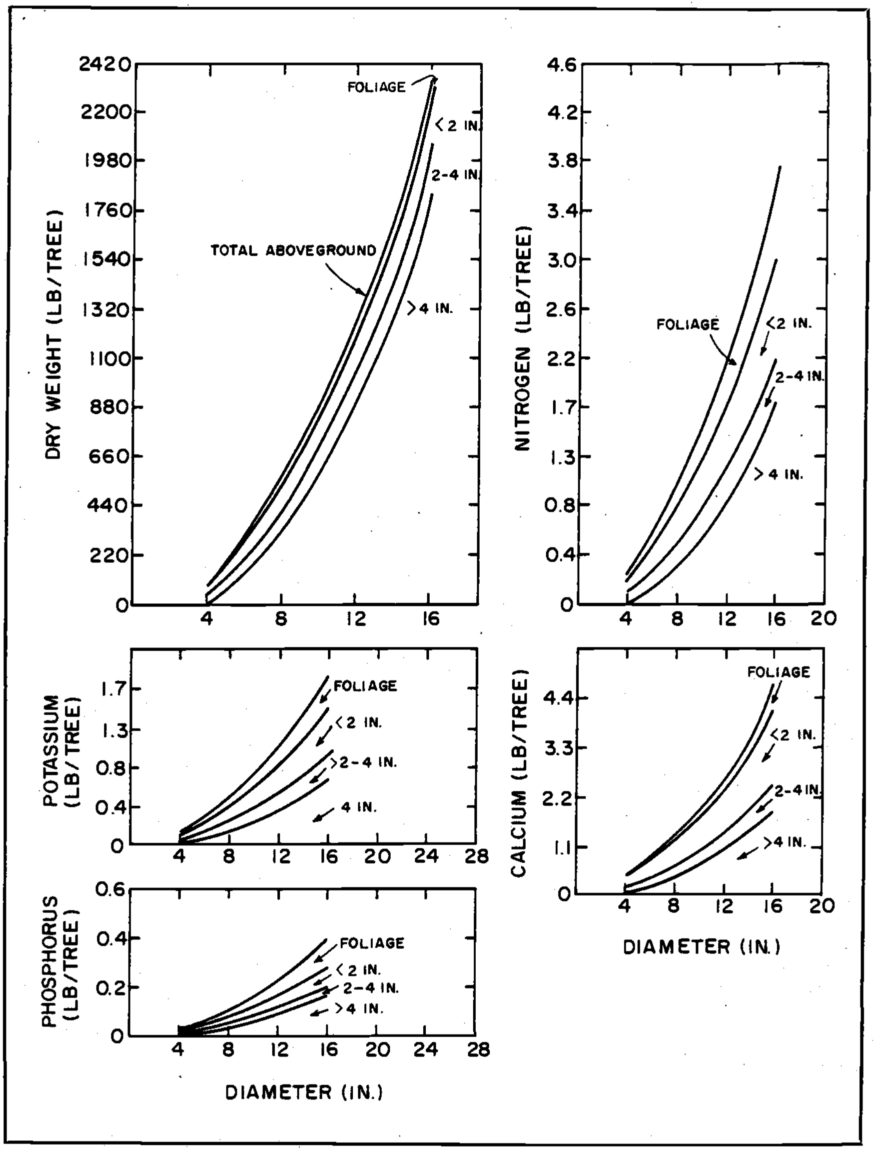


FIGURE 10

CUMULATIVE WEIGHT AND NUTRIENT CONTENT OF VARIOUS TREE COMPONENTS, AS A FUNCTION OF AVERAGE DIAMETER: TANOAK TREES.

an area basis can be misleading. However, we can couple the nutrient concentrations shown in Fig. 10 with stand examinations from the Chetco District of the Siskiyou National Forest (Fig. 7) to estimate nutrient removal associated with biomass harvesting of the "average" tanoak stand. Table 12 gives approximate nitrogen contents in the "average" stand, by diameter class and tree component. Nitrogen is the nutrient most likely to limit growth on these sites. Harvest at the level recommended by Avery (this report)--all stems greater than 7 inches in diameter, with whole-tree logging of trees in the 7.0- to 10.9-inch class--would remove 384 lb per acre, or 60 percent of nitrogen in living biomass. If the 7.0- to 10.9-inch class were not logged on a whole-tree basis, nitrogen removal would drop to 174 lb/acre. Although nutrient concentrations in red alder and maple are 1-1/2 to 2 times greater than in tanoak, nitrogen removals from stands of these species is of little concern because the two species often occur together and red alder is an effective nitrogen fixer. Later, we will discuss possible effects of nitrogen removal on future site productivity.

TABLE 12.

DISTRIBUTION OF NITROGEN IN A REPRESENTATIVE TANOAK STAND.

Diameter	Nitrogen (lb/acre)				
class	Foli-	Wood			Total
(inch)	age	<2 in	2-4 in	>4 in	
<3.4	7	7	7	0	21
3.5-6.9	28	49	49	16	144
7.0-10.9	80	84	47	94	304
11.0-16.9	24	48	19	74	165
17.0-23.9	3	4	2	6	15
					649

EROSION AND MASS SOIL MOVEMENTS

After forests are harvested, there are basically two ways in which soil may be lost: surface erosion and mass erosion of the soil mantle (landslide). Either may result in both nutrient loss and stream sedimentation. Removal of vegetative cover and soil litter layers often results in accelerated surface erosion. Soil removed in this way comes from nutrient-rich upper layers, and continuous surface erosion for a number of years can affect site productivity. Management practices that minimize disturbance of soil organic layers and allow rapid revegetation should prevent excessive soil loss. Woody residues act as "dams" that help prevent surface erosion. Thus, logs too small to yard economically (less than 9 inches in diameter--see Fig. 3), if left on site, can conserve soil.

Landslides are a major factor in sedimentation of western Oregon streams. They may result from both clearcutting and road building. However, because road building in order to harvest hardwood is unlikely, we will deal only with potential impacts of clearcutting.

Slope failures related to clearcuts[8]

Clearcutting can undoubtedly change the timing of landslides, but there is disagreement about longterm effects. Published data on erosion indicate that from 2 to 25 times more soil may be lost from clearcuts than from undisturbed forests. Whether longer records would show that similar amounts of loss would eventually occur on undisturbed areas is not known. Erosion rates are a function of local climate and geology; thus, published data may not be applicable to other than the area for which they were obtained. On the other hand, results are reasonably consistent over about 10 studies from southeast Alaska to western Oregon.

In the particular case of logging residue after clearcutting, the impact has already occurred, and yarding the residues should have essentially no influence on slope stability. Clearcutting hardwood stands, however, could adversely affect such stability.

Mitigation of landslides

Slope failures associated with roads or clearcut logging probably cannot be eliminated. Their incidence and severity can be

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[8] Dr. Marvin Pyles, Department of Forest Engineering, Oregon State University, and Dr. Fred Swanson, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, contributed substantially to this and the following section. We take sole responsibility for conclusions and recommendations, however.

lessened, however, by proper planning, location, design, and maintenance and good logging practices. Proper planning and design will include consideration of bedrock geology, precipitation patterns, soil mantle properties, and the role of rooting strength in stabilizing soils.

Geologic factors in Coos and Curry counties[9]

Potential for erosion and landslide varies greatly with geologic and soil type. Furthermore, these two types of soil loss are independent of each other, i.e., an erosion-prone site may have a low landslide potential and vice versa. In this section we discuss in detail geologic types in the coastal zone and their potential for soil loss through both processes. Pertinent details are summarized in Table 13.

TABLE 13

MAJOR GEOLOGIC AND ROCK TYPES OF THE STUDY ZONE, ALONG WITH THEIR SLOPE STABILITIES, EROSION HAZARDS, LEACHING POTENTIAL, AND FERTILITY.

Formation or rock type	Percent of study area	Landslide potential	Surface erosion hazard	Leaching potential	Fertility
Tyee and Coaledo	40	Moderate	Low	Low	Moderate
Dothan	16	Moderate	Moderate	High	Low-Moderate
Umpqua	13	Moderate	Moderate	Low	Moderate
Galice	13	Low	Low	High	Low-Moderate
Serpentine	6	Low	Low	Moderate	Low
Granitic Intrusions	3	Moderate	High	Moderate	Low
Otter Point	3	High	Moderate	Low	High
Days Creek	2	High	Moderate	High	Moderate

Tyee and Coaledo Formations

Roughly, the northern half (40 percent) of the study area is covered by alternately bedded sandstone and siltstone. The boundary of this zone extends from about Roseburg in the northeast, south to Agness, and then north to Coos Bay. Because of its location and areal extent, this formation would be an important source of fuel for a plant located in Powers. The deep, loamy soils derived from these formations are very productive. Soils over most of this zone exhibit moderate slope stability, low to moderate erosion hazard, and moderate fertility. The slopes in the zone are very steep, and great care is required to avoid slope failures along roadways and within clearcut units. Roads are located so that they avoid extremely steep headwall areas that are especially susceptible to failure, and road design provides for comprehensive drainage works and hauling of excavated material to stable disposal sites. Where slopes exceed 65 percent and soils are shallow (about 20 percent of this zone), slope stability may be low after clearcutting. Extra care in logging operations is advisable in these very steep areas.

Dothan Formation

The Dothan formation consists of hard, strongly folded and fractured, dark-gray sandstone and siltstone. It occupies a broad band about 15 miles wide extending from Roseburg to Brookings and comprises about 16 percent of the study area. Thus, it would be a potential source of fuel for either a Powers or a Gold Beach plant. Slopes are generally steep, and soils tend to be gravelly or stony. Slope stability is moderate, and sediment yield after logging is also moderate. Because of the prevalence of long, steep slopes in this formation, careful road location and construction is an important factor in minimizing erosion. Fertility is moderate, but high gravel content results in low productivity.

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[9] The following data are taken from a number of sources. These are referenced separately as "Geologic Sources" after the Literature Cited section.

Umpqua Formation

The folded mudstones of the Umpqua formation underlie about 13 percent of the coastal zone, forming an irregular area about 6 to 12 miles wide, just south of the Tyee formation. The area is very close to Powers. Deep clayey soils dominate moderate slopes, while loamy soils are common in the steeper places. Erosion hazard and slope stability are both moderate except on steep slopes, where both are more severe. Potential for stream degradation is high because of the abundance of clay. Productivity is moderate.

Galice Formation

The Galice formation consists of strongly folded and fractured sedimentary and volcanic rocks that have been metamorphosed in some places. Steep slopes and shallow, gravelly soils predominate. The formation makes up 13 percent of the coastal zone and is divided into two locations. The larger of the two extends southward from Glendale to the state line in an area about 15 miles wide and would be important as a fuel source for a Gold Beach plant. The smaller area, approximately 12 miles in diameter, is about 6 miles northeast of Gold Beach and might be utilized by a site at either Powers or Gold Beach. Slope stability is high, and erosion hazard is low. Fertility is moderate, but productivity is rather low because of high gravel content.

Serpentine Soils

Serpentine is the least productive soil within the coastal zone. It makes up only 6 percent of the area and occurs in widely scattered locations throughout the southern half of the zone. By far the largest single occurrence is on the Oregon-California border, about 30 miles southwest of Grants Pass. Slope stability is high, and erosion hazard is low.

The limited areal extent and relative inaccessibility of this formation will restrict the amount of fuel it could supply.

Granitic Intrusions

Soils formed from granitic rocks make up only 3 percent of the coastal zone. Their major occurrence is in a rugged, relatively inaccessible area about 25 miles west of Grants Pass. Erosion hazard is high, especially on slopes above 20 percent. Extreme caution is required in road construction and harvesting in order to minimize erosion. Slope stability is moderate. Fertility is low to moderate, as is productivity.

Because of low productivity and inaccessibility, this formation will probably not be heavily utilized as a source of fuel.

Otter Point Formation

The Otter Point formation consists of strongly folded, fractured, and sheared sandstone, siltstone, and chert. Although it makes up only 3 percent of the coastal zone, it is concentrated in a single block of about four townships, immediately west of Powers, and would therefore be an important source of fuel for a plant at that site. Slope stability is low. Erosion hazard is high (Fred Swanson, personal communication), and productivity is high. Much of this landscape is unstable; therefore, extreme care is required in road location and culvert placement.

Days Creek Formation

Most of the area covered by the Days Creek formation consists of slopes and valleys. Slopes of 60 percent or more are common. Soils are generally shallow and gravelly. Slope stability is low. Landslides may occur after clearcutting in steeper places. Extreme care is required in road location and logging techniques. Productivity is moderate because of shallow soils.

Although this unit makes up only 2 percent of the coastal zone, its ready accessibility from Route 101 and proximity to both Powers and Gold Beach indicate that it will probably be utilized as a fuel source.

Potential Soil Losses

The Dothan, Galice, and Days Creek formations, all of which form soils with a high gravel content, have a high potential for nutrient loss through leaching below the rooting zone. Amounts of nutrients lost in this way are usually small in western forests. Rapid revegetation on these types will help prevent such loss.

Those formations that comprise the bulk of the coastal zone--Tyee and Coaledo, Dothan, Umpqua, and Galice--have moderate to high slope stability and moderate to low erosion hazard. Figure 11 quantifies sediment yield for three of these major types, plus three minor types. Of the major types, Dothan has the highest potential for soil loss, although steep slopes on any type may be unstable after harvest. The Days Creek and Otter Point formations--two minor types likely to be utilized heavily as fuel sources--have low slope stability and therefore high potential for nutrient loss and stream sedimentation after harvest. Figure 11 illustrates the magnitude of this potential, showing that sediment delivery to streams after clearcutting and broadcast burning on the Otter Point formation is three to four times greater than that after harvesting on the Galice or the Tyee and Coaledo formations.

NUTRIENT INPUTS

Loss figures have no meaning unless balanced against inputs to the system. Inputs of potassium (K) and calcium (Ca) with rainfall are roughly 5-10 lb/acre/year in western Oregon, and yearly input of phosphorus (P) in rain amounts to only 1 lb/acre or less. Nutrient inputs from rock weathering are very difficult to measure and vary considerably.

Nitrogen (N), the most limiting element in most western forests, is introduced at very low rates.[10] It is present in bedrock in only minute quantities and therefore is not added to the system through rock weathering. In western Oregon, N inputs in rainfall are very low--1 to 2 lb/acre/year. In the forests of western Oregon, inputs of N have resulted mainly from the presence of N-fixing plants such as red alder, various species of ceanothus, and legumes. Ceanothus may introduce up to a hundred pounds of N per acre each year and red alder several hundred.

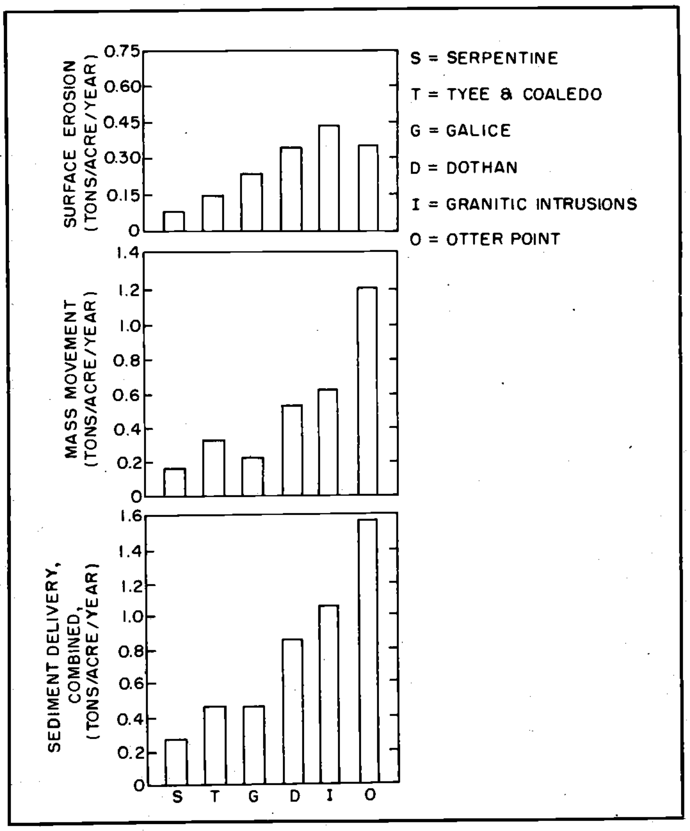

FIGURE 11

SEDIMENT YIELD TO STREAMS AFTER CLEARCUTTING IN SOUTHERN OREGON, BY GEOLOGIC TYPE (UNPUBLISHED DATA OF MIKE AMARANTHUS, SISKIYOU NATIONAL FOREST).

EFFECTS OF NUTRIENT LOSS ON PRODUCTIVITY

Peak nutrient demand in a developing forest is reached during the first 20 to 40 years. In this period trees may require 20 to 50 lb of N/acre/year in order to maintain rapid growth. In the absence of N-fixing plants, natural inputs are insufficient to meet this requirement, and trees must utilize N from soil storage pools. This uptake is shown in Figure 12 for Site III (medium productivity) Douglas-fir. In this figure, solid lines represent net N uptake by trees and the dashed line represents estimated inputs in the absence of symbiotic N-fixers or fertilization. We have estimated inputs of N in

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[10] Decomposition of organic material is simply an internal recycling of nutrients and does not represent an input to the site.

rainfall and of that fixed by free-living bacteria and lichen at 5 lb/acre/year. This estimate is, if anything, a bit high. Note that at any age cumulative natural inputs of N are enough to balance that which would be removed by harvesting stems only. However, harvest of branches or branches plus foliage (whole-tree harvest) would remove N that had been taken up from soil reservoirs and thus would lower the total N available for growth during the next rotation. For example, whole-tree harvest at age 40 would remove 250 lb of stem-N/acre, 150 lb of branch-N/acre, and 130 lb of foliage-N/acre. Cumulative inputs at age 50 amount to about 250 lb/acre--just enough to balance the N removed in stems. The N removed in branches and foliage--280 lb/acre--will represent a loss to soil storage reservoirs.

Nitrogen losses that are not replaced will definitely affect site productivity. Only a small proportion of the soil N is in a form readily available to trees. Therefore, while removal of 280 lb/acre may reduce total site N by 10 percent, it may reduce *readily available* site N by a much greater amount. Quantifying the loss in productivity that results from N loss is difficult, however. In a New Zealand study, 7-year-old trees on sites where slash had been windrowed had only 60 percent as much volume as did trees on unwindrowed sites (Ballard 1978). By harvest at rotation age 26, the volume differential in these trees will probably be even greater. It should be noted that windrowing usually removes topsoil as well as logging slash and is thus a more drastic removal of nutrients than is increased utilization of biomass. Two studies have compared growth of trees on sites where litter alone had been removed from part of the area. Nyland *et al.* (1979) found 9-year-old spruce to be 32 percent shorter, 45 percent lower in foliar N, and 41 percent lower in foliar P when grown on sites without litter. Mullin and Campbell (1975) found that 10-year-old trees were up to 20 percent shorter when litter was removed than when it was left in place.

Figure 12 indicates that whole-tree harvest at 50 years of age would lower the site's N reserves by about 300 lb/acre. Such a loss

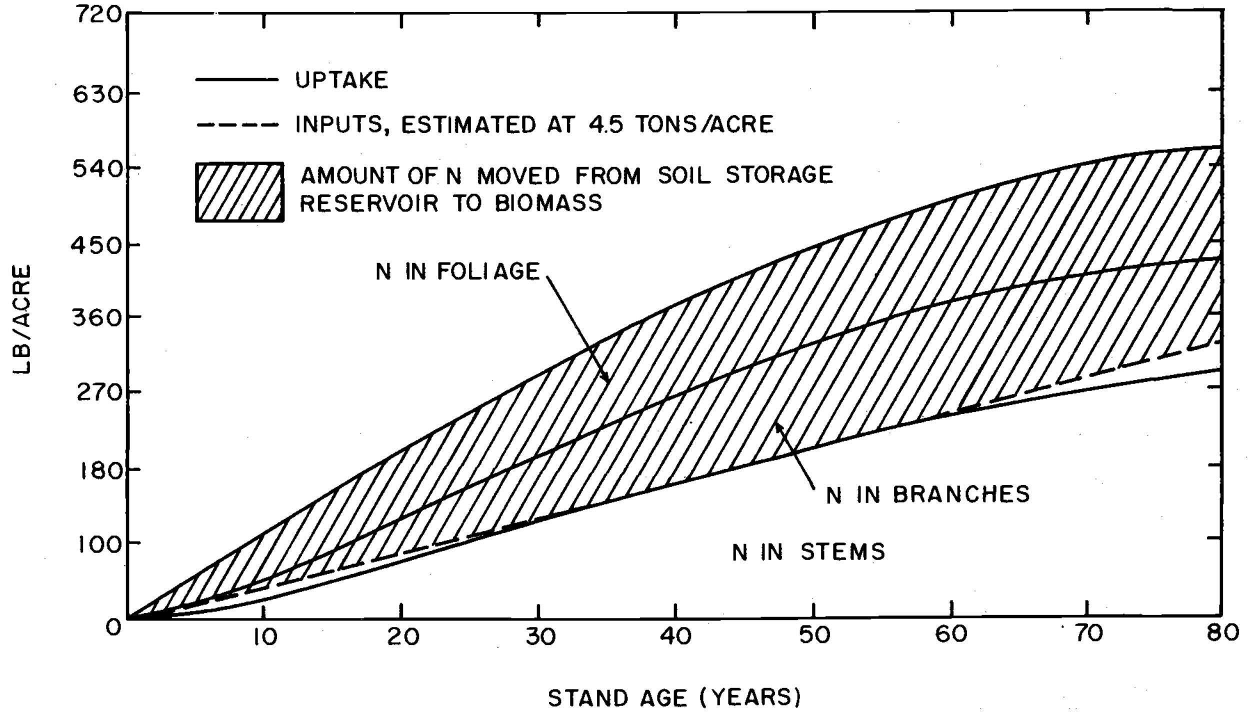

FIGURE 12.

TIME COURSE OF NITROGEN UPTAKE BY SITE III DOUGLAS-FIR FORESTS, ALONG WITH NITROGEN INPUTS IN THE ABSENCE OF FERTILIZATION OR SYMBIOTIC N-FIXING PLANTS.

would amount to 5 to 10 percent of the *total* N on typical sites in southwestern Oregon, but it would amount to a much higher proportion of the *available* pool, i.e., that portion of total site N which is readily decomposable and which therefore plays the most important role in site productivity. Losses of this magnitude, if not replaced, would almost certainly result in decreased site productivity.

As shown in Table 12, biomass harvest in tanoak stands would remove from 180 to 380 lb/acre of N, depending on whether whole-tree removal is practiced. Sites may tolerate removal of the lesser amount; however, if the larger amount is removed, productivity may well suffer unless N is replaced by chemical fertilization or biologically, by N-fixing plants.

Our own work suggests that site productivity may decrease as a result of logging, regardless of how residue is handled. We grew Douglas-fir seedlings in soils collected from three logged and adjacent unlogged areas in southern Oregon. As shown in Figure 13, the weight of seedlings grown in soil from areas that had been logged and either burned or not burned was sharply lower than that of seedlings grown in soil from undisturbed forest. Logged areas were also lower in mineralizable N (a measure of the rate of N release through decomposition), although these differences were not statistically significant and therefore perhaps not a true reflection of conditions on the site.

Nitrogen may be replaced by fertilization or N-fixing plants. Manufacture of nitrogen fertilizer requires large amounts of natural gas, and it is therefore an energy-expensive form of replacement. Table 14 shows the Btu's required to manufacture enough N to replace that lost in one ton of stemwood, large branches, small branches, and foliage. For reference, one ton of wood has 10 ± Btu's. Energy costs for transport and application of fertilizer are not included. If we consider these costs along with the efficiencies of energy conversion from wood to electricity, then utilization of smaller tree components would not produce enough energy to balance the costs of fertilization. We can also calculate the dollar cost of fertilizing to replace additional nutrients lost in whole-tree harvest. Figures 9 and 10 show that for stands with trees 12 inches in diameter, removal of entire trees entails the removal of about 30 tons of dry weight and 350 lb of N above that which is removed in wood greater than 4 inches in diameter. It would cost

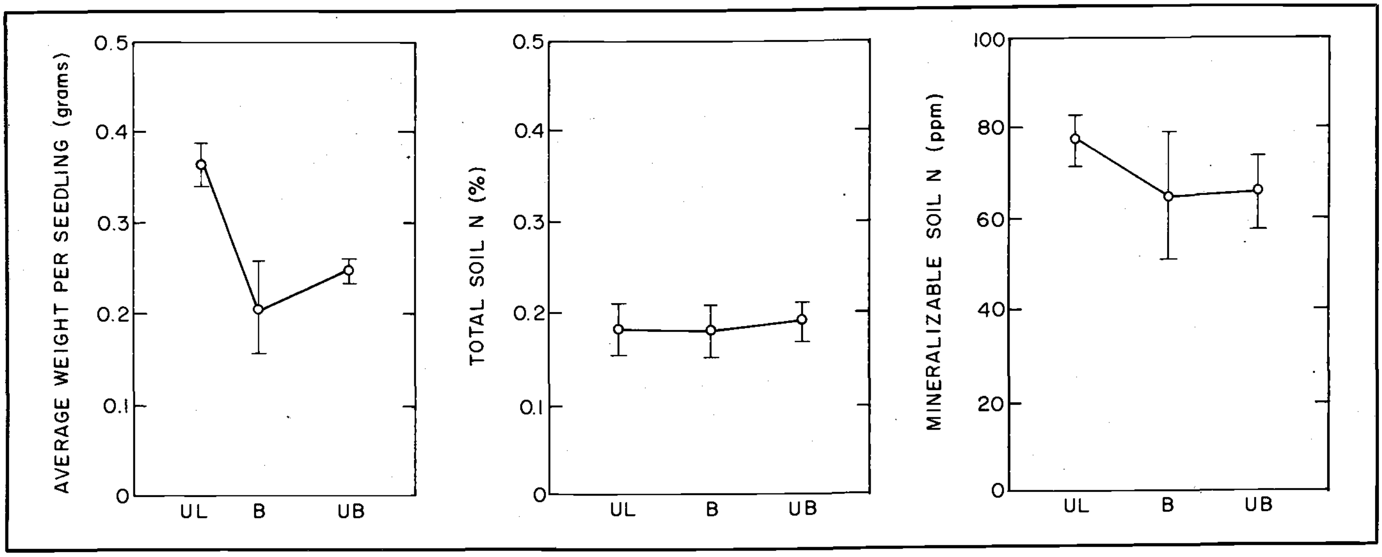

FIGURE 13.

AVERAGE WEIGHT AND TOTAL AND MINERALIZABLE SOIL N FOR DOUGLAS-FIR SEEDLINGS GROWN IN SOILS FROM THREE SETS OF ADJACENT LOGGED AND BURNED (B), LOGGED AND UNBURNED (UB), AND UNLOGGED (UL) SITES IN SOUTHERN OREGON.

roughly $150, or $5 per ton of additional recovered dry fuels, to replace this N. At our estimated transportation rates, $5 per ton would pay for 100 miles of haul distance. Thus, if lost N is replaced by chemical fertilization, it is more economical to travel up to 100 additional miles for fuel than it is to log on a whole-tree basis.

Ten to 20 years of site occupation by an efficient N-fixer such as red alder will replace lost N with no direct energy cost. Alder, in fact, represents a net energy gain, because its very rapid accumulation of biomass would make it a significant source of fuel. A short rotation of alder, coupled with intensive utilization of slash from the subsequent coniferous stand, may represent a system in which both fuel and more valuable commercial crops can be produced on a sustained basis without a deterioration of site quality.

Over-utilization of residues may have negative effects beyond those of nutrient removal. Organic material is a profoundly important component of soils. It provides a structure that increases infiltration of water, aeration, and rooting; and through its electrical properties, it binds nutrients that may otherwise be leached from the soil by rain. Lyon *et al.* (1952) calculated that well-humified, organic material is from 2 to 20 times more efficient than clay in binding nutrients. Harvest of a hardwood stand averaging 12 inches in diameter and having 300 trees per acre would remove about 190 tons of organic material per acre with whole-tree harvesting and about 135 tons if only wood 4 inches or greater in diameter were removed. The difference, 55 tons per acre, is about one-half of the total organic matter content of an average forest soil in southern Oregon (there is a great deal of variation around this average). Leaves and small branches, if left on site, would be incorporated into soil organic material. If taken from the site, soil organic material could decrease by as much as 10 to 20 percent; such a decrease could, in turn, reduce nutrient holding capacity by several hundred pounds per acre. This reduction would probably lower productivity, but the amount is difficult to predict.

EFFECTS OF CLEARCUTTING AND RESIDUE REMOVAL ON SOIL BIOLOGY

Site productivity is governed not only by the presence of nutrients, but by the efficiency with which plants can obtain them. The latter depends to a large extent on complex and poorly understood biological processes within the soil. Decomposition of organic material and release of nutrients in available form is accomplished by numerous species of bacteria and fungi. Weathering of parent rock is accelerated by organic acids released by fungi (Sollins *et al.* 1981). Uptake of nutrients is highly dependent on mycorrhizae, a symbiotic relationship between particular fungi and tree roots. Some species of bacteria and fungi may be important in protecting trees against belowground pathogens.

With the exception of mycorrhizal fungi, which obtain carbon from trees, the vast majority of belowground organisms are dependent of soil organic material for an energy

TABLE 14.

ENERGY REQUIRED FOR MANUFACTURE OF ENOUGH NITROGEN FERTILIZER TO REPLACE THAT REMOVED IN VARIOUS TREE COMPONENTS.

Tree component	Btu's required to manufacture replacement N (per ton of biomass removed)	Ratio of Btu's required to manufacture replacement N to Btu's contained in removed biomass
Stem	3.2×10^5	0.032
Large branches	9.6×10^5	.096
Small branches	1.6×10^6	.160
Foliage	3.2×10^6	.320

source. Thus, over-utilization of residues may adversely affect this very important belowground community.

Perry and colleagues are studying the effect of logging and slash disposal on soil microorganisms. Unfortunately, study sites do not exist on which we can evaluate different levels of biomass removal. Table 15 shows the microbial composition of soils from three areas in southwest Oregon. Note that ratios of (a) bacteria to fungi and (b) actinomycetes (a filimentous bacteria) to fungi are much higher in areas that have been logged and burned than in both undisturbed forest and areas that have been logged but not burned. It is impossible to say whether similar changes might occur if residue is removed through utilization rather than burning. It is also very difficult to predict what effect, if any, such changes may have on growth of subsequent tree crops. With respect to these effects, however, we have some intriguing evidence in the behavior of siderophores on disturbed sites. Siderophores are proteins released by some species of bacteria and fungi; they are thought to play an important role in protecting higher plants against pathogenic microorganisms. We assayed siderophores in soils from adjacent logged and unlogged sites in southern Oregon (Fig. 14) and found siderophore concentration to be lower in both logged and burned and logged and unburned soils than in undisturbed soils. The greatest reduction was in logged and burned soils. We have evidence that, on one site in southern Oregon, reduction in siderophores after burning resulted in loss of growth potential for trees. Whether the same would be true on other sites is not known. We can conclude, however, that burning has a major impact on soil biology in general and siderophore production in particular, and that at least in some cases these impacts can affect tree growth. Thus, sites may benefit if moderate levels of slash utilization reduce the need to burn.

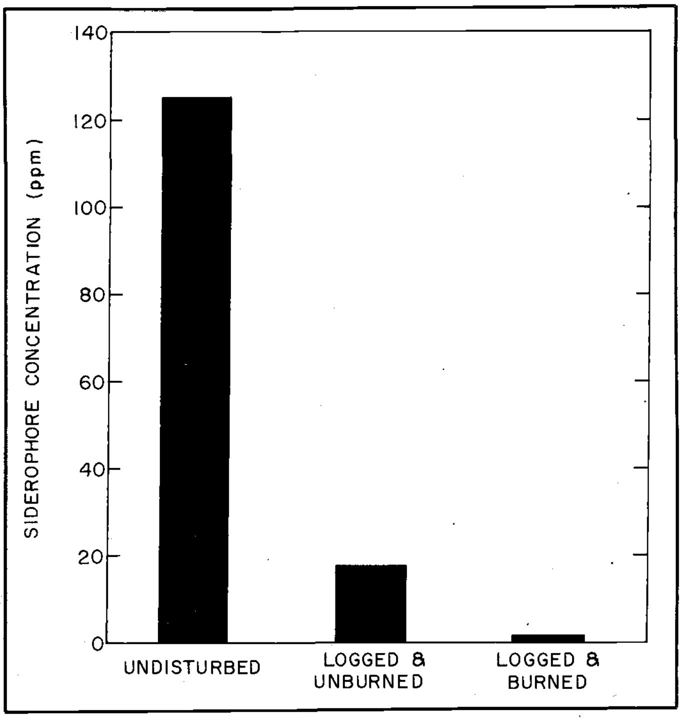

FIGURE 14

CONCENTRATION OF SIDEROPHORES IN SOIL FROM ADJACENT LOGGED AND UNLOGGED AREAS ON ONE SITE IN SOUTHERN OREGON (PERRY AND ROSE, UNPUBLISHED DATA)

TABLE 15

RATIOS OF BACTERIA (B) AND ACTINOMYCETES (ACT) TO FUNGI (F) PER GRAM OF DRY SOIL IN ADJACENT DISTURBED AND UNDISTURBED SITES OF THREE SUBSTRATE TYPES IN SOUTHERN OREGON (FROM PERRY AND ROSE, IN PRESS).

	Substrate					
	Granitic		Marine sediments		Volcanic	
Soil condition	B:F	ACT:F	B:F	ACT:F	B:F	ACT:F
Undisturbed	31:1	22:1	15:1	19:1	29:1	18:1
Logged and burned	63:1	59:1	66:1	17:1	107:1	37:1
Logged and unburned	22:1	31:1	9:1	11:1	38:1	19:1

RECOMMENDATIONS

1. Whole-tree logging (removal of crown along with stems) of tanoak stems larger than 3 inches in diameter should be avoided if possible. If whole-tree yarding is an economic necessity, sites should be fertilized with nitrogen after establishment of a new stand of trees. Most tanoak stands have a relatively large component of smaller trees that will be left for economic reasons; their retention will help considerably in preserving nutrients.

2. On sites with moderate erosion hazard (those on Dothan and Umpqua formations), small residues should be left scattered in order to dam soil flow, litter layers should be disturbed as little as possible in order to maintain high infiltration rates, and rapid revegetation should be encouraged.

3. On all slopes greater than 65 percent and on all sloped sites on the Otter Point or Days Creek formation, logging and especially road building should be carried out cautiously to avoid landslides. Full suspension should be used in yarding. Maintenance of vegetative cover is important because it provides rooting strength and because transpiration prevents saturation, which may lead to mass failure. Unmerchantable trees (less than 3 inches in diameter) should be left standing on these sites. When stocking per acre is less than 30 trees between 4 and 8 inches in diameter, larger trees should be left--i.e., the cut should be a shelterwood rather than a clearcut.

4. Other factors being equal, removal of *moderate* amounts of residue is preferable to broadcast burning.

SUMMARY

Because nitrogen is required in large amounts whereas inputs through natural processes are very small, this is the nutrient most likely to limit tree growth in the study area. Excessive removal of biomass can also affect site productivity through removal of organic material, which, upon decomposition, forms a very important structural component of soils. Hardwood harvest of boles only will remove roughly the same amount of nitrogen that is input by natural processes and therefore should not affect site productivity. Whole-tree harvest, on the other hand, will remove much more nitrogen than is input naturally and will result in eventual declines in productivity unless followed by fertilization. Commercial nitrogen fertilizers have two disadvantages: first, they require large amounts of fossil energy to manufacture; second, they do not return organic matter to the soil. Use of N-fixing plants will return both nitrogen and organic material to the soil.

Similarly, removal of all residues from a site would reduce productivity; fortunately, however, such removal is impractical both from an operational and an economic standpoint. Removal of residues larger than 10 inches in diameter should not affect site productivity. In fact, if removal of larger residues obviates the need to broadcast burn, negative impacts may actually be reduced.

With the exceptions noted in this chapter, soils in the area are moderately to highly stable. Thus, if normal precautions are taken during logging, landslide and stream sedimentation should not occur. Very steep slopes, which are relatively common in the area, do tend toward instability, and some tree cover should be left to provide rooting strength within the soil mantle when these sites are logged.

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TRANSPORTATION IMPACTS

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Oregon State University

Supplying a 50-MWe generating plant fueled primarily by wood will require over 100 truck trips a day. This chapter evaluates the impacts of the trucking needed to supply such a facility in the study area. Particular attention is paid to level of traffic, delays, and safety hazards during peak periods. The procedure for analyzing transportation costs is described in Appendix V.

AVAILABLE ROADS

U.S. Highway 101 is the primary north-south route through the zone. This undivided road generally follows the coast through the entire zone. The dependence of north-south traffic on this route and its linkage of the two proposed plants make it the focus of this analysis.

Several major highways provide for east-west movement through the zone:

State Route 126 (Florence-Eugene),
State Route 38 (Umpqua Highway), and
State Route 42 (Coos Bay-Roseburg Highway).

Other secondary highways in the zone include:

Cape Arago Highway No. 240,
Coos River Highway No. 241,
Powers Highway No. 242,
Empire-Coos Bay Highway No. 243,
Coquille-Bandon Highway No. 244,
Cape Blanco Highway No. 250, and
Port Orford Highway No. 251.

Together, these highways constitute the major traffic arteries for the zone. Other local and forest roads in the zone provide access to the forest resources, although the impacts from increased traffic on these roads would be minimal.

The potential use of existing rail transport in the northern portion of the zone was evaluated. Such transportation is typically less expensive per ton-mile than is trucking. Evaluation revealed, however, that construction of the loading and unloading terminals and reconstruction of the abandoned tracks into the Powers site would outweigh the savings. Furthermore, there are no available rail facilities serving the Gold Beach site.

ROAD CHARACTERISTICS

The impact of additional truck traffic on any road is dependent on existing roadway conditions. The most important factors include current volume of traffic, number and width of lanes, shoulder width, steepness of the grade, and available passing room. Each of these factors was evaluated for each of the heavily used roadway sections. A road was considered heavily used by the public if 1980 usage as published by the Oregon State Highway Division exceeded 3,000 vehicles per day. A road with less daily usage would not be significantly affected by the addition of the expected truck traffic.

Each of the zone's roadway sections projected to be traveled by trucks hauling fuelwoods and already heavily used by other vehicles was analyzed to determine its carrying capacity and projected level of service (usage relative to capacity) with and without the additional truck traffic. The projections were made for the year 1985 on the assumption that annual traffic increases recorded by the Oregon State Highway Division for each road between 1970 to 1980 would continue.

The projection established that the addition of up to 20 chip trucks per hour would not significantly affect the anticipated levels of service of any of the roadways. It also established that Highway 101 between Winchester Bay and the Umpqua River Highway (Highway 42) and the Umpqua River Highway between Highway 101 and Coquille will have reduced levels of service by 1985, with or without the added truck traffic.

The reduced levels of service for these roads will have several effects. Overall, there will be less freedom to maneuver and fewer opportunities to pass. Total delay for all drivers will be increased, and average operating speeds will decrease. The roads are not expected to be significantly affected by additional truck traffic except under extraordinary conditions such as periods of highway construction or road closures.

These analyses assume an even distribution of chip trucks between 8 AM and 4 PM. It may be necessary to schedule hauls during non-peak periods to diminish the impacts of the truck traffic, especially during summer.

Determination of pavement damage expected from truck traffic is beyond the scope of this report. It was assumed that the road taxes included in the trucking costs are equivalent to the damage costs.

ECONOMIC IMPACTS

The principal economic impact of transporting wood chips will be the additional employment provided. This employment can be estimated from the average number of trips a truck driver can be expected to make per shift and the anticipated demand from the generating plant. For example, if a plant requires an average of 150 truck trips per day and a driver can make an average of 3 round trips per shift, then 50 drivers are required on a daily basis, and approximately 65 jobs are generated. The exact figures will depend on the plant location and size. Table 16 provides projections of transportation-related employment for the proposed sites and plant sizes.

Economic impacts such as potential loss of tourism can be offset by scheduling truck trips during non-peak periods.

SOCIAL IMPACTS

The most important social impact of the trucking operations will be the costs of accidents. Quantifying accident costs is beyond the scope of this chapter. It was assumed that the insurance costs will equal the accident costs.

Other social costs such as the environmental degradation caused by noise and air pollution or the barrier effects caused by roadways are not quantifiable. Although it is beyond the scope of this report to evaluate these impacts, they will exist.

CONCLUSION

The additional truck traffic projected will not significantly affect the levels of service of any of the roadways used.

TABLE 16

MILEAGE, COST, AND MANPOWER INVOLVED IN HAULING CHIPS TO TWO PROPOSED PLANT SITES IN SOUTHERN COASTAL OREGON.

Plant site	Plant capacity	Total one-way miles	Total haul cost	Total number of trips per year	Average trip distance[a]	Average number of trips per day[b]	Employment[c]
	MWe		$		Miles		Jobs
Powers	30	601,429	721,707	17,183	35	88	32
	50	1,330,201	1,717,290	27,801	48	143	63
Gold Beach	30	625,038	879,996	17,663	35	91	33
	50	1,658,718	2,291,939	28,281	59	145	73

[a] Number of miles divided by number of trips.

[b] Total trips divided by 195 hauling days per year.

[c] Anticipated employment related directly to transportation including maintenance workers, truck drivers, loader operators, etc., assuming a driver travels 300 miles per day.

LEGAL IMPLICATIONS

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Many legal issues are raised by the construction and operation of an electrical generating plant fueled primarily by wood. Indeed, the law prescribes the social and legal framework into which such a project must fit and establishes the guidelines within which it must operate. The legal issues discussed here are intended merely to provide an overall view.

In this chapter, I have listed the issues, not in their order of importance, but in the order in which they should be addressed in the planning phase of the project. The first such issue is *land use*. This is primarily a problem of satisfying local ordinances while at the same time addressing the standards of the statewide goals for land use. Of concern here are local zoning ordinances, state laws, and the county Comprehensive Plans which include sections on economics, transportation, and environmental quality, as well as traditional zoning standards. The next legal issue is *air quality*. This aspect is regulated primarily by state and federal authorities. The State Department of Environmental Quality has specific standards of air quality that must be satisfied in the coast area. Another issue is *water quality*. Water quality is also primarily a concern of the State Department of Environmental Quality and of EPA standards. It may become a local concern if local public health is perceived as being affected. Still another issue is the need for *local building permits*. Construction and building permits are regulated by local rules on building, although local bodies have primarily adopted the Uniform Building Code as modified by the Oregon Amendments. Because this topic is so specific to the sites selected, it will not be discussed in the following chapter. Two other issues are the regulations affecting the *storage of solid wastes* and the applicable *tax laws*, which have decided benefits for alternative energy sources. The final issue is *transportation*. The movement of materials for a project such as this would be subject to standards set by the State Public Utility Commission and the Highway Department. In addition, the project would be affected by local county load limits and travel restrictions. Although private off-road systems may be used, the hauling equipment would still be subject to state and federal safety standards.

Because this project is primarily designed to utilize waste products from local forests, its operations will be affected by the Oregon Forest Practices Act. This act governs not only the collection and transfer of products from forest sites, but also the removal of slash and debris and the maintenance of ground cover.

LAND USE

Oregon has recently developed a complex system of land use regulations affecting all phases of development. Zoning, although initiated at the local level, is subject to standards administered by the State Commission on Land Conservation and Development. A generating plant must therefore comply not only with local zoning ordinances but also with state land use goals. These goals are reflected in the provisions of the local county or municipal Comprehensive Plan, which is implemented by the local county or municipal zoning ordinance.

This review is not intended to be site-specific. I have not reviewed specific locations for either the generating facilities or for the collection of wood residues. It is therefore impossible at this stage to identify the specific zoning standards with which the developers must comply. If the project is located in a resource zone, then obviously the standards of the zone must be met. Perhaps the Coos County and the Curry County Comprehensive Plans will have been approved by the Land Conservation and Development Commission by the time this project reaches the design stage; in that case the designers need only address the issues raised in the Comprehensive Plans. If, however, the plans have not yet been approved by LCDC, then Goals 3 (Agriculture) and 4 (Forestry) of the statewide planning goals must also be addressed.

The general provisions of the Coos County Comprehensive Plan apparently permit the development of a generating plant fueled primarily by wood. The background statement for the plan specifically acknowledges that a potential exists for the production of energy from wood biomass and wood wastes. It cites the low fuel costs with such an operation but does not provide specific provisions or suggestions for future development. The plan recognizes the possiblity of power deficits in the area by 1983. It also implies that construction of some of the projected power supplies for the area will be delayed for an indeterminable period. Apparently, energy from Washignton Public Power Supply System's nuclear faciltiies and the Pacific Power & Light's Pebble Springs plant is optimistically included in the plan's projection. Thus, although a generating plant fueled by wood residues is not part of the Comprehensive Plan for Coos County, it would certainly fit as an alternative to the projected power sources and would comply with the plan's general outlines.

Zoning issues to be addressed include not only the general siting of a generating plant but the location and use of the various ancillary components essential to the system. Zoning laws determine the existence and placement of sites for the transfer of forest products and the means and availability of transportation. The location of these components must also comply with local land use regulations. Local zoning laws generally permit the inclusion of support facilities in a resource zone if they are directly related to activities permitted in the zone. Thus, a transfer site would generally be permitted in a forestry zone but not in an agricultural one.

AIR QUALITY

Air quality standards have been established by the federal government under provisions of the Clean Air Act as specifically determined and implemented by the EPA. Such standards are also established by the Oregon Department of Environmental Quality. These regulations apply to fuel-burning systems such as are contemplated in this project. The primary airborne byproducts of combustion from the fuels to be used are carbon in the form of ash, CO, and CO_2; moisture in the form of water vapor; and sulfur. These products are all directly regulated by specific standards established by the EPA and the Oregon DEQ.

The proposed plant could operate only under a permit issued by the State as required by Oregon Administrative Rules 340-20-020 and 340-20-025. Such permits are required of any plant burning fuel at a rate exceeding 400,000 Btu per hour. Title 40 of the Code of Federal Regulations also subjects the facility to federal standards. Both federal and state regulations require the builders and operators to use the best technology and control available.

This report contains information developed by Dr. David C. Junge on the probable amounts of air contaminants from the proposed plant. These amounts can be controlled by presently available equipment. Installation and planning of such equipment, and of the plant itself, would be subject to review by the DEQ.

WATER QUALITY

A generating plant fueled by wood would probably impinge upon water quality standards. The principal problem is the process water of the generating plant. Discharge of such water would probably raise the temperature of the receiving system above the levels considered ideal for migrating fish--48° to 58°F. According to the background study for the Coos County Comprehensive Plan, the average maximum temperature in Coos Bay waters from 1964 to 1970 was 73.3°F and the average minimum temperature was 39.7°F. Obviously, if the streams around Coos Bay were to receive process cooling water, the effect would be negligible in winter but might be harmful in summer.

Water quality including temperature is jointly regulated by the federal government under standards established by the EPA and by the State of Oregon under standards established by the DEQ. These standards apply not only to the process water that may flow directly into the receiving waterways, but to the runoff from fuel storage sites. Thus, storage sites must be constructed in such a way as to prevent degradation of surface water by runoff.

SOLID WASTE STORAGE

The state of Oregon has several regulations on the siting of facilities for the storage and disposal of solid waste. Except for the above-noted problems with water quality, however, preliminary discussion with staff members of the DEQ indicates that no permits for the storage of forest residues as fuel for a generating plant would be required.

TAX STRUCTURE

Alternative energy sources are subject to substantial tax credits and tax benefits. Development of an energy-generating facility from private capital would thus be partially supported by the public as a result of the tax credits. The full implications of the tax laws applying to this project were not fully known at the time this report was written.

TRANSPORTATION

Preliminary data indicate that the fuel for the generating plant will be primarily transported by truck--both from the forest to the chipper and from the chipper to the plant. Truck transportation is subject to specific standards and limitations established by the Public Utilities Commission. The economic viability of the project partially depends on the cost of transportation, which in turn depends partially on the tariffs and taxes imposed. Oregon Administrative Rules established by the Public Utilities Commission in chapter 860, divisions 61, 62, and 67, generally outline the guidelines with which transporters must comply. These rules specifically establish standards for hog fuel carriers. Coal is not listed specifically, but trucks transporting coal would probably fall into class D along with ore carriers. Cargo insurance would not be required.

Local land limitations would depend on the routes established.

FOREST PRACTICES ACT

The Oregon Forest Practices Act establishes detailed procedures for logging and for protection of the forest and of the natural resources within it. Thus, removals of fuel from the forest must comply with the specific requirements of this act.

The rules set forth by the act are mandated by Oregon Revised Statutes 527.610-527.730. These statutes declare the public policy of the state to be "to encourage forest practices that maintain and enhance [the forest's] benefits and resources and that recognize varying forest conditions." The statutes further declare it to be the policy of the Forest Practices Act to "achieve coordination among such state agencies [as] are concerned with the forest environment." Obviously, several state agencies may become involved in interpreting permissible usage of forest land. The Forest Practices Act specifically requires that forest-related operations comply with local zoning standards and with applicable rules concerning air and water quality.

Oregon Administrative Rule 629-24-300, which requires the removal of slash and debris from the logging site, would seem to favor the use of this debris as fuel. The provision also promotes the increased utilization of wood fiber by salvage, prelogging, and relogging. Thus, the provision appears to promote the removal of nonmarketable tree species from the forest. However, OAR 629-24-603 requires the reforestation of southwestern federal regions with "acceptable species" and thus may limit the long-term use of the forest as a regenerative fuel supply.

Road design and construction in forest areas must comply with the Forest Practices Act, regardless of whether the wood removed is for lumber or for fuel. This cost must be considered when and if any new roads are required for the recovery of fuel from the forest.

OAR 629-24-645(4) requires that waste material be removed with care in order to protect unstable soils and game forage plants. Subsequent sections of the statute also require protection of streams and shade as well as of critical wildlife habitat. All of these statutes may well limit the amount of material that can be removed from the forest site.

APPENDICES

APPENDIX I

TABLE I-A

WEIGHT-DENSITY FACTORS FOR TREE SPECIES IN THE STUDY AREA.

Species	Green specific gravity[a]	Ovendry density (lb/ft^3)	Density at 40 percent moisture content (lb/ft^3)
Coastal Douglas-fir			
wood	0.45	28.1 } 27.9	} 39.1
bark	.436[b]	27.2	
Red alder	.37	23.1	32.3
Maple	.44	27.5	38.5
Tanoak	.58	36.2	50.7
Madrone	.58	36.2	50.7
Chinkapin	.42	26.2	36.7
Oregon myrtle	.51	31.8	44.5
Oregon white oak	.59[c]	36.8	51.5
Black oak	.57	35.6	49.8

[a] Specific gravity is in terms of ovendry weight of 1 ft^3 of green volume.

[b] Specific gravity as a weighted average of inner and outer bark. Taken from: Smith, J.H.G., and A. Kozak. 1971. Thickness, moisture content, and specific gravity of inner and outer bark of some Pacific Northwest trees. Forest Products Journal 21(2):38-40.

[c] Taken from: Isenberg, H. 1981. Plywoods of the U.S. and Canada. Vol. II. 34th ed. Institute of Paper Chemistry, Appleton, Wisconsin.

APPENDIX II: HARVESTING COST CALCULATIONS

TABLE II-A
AVERAGE FELLING TIME PER TREE ACCORDING TO DIAMETER CLASS.

Diameter class (inches)	Trees/acre	Felled[a] (1st pass)	Felled[b] (2nd pass)	Estimated average[c,d] time/tree
	No.	- - Percent	- -	Minutes
1-3.49	722.25	15	25	0.21
3.50-6.99	412.09	20	20	.29
7.0-10.99	233.99	100	--	.84
11.0-16.99	55.05	100	--	2.02
17.0-22.99	3.13	100	--	3.37
23.0-28.99	.096	100	--	4.21

[a] Assumes that only trees blocking access to stems 7.0 inches and larger are felled on first pass.

[b] Assumes that 60 percent of the trees per acre either had other trees dropped across them in felling or were uprooted during yarding.

[c] All times are productive minutes only. Assume scheduled time equals 1.67 x productive time.

[d] Limbing not required.

TABLE II-B
AVERAGE FELLING TIME PER ACRE ACCORDING TO DIAMETER CLASS.

Diameter class (inches)	Trees/acre felled[a]	Time/tree	Time/acre,[b] indicated class	Productive time/acre, indicated plus all higher classes
	No.	- - - -	- Minutes	- - - -
1-3.49	288.9	0.21	60.67	427.09
3.50-6.99	164.8	.29	47.79	366.42
7.0-10.99	233.90	.84	196.48	318.63
11.0-16.99	55.05	2.02	111.20	122.15
17.0-22.99	3.13	3.37	10.55	10.95
23.0-28.99	.096	4.21	.40	.40

[a] 0.40 x trees/acre for first two diameter classes, and 1.0 x trees/acre for third and all higher diameter classes.

[b] Trees/acre x time/tree.

TABLE II-C
AVERAGE CUBIC FEET PER STEM BY DIAMETER CLASS FOR HARDWOOD.

Diameter class (inches)	Stems/acre	Ft^3/stem[a]	Average ft^3/stem[b]
1-3.49	722.25	.50	2.82
3.50-6.99	412.09	1.10	5.20
7.0-10.99	233.99	7.5	10.98
11.0-16.99	55.05	23.1	24.94
17.0-23.99	3.13	55.0	56.43
23.0-28.99	.096	103.1	103.1

[a] Taken from: McDonald, Philip. 1978. Silviculture-ecology of three native California hardwoods on high sites in north central California. Ph.D. dissertation, Oregon State University, Corvallis.

[b] Average cubic feet per stem calculated by multiplying stems per acre by cubic feet per stem from the largest diameters down. This running summation is then divided by the sum of stems per acre. Thus, interpretation of column 4 is as follows: the 2.82 indicates that if all stems 1.0 inch and larger were harvested, the average cubic feet per stem would be 2.82.

TABLE II-D

PIECE SIZE FOR RESIDUE FROM WESTERN OREGON--CLEARCUT ONLY (AVERAGE FOR PUBLIC AND INDUSTRIAL PRIVATE OWNERS).

Diameter (inches)	Length (ft) 1.0-3.9	4.0-5.9	6-7.9	Gross volume, solid wood (ft^3) 8-15.9	16.0-31.9	32+
			Ft^3			
3.1-3.9	0.27	0.32	0.47	- -	--	--
4.0-4.9	.27	.45	.74	- -	--	--
5.0-5.9	.34[a]	.76	1.20	- -	--	--
6.0-6.9	.46	.87	1.53	- -	--	--
7.0-7.9	.65[a]	1.42	2.33	1.63[b]	3.99[b]	9.95[b]
8.0-11.9	1.12	2.06	3.14	5.86	13.02	31.81
12.0-15.9	2.22	4.17	6.20	11.22	24.15	75.10
16.0-19.9	--	--	7.94[b]	19.14	42.56	100.77
20.0-23.9	--	--	11.11[b]	28.63	60.33	112.38
24.0-27.9	--	--	14.50[b]	43.87	78.33	146.17
28.0-35.9	--	--	17.86[b]	56.86	128.53	237.02
36+	--	--	37.86[b]	75.00	213.42	363.75

[a] Estimated value.

[b] Includes volume from several lower diameter or length categories.

TABLE II-E

AVERAGE GROSS VOLUME OF RESIDUE (WOOD ONLY) BY OWNER CLASS, HARVEST METHOD, AND DISTANCE FROM ROAD--WESTERN OREGON CLEARCUTS ON SLOPES GREATER THAN 35 PERCENT.

Owner	Total volume	Volume according to distance from road (ft) 0 - 500	501 - 1,000	1,001+
			Ft^3	
National forest	2,210.6	1,127.3	725.6	357.8
Other public	2,588.9	1,888.1	602.2	98.7
Private	1,414.2	1,136.4	230.1	47.7

TABLE II-F

PERCENTAGES OF TOTAL GROSS RESIDUE VOLUMES PER ACRE ACCORDING TO PIECE SIZE AND DISTANCE FROM ROAD FOR CLEARCUTS IN WESTERN OREGON NATIONAL FORESTS--SLOPES GREATER THAN 35 PERCENT.[a]

	Piece length (ft)[b]														
Diameter	1.0-7.9			8.0-15.9			16.0-31.9			32.0+			Total		
(inches)	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
								Percent							
3.1- 7.9	0.62	0.40	0.20	1.26	0.81	0.40	2.43	1.56	0.77	1.34	0.87	0.43	5.66	3.64	1.80
8.0-11.9	.68	.44	.22	1.22	.79	.39	1.16	.75	.37	.33	.21	.11	3.39	2.18	1.08
12.0-15.9	.94	.61	1.00	2.01	1.29	.64	1.37	.88	.43	2.41	1.55	.76	6.72	4.33	2.13
16.0-19.9	.56	.36	.18	.97	.63	.31	1.45	.93	.46	1.39	.89	.44	4.37	2.81	1.39
20.0-23.9	.38	.25	.12	.80	.51	.25	2.22	1.43	.71	.72	.47	.23	4.13	2.66	1.31
24.0-27.9	.14	.09	.05	1.01	.65	.32	2.45	1.58	.78	.48	.31	.15	4.09	2.63	1.30
28.0-35.9	.27	.17	.09	.48	.31	.15	1.01	.65	.32	1.80	1.16	.57	3.56	2.29	1.13
36.0+	.17	.11	.05	--	--	--	1.32	.85	.42	--	--	--	1.49	.96	.47
Total	3.76	2.43	1.91	7.75	4.99	2.46	13.41	8.63	4.26	8.47	5.46	2.69	33.41	21.50	10.61

[a] Average gross total residue volume per acre for all slopes = 3,229 ft^3; 65.5 percent of total gross is on slopes greater than 35 percent. Volumes do not include bark.

[b] A = 0-500 ft from road. B = 501-1,000 ft from road. C = 1,001+ ft from road.

TABLE II-G

PERCENTAGES OF TOTAL GROSS RESIDUE VOLUMES PER ACRE ACCORDING TO PIECE SIZE AND DISTANCE FROM ROAD FOR CLEARCUTS ON PUBLIC LAND OTHER THAN NATIONAL FORESTS IN WESTERN OREGON--SLOPES GREATER THAN 35 PERCENT.[a]

	Piece length (ft)[b]														
Diameter	1.0-7.9			8.0-15.9			16.0-31.9			32.0+			Total		
(inches)	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
	Percent														
3.1- 7.9	0.68	0.22	0.04	2.57	0.82	0.13	4.59	1.46	0.24	4.05	1.29	0.21	11.89	3.79	0.62
8.0-11.9	.63	.20	.03	1.99	.63	.10	2.97	.95	.16	2.17	.69	.11	7.76	2.47	.41
12.0-15.9	.65	.21	.03	1.52	.48	.08	3.62	1.15	.19	5.05	1.61	.26	10.84	3.46	.57
16.0-19.9	.30	.10	.02	1.32	.42	.07	2.15	.69	.11	2.27	.72	.12	6.04	1.93	.32
20.0-23.9	.18	.06	.01	.73	.23	.04	1.43	.46	.07	.87	.28	.05	3.22	1.03	.17
24.0-27.9	.00	.00	.00	.82	.26	.04	.40	.13	.02	2.80	.89	.15	4.02	1.28	.21
28.0-35.9	.10	.03	.01	1.12	.36	.06	1.53	.49	.08	1.28	.41	.07	4.04	1.29	.21
36.0+	.00	.00	.00	.50	.16	.03	4.97	1.59	.26	2.22	.71	.12	7.69	2.45	.40
Total	2.54	.82	.14	10.57	3.36	.55	21.66	6.92	1.13	20.71	6.60	1.09	55.50	17.70	2.91

[a] Average gross total residue volume per acre for all slopes = 3,327 ft^3; 76.10 percent of total gross volume is on slopes greater than 35 percent. Volumes do not include bark.

[b] A = 0-500 ft from road. B = 501-1,000 ft from road. C = 1,001+ ft from road.

TABLE II-H

PERCENTAGES OF TOTAL GROSS RESIDUE VOLUMES PER ACRE ACCORDING TO PIECE SIZE AND DISTANCE FROM ROAD FOR CLEARCUTS ON PRIVATE LAND IN WESTERN OREGON--SLOPES GREATER THAN 35 PERCENT.[a]

	Piece length (ft)[b]														
Diameter	1.0-7.9			8.0-15.9			16.0-31.9			32.0+			Total		
(inches)	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
	Percent														
3.1- 7.9	0.45	0.09	0.02	1.12	0.23	0.05	2.35	0.48	0.10	2.20	0.45	0.09	6.13	1.24	0.26
8.0-11.9	.39	.08	.02	1.11	.22	.05	1.50	.30	.06	.60	.12	.03	3.60	.73	.15
12.0-15.9	.41	.08	.02	.89	.18	.04	1.84	.37	.08	2.13	.43	.09	5.27	1.07	.22
16.0-19.9	.41	.08	.02	1.44	.29	.06	2.06	.42	.09	2.04	.41	.09	5.95	1.21	.25
20.0-23.9	.04	.01	.002	.96	.19	.04	1.81	.37	.08	1.09	.22	.05	3.91	.79	.16
24.0-27.9	.13	.03	.01	.70	.14	.03	2.29	.46	.10	1.98	.40	.08	5.11	1.03	.21
28.0-35.9	.07	.01	.003	.47	.09	.02	2.00	.40	.08	1.18	.24	.05	3.72	.75	.16
36.0+	.36	.07	.02	.22	.04	.01	3.92	.79	.16	2.31	.47	.10	6.81	1.38	.29
Total	2.26	.45	.115	6.91	1.38	.30	17.77	3.59	.75	13.53	2.74	.58	40.50	8.20	1.70

[a] Average gross total residue volume per acre for all slopes = 3,327 ft^3; 50.4 percent of total gross volume is on slopes greater than 35 percent. Volumes do not include bark.

[b] A = 0-500 ft from road. B = 501-1,000 ft from road. C = 1,001+ ft from road.

TABLE II-I

PERCENTAGES OF TOTAL NUMBER OF RESIDUE PIECES PER ACRE ACCORDING TO PIECE SIZE AND DISTANCE FROM ROAD FOR CLEARCUTS ON NATIONAL FORESTS IN WESTERN OREGON--SLOPES EXCEEDING 35 PERCENT.[a]

	Piece length (ft)[b]									
Diameter (inches)	1.0-7.9		8.0-15.9		16.0-31.9		32.0+		Total	
	A	B	A	B	A	B	A	B	A	B
	Percent									
3.1- 7.9	8.32	5.35	6.13	3.95	5.00	3.22	1.56	1.00	21.00	13.52
8.0-11.9	2.42	1.56	1.78	1.15	.78	.50	.09	.05	5.07	3.26
12.0-15.9	1.86	1.20	1.39	.89	.53	.34	.26	.16	4.04	2.60
16.0-19.9	.61	.39	.42	.27	.31	.20	.14	.09	1.48	.95
20.0-23.9	.26	.16	.28	.18	.28	.18	.06	.04	.88	.56
24.0-27.9	.09	.05	.20	.13	.23	.15	.03	.02	.54	.35
28.0-35.9	.12	.08	.06	.04	.06	.04	.06	.04	.30	.19
36.0+	.03	.02	--	--	.06	.04	--	--	.09	.06
Total	13.71	8.82	10.25	6.60	7.25	4.66	2.20	1.41	33.40	21.50
									Total = 54.90%	

[a] Average total number of pieces per acre for all slopes = 392.3. Approximately 54.90 percent of total number of pieces is on slopes exceeding 35 percent.

[b] A = 0-500 ft from road. B = 501-1,000 ft from road.

TABLE II-J

PERCENTAGES OF TOTAL NUMBER OF RESIDUE PIECES PER ACRE ACCORDING TO PIECE SIZE AND DISTANCE FROM ROAD FOR CLEARCUTS ON PUBLIC LAND OTHER THAN NATIONAL FORESTS IN WESTERN OREGON--SLOPES EXCEEDING 35 PERCENT.[a]

	Piece length (ft)[b]									
Diameter (inches)	1.0-7.9		8.0-15.9		16.0-31.9		32.0+		Total	
	A	B	A	B	A	B	A	B	A	B
	Percent									
3.1- 7.9	11.22	3.58	14.61	4.66	10.44	3.33	3.45	1.10	39.73	12.67
8.0-11.9	2.73	.87	2.87	.91	1.95	.62	.54	.17	8.08	2.58
12.0-15.9	1.37	.44	1.22	.39	1.17	.37	.54	.17	4.29	1.37
16.0-19.9	.35	.11	.69	.22	.39	.12	.15	.05	1.58	.50
20.0-23.9	.15	.05	.20	.06	.26	.08	.06	.02	.66	.21
24.0-27.9	.00	.00	.15	.05	.06	.02	.20	.06	.41	.13
28.0-35.9	.06	.02	.20	.06	.11	.03	.06	.02	.42	.13
36.0+	.00	.00	.06	.02	.21	.07	.06	.02	.33	.11
Total	15.87	5.06	19.99	6.37	14.58	4.65	5.06	1.61	55.50	17.70
									Total = 73.20%	

[a] Average total number of pieces per acre for all slopes = 369.9. Approximately 73.20 percent of total number of pieces is on slopes exceeding 35 percent.

[b] A = 0-500 ft from road. B = 501-1,000 ft from road.

TABLE II-K

PERCENTAGES OF TOTAL NUMBER OF RESIDUE PIECES PER ACRE ACCORDING TO PIECE SIZE AND DISTANCE FROM ROAD FOR CLEARCUTS ON PRIVATE LAND IN WESTERN OREGON--SLOPES EXCEEDING 35 PERCENT.[a]

	Piece length (ft)[b]									
Diameter (inches)	1.0-7.9		8.0-15.9		16.0-31.9		32.0+		Total	
	A	B	A	B	A	B	A	B	A	B
	Percent									
3.1- 7.9	8.44	1.71	8.33	1.69	7.07	1.43	2.18	0.44	26.02	5.27
8.0-11.9	2.25	.46	2.34	.47	1.37	.28	.26	.05	6.22	1.26
12.0-15.9	1.05	.21	1.02	.21	.95	.19	.40	.08	3.43	.69
16.0-19.9	.58	.12	.83	.17	.63	.13	.28	.06	2.32	.47
20.0-23.9	.05	.01	.40	.08	.33	.07	.12	.02	.91	.19
24.0-27.9	.12	.025	.21	.04	.32	.06	.12	.02	.77	.16
28.0-35.9	.035	.007	.11	.02	.21	.04	.05	.01	.40	.08
36.0+	.12	.025	.04	.007	.19	.04	.07	.01	.42	.09
Total	12.66	2.56	13.27	2.69	11.07	2.24	3.50	.71	40.50	8.20
									Total = 48.70%	

[a] Average total number of pieces per acre for all slopes = 230.4. Approximately 48.70 percent of total number of pieces is on slopes exceeding 35 percent.

[b] A = 0-500 ft from road. B = 501-1,000 ft from road.

TABLE II-L

NUMBER OF PIECES OF LOGGING RESIDUE FROM NATIONAL FOREST CLEARCUTS IN WESTERN OREGON TO EQUAL 100 FT^3 OF GROSS VOLUME, BY PIECE SIZE.

Diameter	Piece length (ft)			
(inches)	1.0-7.9	8.0-15.9	16.0-31.9	32.0+
	No. pieces			
3.1- 7.9	162.8	59	25.0	14.1
8.0-11.9	43.0	17.7	8.2	3.1
12.0-15.9	24.1	8.4	4.7	1.3
16.0-19.9	13.1	5.2	2.6	1.3
20.0-23.9	8.1	4.3	1.5	1.0
24.0-27.9	7.1	2.3	1.1	.9
28.0-35.9	5.4	1.5	.7	.4
36.0+	2.5	1.3[a]	.5	.3[a]

[a] Estimated.

TABLE II-M

NUMBER OF PIECES OF LOGGING RESIDUE FROM CLEARCUTS ON PUBLIC LANDS OTHER THAN NATIONAL FORESTS IN WESTERN OREGON TO EQUAL 100 FT^3 OF GROSS VOLUME, BY PIECE SIZE.

Diameter	Piece length (ft)			
(inches)	1.0-7.9	8.0-15.9	16.0-31.9	32.0+
	No. pieces			
3.1- 7.9	182.4	63.2	25.3	9.5
8.0-11.9	47.9	16.1	7.3	2.8
12.0-15.9	23.3	8.9	3.6	1.2
16.0-19.9	12.8	5.8	2.0	.7
20.0-23.9	9.1	3.0	2.0	.8
24.0-27.9	7.5	2.0	1.7	.8
28.0-35.9	6.7	1.9	.8	.5
36.0+	2.65[a]	1.3	.5	.3

[a] Estimated.

TABLE II-N

NUMBER OF PIECES OF LOGGING RESIDUE FROM CLEARCUTS ON PRIVATE LAND IN WESTERN OREGON TO EQUAL 100 FT^3 OF GROSS VOLUME, BY PIECE SIZE.

Diameter (inches)	Piece length (ft)			
	1.0-7.9	8.0-15.9	16.0-31.9	32.0+
	- - - - - - - No. pieces - - - - - -			
3.1- 7.9	154.8	61.6	25.0	8.2
8.0-11.9	47.4	17.5	7.6	3.7
12.0-15.9	21.4	9.5	4.3	1.6
16.0-19.9	11.8	4.7	2.6	1.1
20.0-23.9	10.0	3.5	1.5	.9
24.0-27.9	7.8	2.5	1.1	.5
28.0-35.9	4.0	1.9	.9	.4
36.0+				

APPENDIX III: NOTES ON PROGRAM "COGEN"

The purpose of this program is to calculate the quantities of fuel that must be supplied to generation plants having various capacities and capable of burning various types of fuel. The program asks for 17 input variables and provides output data on 10 variables as noted below.

The program is designed to run on a Hewlett Packard-41CV calculator. The program can be input directly on the keyboard or it can be input through the use of cards. The program does *not* require the use of a printer.

To operate the program, XEQ SIZE = 40
XEQ COGEN

Input the variables through the keyboard as noted below. It is recommended that an input and output format sheet be used for the program so that the data can be kept in proper sequence and the input and output variables can be recorded.

Input variables	Typical value
(1) Feed water enthalpy	323.9 Btu/lb
(2) Maximum steam enthalpy leaving boiler	1,369.2 Btu/lb
(3) Enthalpy of steam bled from turbine for use as process steam in the plant site	
(4) Enthalpy of steam exhaust from turbine	935.0 Btu/lb
(5) Thermal efficiency of boiler operating on wood or bark fuels	72.0 percent
(6) Higher heating value of the dry wood/bark fuel	8,800.0 Btu/dry lb
(7) Non-combustible ash content of wood/bark fuel	4.0 percent
(8) Density of the wood/bark fuel on an "as-received" basis	22.0 lb/ft^3
(9) Moisture content of wet wood/bark on an "as-fired" basis	50.0 percent
(10) Thermal efficiency of boiler operating on coal or other fossil fuel	75.0 percent
(11) Higher heating value of the dry coal (or other fossil fuel)	8,752.0 Btu/dry lb
(12) Non-combustible ash content of the coal (or other fossil fuel)	34.2 percent
(13) Density of the coal (or other fossil fuel) on an "as-received" basis	45.0 lb/ft^3
(14) Moisture content of the wet coal	4.6 percent

Note: The 14 input variables noted above are input as the first data for the program. In addition, 3 more input variables are requested on a repeated basis as noted below. For each set of the 3 additional input variables, the calculations are made for the output variables.

(15) Condensing steam load of the plant site. This is the rate at which the plant site demands steam for process heat, space heating, etc.	60,000.0 lb/hr
(16) Maximum electric power generation capability of the plant site	50.0 MWe
(17) Percentage of the fuel energy supplied to the plant by wood/bark. Note that it is assumed that the remainder of the plant energy from fuel is assumed to come from coal (or other fossil fuel)	100.0 percent

Output variables	Typical value
(1) Maximum steam generation rate (SGR =)	535,526.0 lb/hr
(2) Maximum wet wood use rate (WPPH =)	176,700.0 lb/hr
(3) Maximum wet wood use rate (WTPD =)	2,120.0 tons/day
(4) Maximum wet wood use rate (WUPM =)	28,915.0 units/month*
(5) Maximum number of wood trucks per day (WTKS =)	96.0 trucks/day**
(6) Maximum wet coal use rate (CPPH =)	0 lb/hr
(7) Maximum wet coal use rate (CTPD =)	0 tons/day
(8) Maximum wet coal use rate (CUPM =)	0 units/month*
(9) Maximum number of coal trucks per day (CTKS =)	0 trucks/day**
(10) Maximum rate of ash removal per day	42.0 tons/day

* 1 unit = 200 ft^3.

** It is assumed in the calculations that each truck can haul 44,000 lb of fuel (either coal or wood) per load.

APPENDIX IV: BIOMASS AND NUTRIENT CALCULATIONS

Coniferous biomass equations are taken from T. W. Weaver and Frank Forcella (Department of Biology, Montana State University, Bozeman, personal communication) and are valid for a wide range of coniferous species. Nutrient calculations used are averages of numerous published sources:

		Stem diameters (cm)		
Nutrient	Foliage	< 1	1-10	> 10
		- - -	Percent	- - -
N	1.0	0.50	0.30	0.10
P	.15	.06	.04	.01
K	.55	.22	.18	.04
Ca	.30	.40	.30	.10

Stocking densities are taken from normal yield tables for naturally established Douglas-fir stands (McArdle *et al.* 1961). Planted stands will be less dense in the small diameter range (< 15 cm) and will therefore contain fewer nutrients than shown.

Equations for branch biomass of black oak are from King and Schnell (1972), while those for red oak foliage are from Telfer (1969). Stem volumes are taken from volume tables for California black oak. Tanoak stem volumes are about 20 percent less than those for black oak, and those for Pacific madrone are about 20 percent greater. Conversion of volumes to weight was based on an assumed specific gravity of 0.66. Nitrogen concentrations are from the analyses of tanoak in this report, while other hardwood nutrient concentrations are assumed to be the same as for conifers. (All values are in percent.)

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McARDLE, R.E., W.H. MEYER, and D. BRUCE. 1961 (rev.). The yield of Douglas-fir in the Pacific Northwest. U.S. Department of Agriculture, Technical Bulletin 201. 74 p. Washington, D.C.

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APPENDIX V:
ANALYSIS OF TRANSPORTATION COSTS

The first step in analyzing how the proposed facility will affect transportation is to determine the number and length of truck trips from the resource sites to the generating plant. A system of map overlays provides a useful method of managing the data on available resources. Prerequisite to the analysis are data on the fuel requirements of the generating plant, the location of all available biomass fuel, and the network of roads available to move that fuel.

Initially, we established a "zone" system on a master base map. Zones were defined as townships and mill sites with available residue. Next, the road systems that serve the zones were identified, and all biomass resources expected to be available annually in each zone were identified. If we know the annual biomass resources available and the annual fuel demand for a specific generating plant, then we can assess the transportation requirements for an average year by assuming that the shortest path to the resources will be used. Determination of the shortest path was based on travel time rather than distance. If it is faster to travel the long way on better roads, we assumed that the trip will be made the long way. The assumed average travel speeds are 55 miles per hour on highways, 35 miles per hour on major secondary roads and forest arterials, and 15 miles per hour on minor roads.

Next, we devised a representative network consisting of a linknode map that converts the transportation system and zones to a network format. The network format was designed for standard network-analysis algorithms and for computer translation if warranted. Links connect all nodes, and travel distance and travel time are known for each link. A shortest-path algorithm was used to determine the minimum travel time from the proposed generating plant to the resource sites.

The travel times are used to determine haul costs. For the purposes of this study, haul costs were assumed to be $1.57 per minute for highway miles and $0.84 per minute for the off-highway miles (1985 dollars). These costs were obtained from telephone interviews of local private trucking firms. They cover all operating costs including fuel, maintenance, taxes, insurance, and profit. For the purposes of this analysis, the following assumptions are also made:

1. The biomass materials are transported in a chipped form in standard high-volume chip trucks with an average capacity of 22 green tons.
2. Two percent of the "return" truck trips will return the ash from the generating plant to the point of origin.
3. Trips from logging sites to chipper sites are made by vehicles with a green-ton capacity equal to that of a loaded chip truck.
4. Trips generated by related logging operations at resource sites have negligible impacts on this analysis.
5. Residue collection is restricted during 3 months of the year by unfavorable weather conditions for logging operations or hauling.
6. Biomass resources are transported 5 days per week and 8 hours per day.

These assumptions permit the estimation of trips generated on an average daily basis.

Perry, D.A. (Principal investigator). GENERATING ELECTRICITY WITH WOOD AND SOLID WASTES IN SOUTHERN OREGON. Forest Research Laboratory, Oregon State University, Corvallis. Bulletin 40. 88 p.

There are four sources of biomass fuels for generating electricity in southwest Oregon: noncommercial hardwoods, logging residues, mill residues, and municipal solid wastes. Noncommercial hardwoods and logging residues exist in sufficient quantities to support 100 MWe of generating capacity for 20 years. Logging residues are costly to harvest and would result in relatively expensive electricity. Hardwoods, in contrast, are relatively inexpensive to harvest and could be used to produce electicity at a cost only slightly greater than that incurred with coal.

A biomass-fueled generating plant would emit slightly more carbon monoxide than a coal-fired plant; however, nitrous oxide emission would be less than one-half, and sulfur dioxide emissions only 1 percent, of those of a plant burning coal. Impacts of biomass harvest on soil fertility, water quality, and traffic patterns would be minor if proper procedures are followed.

Perry, D.A. (Principal investigator). GENERATING ELECTRICITY WITH WOOD AND SOLID WASTES IN SOUTHERN OREGON. Forest Research Laboratory, Oregon State University, Corvallis. Bulletin 40. 88 p.

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