D AND BARK AS FUEL

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Forest Research Laboratory
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PREFACE

A characteristic of an industrial society is its enormous consumption of energy. Until recently, the "energy barrel" available in the United States seemed to have no bottom, and most people were little concerned with energy supply. But now, our news media constantly remind us of the problem. We are told to expect shortages of fuel and electricity; curtailments for some users have occurred already, and rising costs for energy seem assured.

Wood—a fuel that once supplied most of this country's energy, but now is of commercial importance mainly at or near forest industry plants—is the subject of this report. It includes some information on historical trends in the use of wood and bark fuels, summarizes fuel properties, and discusses technical and economic considerations in using such fuels. Sometimes, wood and bark residues are the lowest cost fuel for providing heat and power for a plant—and their use as fuel can solve the problem of disposal.

Our laboratory published a report in 1963 by George H. Atherton, "Burning West Coast Hemlock Hogged Fuel in Boiler Furnaces." This report is now out of print, but some information from it is included here and it was most helpful in preparing the present report.

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INTRODUCTION

The usual response to the question, "What single use, world wide, consumes the greatest quantity of wood?" is "Construction." Not so—the largest single use of wood is still the oldest one—fuel!

In 1969, 43 percent[1] of the wood cut was for fuel (35), and 34 percent of the world's roundwood production was for sawlogs, veneer logs, and railroad ties. Much variation of roundwood use for fuel occurred among various countries. The more industrialized countries used less and the less industrialized countries used more of their roundwood for fuel. In 1969, Latin American countries used 83 percent; Africa, 89 percent; Mainland China, 77 percent; Western Europe, 20 percent; and the United States only 6 percent.

In 1952, the latest year for which we have complete national statistics for roundwood and residues, the Forest Service reports that 25 percent of the timber output of the highly industrialized United States was used for fuel (36). The amount of wood used for fuel was greater than that for lumber.

The quantity of wood burned for fuel in this country has been decreasing continually since the late 1800's. Sixteen percent of the roundwood cut in 1952 was for fuelwood (36) but, in 1969, it was only 6 percent (35). Reasons for the decrease are easy to find. Increasing value for other uses of roundwood and expanding uses of wood residues for pulp and board manufacture, as well as the convenience and low cost (at least until recently) of other fuels, have been major reasons.

Historical Production

Less than a century ago, the United States was well into the Industrial Revolution, and wood was the major source of energy for industrial expansion. In 1850, about 90 percent of the energy was supplied by fuelwood (Figure 1); by 1875, two-thirds of the energy still came from fuelwood. In the 1880's, coal supplanted wood as the major supplier of energy.

Fuelwood consumption reached a peak of about 140 million cords in 1875 and has declined steadily to about 40 million cords in 1970 (Figure 2). Fuelwood now accounts for about 1 percent of the national use of energy (Figure 1).

Historical Uses

Domestic. More than 90 percent of the 100 million cords of firewood consumed in 1850 was used domestically for heating and cooking, and about 75 percent of the total was burned in open fireplaces. An American family in the 1850's used about 18 cords of wood per year for home heating (32).

George B. Abdill[2] noted:

> Residential needs of people in Western Oregon from pioneer days up to fairly recent times must have consumed mountains of fuel wood. It staggers the imagination to think how many cords of wood went into the cookstoves, furnaces and fireplaces over the years. Train load after train load was hauled into Portland every year; . . . . Curbside parking strips in every residential area were stacked with cordwood and the hum of buzz saws filled the air as cutting crews moved through the neighborhoods, cutting 4-foot stacks of cord and mill slab wood into stovewood or furnace lengths.

[1] This includes only roundwood used for fuel. If residues were considered, the use would be greater.
[2] Curator, Douglas County Museum, Roseburg, Oregon. Personal communication. December 26, 1972.

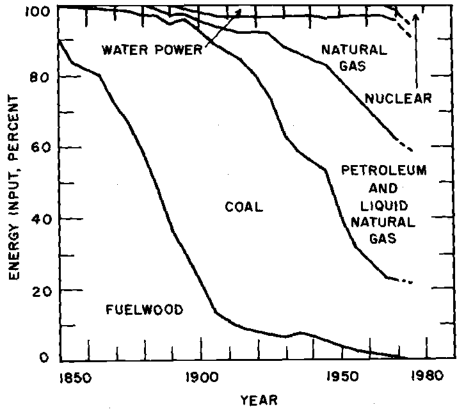

Figure 1. Sources of energy in the United States (6).

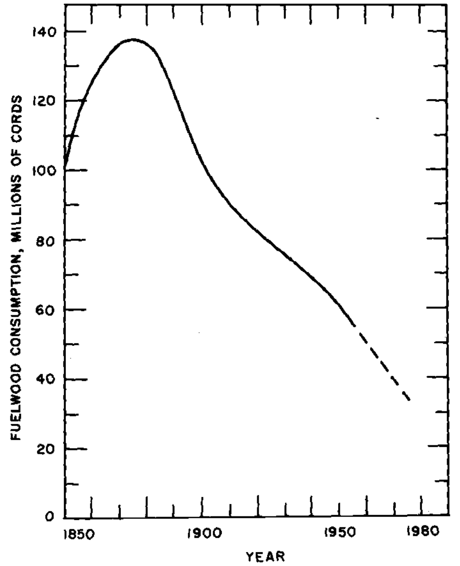

Figure 2. Annual consumption of fuelwood in the United States (32, 36). →

As recently as 1940, 20 percent of occupied dwellings used wood fuel for central heating or cooking, but these uses dropped to about 10 percent by 1950 (32, 36). A further decrease in domestic use of wood fuel has occurred since 1950. Stanford Research Institute (33) predicted a decrease in consumption for all except industrial uses of about 50 percent between 1952 and 1975. Similar decreases were predicted by the U.S. Forest Service (36).

One domestic use of wood fuel has not declined–for fireplaces (Figure 3). Stanford Research Institute reported (33) 14 million cords of wood used in fireplaces in 1950 and projected use of 17 million cords in 1975. Indeed, what 100 years ago was an enormous use of fireplace fuel by necessity has become a small, steady, luxury use today.

Industrial and Transportation Uses. The first railroads and steamboats in this country were fired with wood fuel. Wood was the principal fuel for railroads nationally until about 1870, when about 6 million cords were burned annually (32). Wood continued to be the principal fuel for Oregon's locomotives until the early 1900's, as illustrated in Figures 4 and 5.

George Abdill told me that wood contractors received about $2.75 per cord for 2-foot lengths of wood delivered to the railroad right-of-way, and that Oregon and California railroad engines burned as much as 18 cords of wood on the 144-mile trip from Roseburg to Ashland, Oregon.

Wood fuel was commonly the energy source for early day lumbering as well. Figures 6 and 7 show Pacific Northwest operations where steam produced from wood fuel provided power to yard and saw logs into lumber.

Although coal and oil replaced wood for rail and water transport in this country at about the turn of the century, wood fuel has continued to supply heat and power for many industrial, commercial, institutional, and utility operations. Most industrial use of wood fuel is now at forest industry plants, where it supplies heat and power for their own operations.

In Oregon, 32 forest industry operations generated electricity with wood and bark residues in 1949 and 21 in 1968, according to maps issued by the Federal Power Commission.

Figure 3. Wood fuel for domestic use, at a concentration yard.

Figure 4. "Wooding up" a steam locomotive on the Oregon Pacific Railroad between Corvallis and Yaquina in the 1880's (photograph from the G. B. Abdill collection, Douglas County Museum).

Installed generating capacity of the plants was about 90 megawatts. Many more forest industry companies were using wood and bark residues to produce steam, mainly for drying lumber and veneer.

Two of the largest users of wood and bark fuel in Oregon are at Eugene. The Eugene Water and Electric Board uses about 125,000 units[3] of wood and bark fuel a year to generate electricity and to produce steam for distribution to the Eugene business area. The University of Oregon uses about 75,000 units of fuel annually to supply heat and power to its campus (Figure 8). Wood and bark residues from forest industry operations still provide the cheapest source of heat and power at many installations.

WOOD-BARK RESIDUES

Most logs harvested in this country go into the manufacture of lumber, plywood, or pulp. Less than half the volume of a log ends up as lumber or plywood; the rest is such items as bark, slabs, edgings, sawdust, shavings, veneer and plywood trim, cores, and sander dust. Although

[3]A unit is a bulk volume of 200 cubic feet.

Figure 5. Refueling Engine No. 2 of the Corvallis and Eastern Railroad at Nashville, Oregon, about the turn of the century (photograph from the G. B. Abdill collection, Douglas County Museum).

Figure 6. Wood fuel supplied the energy for yarding logs with early steam logging "donkeys".

Figure 7. Early sawmills used steam produced from wood fuel as a power supply for the mill.

Figure 8. Unloading hogged fuel at the University of Oregon steam plant, Eugene.

more of this residue, in recent years, has been used as a raw material for pulp and composition board manufacture, large amounts still are available for other uses, such as fuel.

In Oregon, most of the raw material for pulp plants is obtained from wood residues of sawmills and plywood plants, but, in the eastern part of the country, much pulp is made from roundwood. Before processing, the bark normally is removed from the roundwood and remains as a residue.

A variety of uses can be made of these wood and bark residues. If a plant does not have sufficient uses and markets for residues, however, then it has a disposal problem. Use as fuel could be a solution.

Characteristics

One term that best describes residues is **variable**. Residues range in size from fine sander dust up to large slabs. Moisture ranges from a small amount in sander dust and plywood trim up to where it exceeds the amount of dry material in wood and bark for some species. And bark looks different from wood (Figure 9).

To reduce many kinds of residue to a particle size that can be more conveniently handled, it frequently is put through a machine called a "hog." The name probably originated because

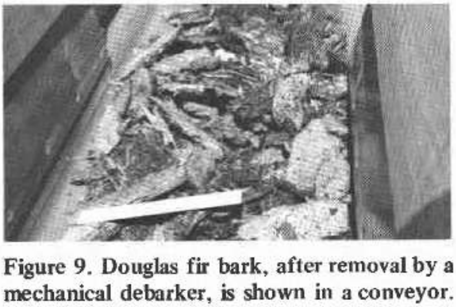

Figure 9. Douglas fir bark, after removal by a mechanical debarker, is shown in a conveyor. Scale is shown by the 12-inch ruler in the foreground.

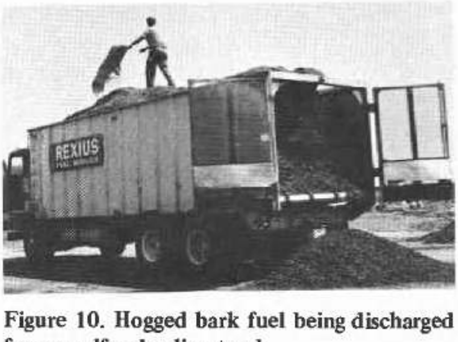

Figure 10. Hogged bark fuel being discharged from a self-unloading truck.

of the voracious capacity of the equipment to consume residue. The processed residue commonly is called hogged fuel or hog fuel, a term that is not specific; it can include wood or bark material, in any proportion, that has been reduced to a particular size. Sometimes sawdust and shavings are added to the hogged material, and the mixture still is called hogged fuel. After bark (Figure 9) is hogged, it is called hogged bark or, again, hogged fuel (Figure 10).

Marketing Measure

In the Pacific Northwest, hogged fuel, as well as other types of residue, usually is sold by bulk volume, or unit. A unit is the amount of material contained in a volume of 200 cubic feet.

A unit of hogged fuel frequently contains about a ton of dry substance (excluding the weight of moisture). The dry weight might range from 1,200 pounds for Douglas fir shavings to 1,900 pounds for sawdust and up to 2,600 pounds for hogged Douglas fir bark (8).

The amount of moisture in hogged fuel varies with the species, time of year, type of hogged fuel, and whether the logs were handled on a dry deck or in a pond. Douglas fir bark from ponded logs frequently contains an amount of moisture about equal to the dry weight. Thus, the weight of a unit of hogged Douglas fir bark from such logs might have a wet weight of about 5,200 pounds.

Amounts

To estimate the amount of different types of residue produced from lumber and plywood manufacture, average conversion factors are given in Tables 1 and 2 (8). I emphasize that these values are intended only as averages for Oregon mills, and much variation occurs between mills and within mills depending on such factors as size of log, quality of log, species, equipment, and kind and size of product, as well as quality control within the mill. To assess the residue for a particular mill, that plant should study its own conditions.

About 4 million dry tons of residues from Oregon sawmills and plywood plants, or 27 percent of the total residues produced, were used for fuel in 1967 (8). The 70×10^{12} Btu of heat contained in that amount of residues used for fuel was about equal to the heat from the

Table 1. Average Conversion Factors for Estimating Residues from the Manufacture of a Thousand Board Feet of Lumber in Oregon (8).

Item	Solid volume[1]	Proportion by volume	Dry weight	
			Western Oregon	Eastern Oregon
	Cu ft	*Percent*	*Tons*	*Tons*
Coarse wood residue[2]	43	26.0	0.580	0.516
Sawdust	22	13.4	0.297	0.264
Planer shavings	16	9.7	0.216	0.192
Total wood residue	81	49.1	1.093	0.972
Bark residue	19	11.5	0.285	0.228
Lumber	65	39.4	0.878	0.780
Total log	165	100.0	2.256	1.980

[1]Equivalent undried solid volume.
[2]Includes slabs, edgings, and lumber trim.

Table 2. Average Conversion Factors for Estimating Residues Developed from the Manufacture of a Thousand Square Feet of Equivalent 3/8-Inch Plywood (Rough Basis) in Oregon (8).

Item	Solid volume[1]	Proportion by volume	Dry weight
	Cu ft	*Percent*	*Tons*
Log trim	3.4	4.4	0.046
Cores	3.7	4.8	0.050
Undried veneer[2]	18.5	24.1	0.250
Dried veneer[3]	6.5	8.5	0.088
Sander dust	1.6	2.1	0.021
Total wood residue	33.7	43.9	0.455
Bark residue	8.8	11.5	0.132
Plywood	34.3	44.6	0.463
Total log	76.8	100.0	1.050

[1]Volumes are based on equivalent undried solid volume.
[2]Undried veneer residue includes veneer clippings, roundup, and spur trim.
[3]Dried veneer residue includes dry veneer loss and panel trim.

total sales in 1967 of the Northwest Natural Gas Company—which supplies most of the natural gas to western Oregon, as well as some areas along the Columbia River in Washington.

Incidentally, while 4 million dry tons of wood and bark were used for fuel in Oregon in 1967, India burned about 100 million tons of cow dung for cooking and heat (38). Indeed, not everyone is cooking with gas!

FUEL PROPERTIES

Ultimate Analysis

Different species of wood show remarkable uniformity in their elemental composition (27), which also is not greatly different for wood and bark (2, 7, 20, 24). Typical, moisture-free, elemental composition of Douglas fir and western hemlock bark is shown in Table 3. The samples were hogged bark from a sawmill (7), so they also contained some wood—a normal component of hogged bark fuel. Ultimate analysis of 14 different species of eastern Canadian barks (24) gave compositions similar to those listed in Table 3.

Bark and wood fuels contain negligible sulfur, and do not, therefore, cause air pollution from sulfur compounds. Most coals and some heavy oils have sufficient sulfur to cause some problems.

Ash is the noncombustible part of fuel that often becomes entrained in the combustion gases and usually is removed in part by some separating device. Wood has a low ash content, generally less than 1 percent of dry weight (2, 15, 25). The ash content of bark is usually greater than that of wood. Handling and harvesting of logs frequently causes dirt and sand to cling to the bark, which adds to the noncombustible content. Table 4 gives reported ash contents for some western species. Chang and Mitchell (5) reported ash content on a dry-weight basis for nine species of softwood barks, which ranged from 0.6 for sugar pine up

Table 3. Typical Ultimate Analysis of Two Bark Fuels on a Dry-Weight Basis (7).

Component	Douglas fir bark	Western hemlock bark
	Percent	*Percent*
Hydrogen	6.2	5.8
Carbon	53.0	51.2
Oxygen	39.3	39.2
Nitrogen	0.0	0.1
Ash	1.5	3.7

to 2.5 percent for Engelmann spruce. Fifteen species of hardwood barks had ash contents ranging from 1.5 for paper birch up to 10.7 percent for white oak. Millikin (24) reported ash contents of several coniferous eastern Canadian barks ranging from 2.0 percent for jack pine up to 4.2 percent for tamarack.

Proximate Analysis

The proximate analysis of a solid fuel is a standard test for determining the relative amount of volatile material it contains. Results usually are reported as a percentage of dry weight for volatile matter, fixed carbon, and ash. Volatile matter for Douglas fir wood generally has been reported (2, 15, 25) at about 85 percent and fixed carbon at about 15 percent. Most other western species of wood were similar in composition (25).

Barks generally have less volatile material and therefore a higher percentage of fixed carbon than does wood. Mingle and Boubel (25) indicated Douglas fir bark contained about 72

Table 4. Reported Ash Contents on a Dry-Weight Basis of Some Western Species.

Species	Reference	Ash content, dry basis	
		Wood	Bark
		Percent	*Percent*
Douglas fir	(25)	0.1	1.2-2.2
Douglas fir	(15)	0.3	---
Douglas fir	(7)	---	1.5
Douglas fir	(2)	0.8	---
Western hemlock	(25)	0.2	1.7
Western hemlock	(7)	---	3.7
Western hemlock	(2)	2.1	---
White fir	(25)	0.5	2.6
Ponderosa pine	(25)	0.2	0.7
Lodgepole pine	(5)	---	2.0
Sugar pine	(5)	---	0.6
Red alder	(5)	---	3.1
Red alder	(25)	---	2.4
Engelmann spruce	(5)	---	2.5
Western larch	(5)	---	1.6

percent volatiles and about 26 percent fixed carbon. They concluded that bark consistently has about 10 percent less volatile matter than does wood. A similar conclusion was made by Koch and Mullen (20) for southern pine. Millikin (24) reported volatile matter from bark of seven coniferous and five hardwood species from eastern Canada ranged between about 70 and 80 percent.

Heating Value

One of the most important properties of a fuel is its heating value. The heating value usually is obtained by burning a known quantity of fuel and measuring the heat released. Because the water vapor from the products of combustion is condensed by the laboratory procedure, the higher heating value usually is reported. When fuel actually is utilized, the water vapor normally is not condensed, so the heat of condensation is not available. This loss, as well as others, is taken into consideration when combustion efficiencies are calculated.

Not much difference in the heating value of moisture and resin-free wood of different species has been found. It is about 8,300 Btu per pound. Resin has a value of about 16,900 Btu per pound (2), so resinous woods have heating values higher than those of nonresinous woods. A summary of published heating values for wood and bark of some western species is given in Table 5. Bark, in general, has higher values than does wood. A higher proportion of resin-like compounds in barks probably accounts for the difference. Chang and Mitchell (5) indicated that the heating value of hardwood barks was lower than that of softwood barks. All softwood barks evaluated (eight species) had values greater than 8,500 Btu per dry pound, but nine of the twelve hardwood barks had lower values.

Because wood fuel often is marketed by volume rather than weight, the heating value of some western woods is shown by volume in Table 6. The volumetric heating values are compared to that of Douglas fir. I would like to emphasize that heating values given in Table 6 are based on the heat contained in dry wood and do not take into account different moisture contents that might occur in the different kinds of wood.

Moisture

An important characteristic of a fuel—especially wood and bark—is the amount of moisture or water included with the dry substance. Moisture has a negative heating value, because heat is required to evaporate it, and the heat in the evaporated moisture is lost up the stask.

The amount of moisture in a material can be expressed in several ways. In the forest products field, moisture content is given usually in terms of the weight of water in a material divided by the weight of dry substance, and then this proportion is expressed as a percentage. A material with equal weights of water and dry substance would have a moisture content of 1/1 = 1.0 or 100 percent, reported on the dry basis.

Another way of reporting moisture content—the one more common in the field of fuels and combustion—is to express moisture as the weight of water in a material divided by the total wet weight of the material, with this ratio then expressed as a percentage. A material with equal weights of water and dry substance would have a moisture content of 1/2 = 0.5 or 50 percent, reported on the wet basis.

If the moisture content on either the wet or the dry basis is known, it can be converted to the other by the following:

M.C. (wet) = 100 M.C. (dry)/[100 + M.C. (dry)]

M.C. (dry) = 100 M.C. (wet)/[100 - M.C. (wet)], where M.C. = moisture content in percent, either wet or dry basis, as designated.

The relations of moisture contents on wet and dry bases are shown for the normal ranges of wood and bark fuels in Figure 11.

In this paper, I will express moisture content on the dry basis for two reasons. First, it is the expression most familiar to persons in the forest products industry. Second, it gives a more understandable concept of the relative amount of water compared to the dry weight of wood, which is directly related to heat supplied. For example, if we had 1 pound of dry wood at a moisture content of 50 percent, wet basis, and then added enough water to have 60 percent moisture on the wet basis, the moisture increase on the wet basis is from 50 to 60 percent–that is, 10 percentage points–an apparently small increase. The actual water

Table 5. Summary of Published Heating Values for Wood and Bark of Some Western Species.

Species	Reference	Higher heating value, per dry pound	
		Wood	Bark
		Btu	*Btu*
Douglas fir	(7)	---	9,400[1]
Douglas fir	(9)	9,200	10,100
Douglas fir	(15)	8,860	---
Douglas fir	(41)	8,800	10,100
Douglas fir	(2)	8,910[2]	---
Western hemlock	(7)	---	8,900[1]
Western hemlock	(9)	8,500	9,800
Western hemlock	(41)	8,000	---
Western hemlock	(2)	8,620	---
True firs	(9)	8,300	---
(White fir)	(41)	8,000	---
Ponderosa pine	(9)	9,100	---
Ponderosa pine	(41)	9,140	---
Lodgepole pine	(9)	8,600	---
Lodgepole pine	(5)	---	10,760
Sitka spruce	(9)	8,100	---
Engelmann spruce	(5)	---	8,820
Western larch	(5)	---	8,750
Western redcedar	(9)	9,700	8,700
Western redcedar	(41)	9,700	---
Redwood	(2)	9,210	---
Red alder	(9)	8,000	---
Red alder	(41)	8,000	---
Red alder	(5)	---	8,410
Oregon ash	(41)	8,200	---
Bigleaf maple	(41)	8,410	---
Bigleaf maple	(9)	8,400	---
Black cottonwood	(9)	8,800	9,000
Oregon white oak	(41)	8,110	---

[1]Hogged bark as obtained from a mechanical debarker had some wood included.
[2]Sawdust.

Table 6. A Comparison of the Densities and Heating Values on a Volume Basis of Some West Coast Species of Wood.

Kind of wood	Density dry	Higher heating value, dry	Heating value reference	Higher heating value	Relative[2] heating value
	Lb per cu ft[1]	*Btu per lb*		*Btu per cu ft*[1]	
Douglas fir	28	8,900	(2)	249,000	1.00
Western hemlock	24	8,500	(9)	204,000	0.82
Ponderosa pine	24	9,100	(9)	218,000	0.88
Lodgepole pine	24	8,600	(9)	206,000	0.83
Sitka spruce	23	8,100	(9)	186,000	0.75
Western redcedar	19	9,700	(9)	184,000	0.74
Redwood	24	9,210	(2)	221,000	0.89
Red alder	23	8,000	(9)	184,000	0.74
Black cottonwood	20	8,800	(9)	176,000	0.71
Bigleaf maple	27	8,400	(9)	227,000	0.91
Oregon ash	31	8,200	(41)	254,000	1.02
Oregon white oak	37	8,110	(41)	300,000	1.20

[1]Volume based on green condition, solid volume.
[2]Relative basis, Douglas fir equal 1.0, different fuel moisture not considered.

associated with that 1 pound of dry wood is 1 pound at 50 percent moisture, wet basis, and 1.5 pounds of water at 60 percent moisture, wet basis—a 50-percent increase in the amount of water. The dry-basis moisture reflects this 50-percent increase in water by going from 100-percent moisture, dry basis, to 150-percent moisture, dry basis.

Wood and bark fuels vary widely in moisture content; the range for commercial hogged fuels in the Northwest is usually between 75 and 125 percent (2, 4, 12, 15, 17, 22, 31). It is generally lower in summer than in winter and is higher for some species than others. Douglas fir hogged fuel is usually less than 100 percent moisture (2, 7, 15), but western hemlock hogged fuels are frequently over 100 percent (2, 17). Some species, such as sugar pine, might have moisture contents of nearly 200 percent.

Certain types of wood residues used for fuel might have extemely high or extremely low moisture contents. Sander dust, for example, would be low—perhaps, 10 percent—but sawdust coming from water-cooled saws could have in excess of 200 percent moisture. When the moisture exceeds about 150 percent, the fuel is difficult to burn in most commercial installations.

COMBUSTION

Combustion is a chemical combination of hydrogen and carbon in the fuel with oxygen in the air, in which heat is evolved. If combustion is complete, hydrogen combines with oxygen to form water vapor, and the carbon combines with oxygen to form carbon dioxide. Small amounts of carbon monoxide, hydrocarbons, and other gases usually form because some of the carbon and hydrogen does not react completely with oxygen. The ash is noncombustible, so it either falls to the grate or is entrained with combustion gases.

Three successive, overlapping steps occur in the combustion of wood and bark: water evaporation, distillation and combustion of volatile matter, and reaction of fixed carbon with oxygen. Before combustion can occur, water first must be evaporated from the fuel, and this step requires heat. In the second step, volatile hydrocarbon gases are evolved and mixed with oxygen, which releases heat. In the final step, the fixed carbon combines with oxygen at high temperature to produce carbon dioxide, which also releases heat.

Air Requirements

The amount of air theoretically needed for combustion can be calculated if the fuel analysis is known and the carbon and hydrogen in the fuel are assumed to burn completely to carbon dioxide and water. This amount is called "theoretical air." In practice, a quantity of air greater than the amount indicated by theoretical calculations must be supplied to insure adequate mixing and to have optimum conditions for combustion. Air supplied in excess of theoretical air is defined as "excess air."

Using the fuel analysis for Douglas fir bark given in Table 3, about 6.5 pounds of air theoretically are required to burn 1 pound of dry fuel. The quantity of air required for complete burning of 1 dry pound of this Douglas fir bark fuel with up to 100 percent excess air is shown in Figure 12. Air quantities are given in both weight and volume, assuming air is at standard atmospheric pressure and at a temperature of 70 F. The curve should help in determining capacity for forced-draft fans.

Stack Gases

When 1 pound of dry Douglas fir bark fuel at 100 percent moisture (2 pounds of fuel including moisture) is burned completely with theoretical air, about 8.5 pounds of stack gas

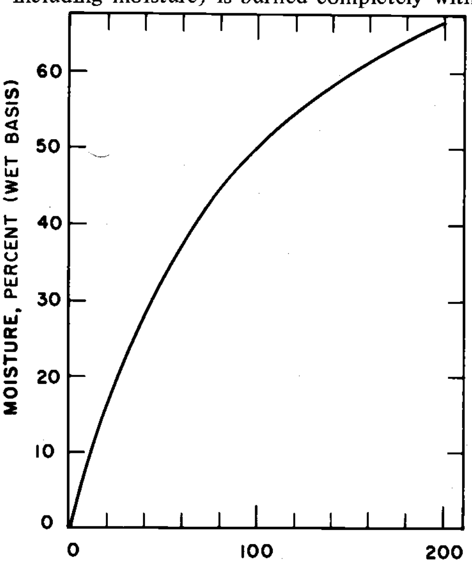

Figure 11. The relation between moisture contents as expressed on percentages of wet and dry weights.

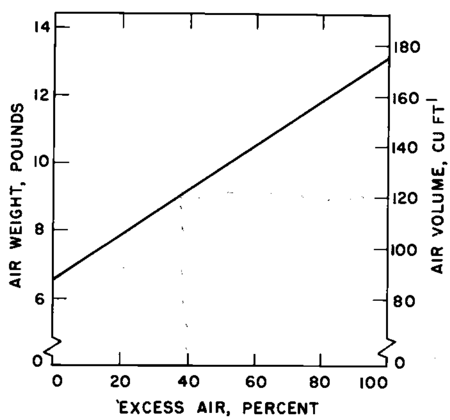

Figure 12. Air required for complete burning of 1 pound of dry Douglas fir bark fuel. Volume in cubic feet is calculated for standard air at 70 F with a density of 0.075 of a pound per cubic foot.

are produced. The weight of stack gases from complete burning of 1 pound of dry Douglas fir bark with a range of moisture content and amounts of excess air is given in Figure 13.

The volume of stack gases produced in burning fuel increases with the temperature of the gases. Figure 14 indicates the volume of stack gases produced in burning 1 pound of dry Douglas fir bark with 40-percent excess air and with a range of stack temperatures and fuel moistures that might occur with this fuel. An air supply of 40-percent excess was selected because it represents a condition that might exist in a boiler plant using such fuel. The curve could assist in determining size of induced-draft fans.

The main components of the stack gases are carbon dioxide, nitrogen, oxygen, and water vapor. To determine excess air in a combustion process, a sample of stack gases is analyzed for carbon dioxide or oxygen on a dry volumetric basis. An indication of excess air used for combustion can be determined by assuming complete combustion. Such a relation of carbon dioxide and oxygen to excess air is shown for Douglas fir bark in Figure 15. Because most wood and bark fuels are similar in composition, their relation would be similar.

STEAM PLANTS

Wood and bark residue fuels are used extensively for producing steam. They also are burned in stoves, furnaces, and fireplaces for home heating. Sander dust is used to supply heat directly to veneer dryers (37, 39) and to dryers for wood particles (21), as well as to fire steam plants. The biggest industrial application of wood and bark fuels, however, is burning them in furnaces to produce steam, which is then used for heating, processing, power, or the generation of electricity. Steam plants burning hogged fuel range in capacity from small plants producing 10,000 pounds of steam per hour up to plants at large paper mills producing over 500,000 pounds.

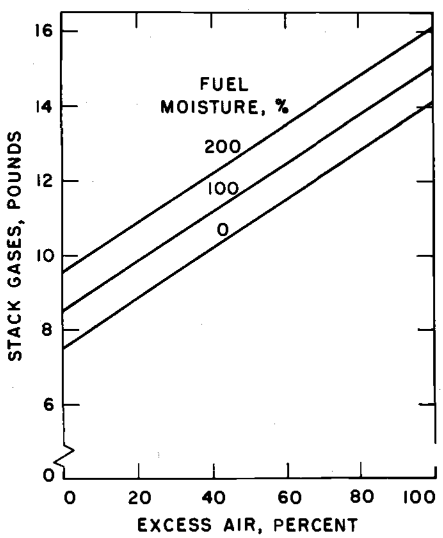

Figure 13. Weight flow of stack gases when 1 pound of dry Douglas fir bark fuel is burned completely.

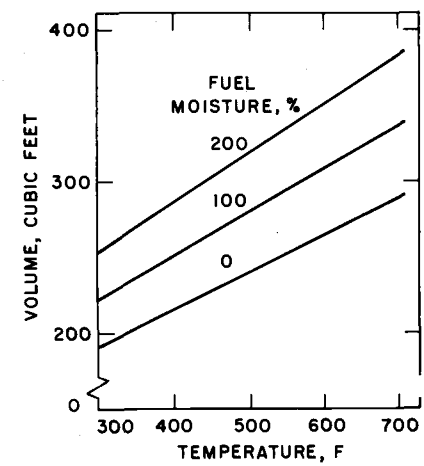

Figure 14. Volume of stack gases from the burning of 1 pound of dry Douglas fir bark fuel with 40 percent excess air.

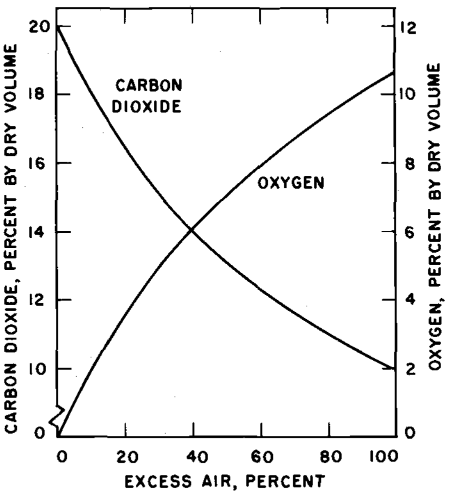

Figure 15. Carbon dioxide and oxygen as volumetric percentages of dry stack gases when Douglas fir bark fuel is burned completely with various amounts of excess air.

Burning Methods

Dutch Oven. A common way of burning wood and bark hogged fuel has been a two-stage furnace consisting of a dutch oven in which moisture is evaporated and fuel gasified, and a secondary furnace where combustion is completed (Figure 16). The fuel is fed by gravity through an opening in the primary furnace and forms a conical fuel pile. Although the dutch-oven furnace has been used widely in the past (2), and almost exclusively until the late 1940's, most newer installations follow other burning methods.

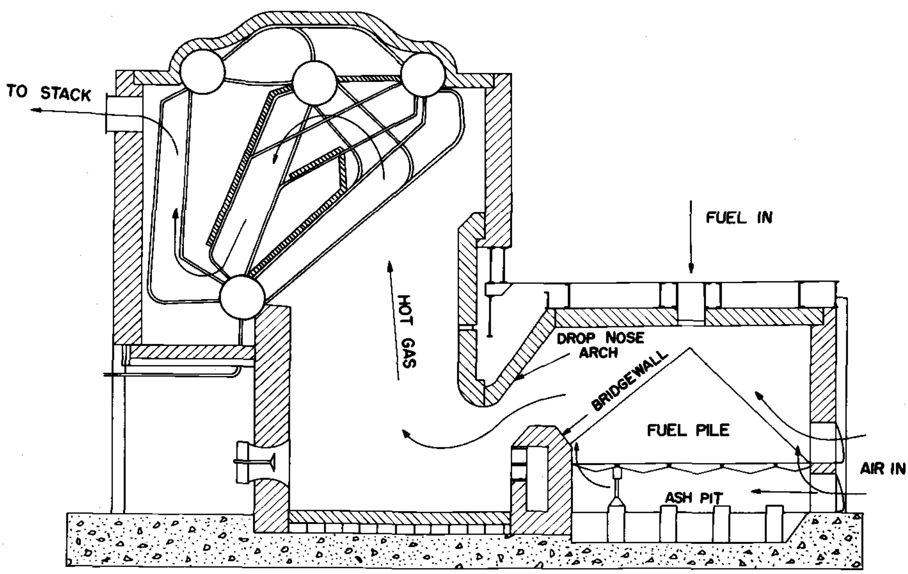

Figure 16. Boiler with a dutch-oven furnace.

Fuel Cell. Another two-stage furnace is called a fuel cell. The fuel drops from above onto a water-cooled grate in the primary furnace, and the gases pass into a secondary combustion chamber where burning is completed (Figure 17). Many boilers of this type have been installed in the western United States. The steam plants are automated so that little labor is required for their operation. They operate at low pressure (below 25 psi) with capacities usually ranging between 10,000 and 30,000 pounds of steam per hour. Most of them are at lumber plants

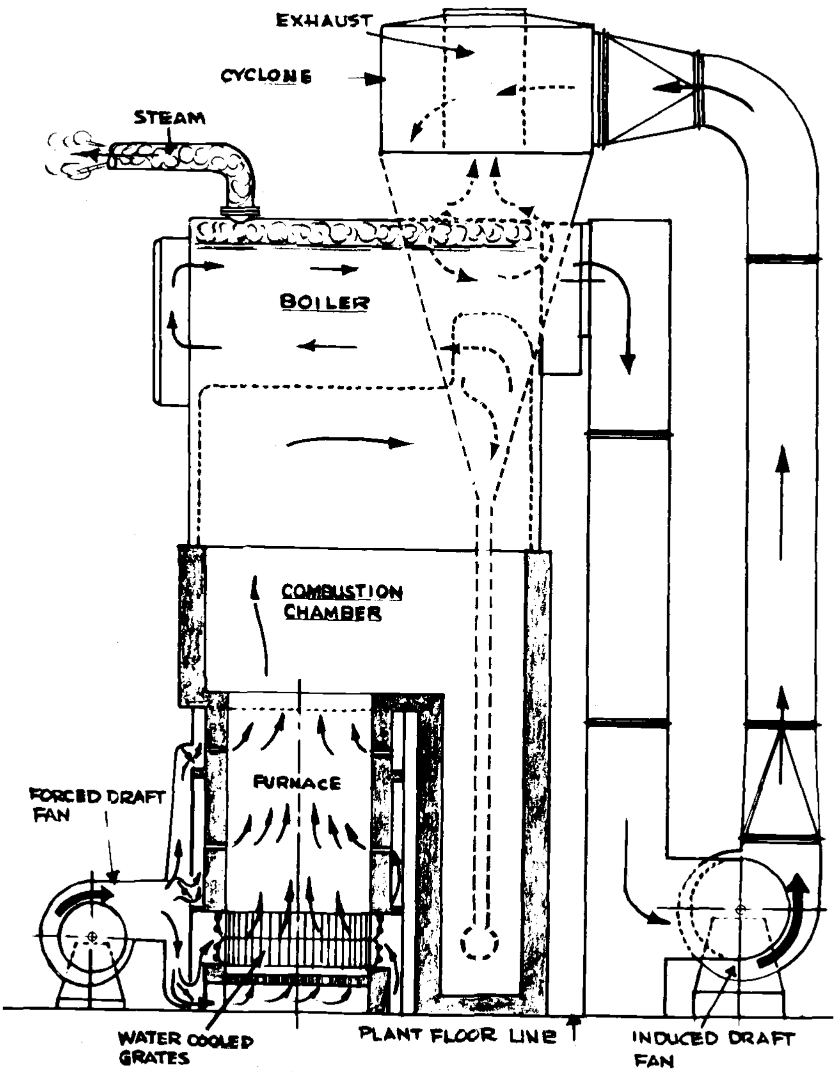

Figure 17. Automatically controlled steam plant that uses wood and bark residues for fuel (from Larry Wellons and Associates, Inc.).

Figure 18. Automatically fired steam plant at a lumber mill in Grant's Pass, Oregon, that uses sawdust to produce steam for dry kilns.

where the steam is used in kilns for drying lumber (10). Some units (Figure 18) incorporate fuel dryers, which become necessary if the fuel moisture is much above 100 percent.

Spreader Stoker. Many recently installed steam plants fueled by wood and bark have been the spreader-stoker type (4, 12, 13, 16, 17, 22, 29, 31, 40). With the spreader stoker, fuel is introduced above the grate into the furnace by either a pneumatic or mechanical spreader. Part of the fuel is burned in suspension, and the remainder drops to the grates where burning is completed. Spreader stokers are used with small boilers that have capacities as low as 25,000 pounds of steam per hour up to large plants with capacities in excess of 500,000 pounds. The general arrangement of such plants is illustrated in Figures 19 and 20.

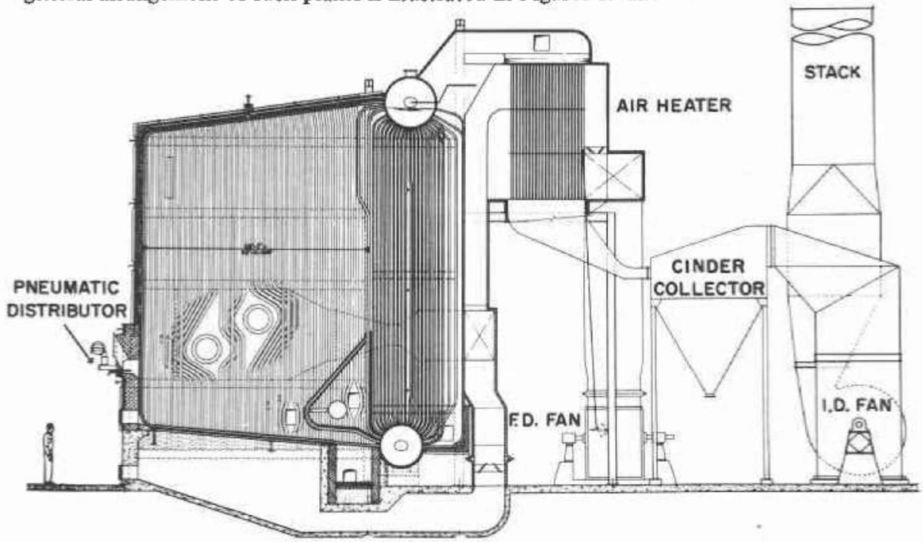

Figure 19. Recent steam-plant installation in Idaho, designed to produce 180,000 pounds of steam per hour using hogged fuel. The fuel is spread by pneumatic spreaders (drawing courtesy of Riley Stoker Corporation).

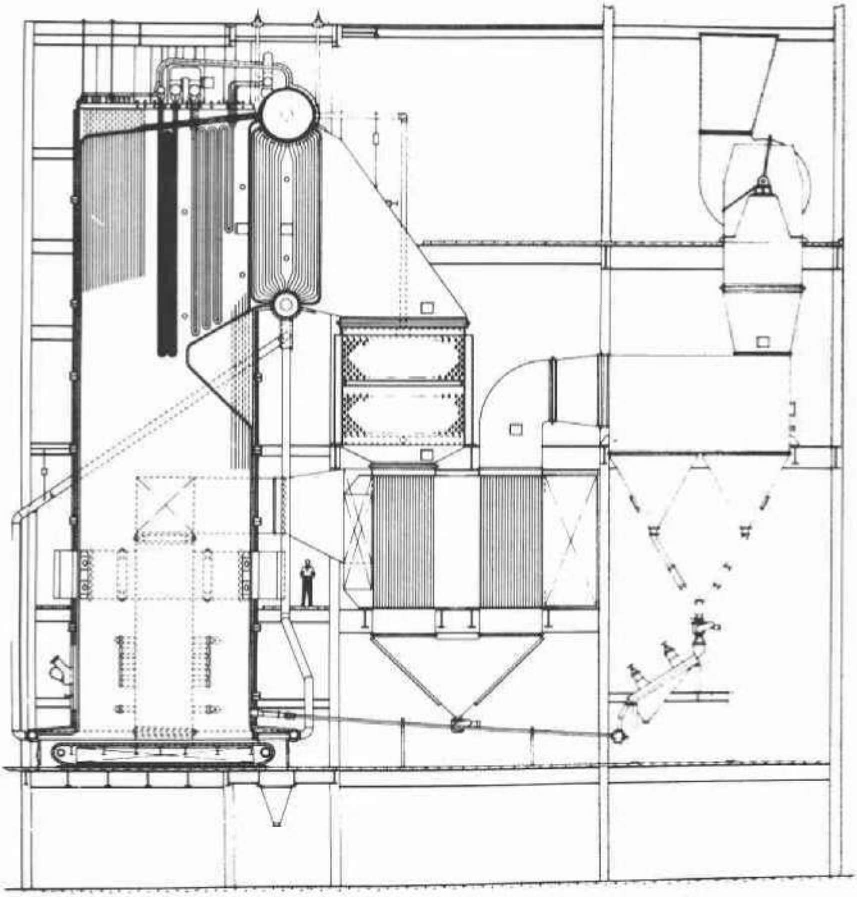

Figure 20. Steam boiler at a Louisiana paper company, designed to burn hogged bark with a spreader stoker. The plant can generate 450,000 pounds of steam per hour (drawing courtesy of Combustion Engineering, Inc.).

Inclined Grate. The inclined grate furnace is shown in Figure 21. Fuel enters the furnace at the top part of the grate in a continuous ribbon, passes over the upper drying section where moisture is removed, and then descends into the lower burning section. Finally, the ash is removed at the lowest part of the grate.

Boiler Performance

When boiler performance is examined, a heat balance is made to see where the heat in the fuel is distributed. Energy supplied by the fuel is distributed among the following items:

a. Heat absorbed by boiler fluid (to steam),

b. Heat loss to dry stack gases,

c. Heat loss to moisture in the fuel,

d. Heat loss from formation of moisture from hydrogen in the fuel,

e. Heat loss from incomplete combustion, and

f. Heat loss from radiation and unaccounted for.

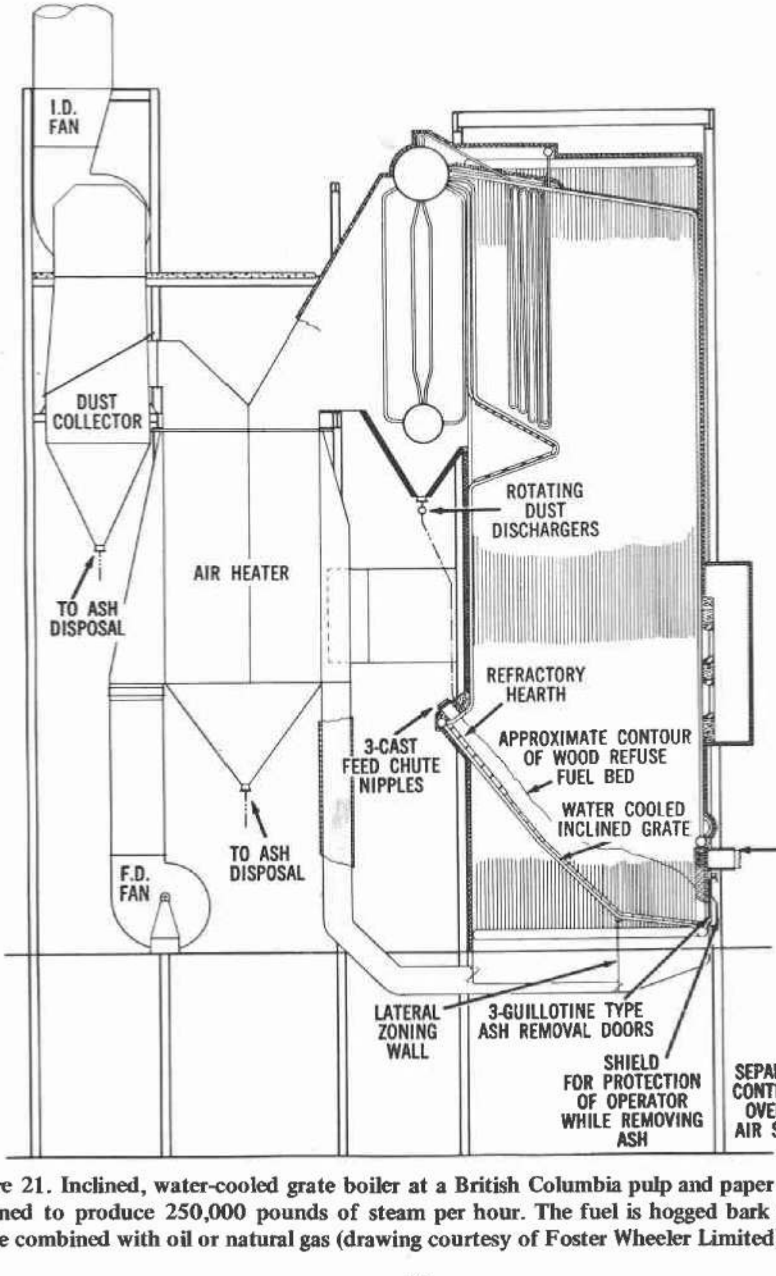

Figure 21. Inclined, water-cooled grate boiler at a British Columbia pulp and paper company, designed to produce 250,000 pounds of steam per hour. The fuel is hogged bark and wood refuse combined with oil or natural gas (drawing courtesy of Foster Wheeler Limited).

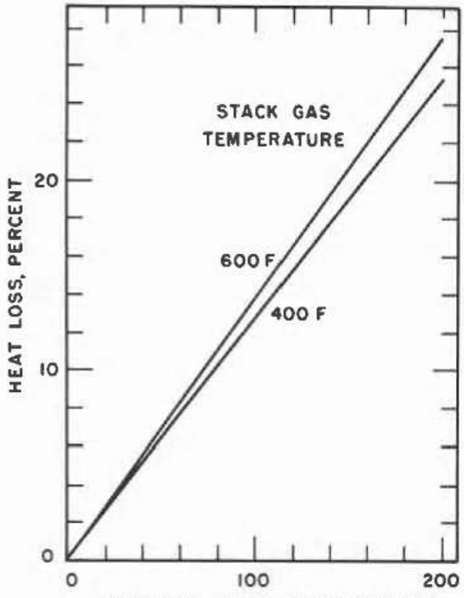

Figure 22. Heat loss because of moisture content as a percentage of heating value. The fuel is assumed to be Douglas fir bark with a heating value of 9,400 Btu per pound.

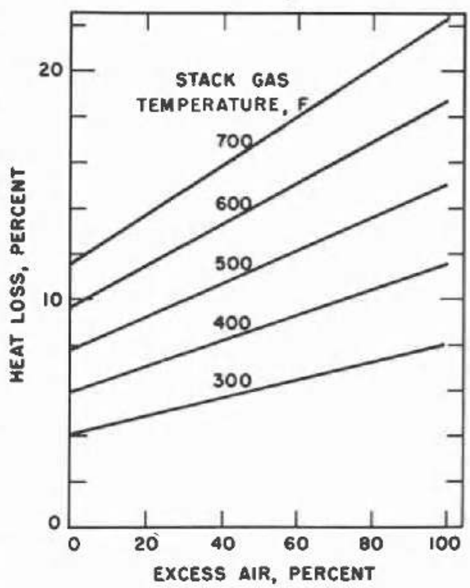

Figure 23. Heat loss because of dry stack gases as a percentage of the heating value for Douglas fir bark fuel. Complete combustion was assumed and entering air was assumed to be at 70 F.

The most important performance parameter for a boiler is the overall efficiency, which is item a above divided by the total heat supplied by the fuel. To arrive at overall efficiency, evaluating the various heat losses (items b through f above) and then calculating overall efficiency, or item a, by difference, often is simpler.

The last two items of heat loss (e and f) are small and might be assumed to be about 4 percent (23). Heat loss from formation of moisture from hydrogen in the fuel (item d) will vary from about 7 to 8 percent for Douglas fir bark fuel depending on stack temperature.

Fuel Moisture. Because most wood and bark fuels have high moisture contents, heat loss from fuel moisture is correspondingly high. Figure 22 shows heat loss from a range of fuel moisture contents for Douglas fir bark. About 13 percent of the total heat in the fuel is required for moisture evaporation at 100 percent fuel moisture, and about 26 percent of the fuel heat is needed at a fuel moisture of 200 percent.

Not only does increasing fuel moisture content increase heat losses and thereby reduce overall efficiency, but an increasing moisture content also retards combustion and lowers flame temperature, which reduces steam rate capacity. At a point between about 180 and 230 percent moisture, a stable fire no longer can be maintained (23).

Preliminary treatments might aid in burning excessively wet fuels. A moisture press or a fuel dryer (Figure 18) might remove enough moisture so the fuel will burn satisfactorily in the furnace, or auxiliary oil or gas firing can be used.

Dry Stack Gases. The heat loss in a boiler from dry stack gases depends on the amount of excess air used for combustion and also on the stack gas temperature. Figure 23 shows heat loss from dry stack gases for different values of excess air and stack gas temperature. Heat loss to stack gases can be reduced by minimizing excess air into the furnace and by passing stack gases through an air preheater after they have passed through the boiler (Figures 19 and 21).

Overall Efficiency. When various items of heat loss have been evaluated, the overall efficiency of a steam plant can be predicted. Figure 24 indicates overall efficiencies for a steam plant using Douglas fir bark fuel with 40-percent excess air. Excess air amounting to 40 percent was chosen as a value that might be expected with hogged fuel firing. Because the main effect of excess air is on losses of dry stack gas, corrections for other values of excess air could be obtained by referring to Figure 23.

With stack temperatures of 400-500 F and fuel with 100 percent moisture, a boiler efficiency of 65-68 percent is indicated from Figure 24. Reported efficiencies of operating plants (4, 22, 23, 31) also indicate similar values for boiler efficiencies with fuel of about 100 percent moisture. To obtain above efficiencies, heat-recovery equipment such as air heaters or economizers usually is required.

Air-Pollution Control

One of the most important considerations for any plant now in operation or being planned is, "Will it meet air-pollution-control regulations?" Wood and bark fuels have negligible amounts of sulfur so emissions of sulfur compounds are not a problem. The regulations most applicable to wood and bark-fired steam plants pertain to visible smoke and particulate loading from the stack. Oregon's laws are among the most stringent in this country

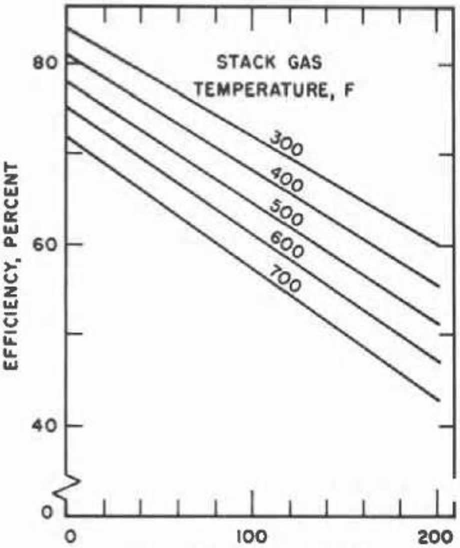

Figure 24. Calculated efficiency of a steam plant using Douglas fir bark fuel with 40-percent excess air. Heat loss from unburned fuel, radiation, and unaccounted for was assumed to be 4 percent.

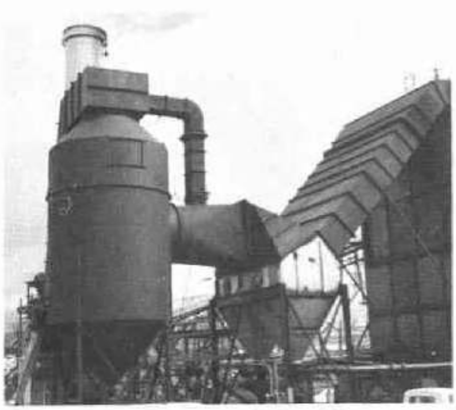

Figure 25. Multitubular dust collector and wet scrubber, installed by Bumstead Woodford Company, on a hogged fuel boiler at Missoula, Montana (photograph courtesy of Western Precipitation Division, Joy Manufacturing Company).

and limit particulate emissions from new boilers to 0.1 grain per standard cubic foot of gas corrected to 12 percent carbon dioxide (1).

Dust loading from bark-burning furnaces has been reported (3) to range from 0.5 to 5.0 grains per standard cubic foot. Dust concentration increases with the second or third power of the boiler load (3, 22). Therefore, reducing the boiler output reduces the particulate concentration of stack gases.

Fly Ash Characteristics. Particulate emissions from hogged-fuel boilers depend on the nature of the hogged fuel. Bark has a higher ash content than wood and it also has significant amounts of dirt or sand that result from log handling. Because most hogged fuels contain bark, they also contain various amounts of dirt and sand.

Particulate emissions from hogged fuel or hogged bark-burning boiler stacks are, therefore, usually a mixture of two separate kinds of material, sand (or dirt) and char. Sand is fine, dense or heavy, highly abrasive, and not a highly visible component of stack emission (3). Char is small, incompletely burned fuel particles that are mainly unburned carbon. This unburned carbon, or char, has low density and is irregular in shape, extremely fragile, and highly visible (3).

Fly Ash Collectors. Normally, mechanical fly ash collectors are installed on most hogged-fuel stoker-fired boilers, although not on dutch-oven installations. The usual type of mechanical collector consists of multiple small-diameter cyclones. Barron (3) gives a good description and discussion of the operation of mechanical collectors with bark-fired boilers.

Reinjection. Because unburned char contains appreciable combustible material, the fly ash obtained from mechanical collectors frequently is reinjected into the furnace for further combustion. The noncombustible fraction, however, will not be burned, so that complete reinjection causes an increase in dust concentration coming from the furnace. Particulate emissions from stacks, therefore, will be reduced by installing a screening system to separate the char from the sand or ash (3, 26, 29). The screened portion high in ash and sand then is discarded, and that portion having a large amount of char is reinjected into the furnace.

Two-Stage Particulate Removal. To meet present regulations for particulate emissions, two-stage collection may be required (1, 3, 12, 18, 30, 34). A two-stage, mechanical, dust-collection system is reported (3, 18) to increase efficiency of overall particulate collection to about 95 percent as compared to about 90 for a single stage.

Another system of two-stage particulate collection has a mechanical collector for the first stage and a wet scrubber for the second stage. Such two-stage systems (Figure 25) have been installed on hogged-fuel boilers (12, 30), and are reported (1, 12, 18) able to meet present emission regulations. The wet scrubber has several disadvantages: a visible steam plume is discharged from the stack; water supply to the scrubbers is required; and the ash slurry requires disposal (12).

Another possibility for two-stage collection is mechanical collectors followed by electrostatic collectors. The use of electrostatic collectors, however, has not been proven with hogged-fuel boilers (1).

ECONOMICS

Fuel-Cost Comparison

Three principal industrial fuels in Oregon are oil, natural gas, and hogged fuel: oil is sold by the barrel, natural gas by the therm (equivalent to 100,000 Btu's), and hogged fuel by the unit (200 cubic feet of volume).

To compare fuels, the costs should be for equivalent heat output. The last column of Table 7 and Figure 26 show costs in dollars per million Btu of fuel utilized in a steam plant with assumptions as given in the table. Costs listed are those that prevailed in the Willamette Valley of Oregon in December, 1972. Other fuel costs or assumptions could be used for different conditions. For a plant with unused wood and bark residues available for which they have no market, no direct cost for fuel would be incurred if the residues were used for fuel at the plant site.

Table 7 and Figure 26 show that costs for hogged fuel are considerably lower than for oil or natural gas. Fuel is a big item in steam generation, but overall costs must take into account the higher costs of capital and fuel handling associated with hogged fuel.

Although costs appear lower for natural gas than for oil, industrial use of natural gas for steam plants is one of lowest priority. If natural gas were in limited supply, large steam plants would be among those customers first curtailed. Customers on interruptible gas service have to use other fuels when natural gas is interrupted. For example, natural gas at the Oregon State University's heating plant, which uses it on an interruptible schedule, was curtailed over 3 months in the 1971-1972 heating season and about 2½ months in the 1972-1973 heating season.

We are reminded constantly of an energy crisis, impending fuel shortages, and expected rising fuel prices. Indeed, most fuel prices have increased significantly in the past few years. For example, the price of No. 5 fuel oil used by Corvallis schools increased 55 percent in the 3-year period from 1969 to 1972. Natural gas prices in the Willamette Valley, on an interruptible schedule with a usage of 500,000 therms per month, increased 23 percent for the same period, with another increase of 13 percent effective April 1, 1973. Along with higher prices have been longer periods of interruption of service. Prices for hogged fuel depend markedly on location and on local conditions of supply and demand. In January 1973, the University of Oregon paid half the price for hogged fuel that they had paid 10 years previously although prices of most fuels generally were increasing.

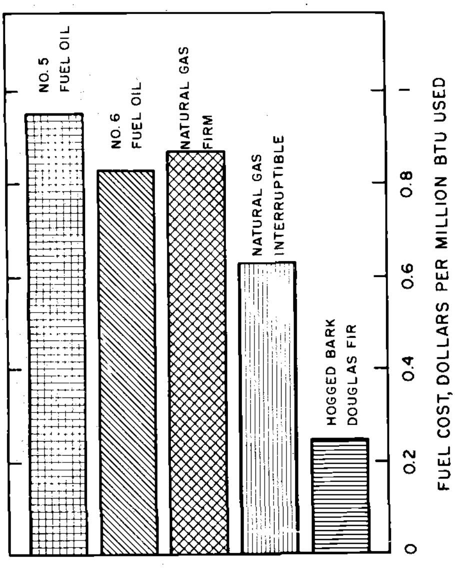

Figure 26. A comparison of costs of some industrial fuels for steam generation from data in Table 7. Natural gas usage assumed was 100,000 therms per month, and the cost of hogged Douglas fir bark assumed was $4.00 per unit.

Hogged Fuel Comparisons

For a given heat content, hogged fuel is heavier and bulkier than oil. For example, 4.3 pounds of Douglas fir bark are needed for the same heat output as 1 pound of oil (Figure 27) with the assumptions given in Table 7. By volume, about 11 cubic feet of hogged Douglas fir bark supply about the same heat as 1 cubic foot of oil (Figure 27). Transportation costs are therefore higher (Figure 28), and much larger storage volumes are needed for hogged fuel than for oil.

A comparison of how much oil or gas is needed to supply the same heat as a unit of hogged fuel would be of interest. Table 8 and Figure 29 show the quantities of oil and gas that have the same heat output as a unit of hogged fuel, based on assumptions given in Table 7.

Using information for western hemlock bark given in Table 7 and generating steam at 600 psi and 750 F from water at 212 F, we find that one unit of hemlock bark will produce about 10,800 pounds of steam.

Steam-Plant Costs

Because hogged fuel is bulky and has high moisture content, steam plants that use it cost more than steam plants that use oil or gas. Koch and Mullen (20) reported that a steam boiler for burning bark and oil would cost about twice that for a boiler burning oil only. J. Donald Kroeker and Associates[4] indicated that a hogged fuel boiler with capacity for 100,000 pounds of steam per hour would cost about twice as much as one that burns oil and gas only. Dost (11) indicated that a small, automated, wood or bark-fired boiler of the type illustrated in Figure 18, complete with fuel-storage silo, would cost about four times as much as the same size oil-fired boiler.

To give an indication of costs for steam plants fired with hogged fuel, Haley (17) reported a bark-fired steam plant with a capacity of 27,000 pounds of steam per hour had an installed cost of $340,000. Evanson (14) indicated a boiler fired with hogged fuel, with a capacity of 100,000 pounds of steam per hour, would cost about $650,000. For an automated,

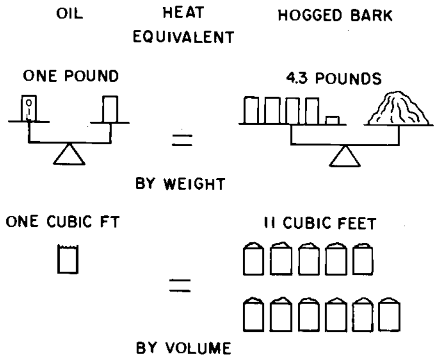

Figure 27. Weight and volume comparison of equivalent heat for oil and hogged Douglas fir bark with 80-percent moisture.

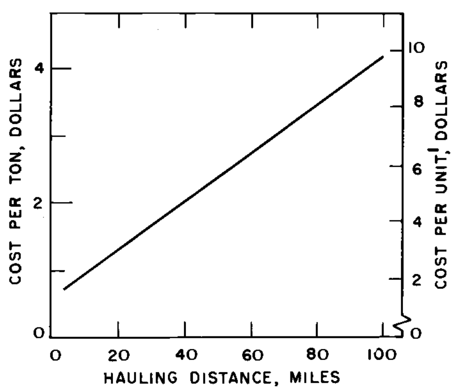

Figure 28. Truck hauling cost for Douglas fir hogged bark with 80-percent moisture. Costs shown are 15 percent higher than those reported (19) because of estimated cost increase. Hogged bark weight is assumed to be 4,700 pounds per unit.

[4] Unpublished report on fuels for use in the heating and power plant of the University of Oregon. 1963.

Table 7. Fuel Cost Comparison of Some Industrial Fuels Used for Steam Generation.

Kind of fuel	Quantity of measure	Cost per quantity	Heating value per quantity	Assumed steam gen. efficiency	Fuel cost
		Dollars	*Million Btu*	*Percent*	*$ per million Btu*
Oil					
No. 5 fuel oil	Barrel	4.80	6.3	80	0.95
No. 6 fuel oil	Barrel	4.20	6.3	80	0.83
Natural gas					
Industrial firm[1]					
100,000 therms per month	Therm	0.0661	0.1	76	0.87
500,000 therms per month	Therm	0.0612	0.1	76	0.81
Industrial interruptible[2]					
100,000 therms per month	Therm	0.0480	0.1	76	0.63
500,000 therms per month	Therm	0.0444	0.1	76	0.58
Wood-bark residues					
Douglas fir sawdust	Unit[3]	2.0-4.0	16.9[4]	66[5]	0.18-0.36
Western hemlock sawdust	Unit[3]	2.0-4.0	14.3[4]	58[5]	0.24-0.48
Douglas fir hogged bark	Unit[3]	2.0-4.0	24.4[4]	67[5]	0.12-0.24
Western hemlock hogged bark	Unit[3]	2.0-4.0	19.6[4]	66[5]	0.16-0.31

[1]Northwest Natural Gas Co., Schedule 21, high load factor, additional charge for excess peak period usage. Effective November 14, 1971.

[2]Northwest Natural Gas Co., Schedule 23. Effective November 14, 1971.

[3]A unit is 200 cubic feet of bulk volume assumed to contain 1,900 pounds of dry Douglas fir sawdust, 1,700 of western hemlock sawdust, 2,600 of Douglas fir bark, and 2,200 pounds of dry western hemlock bark.

[4]Higher heating values per pound, dry, assumed; Douglas fir sawdust, 8,900; western hemlock sawdust, 8,400; Douglas fir bark, 9,400; and western hemlock bark, 8,900.

[5]Efficiencies assumed 40-percent excess air, 500 F stack temperature, fuel moisture 80 percent for Douglas fir sawdust and bark and western hemlock bark, 120 percent for western hemlock sawdust.

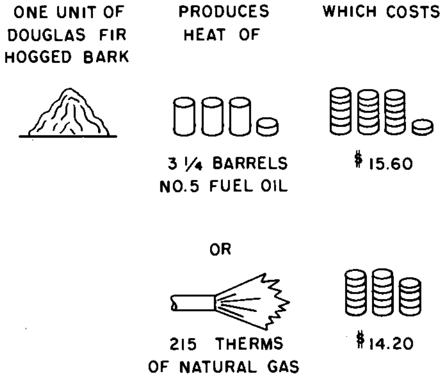

Figure 29. Comparison of heat produced from different fuels. Cost of oil is assumed to be $4.80 per barrel; natural gas is assumed to be 6.61 cents per therm by Northwest Natural Gas Company Schedule 21–Firm High Load Factor–100,000 therms per month. Other assumptions are listed in Table 7.

Table 8. A Comparison of the Quantity of Oil or Natural Gas Required to Provide the Heat Equivalent to One Unit (200 Cu Ft) of Wood-bark Residues for Steam Generation. Assumptions Given in Table 7.

Kind of residue	Heat equivalent	
	Oil	Natural gas
	Barrels	*Therms*
Douglas fir sawdust	2.21	147
Western hemlock sawdust	1.65	109
Douglas fir hogged bark	3.24	215
Western hemlock hogged bark	2.57	170

low-pressure, wood-fired boiler complete with fuel silo and all fuel-processing and conveying equipment, Pratt (28) reported a total cost of $241,000 for a plant with a capacity of about 20,000 pounds of steam per hour.

Overall Economics

As I mentioned before, where hogged fuel is available, it is frequently the lowest cost fuel, but capital and operational costs are greater for a steam plant fired with hogged fuel than for one that uses oil or gas. An indication of the overall economics of steam generation with hogged fuel compared to oil or gas can be obtained from reported plant operations or studies.

Dost (11) reported that for a sawmill kiln-drying about 18 million board feet of white fir and pine annually, the fuel savings for a wood-fired steam plant would be about $41,000 annually over that of an oil-fired plant. Fuel savings would pay for the added cost of the wood-fired plant in about 2 years, assuming that wood fuel was available at the plant at no cost.

Pratt (28) indicated that the fuel savings for a wood-fired steam plant supplying heat to 17 double-track dry kilns (each with a capacity of 55,000 board feet of lumber) was about $65,000 annually, as compared with natural gas. The added cost of the wood-fired plant could be repaid in slightly over 3 years with the fuel savings.

Haley (17) reported that a bark-fired steam plant (27,000 pounds of steam per hour) to dry from 50 to 60 million board feet of western hemlock lumber annually would have a payout period of 3.3 years. The payout period considered not only savings on fuel, but also others, such as elimination of costs associated with operating a wigwam burner. Annual fuel savings were given as $60,000.

In 1963, J. Donald Kroeker and Associates (unpublished report) compared the economics of using hogged fuel or natural gas for the heating and power plant at the University of Oregon in Eugene. An additional boiler with a capacity of 110,000 pounds of steam per hour was being considered. The analysis indicated the cost for a boiler using hogged fuel was $184,000 greater than for a gas-fueled boiler, but an annual net savings of about $92,000 could be made using hogged fuel. The added cost of the hogged-fuel installation would be recovered in 2 years. The report recommended that the additional boiler use hogged fuel, with oil as a standby. The conclusions were based on a price of $3.35 per unit for hogged fuel: since the study, interruptible gas prices increased 25-30 percent, but the price now paid for hogged fuel is only about half of what it was in 1963. The savings by using hogged fuel, therefore, are greater than anticipated.

Another example of savings using wood fuel is an installation at Eugene, Oregon, where sander dust supplies heat to a veneer dryer. It uses about 1,500 pounds of sander dust to heat the dryer, with a monthly fuel savings of $2,300 (39). The fuel savings is expected to pay for the cost of the installation in less than 3 years (37).

CONCLUSIONS

Wood and bark fuels, at one time, supplied most of the energy used in this country. Marked changes have occurred in patterns of energy use in the last 100 years. Although total energy use has grown tremendously, use of wood for fuel has declined. Still, wood and bark are commercially important fuels in some areas. Most of the wood and bark fuel used in this country today comes from residues at forest industry plants. Because wood and bark fuels have a relatively low heating value per unit of volume as well as per pound, transportation costs are high. Such fuels are therefore economical only near or at mills where the residue is produced. Use of wood and bark residues for fuel sometimes can provide the cheapest source of heat and power for a plant, and also can help solve a troublesome and expensive disposal problem. As other fuels increase in price and become less plentiful, even more incentive to use residues for fuel will exist.

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