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BARK AND ITS POSSIBLE USES

Summary

What to do with bark is a major question facing the wood conversion industries. Optimum utilization of bark residues demands appreciation of the complexity of bark and the extreme variation in chemical and physical properties between barks of different wood species. This report discusses bark structure, past and present utilization, and methods of upgrading bark both physically and chemically for increased utilization. Pertinent literature citations and continuing bibliographic sources of information on bark are included. Appended directories indicate sources of technical assistance and utilization equipment.

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BARK AND ITS POSSIBLE USES¹

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Need for Maximum Utilization

Surplus bark is currently the most perplexing residue problem facing the wood conversion industries. The volume of bark residue is so great that it must be continually removed from mill sites. New technology has developed methods for converting slabs and edgings from a liability to an asset (58)³, and now utilization of bark is receiving increasing attention.

Bark has useful byproducts waiting for the right economic conditions or the development of satisfactory commercial processes.

Markets for bark have never been in greater demand. Air pollution regulations and high stumpage prices make maximum utilization of forest products a must. Efficient bark utilization can create a new industry and boost the economy by making a valuable asset out of a costly waste. It is significant that many major wood processing companies are currently investing huge sums in the construction of bark processing plants.

Because of strong competition from other materials, bark product manufacturers will have to advertise their wares vigorously, and strive to educate the public in their use in order to gain wide consumer acceptance. Recognizing this, the Bark Utilization Committee of the Forest Products Research Society sponsors an annual Bark Products Promotion Award for the best material from any

¹This research note represents a major revision of a report of the same title and number issued in 1969.

²Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

³Underlined numbers in parentheses refer to Literature Cited at the end of this report.

U.S or Canadian company, firm, or dealer used to help advertise and merchandise any product made mainly from bark.

This report outlines the various methods of bark utilization, and indicates through literature references sources of detailed practical information.

Bark Structure

Bark comprises the outer part of woody stems and branches (30,31,42,67,94). Anatomically it includes all the plant tissues outside the cambium. Although the term "bast" is sometimes used as the equivalent of bark, or inner bark, it applies more correctly only to the lignified fibers commonly found in many barks and other fibrous plant materials. These may amount to 35-45 percent of some inner barks.

Bark formation is initiated by the process of cell division at the cambium, which produces xylem on the woody side (inside) and phloem, the primary bark tissue, on the exterior bark side. Phloem tissue contains phloem parenchyma, bast fibers, companion cells, and the very important sieve cells or sieve tubes. The sieve elements are the main channel for downward movement of sap and nutrients from the leaves contra to the upward rise of water from the roots in the xylem. The layer of physiologically active tissue adjacent to the cambium is known as the inner bark and is generally relatively thin and light colored. As subsequent layers of phloem are laid down year by year, the outer layers become crushed and compressed, and the sieve elements and similar structures collapse. This tissue then ceases to take part in active physiological processes and is transformed into the relatively inert, dark outer bark that comprises the bulk of most tree barks. The rifted or scaly outermost layer of such bark on mature trees is then called the rhytidome.

The structure of bark is further complicated by the presence of a second cambial layer within the bark called the phellogen or cork cambium. Periderm, or cork, is produced by this cork cambium and contributes appreciably to the structure of the outer bark. The innermost layer of periderm is normally considered as the boundary between the inner and outer bark. A number of other types of auxiliary tissues, e.g. lignified sclerynchyma and medullary ray parenchyma, are also found in bark.

This brief description indicates that bark is a highly complex, heterogeneous material composed mainly of a thin, physiologically active inner layer and a complex, relatively inert outer layer, whose principal functions are to protect the cambium and prevent loss of water. Some barks, such as spruce, are

relatively thin and contain a high proportion of inner bark. Other barks, such as Douglas-fir and redwood, are quite thick and contain a very high percentage of outer bark.

Bark Composition

In keeping with its heterogeneous structure, the chemical composition of bark exhibits great diversity, so that analytical data on bark samples are difficult to obtain and are often not very meaningful. Vast differences in the nature and amounts of various chemical components and of various extraneous materials contained within the bark can be found within even a single species, depending on the age and growth site of the trees sampled and the fraction of bark examined, etc. Differences in composition and variation in amounts of common constituents can, of course, be much larger between species and, for these reasons, there are no good standardized methods of bark analysis.

Bark constituents are generally examined by extracting comminuted bark samples with various solvents (23). Frequently, the investigator will start extracting with cold, nonpolar organic solvents such as light petroleum or ether and then proceed through extractions with more polar solvents such as benzene, chloroform, or alcohol (cold or hot), to polar solvents such as acetone, aqueous acetone or alcohols, and water. Subsequent extraction with alkali or hydrolysis with acid is used to analyze the residue.

Some types of materials extracted in sequence by these solvents are indicated below:

<u>Solvent</u>	<u>Typical Substances Removed in Whole or Part</u>
Petroleum ether, ether, benzene, chloroform	Terpenes and their derivatives, fats, waxes, free fatty and wax acids and alcohols, sterols, resins.
Alcohol, acetone, aqueous alcohol, aqueous acetone	Simple polyphenols and their glycosides, tannins, mono- and disaccharides (sugars).

<u>Solvent</u> (con.)	<u>Typical Substances Removed in Whole or Part</u> (con.)
Hot or cold water	Disaccharides, starch, gums, pectins, tannins, mucilages.
Aqueous alkali	Phlobaphenes, phenolic acids, some bark lignin and hemicellulose, suberin fragments.
Acid hydrolysis	Simple sugars and uronic acids derived from holocellulose, leaves residue of "lignin."

The cellulose and hemicelluloses in the fiber portions of bark are largely similar to the corresponding materials from wood. However, when applied even to extractive-free bark, the standard lignin analysis gives misleading results since the "lignin" product consists of a mixture of true lignin and suberized phlobaphene (cork). This mixture has a methoxyl content of only 8-10 percent versus the characteristic 15-17 percent for a true softwood lignin or 20-22 percent for a true hardwood lignin. Some average figures delineating limits for the proximate composition of wood and bark are shown below; individual analyses for certain species can still lie beyond these limits.

Proximate Composition of Ash-Free Wood and Bark (Percent)

	:	Softwoods		:	Hardwoods	
	:	Wood	Bark	:	Wood	Bark
"Lignin"*	:	25-30	:	40-55	:	18-25 : 40-50
Polysaccharides*	:	66-72	:	30-48	:	74-80 : 32-45
Extractives	:	2-9	:	2-25	:	2-5 : 5-10
Ash*	:	0.2-0.6	:	Up to 20	:	0.2-0.6 : Up to 20

*Based on extractive-free material.

It is immediately noticeable that the range of composition is much more extensive for bark than wood. The high "lignin" contents make it difficult to prepare holocellulose even from well-extracted bark. To get a rough estimate of the polysaccharide fiber content of bark, it is best to extract the bark with solvents to remove extractives and then to hydrolyze the residue with acid and determine the monosaccharides formed by measuring their reducing power with copper salts, or as individual sugars using some chromatographic and colorimetric method. Typical barks will produce hydrolysates containing about

60-70 percent glucose, 5-15 percent xylose, 5-10 percent arabinose, and 3-4 percent each of galactose and mannose. Again, individual species can have unusually high contents of a single sugar, e.g., 8 percent mannose from spruce bark or 9 percent arabinose from pine bark.

Among bark extractives, polar materials (tannins, polyphenols, glycosides) are generally three to five times as abundant as nonpolar constituents (fats, waxes, terpenes, steroids, etc.).

Although native bark tissue carefully sectioned out of the bark does not normally contain substantially more inorganic materials (which can be assayed by igniting the sample and weighing the ash) than wood (maximum ca. 1 percent), ordinary extractive-free bark is found to contain up to 20 percent ash. This is because windborne soil or sand particles are usually trapped in the rhytidome, raising the apparent ash content. Further, bark from logs that have been felled and skidded may contain a lot of sand and grit embedded in the bark that can create speciously high ash contents. This grit is also troublesome in causing dulling of sawing and cutting tools.

Bark Utilization

On the average, bark comprises about 9 to 15 percent of a typical log by volume (table 1), or slightly more (13 to 21 percent) on a dry weight basis (cf. 29,163). There are roughly 225 pounds of bark per cord, or 1/4 ton for each thousand board feet log scale (see fig. 1 and 2). The total annual United States production of bark may be well above 20 million tons. Since one of the major costs in processing any natural material is the cost of collection, bark, for which collection costs have already been paid, has become increasingly attractive as a potential raw material.

Centralized Debarking

Centralized debarking of trees, especially for pulpwood and sawlogs, has resulted in more efficient utilization of wood substance and in the accumulation of huge tonnages of relatively wood-free bark at central industrial locations. Mechanical debarking of logs before sawing to lumber provides clean slabs, edgings, and trims that can be used for crating or processed to chips for pulping. It is profitable for sawmills cutting more than 1-1/2 million board feet of lumber

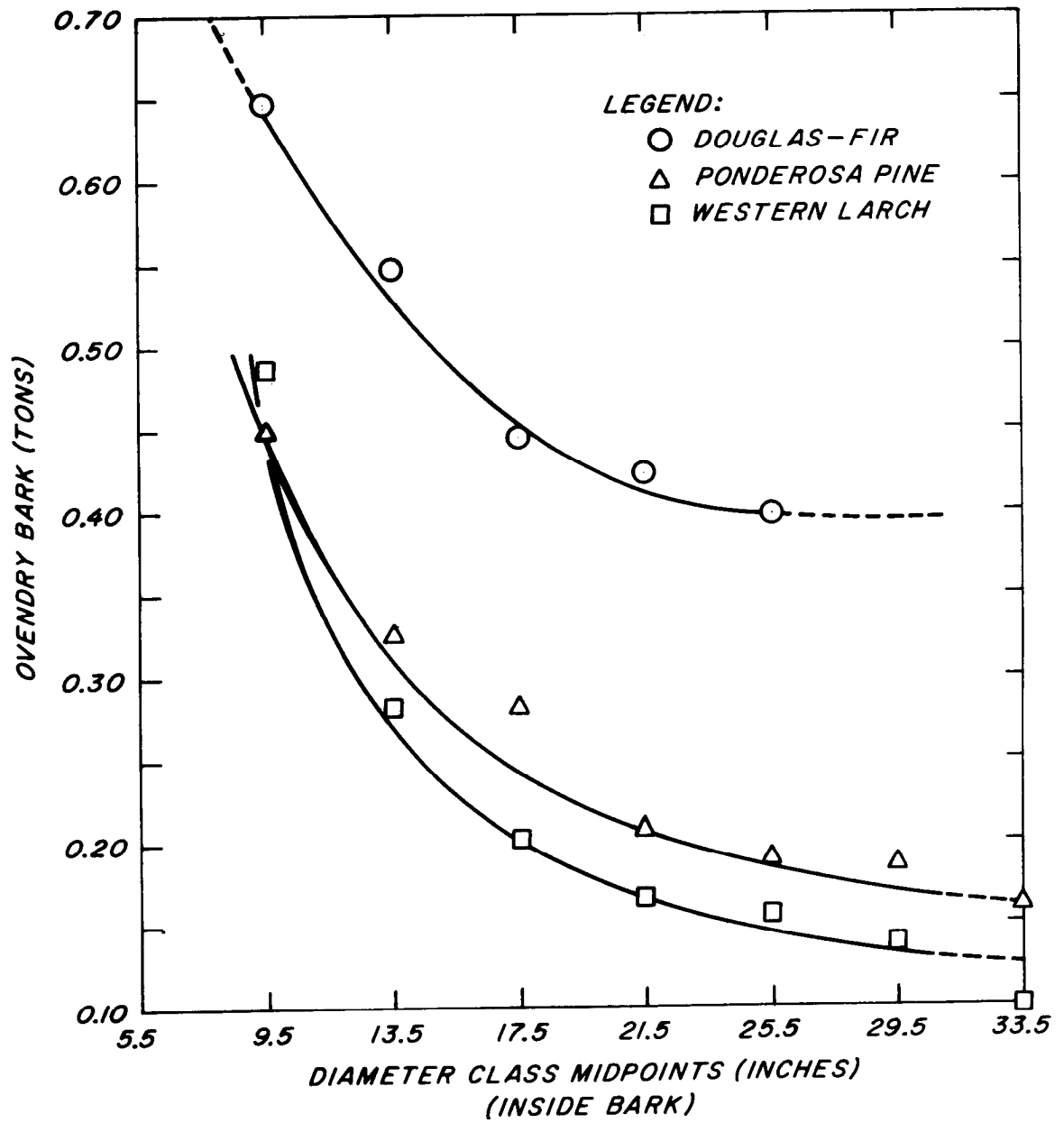


Figure 1.--Tons of bark per thousand board feet gross log scale by diameter classes.

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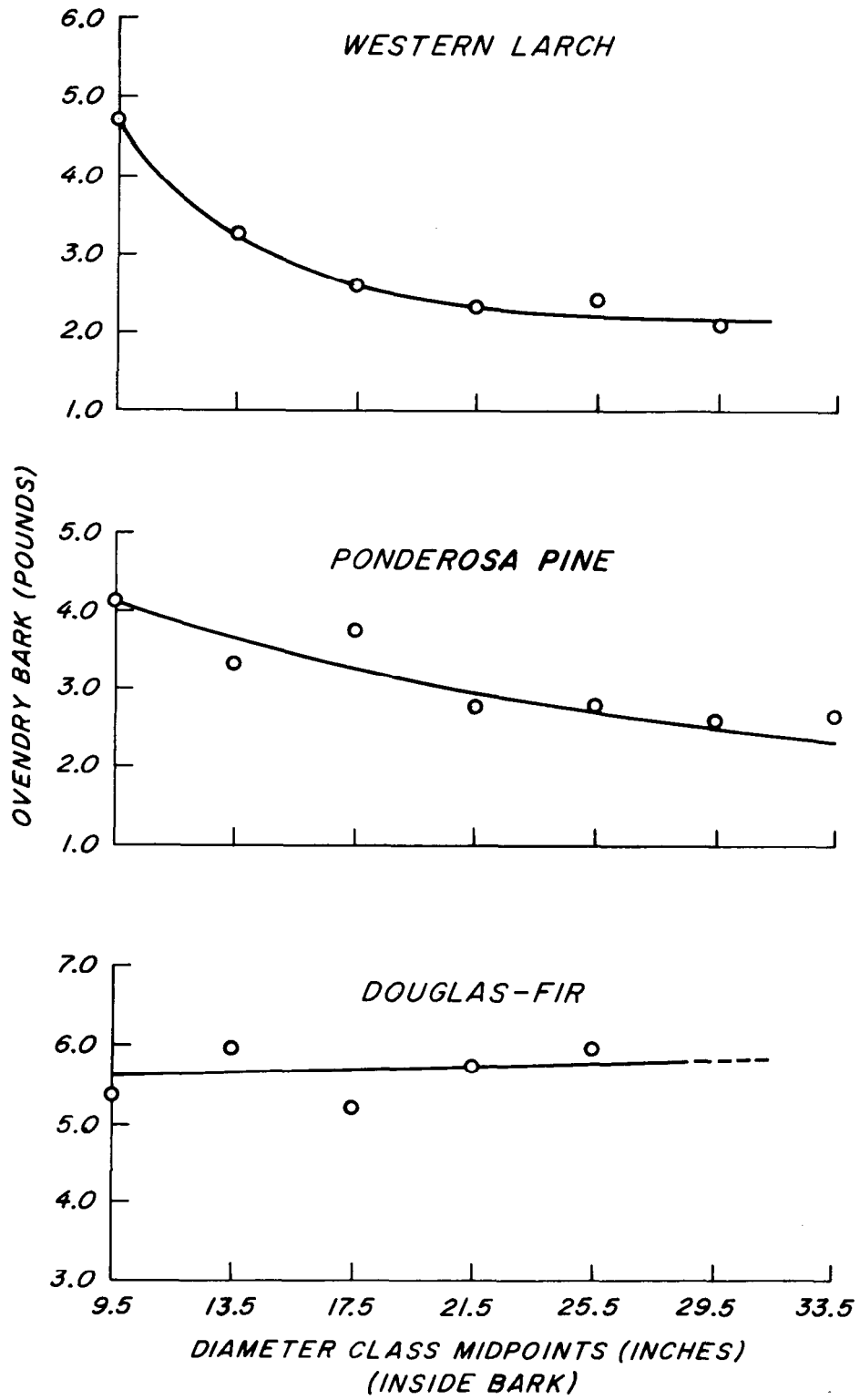


Figure 2.--Pounds of bark per cubic foot of wood by diameter classes.

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yearly to install and use a mechanical debarker. A recently compiled directory of debarking equipment is available (47). The designs and performance features of different types of power debarkers were analyzed in an early review (46). Information and experience reports on the latest equipment can generally be obtained from the American Pulpwood Association, 605 Third Avenue, New York, N.Y. 10016. Bibliographic information on debarkers and debarking practices has also appeared (126,128). Attempts have been made to remove bark from wood after chipping logs or thinnings without prior debarking; this subject has been reviewed (10,41). So far, results are not promising or only applicable to a few species. Many machines (hammermills, choppers, shredders, grinders) are also available for pulverizing or shredding bark; lists of manufacturers are available (57,147). There are several publications that deal with mensuration of the amounts of bark obtained from various species of trees (29,37,70,83,84,109,135,136,159,163).

Bark Product Variety

Bark has a long history of utility ranging from the Indian's birch-bark canoes to the tapa cloth of the South Pacific. Cork, fiber, tannins, dyes, gums, resins, latex materials, foodstuffs, flavorings, fish and arrow poisons, antibiotics, and medicinals can all be derived from bark. Among some of the varied products obtained from bark are the flavoring, cinnamon; the antimalarial drug, quinine; the powerful aphrodisiac, yohimbine, used by natives and animal breeders; the cocktail ingredient, Angostura bitters, and the root beer flavoring, sassafras. The tremendous range of products obtainable from bark is a reflection not only of the complexity of bark itself, but also of the extreme differences between barks of different species. A most interesting utilization of bark is as a source of chemical extracts with medicinal or physiological properties. Barks containing this type of extract are largely limited to tropical species--our domestic temperature zone species are deficient in this respect.

Utilization Information and Research

Occasionally, symposia are held on bark and other wood waste utilization. The transactions of these meetings are generally published (2,49,102,105,115,149). A European meeting on mechanical peeling of logs also covered bark utilization (48).

Fortunately, the tremendous literature on bark has been reviewed and surveyed by a number of people (e.g. 139,165). Some excellent bibliographies (91, 125,127,129) provide a thorough index to the literature on bark, so that extensive general references will not be given here. Warren S. Thompson is preparing a new bark literature review at the Mississippi Forest Products Laboratory, State College, Miss. There are many patents dealing with the utilization of bark and these can be rapidly located through the bibliographies of the Institute of Paper Chemistry, Appleton, Wis. (127,129) and their abstract bulletin (cf. p. 23).

The Institute of Paper Chemistry is undertaking a new research program on the chemical utilization of southern pine bark. The Forest Research Laboratory of Oregon State University (Corvallis, Oreg.) is also expanding its research on bark utilization. Prof. Leonard Burkhart is conducting research on the use of bark as a mulch and in particleboard and on the extraction of terpenes and polyphenols from bark at the Forestry Department of the Stephen F. Austin State College, Tex. Research on horticultural applications of hardwood barks is being conducted in Illinois (50-52).

It is well known that deer sometimes browse on the bark of aspen trees when other food is not available in hard winters. Research is being carried on at the U.S. Forest Products Laboratory in cooperation with three land grant universities on the possibility of including certain barks in feeds for domesticated ruminants. Preliminary findings suggest that the inner bark of certain hardwoods should be readily digested by these animals. A cooperative project involving six departments of the University of Wisconsin College of Agriculture, and headed by J. N. McGovern of Forestry, is examining the use of bark as animal bedding and poultry litter, with subsequent disposal through agricultural outlets. Prof. Robert E. Martin at Virginia Polytechnic Institute is carrying out a research program on the physical properties of bark: density, thermal and mechanical properties, moisture relationships, etc.; some reports have already been published (93-99). He has also summarized bark research activities at universities at home and abroad in (102). Other physical data on barks have also appeared recently (84,113). Chapters in two recent books also discussed bark (74,140).

The Forest Products Research Society through the Technical Committee "Bark and Residues" is trying to focus interest on bark utilization. This committee promotes activities to increase the utilization of bark, and has conducted a survey of bark processors and the nature and sales volume of their products (101,104). A short first listing appeared in 1971 (Directory of the Forest Products Industry, pp. 401-402, Miller-Freeman Publications. 500 Howard St.,

San Francisco, Calif. 94105). Another more complete listing that includes the names of brokers, consultants and machinery and packaging manufacturers appeared more recently (57). The proceedings of symposia on making and selling bark products held at annual meetings of the FPRS can be purchased as booklets from the Society at 2801 Marshall Court, Madison, Wis. 53705 at \$5 (102) and \$4 (105) a copy. A third book, on "Processing Bark for Bark Products," is in preparation (1971).

Low-Grade Utilization

The complexity of bark and the extreme variation in chemical and physical properties between barks has already been pointed out. Thus, any high-grade utilization scheme will usually require large amounts of clean, dry bark from a single species. Frequently, this requirement is not met--the bark is obtained as a mixture of species or in amounts insufficient for economical commercial processing to high-grade products. Even when bark is processed to high-grade products, some residue always remains. These factors indicate that initial commercial development should concentrate on schemes that can utilize whole bark independent of its physical and chemical properties.

Fuel.--Initial outlets for bark can well be identical with those of other wood residue. For example, bark may be used as a fuel (9,65,80,109,110,114,118,151). Improved multiple-fired burners have been developed (27,40,53,54,145), together with heavy-duty presses that are capable of obtaining positive fuel values even from water-soaked bark (154). The fuel value of such bark is low, but at least some returns are being obtained. Ten tons of completely dry bark have, on the average, a gross heating value equivalent to some 7 tons of coal. The effective heating value of bark is about 8,000 to 10,000 B.t.u. per pound of bone dry material, depending on species; that is about half of the value for fuel oil, but these values fall off to zero for bark with around 87 to 90 percent moisture content (see fig. 3). Bark peeled mechanically from logs in dry summer weather has a moisture content of about 34 to 40 percent, but bark removed in wet weather or in winter may contain up to 60 percent water. The practice of bark disposal by incineration in tepee burners is still widespread (20,21,33), but this seems like a shameful waste of good fuel, especially since at some \$40,000 to over \$100,000 (1971) the costs of installing modern smoke and fly-ash free burners efficient enough to comply with most current air quality control standards (or of modifying existing burners) are a sizable fraction of the costs of a bark fuel boiler (21,65). Cost data for the use of wood waste as a fuel (38) should

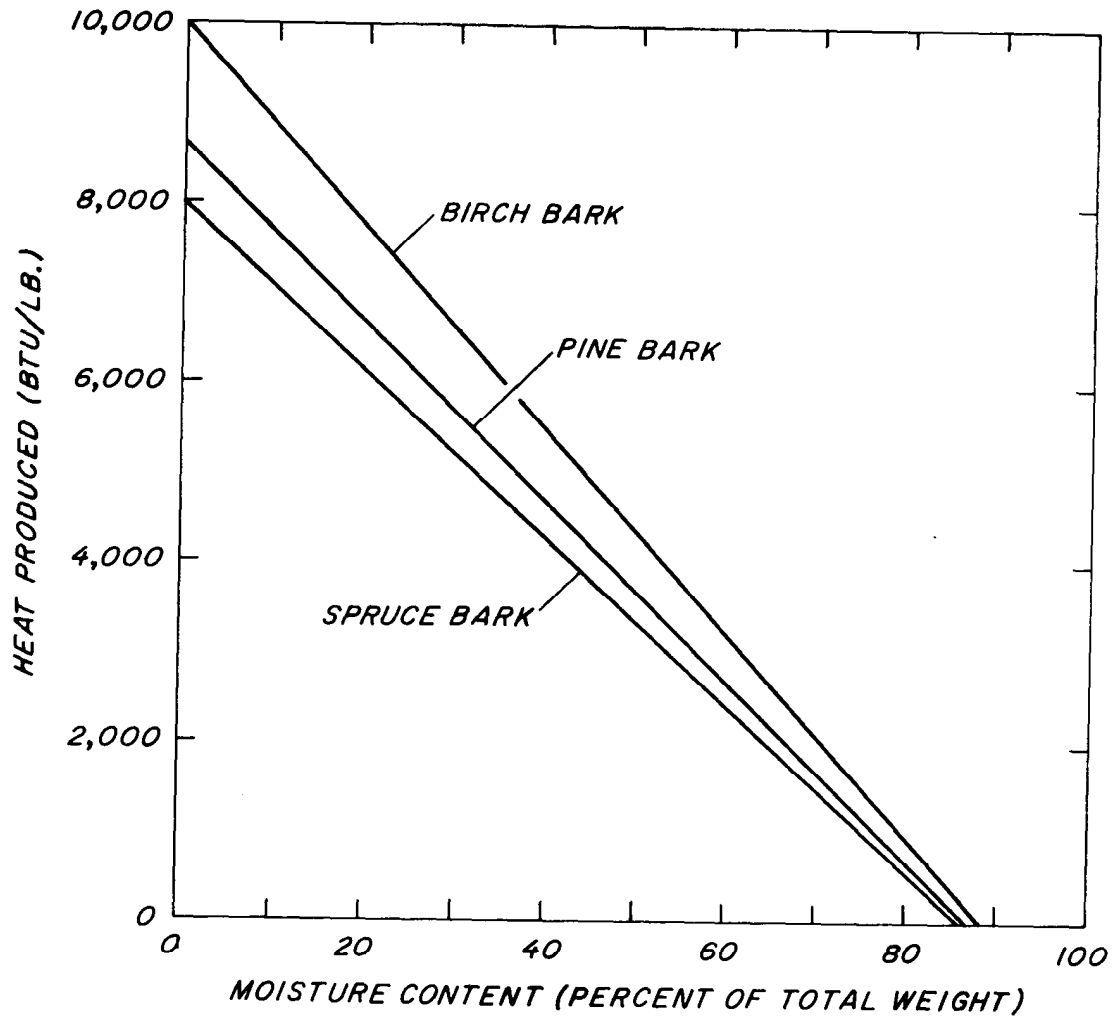


Figure 3.--Effective heat produced by combustion of birch, pine, and spruce barks at different moisture levels.

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also be roughly pertinent to dry bark combustion (80). Some good appraisals of the use of bark as a fuel and of the equipment necessary for firing bark have appeared in recent years (9,27,40,53,54,65,80,109,110,114,116,118,123,145,151,152). Air blowers in the furnaces greatly promote complete combustion of fuel bark (53,54). One company in Illinois makes incinerators for fluidized-bed combustion of sander dust and wood fines that might be readily adapted to efficient firing of bark particles. Table 2 lists the densities of some dry barks; these densities increase as the water content of the bark goes up. Table 3 contains data on the ash content and heat of combustion of some barks. Considerations have even been given to the utilization of ash, e.g. as lightweight aggregate in concrete or in water purification (80,144).

Bark can also be pressed into briquets for use as fireplace fuel (36). This is commonly done with other wood residues (58), and various kinds of fireplace logs have been marketed throughout the country. Bark has hitherto found only limited use in this form because it usually contains excessive amounts of water. When dried, however, it may be equal and perhaps superior to other wood residue in fireplace logs. Binders and sizing would probably not be needed. Some companies have investigated the possibility of adding salts to the logs to produce colored flames; for example, copper sulfate for green, calcium chloride for orange, copper chloride for blue, lithium chloride for red, and potassium chloride for purple. Although the idea appears attractive, in practice the cost of mixing in the chemicals, the necessity of keeping various colors separated to prevent them from obscuring one another, and corrosive and other deleterious effects of the chemicals have limited this feature.

Charcoal. --Another major outlet is in charcoal (8,34,74,78,79,148). Demand for charcoal for recreational use has increased sharply (146). Bark from mechanical debarkers, and slabwood, high in bark content, form an important portion of the raw material for this charcoal. Bark is normally assumed to have a high ash content. This is not necessarily true. Clean bark has an ash content only slightly higher than that of wood (table 3). Bark does, however, readily pick up dirt, sand, and grit, both windborne while the tree is still standing, and from the ground during felling and dragging. The ash is enriched some 3-4 times in the charcoal, since this is only some 25-30 percent of the initial bark. Nevertheless, a moderately high ash content is not disadvantageous for charcoal used in the home barbecue. Charcoal from bark is more easily crumbled than wood charcoal and contains a higher percentage of fines. These factors are undesirable in lump charcoal, but would be advantageous if bark charcoal were incorporated into briquets (55), since grinding costs would be lower than those for wood charcoal. A 12,000 ton per year continuous charcoal plant using only bark as feed

is being operated by Kingsford Co., Luke, Md. The same company uses 225 tons of bark a day in another plant in Oregon. Many other plants now use bark as a substantial portion of their feedstock

Wood-base materials. --Another outlet for bark is in various types of building insulation boards, hardboards, fiberboards, and particleboards, and many publications (including many foreign ones not considered here) have dealt with this possibility (6,12,22,25,69,86,92,111,112,131,141,143). Various barks have been incorporated into almost every type of board. The practice has hitherto been more prevalent in other countries (6,12,22,92), and opinions on the value of this form of utilization range from highly enthusiastic to mildly skeptical. Since bark conducts heat less readily than wood (93,94,97), its use in insulation board would seem particularly attractive. Wood chipped for board materials may not need to be debarked if certain production difficulties; e.g., variations in quality that are hard to control, can be tolerated. An insulation board is made from unbarked wood by a firm in Duluth, Minn., while a plant in Dee, Oreg., used unbarked slabs. In general, bark has less fiber than wood, so that strength is somewhat lower. Nonetheless, boards containing up to 30 to 40 percent bark that still meet standard specifications have been produced in Scandinavia. In addition, many softwood barks are relatively rich in resins and waxes, and this can obviate the need for sizing. Indeed, the higher extractive content of bark may be an aid in binding the particles together. The Oregon State University Forest Research Laboratory has prepared boards from Douglas-fir bark alone, with no sizing, or adhesive, merely by pressing the bark under heat and overlaying the resultant sheet with paper or veneer (25).

Information concerning the latest trends in particleboard manufacture and use can be obtained from the National Particleboard Association, Suite 720, 711 14th St., NW., Washington, D.C. 20005. At Pennsylvania State University, the properties of hardwood barks are being examined relative to their use in boards (111,112). Boards containing up to 25 percent pine bark that meet the specifications for floor underlayment are now being manufactured (141).

Other uses.--Experimental work has been done with encouraging results on the incorporation of Douglas-fir bark fiber into plastics as a reinforcement for molded products (85,137).

Minor amounts of bark can be tolerated in certain types of paper, although in general this is not particularly advantageous (130). However, bark fibers, such as those from the inner bark of paper mulberry, have been used for many generations for handmade paper. Pine bark powder has recently been found by the Korsnaes-Marma AB in Gäfle, Sweden, to be very effective in absorbing oil

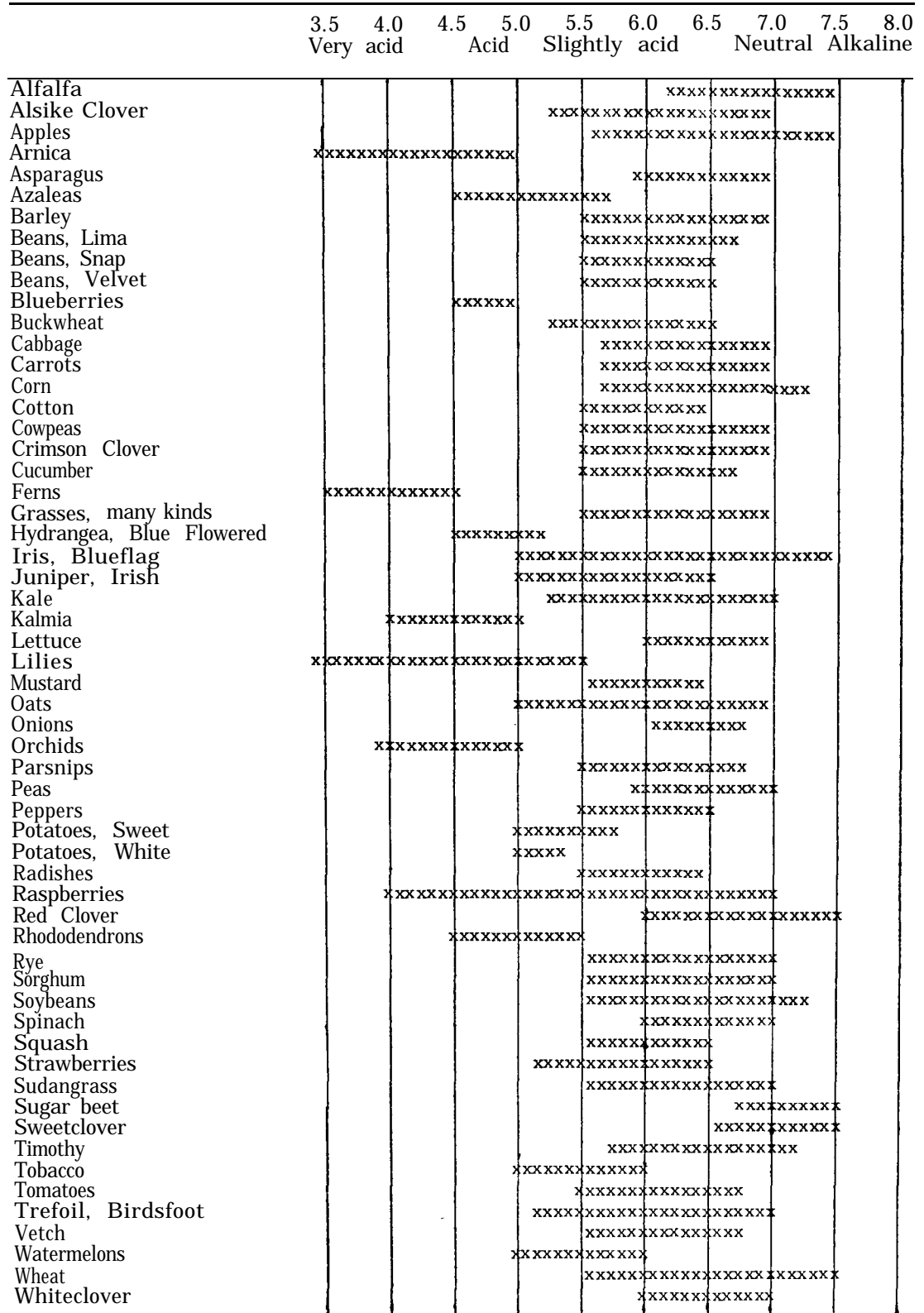
slicks from water. A boom made from netting filled with bark is laid around the slick. Research on the use of pine bark and sawdust as an oil scavenger is being conducted by the Texas Forest Products Laboratory, Lufkin, Tex. (153). Shredded bark has been used successfully on playgrounds, bridle paths, golf cart tracks, etc., and as a base for practice ski slopes (104).

Uses of Bark in Mulching and Soil Amendment

It is as a soil conditioner or mulch that bark finds one of its most attractive low-grade outlets. This practice originated with barks of western conifers, e.g. redwood, Douglas-fir, and western hemlock (see for example refs. 14,15), but has since been extended to hardwood barks (see for example refs. and other softwood barks. Transporting bark is expensive, however, so this form of utilization is usually limited to a reasonable radius from the debarking plant. Bark weighs around 6,000 pounds per unit (200 cu. ft.) and this creates a problem in transportation over long distances. Locations near a large city offer possibilities of preparing balanced soil conditioner/fertilizers or mulches for retail sale to the home gardener, as well as for substitutes for the nurseryman's peat moss. In general, however, landscapers, nurserymen, and farmers prefer to buy raw bark wholesale at the lowest price possible and then alter it themselves as needed. Debarker locations near farming areas open up potential large-scale markets, and in cattle or poultry raising areas the marketing of bark as livestock bedding or chicken litter should be advantageous. For small retail sales, it is advisable to dry the bark to about 10-15 percent moisture content based on oven-dry weight and store it in plastic bags (50 lb. lots are customary). This reduces transportation costs and prevents decomposition of the bark by fungus during storage or transit. Stock piles of horticultural bark should be protected from rain since molds can grow on the bark at moisture levels above about 50 percent. The problems of selling bark for agricultural and horticultural uses have recently been discussed (102,105,121,160). A review containing details of many aspects of this field has just appeared (14).

Advantages of Bark.--Bark has some advantages over wood when used as a mulch or soil amendment, i.e., when worked directly into the soil without previous use as animal bedding. The decomposition rate of bark is considerably slower than that of wood (3), hence it will last longer as a mulch and will have a lower nitrogen consumption when incorporated into the soil; this means it will cause less nitrogen starvation of crop plants or need smaller corrective additions of fertilizer.

Figure 5. --Suitable pH ranges for various crops and ornamental plants



Bark has no intrinsic value as a fertilizer. Nevertheless, the benefits that it can confer on poor soils as a soil conditioner are appreciable. It lends body to sandy or silty soils, yet loosens up clay soils: bark can improve the tilth, structure, and aeration of heavy soils, and increases water absorption and penetration. It has a high ion-exchange capacity and, except for nitrogen, contains all the nutrients necessary for a good organic soil. As a mulch, it conserves moisture through weed control and reduced evaporation; it maintains uniformity of the soil and improves granulation of surface soils; it reduces topsoil erosion, and builds up organic matter and humus in soil with concurrent benefits to the soil microflora.

Some publications deal with use of bark alone in the soil (13,15,39,50-52,66,71,72,75,87,105,132,138,142,160,161); others discuss the use of bark plus sawdust and other wood residues in the soil (3,4,7,11,16,17,156,157). An economic analysis of the production of mulch and soil amendments from sawdust and bark has recently been made (11). Bark should behave like other wood residues in soil treatment, but with four differences. First, bark is darker than other wood residue--a positive factor when the bark is used as a mulch, since it is more pleasing to the eye. Second, bark decomposes more slowly than wood in soil--a positive factor, since the nitrogen depletion factor (see p. 16,17) is lessened. Third, bark does not attract and does not provide nutrients for termites; this can be a major advantage in the South. Finally, bark is richer in extractives. This may be either a positive or a negative factor; it has not been completely assessed. Bark tannins will form chelates with heavy metal cations and help retain important minerals in the soil; they also complex with soil nitrogen compounds and prevent their rapid breakdown or elution. Both effects can promote soil fertility. Beneficial effects in depressing soil-borne plant diseases have been observed. Treated Douglas-fir bark is quite effective in controlling red stele disease when used as a mulch around strawberries (16). Because it improves drainage in certain soils, bark has also been found to reduce root knot, damping off, and olive wilt.

Effects of residues.--Subsequent comments apply equally to bark and other wood residues (sawdust, shavings, chips, chipped slash or thinnings, etc.).

Older literature is filled with reports on toxic effects of wood residue in the soil. We now know that reduction in crop yields following addition of wood wastes or bark to soils are almost entirely due to depletion of nitrogen in the soil. Reports of allelopathy, that is, actual toxicity due to extractive chemicals present in wood or bark, are extremely rare (19,150,155). True soil toxicity due to organic constituents is usually associated with heavy, badly aerated or waterlogged soils. Fatty acids and phenolic compounds derived from plant lignins

lignans, and flavanoids (e.g. syringaldehyde, vanillin, p-hydroxybenzaldehyde, and benzoic, p-hydroxybenzoic, protocatechuic, vanillic, syringic, ferulic, phenylacetic, phenylpropionic, and phenylbutyric acids) are held responsible (167).

Inhibitor effects on germination and early growth are occasionally observed. However, since this is generally coupled with increased growth at later stages, net increases in crops may actually be obtained (24). For example, Douglas-fir bark inhibits germination of Douglas-fir seeds, but the seeds that do germinate afford healthier stronger saplings than controls; the bark appears to regulate the growth density of its own species.

Pure cedar sawdust depresses growth of young legumes, probably because its extractives interfere with nitrogen fixation by azotobacteria in the soil. Incense cedar wood and pine bark are severely harmful to garden pea seedlings (3). The cause may be the fact that the soil bacteria are incapable of symbiotic fixation of nitrogen below pH 6, and require addition of fixed nitrogen in acid soils. Fresh walnut bark occasionally may inhibit germination of many types of seed owing to the phytotoxic glycoside juglone it contains. This is the material washed down by rain from the branches of black walnut trees that prevent the growth of other plants around the trees (19,150,155).

The effects that plant extractives may have upon the soil microflora and consequently upon plant growth are difficult to assess or forecast. The picture is clouded by the possible influence of changes in soil acidity caused by rotting wood wastes. In any case, most plant extractives are rapidly decomposed in the soil, and toxic effects are seldom observed beyond a short time after initial application of the wood wastes.

When bark or wood residue is added to the soil, it rapidly begins to decompose, especially in sandy soils and if it is finely divided and rich in sapwood. The soil micro-organisms that decompose this wood residue proliferate very rapidly. Since the soil bacteria require nitrogen to form their proteinaceous cells, they use up all the available nitrogen in the soil, robbing nitrogen from the growing plants if necessary. This situation is temporary. The nitrogen is not lost, but merely transiently stored in unavailable form by the micro-organisms. For this reason, the first crop after addition of wood or bark as a soil amendment may be poorer than usual, but subsequent crops are generally improved for the following few years. Yields of nitrogen-fixing, leguminous plants (peas, beans, alfalfa, sweet clover, vetch) are, however, not normally affected provided the soil is not allowed to turn acidic. Combination of wood wastes plus a legume will lead within a single season to considerable upgrading of poor soils, if the pH of the soil is kept above six.

The problem of poor first crops can be met in several different ways--by prior use of the wood residue as a mulch, by prior use as animal bedding, by addition of mineral nutrients, by ammoniation, or by prior composting of the wood residue, preferably with added nutrients.

Addition of mineral nutrients.--Addition of nitrogen and other mineral nutrients along with the wood residue is not always attractive. Sizable amounts of nitrogen are needed, and the system is difficult to control. Some data on the natural mineral content of barks are available (163).

The potassium (potash) and phosphorus (phosphate) generally included in commercial mineral fertilizers are often not needed. However, it is often preferable to add a nitrogen compound to the bark or wood waste before this is applied to the soil. Recommended levels are about 25 pounds of anhydrous ammonia, or 80 pounds of urea, or 100 pounds of ammonium nitrate, or 200 pounds of ammonium sulfate per ton of wood (3 to 4 cu. yards depending on species and particle size). Some experimenters suggest that half of these amounts will often suffice. Only about one-fourth of these quantities is needed for bark because of its slower rate of decomposition. Other wood wastes that decompose very slowly, for example, redwood sawdust (because of its high extractive content), also require only lesser amounts of nitrogen.

If desired, to increase the potassium and phosphorus content of bark for agricultural use, about 8 to 15 pounds each of potash and superphosphate, suitably diluted with water, can be added per ton of bark.

A few patents have been issued covering processing or treatment of wood wastes for use in agriculture. It should be noted that in some states, even the wood waste products enriched with inorganic additives may not legally be designated as fertilizers.

As wood wastes decompose in the soil, they tend to become acidic. This reaction may not be harmful, depending upon the type of crop to be grown upon the treated soil. Generally conifers, especially hemlock, balsam fir, and black spruce, prefer an acidic soil, and so do most berries, flowering shrubs, and many flowers. Figures 4 and 5 show the pH ranges (degree of acidity) in which some North American trees and plants will thrive.

Soil nitrogen depletion problem.--Undesired acidity in the soil caused by decomposing wood waste can easily be counteracted by light liming. It is best to measure the pH (acidity) of the soil before applying agricultural lime. The state universities run soil-testing laboratories, generally at their Agricultural Experiment Stations as part of their Extension Service program. Personnel there carry out soil analyses and give advice and recommendations on lime or fertilizer requirements. Samples of topsoil taken from at least half a dozen different spots down to a depth of several inches should be thoroughly mixed and about two cupfuls of the mixture sent as the sample for analysis. Soil testing

kits for home use are also frequently available from garden and agricultural supply stores. Appearance of sour dock and other acid loving weeds indicates that the soil is too acid. However, it generally will be found that occasional (2 to 3) applications several months apart of 40 to 80 pounds of lime will neutralize the acidity produced by decomposition of a ton of dry sawdust, while 15 to 25 pounds will suffice for a ton of dry bark. Some authors state that bark will reduce the acidity of very acid soils: this effect may be due to an increase in the cation exchanging capacity of the soil produced by the decomposing bark.

Other ways of meeting the nitrogen depletion problem are often convenient and work excellently. Bark makes a fine mulch (11,13-16,45,50-52,66,71,87,142,160,161). This is at present its commonest outlet. Since it decomposes only slowly on the surface of the ground, there is no nitrogen depletion problem. For either the home gardener or the nurseryman, bark can compete favorably with peat moss. It is not readily windblown and does not attract nematodes or termites. As an animal bedding, bark should be equivalent to other wood residues, although excessive fines might be undesirable. After use as a bedding for cattle or poultry, the bark is sufficiently fortified with nitrogen from the animal excrements to be used directly in soil. The practice of barking and chipping timber at the logging site (28) could make bark available in situ for mulching forest lands.

Composting also appears most attractive, especially for wet bark from hydraulic debarking. The journal "Compost Science" includes many articles of interest along this line. The staff of this magazine also issues a directory of compost science, dealing with manufacturers of equipment and research being carried on in this field. Information on various methods of composting and on the requisite machinery also can be obtained from a manual on the subject (124). Appendix I lists United States manufacturers of composting equipment.

Occasionally pure strains of micro-organisms are used for preparing the compost, e.g., Coprinus ephemerus (156,157) or "Eokomit" bacteria in Austria and Finland (81,164), but generally no special inoculum is used (13,17,44,71,72,82,132,162). Conventional farm equipment can be adapted for use in composting wood wastes (82). Ordinary snow blowers, which are made in various sizes for cleaning areas ranging from sidewalks to roadways, can be used both for grinding and spreading bark mulches or composts. Composting can, of course, be accelerated by adding nitrogen and other mineral nutrients. These can be added either as chemical fertilizers or as nitrogenous materials such as whey (106), brewery waste, sterilized sewage sludge, fish waste, or manure. If sewage sludge is added to the compost, it must be sterilized first, since some pathogenic bacteria harmful to plants or animals present in the raw sludge may withstand windrow composting conditions (120,158). Moreover, although the nitrogen content of sewage is quite high, most of it is bound up in a form unavailable to plants. The sludge also tends to have an obnoxious odor when wet. Composting with added nutrients has four important advantages. The nitrogen depletion problem is solved; the product can often be marketed as a combined soil conditioner and

fertilizer; any possible toxicity is removed in the composting process; and the composting process is greatly accelerated

Lately, successful experimentation has been conducted for using hardwood bark as litter for poultry (77). After an 18-week trial using hardwood bark litter for 1,500 20-week-old laying pullets, there appears to be no detrimental effects on the birds' health. Hard maple bark, initially at 52 percent moisture content, met all the requirements of a good poultry litter, viz. no dust, mold, matting, staining of eggs, or interference with automatic feeding and watering operations. Five thousand chicks are being raised satisfactorily on black cherry bark litter with no abnormal mortality. As of July 31, 1968, the trial period had been observed for 15 weeks. Chicks adjusted well to the bark litter. Particle size was large enough (not over 2 inches long and less than 1/2 inch wide) and included all sizes down to fine particles that approximate the size of fine shaving particles to eliminate cleaning waterers and feeders (77). Polluted litter should be an excellent fertilizer/soil conditioner.

Another approach to the nitrogen depletion problem has involved chemical treatment of the wood residue to render it resistant to decay. Decayed wood consists mainly of a mixture called humus. A closely related material, humin, is produced when wood residue is treated with acid at high temperatures (44), sometimes with added formaldehyde. This product, however, is strictly a soil conditioner. It still contains no nitrogen or other fertilizer elements. These may, of course, be added.

Still another approach is ammoniation of bark (17,82). Bark contains many chemical groups that will combine with ammonia. In the soil, some of this ammonia is released to the plants rapidly, and some slowly. Another scheme is the use of bark fibers in trickling filters for secondary treatment of sewage effluent (26); the expended material is then used as a soil conditioner. One objection to this process might be that harmful bacteria could be passed on from the sewage with the bark (120,158). However, a well-composted product made from bark and sewage using a method successful for bark alone was recently described to be non-noxious and is thought to be free from pathogens (166). Another danger is from numerous enteroviruses, including the poliomyelitis virus, which are normally present in sewage and which may survive even the high temperatures of windrow composting.

A related use of bark is as a potting medium for container stock and for rooting plant cuttings (45,50-52,75,76,88,119,122). Several companies are marketing bark for this purpose. Plants that grow well on a bark potting medium include pines, firs, junipers, holly, forsythia, rhododendrons, gardenias, azaleas, pieris, camellias, heather, and orchids. Douglas-fir, hemlock, white fir, and pine barks were those originally used, but recently hardwood barks have been used as well.

Use of bark for growing orchids is very attractive (35,68,89,133). Douglas-fir and southern pine bark, like peat moss, has also been used for making planter pots that need not be removed when rooted cuttings are put into the ground.

Both hardwood and softwood barks can be mixed with soil to give media for packing root balls of young trees, ornamental shrubs, etc. for storage as nursery stock. The packaged root balls can be held together in preservative-treated burlap sacking or in plastic netting or bags. Incorporation of the stringy portion of inner bark or of wood wool (excelsior) prevents loss of the soil/bark crumbs during transplanting. Additions of slow-release synthetic fertilizers and lime can be used to increase the keeping time and growth of the plants while packaged. Bark should also be a suitable growing medium for mushrooms, and ground bark is finding some use for covering school playgrounds. In Norway, bark has been used as an insulating material in the soil to prevent frost-heaving of railroad tracks (134).

Physical Upgrading of Bark

As already mentioned, bark is a highly heterogeneous material that varies widely from species to species. In order to isolate physical fractions of value from bark, it is probably necessary to start with a single species. Then, by such treatments as grinding, crushing, milling, chemical treatment, screening, water flotation, or even firing from a fiber-exploding gun, various physical fractions can be obtained that usually correspond to different cell types present in the bark. For example, both redwood and Douglas-fir are now processed industrially in this manner (165). Screening of milled softwood barks on sieves subjected to a horizontal swirling motion concentrates the fibrous fraction of the inner bark and any wood splinters the bark contains in a coherent mat atop a layer of smaller round particles or scales of outer bark (59).

One of the most valuable fractions is the cork. The Mediterranean cork oak, our main commercial source of cork, has bark that consists almost entirely of cork. Most barks contain cork, which, although not so predominant as in cork oak, nevertheless can often be separated as discrete particles. Cork granules are commercially produced by physically fractionating Douglas-fir bark. Formerly, a large outlet for these cork granules was in liners for bottle caps, but this market has now been largely lost to synthetic materials.

Another fraction commonly produced is fibrous. These fibers may be either short, tough, brittle, needlelike bast fibers, such as are obtained from Douglas-fir, or longer, more flexible fibers, for example, from redwood or cedar bark. These fibers find outlets in pulp (130), fiberboards (12,22), air and oil filters, as a sealant in oil well preparations (108), as a trickling filter in water purification (26) and as a reinforcing filler in ceramics, concrete, molded products, and the like (85,137). The use of highly fibrous redwood bark in insulation, as a furniture stuffing, and even in combination with wool for felt hats is well known.

A final fraction that is almost always produced during physical upgrading of bark is an amorphous powder. Douglas-fir bark (165) and redwood bark dust are commercial sources of such fractions, which have found use in phenolic molding compounds, as an adhesive extender, as an anticaking agent for insecticides and fertilizers, as an extender in thermoplastic resins and rubber products, and even as an ingredient in foundry sands (107). Douglas-fir bark powder can be used alone as a thermosetting, water-resistant adhesive for plywood, since it flows under heat and pressure, but more commonly it is used as an extender in phenolic-resin glues. Since the bark powder actually undergoes chemical reaction during hot pressing, it is more than an inert filler. Bark dust is being used to cover tailings left after mining operations in Montana.

The use to which any one physical fraction from bark can be put depends on the exact chemical and physical properties of the fraction. The bark of each species is different, and a utilization scheme must be developed individually for each particular bark. Greatest promise is shown, however, by barks that are particularly rich in either cork or fiber. Incidentally, physical fractionation of bark is usually accompanied by chemical fractionation, so that specific physical fractions are often far superior to whole bark for further chemical fractionation.

It is expected that bark fractions will be used more and more as the public becomes aware of their physical properties.

Chemical Upgrading of Bark

Barks generally are much richer in both quantity and complexity of extractives than the corresponding woods. A large number of pure organic chemicals can be isolated from barks, including flavanoids, alkaloids, carbohydrates, inositols, terpenoids, glycosides, saponins, esters, steroids, fats, lignans, and complex phenols. Various chemical fractions, such as tannins, waxes, balsams, essential oils, gums, mucilages, resins, latices, and dyestuffs, which may or may not consist of a relatively pure chemical entity, also are often isolated. There are well established uses for many of these products (1,43,56,61,73,74).

In general, the isolation of pure organic chemicals from bark is economical only if other chemical and physical fractions of value are isolated at the same time. Factors such as plant size, ability of the market to absorb the products at a profitable price, competition from other chemicals, and maintenance of a proper balance between products need careful evaluation. Although many pure chemicals could be isolated from domestic tree barks, no pure organic compound has achieved a profitable large-volume market in this country. Salicin, from aspen bark, which finds medicinal uses, comes closest to this ideal (117).

Crude fractions, on the other hand, have definitely found markets. The largest market is for tannins, which are generally condensed (polymerized) polyphenols (60,61). Tanoak, oak, chestnut, mangrove, hemlock, eucalyptus, redwood, sumac, spruce, Douglas-fir, and even some pine barks have all been processed for tannin. Even though some of these domestic tannins are satisfactory for tanning leather, wattle bark and quebracho wood, both imported, are the main source of natural tannins today. Significant in their ability to capture the main market for leather tanning are their availability in large quantities at a low price and uniform and reproducible high quality. A good bibliography covering mainly work on bark tannins appeared recently (1).

Bark tannins, such as those from western hemlock, redwood, and Douglas-fir find a large market in other outlets, however (56,60,62-64). One is in oil-well drilling; large quantities are used to thin the muds. They act as clay defloculants and control the viscosity and gel strength of drilling muds (63). Some 50,000 tons of mud thinners are used yearly. This field has been reviewed (108,165). A major recent development is a commercial preparation of a chemical grout for stabilizing soils from the phenolics of western hemlock bark.

Another outlet for bark tannins is in adhesives, particularly for plywood and particleboard (5,56,90). Noteworthy is the development of a cold-setting, water-proof adhesive from western hemlock bark (64). These major uses for tannins have been the subject of many recent publications, and a large number of patents have been granted. Of significance is the fact that these polyphenolic fractions can be extracted from bark in an especially high yield with alkaline reagents, sometimes containing pulping additives. Tree barks are remarkably soluble in alkali; often over 50 percent of the bark will go into solution. By varying the extraction conditions as well as the purification and treating steps, a wide variety of different polyphenolic products can be prepared to fit almost any specification. Work in this field has been greatly helped by research into the chemistry of these complicated extracts (60-63,165).

Other uses for these polyphenolic extracts are as dispersants, binders, defloculents in ceramic clays, antioxidants, sequestering agents in boiler feed water, flotation agents in ore beneficiation, and stabilizers in asphalt emulsions, as well as in vat dyeing of nylon and desulfurization of gasoline.

Waxes are another field of interest. Carnauba wax and beeswax are now largely imported. The corky fraction of many softwood barks is rich in wax. A comprehensive market survey on the wax extracted with nonpolar solvents

from Douglas-fir bark has been made, but no commercial production along these lines has been initiated. Wax polishes and carbon paper are two commercial possibilities. However, synthetic waxes now largely dominate the market.

Although the literature is full of publications on bark chemistry, mainly dealing with one or two substances isolated from bark of a single species, really little is known about the subject. For many bark species, not one single pure chemical compound has been isolated. It is therefore no wonder that the chemical utilization of bark is at a relatively primitive stage. Tables 4 to 6 (32) contain general information on the extractives, carbohydrates, and lignin of a series of pulpwood barks.

Sources of Continuing Information

For those who wish to seek comprehensive continuous coverage of the field of bark utilization, the following publications will be useful:

(1) Bibliography of Agriculture. Published monthly by CCM Information Corporation, 909 Third Ave., New York, N. Y. 10022 using data from the National Agricultural Library, USDA, Washington, D.C. 20250 (subscriptions available at \$85.00 per year from the publisher). Look in the annual or monthly subject indices under "Bark" and the subheadings "Waste Utilization," "Utilization Research," "Fuel," etc., as well as under specialized topics such as "Mulch" or "Soil Conditioners" related to specific agricultural uses.

(2) Forestry Abstracts. Published quarterly by the Commonwealth Agricultural Bureaux, Farnham Royal, Buckinghamshire, England (subscriptions available for \$27.50 per year). Look in the annual subject index (no quarterly index) under "Bark," subheading "Uses," or in the individual issues under the code numbers 829.4, "Bark Products; Tanstuffs; Cork," 839.8 "Industrial Waste Wood: Its Processing and Uses" and 523 "Bark" (mensuration).

(3) Abstract Bulletin of the Institute of Paper Chemistry. Published monthly by the Institute of Paper Chemistry, Appleton, Wis. (subscription rate \$70.00 per year). Look in the Table of Contents under "Wood Waste, Bark, and Agricultural Residues" or in the annual subject index under "Bark," "Barking," "Barkers," etc.

(4) Horticultural Abstracts. Published quarterly by the Commonwealth Bureau of Horticulture and Plantation Crops, East Malling, Maidstone, Kent, England. This provides good bibliographic coverage of articles dealing with the utilization of wood wastes in soil. Look in the annual indices under "Soil (s), conditioners and amendments."

When using the abstract journals, it is important to check cross references given at the start of the sections indicated, for sometimes important information is included in papers abstracted under a different heading. Appendix II lists sources of technical assistance for problems of forest products utilization requiring information on local conditions.

Reprints of the journal articles cited can often be obtained from the authors, publishers, or the USDA or state agency concerned. Reprints of all articles from the Forest Products Journal can be purchased from the Forest Products Research Society, 2801 Marshall Court, Madison, Wis. 53705. The Society is preparing to publish a selection of their most important articles on bark utilization in booklet form at a cut rate over the price of the sum of the individual reprints (cf. Ref. 49). Addresses of other journal publishers are given in the bibliography following the first citation from each journal.

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Table 1.-- Bark volume

Wood	Diameter of tree	Number of growth rings	Bark volume based on wet log volume
	<u>Inches</u>		<u>Percent</u>
Spruce	4.2	62	12.06
	8.7	112	9.26
Fir (true)	4.5	38	10.0
	8.4	65	9.4
Birch, white	3.9	46	14.5
	8.3	68	9.5
Birch, yellow	4.2	74	10.1
	9.3	92	9.3
Beech	4.2	63	6.9
	8.9	125	6.1
Maple, sugar	4.1	67	13.5
	7.8	114	18.0

Table 2.--Specific gravity of the bark of U.S. wood collection
Forest Products Laboratory, Madison, Wis.

Scientific name	Common name	Bark specific gravity (ovendry weight and volume)
SOFTWOODS		
<u>Abies amabilis</u>	: Pacific silver fir	: 0.683
<u>Abies balsamea</u>	: balsam fir	: .629
<u>Abies balsamea</u>	: balsam fir	: .640
<u>Abies concolor</u>	: white fir	: .621
<u>Abies grandis</u>	: grand fir	: .644
<u>Abies grandis</u>	: grand fir	: .571
<u>Abies lasiocarpa</u>	: subalpine fir	: .549
<u>Abies lasiocarpa</u>	: subalpine fir	: .497
<u>Abies lasiocarpa arizonica</u>	: corkbark fir	: .342
<u>Abies magnifica</u>	: California red fir	: .500
<u>Abies procera</u>	: noble fir	: .555
<u>Chamaecyparis lawsoniana</u>	: Port-Orford-cedar	: .335
<u>Chamaecyparis lawsoniana</u>	: Port-Orford-cedar	: .523
<u>Chamaecyparis nootkatensis</u>	: Alaska-cedar	: .631
<u>Ginkgo biloba</u>	: ginkgo	: .383
<u>Juniperus californica</u>	: California juniper	: .589
<u>Juniperus occidentalis</u>	: western juniper	: .484
<u>Larix decidua</u>	: European larch	: .349
<u>Larix laricina</u>	: tamarack; Eastern larch	: .626
<u>Libocedrus decurrens</u>	: incense-cedar	: .269
<u>Picea engelmannii</u>	: Engelmann spruce	: .797
<u>Picea glauca</u>	: white spruce	: .618
<u>Picea glauca</u>	: white spruce	: .678
<u>Picea mariana</u>	: black spruce	: .603
<u>Picea rubens</u>	: red spruce	: .595
<u>Picea sitchensis</u>	: Sitka spruce	: .627

Table 2.--Specific gravity of the bark of U.S. wood collection
Forest Products Laboratory, Madison, Wis.--Con.

Scientific name	Common name	Bark specific gravity (ovendry weight and volume)
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SOFTWOODS--Con.

<u>Pinus contorta</u>	: lodgepole pine	: 0.595
<u>Pinus echinata</u>	: shortleaf pine	: .486
<u>Pinus echinata</u>	: shortleaf pine	: .316 ?
<u>Pinus edulis</u>	: pinyon	: .630
<u>Pinus flexilis</u>	: limber pine	: .630
<u>Pinus lambertiana</u>	: sugar pine	: .377 ?
<u>Pinus monticola</u>	: western white pine	: .625
<u>Pinus palustris</u>	: longleaf pine	: .526
<u>Pinus Ponderosa scopulorum</u>	: Ponderosa pine, Rocky Mountain	: .378
<u>Pinus Ponderosa scopulorum</u>	: Ponderosa pine, Rocky Mountain	: .356
<u>Pinus pungens</u>	: table-mountain pine	: .398
<u>Pinus resinosa</u>	: red pine	: .320
<u>Pinus resinosa</u>	: red pine	: .324
<u>Pinus rigida</u>	: pitch pine	: .377
<u>Pinus rigida</u>	: pitch pine	: .403
<u>Pinus strobus</u>	: eastern white pine	: .570
<u>Pinus strobus</u>	: eastern white pine	: .564
<u>Pinus taeda</u>	: loblolly pine	: .560
<u>Pinus virginiana</u>	: Virginia pine	: .631
<u>Pseudotsuga menziesii</u>	: Douglas-fir	: .544
<u>Pseudotsuga menziesii</u>	: Douglas-fir	: .411
<u>Sequoia sempervirens</u>	: redwood	: .459
<u>Taxodium distichum</u>	: baldcypress	: .553
<u>Taxus brevifolia</u>	: Pacific yew	: .618
<u>Thuja occidentalis</u>	: northern white-cedar	: .457
<u>Thuja plicata</u>	: western redcedar	: .439
<u>Thuja plicata</u>	: western redcedar	: .445
<u>Tsuga canadensis</u>	: eastern hemlock	: .514
<u>Tsuga heterophylla</u>	: western hemlock	: .588
<u>Tsuga mertensiana</u>	: mountain hemlock	: .459

Table 2.--Specific gravity of the bark of U.S. wood collection
Forest Products Laboratory, Madison, Wis.--Con.

Scientific name	Common name	Bark specific gravity (oven-dry weight and volume)

HARDWOODS		
<u>Acer macrophyllum</u>	: bigleaf maple	: 0.548
<u>Acer nigrum</u>	: black maple	: .805
<u>Acer rubrum</u>	: red maple	: .655
<u>Acer saccharinum</u>	: silver maple	: .667
<u>Acer saccharum</u>	: sugar maple	: .686
<u>Amelanchier arborea</u>	: downy serviceberry	: .740
<u>Betula alleghaniensis</u>	: yellow birch	: .741
<u>Betula nigra</u>	: river birch	: .704
<u>Betula papyrifera</u>	: paper birch	: .687
<u>Betula papyrifera</u> <u>humilis</u>	: Alaska paper birch	: .813
<u>Carpinus caroliniana</u>	: American hornbeam	: .772
<u>Carya tomentosa</u>	: mockernut hickory	: .983
<u>Castanea dentata</u>	: American chestnut	: .496
<u>Catalpa speciosa</u>	: northern catalpa	: .437
<u>Celtis occidentalis</u>	: hackberry	: .654
<u>Cercidium floridum</u>	: blue paloverde	: 1.070
<u>Chilopsis linearis</u>	: desertwillow	: .587
<u>Cornus florida</u>	: flowering dogwood	: .536
<u>Crataegus pedicellata</u>	: scarlet hawthorn	: .623
<u>Crataegus pedicellata</u>	:	: .605
<u>Diospyros virginiana</u>	: common persimmon	: .421
<u>Fagus grandifolia</u>	: American beech	: .738
<u>Fraxinus americana</u>	: white ash	: .508
<u>Fraxinus americana</u>	: white ash	: .525

Table 2.--Specific gravity of the bark of U.S. wood collection
Forest Products Laboratory, Madison, Wis.-Con.

Scientific name	Common name	Bark specific gravity (ovendry weight and volume)

HARDWOODS--Con.		
<u>Fraxinus nigra</u>	: black ash	: 0.546
<u>Fraxinus latifolia</u>	: Oregon ash	: .502
<u>Fraxinus pennsylvanica</u>	: green ash	: .940
<u>Fraxinus quadrangulata</u>	: blue ash	: .558
<u>Fraxinus profunda</u>	: pumpkin ash	: .590
<u>Gleditsia triacanthos</u>	: honeylocust	: .753
<u>Halesia carolina</u>	: Carolina silverbell	: .470
<u>Ilex opaca</u>	: American holly	: .840
<u>Ilex opaca</u>	: American holly	: .740
<u>Juglans cinerea</u>	: butternut	: .452
<u>Juglans nigra</u>	: black walnut	: .378
<u>Liquidambar styraciflua</u>	: sweetgum	: .582
<u>Liriodendron tulipifera</u>	: yellow-poplar	: .388
<u>Lithocarpus densiflorus</u>	: tanoak	: .752
<u>Maclura pomifera</u>	: osage-orange	: .584
<u>Magnolia acuminata</u>	: cucumbertree	: .436
<u>Magnolia fraseri</u>	: Fraser magnolia	: .581
<u>Magnolia virginiana</u>	: sweetbay	: .635
<u>Morus rubra</u>	: red mulberry	: .655
<u>Nyssa sylvatica</u>	: black tupelo; blackgum	: .546
<u>Ostrya virginiana</u>	: eastern hophornbeam	: .392
<u>Oxydendrum arboreum</u>	: sourwood	: .332
<u>Platanus occidentalis</u>	: American sycamore	: .672
<u>Populus grandidentata</u>	: bigtooth aspen	: .664
<u>Populus tremuloides</u>	: quaking aspen	: .727

Table 2.--Specific gravity of the bark of U.S. wood collection
 Forest Products Laboratory, Madison, Wis.--Con.

Scientific name	Common name	Bark specific gravity (ovendry weight and volume)

HARDWOODS--Con.		
<u>Populus tremuloides</u>	: quaking aspen	: 0.705
<u>Populus tremuloides</u>	: quaking aspen	: .611
<u>Populus trichocarpa</u>	: black cottonwood	: .604
<u>Prosopis juliflora</u>	: mesquite	: .887
<u>Prunus pennsylvanica</u>	: pin cherry	: .610
<u>Prunus serotina</u>	: black cherry	: .711
Red Oak Group		
<u>Quercus rubra</u>	: northern red oak	: .786
<u>Quercus coccinea</u>	: scarlet oak	: .834
<u>Quercus falcata</u>	: southern red oak	: .812
<u>Quercus palustris</u>	: pin oak	: .746
<u>Quercus phellos</u>	: willow oak	: .723
<u>Quercus velutina</u>	: black oak	: .710
White Oak Group		
<u>Quercus alba</u>	: white oak	: .675
<u>Quercus bicolor</u>	: swamp white oak	: .487
<u>Quercus garryana</u>	: Oregon white oak	: .799
<u>Quercus lobata</u>	: California white oak	: .660
<u>Quercus macrocarpa</u>	: bur oak	: .618
<u>Quercus michauxii</u>	: swamp chestnut oak	: .822
<u>Quercus prinus</u>	: chestnut oak	: .644
<u>Quercus stellata</u>	: post oak	: .608
<u>Robinia pseudoacacia</u>	: black locust	: .238
<u>Robinia pseudoacacia</u>	: black locust	: .320
<u>Salix nigra</u>	: black willow	: .368
<u>Salix nigra</u>	: black willow	: .375
<u>Tilia americana</u>	: American basswood	: .567
<u>Tilia americana</u>	: American basswood	: .524
<u>Ulmus alata</u>	: winged elm	: .669
<u>Ulmus americana</u>	: American elm	: .514
<u>Ulmus americana</u>	: American elm	: .430
<u>Ulmus rubra</u>	: slippery elm	: .332

Table 3 .--Heat of combustion of barks

Species	Ash ¹	Moisture content	Calories ₂ per gram ²	British thermal units per pound ²
	<u>Percent</u>	<u>Percent</u>		
Fir, balsam	2.3	6.5	4,923	8,861
Larch, western	1.6	6.7	4,558	8,204
Spruce, Engelmann	2.5	5.5	4,644	8,359
Spruce, black	2.0	6.5	4,581	8,246
Pine, jack	1.7	6.6	4,867	8,761
Pine, lodgepole ³	2.0	5.6	5,661	10,190
Pine, slash	.6	6.4	5,001	9,002
Pine, sugar	.6	...	.....	.....
Pine, western white	2.6	...	¹ 5,047	¹ 9,085
Hemlock, eastern	1.6	6.2	4,890	8,802
Boxelder	6.2	...	.....	.....
Maple, sugar	6.3	6.0	4,056	7,301
Alder, red	3.1	5.8	4,415	7,947
Birch, yellow	1.7	5.2	5,042	9,076
Birch, paper	1.5	4.8	5,241	9,434
Pecan	7.5	...	.....	.....
Sweetgum	5.7	6.2	4,139	7,450
Blackgum	7.2	6.0	4,409	7,936
Sycamore, American	5.8	6.4	4,113	7,403
Cottonwood, swamp	4.0	...	.....	.....
Aspen, quaking	2.8	5.5	4,685	8,433
Oak, white ⁴	10.7	6.5	3,886	6,995
Oak, red	5.4	4.4	4,461	8,030
Willow, black	6.0	6.7	3,982	7,168
Elm, American	9.5	6.7	3,845	6,921

¹Based on weight of oven-dry wood.

²Values are for samples of the indicated moisture content.

³High heat of combustion probably due to high content of benzene extractives.

⁴Low heat of combustion probably due to high ash content.

Table 4. --Various extractions of barks (Percentages based on weight of oven-dry unextracted bark)

Species	Material soluble in 1 percent sodium hydroxide ¹	Material dissolved by successive extractions with--			
		Benzene	95 percent alcohol	Hot water	1 percent sodium hydroxide
	Percent	Percent	Percent	Percent	Percent
Fir, balsam	49.4	13.2	3.3	2.7	30.6
Larch, western ²	43.6	1.3	14.8	3.8	22.7
Spruce, Engelmann ²	64.0	5.2	25.9	10.9	22.2
Spruce, black	51.6	5.0	14.6	4.4	28.0
Pine, jack	62.6	8.0	12.4	3.0	41.3
Pine, lodgepole	72.9	28.7	10.9	5.6	29.8
Pine, slash ²	48.5	3.4	10.6	3.7	28.9
Pine, sugar ²	62.7	1.5	21.7	3.2	36.0
Pine, western white	57.3	3.2	7.5	14.3	33.3
Hemlock, eastern ²	51.7	2.8	21.2	3.3	24.6
Boxelder	39.7	2.4	6.3	6.2	23.7
Maple, sugar	28.3	1.2	3.9	2.4	19.2
Alder, red	37.8	2.3	3.9	3.7	27.5
Birch, yellow	46.9	4.3	10.8	2.3	28.4
Birch, paper	42.9	9.4	10.5	2.5	25.1
Pecan	50.9	.8	18.4	5.4	25.3
Sweetgum	48.3	1.5	17.7	7.4	21.3
Blackgum	39.4	2.5	4.6	5.3	27.8
Sycamore, American	33.4	2.1	6.0	3.6	22.0
Cottonwood, swamp	35.0	1.9	8.0	4.8	20.2
Aspen, quaking	41.8	4.0	11.6	4.7	22.0
Oak, white	38.2	2.7	4.4	5.8	26.5
Oak, northern red	39.8	4.8	7.9	3.6	22.3
Willow, black	35.3	1.6	3.8	4.8	23.8
Elm, American	45.2	.5	10.1	6.0	27.0

¹An appreciable percentage of this extract was reprecipitated on acidification.

²Barks with highest tannin content.

Table 5. --Reducing sugars produced by hydrolysis of bark with 72 percent sulfuric acid (Percentage, as glucose, based on weight of oven-dry, unextracted bark)

Species	Reducing sugars from--		
	Unextracted bark	Extractive-free bark	Alkali-extracted bark ¹
	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>
Fir, balsam	46.6	45.3	32.9
Larch, western	46.6	46.0	38.0
Spruce, Engelmann	42.9	34.3	24.2
Spruce, black	47.9	44.8	32.3
Pine, jack	30.6	28.8	21.1
Pine, lodgepole	38.3	32.9	19.2
Pine, slash	29.7	29.8	26.4
Pine, sugar	22.1	19.8	16.1
Pine, western white	42.6	34.0	26.0
Hemlock, eastern	34.9	33.3	29.1
Boxelder	40.6	37.8	30.0
Maple, sugar	35.4	34.3	31.1
Alder, red	38.6	38.0	30.3
Birch, yellow	32.5	31.8	26.0
Birch, paper	32.2	30.1	21.8
Pecan	33.5	30.7	23.3
Sweetgum	35.6	33.5	26.4
Blackgum	29.6	27.2	22.4
Sycamore, American	40.9	39.0	31.1
Cottonwood, swamp	41.0	39.2	34.1
Aspen, quaking	41.4	39.7	34.9
Oak, white	27.8	28.2	21.2
Oak, northern red	32.4	31.7	28.3
Willow, black	42.9	43.4	35.4
Elm, American	37.0	35.4	27.0

¹Extractive-free bark extracted with 1 percent sodium hydroxide.

Table 6. --Composition of reducing sugars from hydrolysis with 72 percent sulfuric acid (Percentages based on total reducing sugar)

Species	Glucose	Galactose	Mannose	Arabinose	Xylose
	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>
EXTRACTIVE-FREE BARKS					
Fir, balsam	64	5	12	9	7
Larch, western	69	4	11	6	9
Spruce, Engelmann	61	5	9	13	9
Spruce, black	64	6	7	11	9
Pine, jack	64	7	6	10	11
Pine, lodgepole	50	7	6	26	8
Pine, slash	63	7	7	7	15
Pine, sugar	69	6	8	7	9
Pine, western white	75	3	6	2	15
Hemlock, eastern	67	3	13	8	7
Boxelder	65	3	2	7	20
Maple, sugar	63	3	1	6	25
Alder, red	54	3	1	6	34
Birch, yellow	54	3	1	8	32
Birch, paper	53	2	1	6	36
Pecan	69	4	1	11	11
Sweetgum	60	3	3	11	20
Blackgum	60	4	1	8	24
Sycamore, American	59	4	1	4	30
Cottonwood, swamp	61	4	1	5	26
Aspen, quaking	60	2	1	5	30
Oak, white	60	4	2	7	24
Oak, northern red	53	3	1	6	35
Willow, black	69	3	1	6	18
Elm, American	70	4	2	9	11
ALKALI-INSOLUBLE BARK RESIDUES ¹					
Larch, western	74	4	9	4	9
Pine, slash	67	6	7	5	15
Pine, western white	74	2	3	3	17
Hemlock, eastern	76	2	10	5	7
Maple, sugar	69	2	1	4	24
Birch, paper	55	2	1	5	37
Sweetgum	71	2	1	5	21

¹Residue from the 1 percent sodium hydroxide extraction of extractive-free bark.

Table 7.--"Lignin"¹ and methoxyl of "lignin" and of bark

Species	"Lignin" from extractive-free bark		"Lignin" from alkali-extracted bark		Methoxyl in unextracted bark
	Yield ²	Methoxyl ³	Yield ²	Methoxyl ³	
	Percent	Percent	Percent	Percent	
Fir, balsam	27.7	8.5	15.0	12.7	3.30
Larch, western	30.0	8.9	19.6	10.7	3.14
Spruce, Engelmann	17.9	7.2	8.7	9.7	2.90
Spruce, black	25.3	8.2	14.4	10.0	3.20
Pine, jack	42.2	4.7	14.4	10.1	3.07
Pine, lodgepole	14.8	5.1	5.4	8.1	1.99
Pine, slash	49.9	6.3	26.1	10.2	3.95
Pine, sugar	49.9	3.9	20.1	8.2	2.45
Pine, western white	39.3	2.8	16.4	1.7	3.87
Hemlock, eastern	35.8	8.0	20.1	10.5	3.61
Boxelder	30.1	11.1	22.8	12.4	4.03
Maple, sugar	37.3	11.2	27.4	11.9	5.05
Alder, red	40.9	7.9	28.5	9.2	3.85
Birch, yellow	40.6	7.6	26.3	9.2	3.46
Birch, paper	37.8	8.4	22.7	12.1	4.04
Pecan	24.9	7.5	16.0	9.5	2.69
Sweetgum	25.3	10.7	18.7	12.9	3.37
Blackgum	38.3	10.3	25.0	12.5	4.97
Sycamore, American	26.6	15.0	21.3	16.8	5.53
Cottonwood, swamp	33.4	12.0	27.2	13.7	5.36
Aspen, quaking	31.2	10.3	21.0	13.6	4.75
Oak, white	31.8	7.3	20.9	9.3	3.28
Oak, northern red	34.8	9.1	23.3	11.3	4.32
Willow, black	29.0	9.2	20.9	12.0	3.74
Elm, American	27.5	6.9	16.9	9.7	2.91

¹The acid-insoluble residue from bark by the 72 percent sulfuric acid method. This fraction should consist of bark lignin plus insoluble corky substances. Ash was not determined in "lignin" residue.

²Yield based on oven-dry, unextracted bark.

³Yield based on weight of the corresponding oven-dry "lignin" residue.

Appendix I

United States Manufacturers of Composting Equipment

Arizona Biochemical Sales
2500 South 22nd Avenue
Phoenix, Ariz. 85009

Earp-Thomas Laboratories
Highbridge, N.J. 08829

Fairfield Engineering Company
Marion, Ohio 43302

General Products of Ohio, Inc.
Crestline, Ohio 44827

Gruendler Crusher and Pulverizer Co.
2915 North Market Street
St. Louis, Mo. 93103

Hazemag USA, Inc.
60 East 42nd Street
New York, N.Y. 10017

Hobbs Engineering
P.O. Box 1306
Suffolk, Va. 23434

International Disposal Corp.
Box 1586
Shawnee, Okla. 74801

International Eweson Corp.
2840 Hidden Valley Lane
Santa Barbara, Calif. 83101

Logeman Bros.
3150 West Burleigh Street
Milwaukee, Wis. 53206

Metropolitan Waste Conversion Corp.
P.O. Box 202
Wheaton, Ill. 60187

National Organic Corp.
2140 Bank of Georgia Building
Atlanta, Ga. 30303

Richland Company
415 N. Tejon
Colorado Springs, Colo. 80902

United Compost Services, Inc.
1 Main Street
Houston, Tex. 77002

This list is prepared merely for information, and inclusion of names on it implies no endorsement as to quality and prices. Other names will be added to the list upon request. A more comprehensive, international list appeared recently in *Compost Science* 12(1): 23-32 (1971).

Appendix II

Sources of Technical Assistance

Information on local conditions concerning forest products utilization can be obtained from utilization and marketing foresters employed by the State forestry or conservation departments or from Forest Products Utilization personnel in these regional U.S. Forest Service offices:

Northeastern Area State & Private Forestry 6816 Market St. Upper Darby, Pa. 19082	Covers Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, Michigan, Ohio, West Virginia, Pennsylvania, Maryland, Delaware, New Jersey, New York, Connecticut, Massachusetts, Rhode Island, Vermont, New Hampshire, and Maine.
Southeastern Area State & Private Forestry 50 Seventh St., N.E. Atlanta, Ga. 30323	Covers Texas, Oklahoma, Arkansas, Louisiana, Mississippi, Alabama, Georgia, Florida, South Carolina, North Carolina, Tennessee, Kentucky, and Virginia.
Northern Region Federal Building Missoula, Mont. 59801	Covers Montana, northern Idaho, and North Dakota.
Rocky Mountain Region Federal Center, Bldg. 85 Denver, Colo. 80225	Covers Wyoming, Colorado, South Dakota, Nebraska, and Kansas.
Southwestern Region 517 Gold Avenue, S.W. Albuquerque, N. Mex. 87101	Covers Arizona and New Mexico.
Intermountain Region 324 25th St. Ogden, Utah 84401	Covers Utah, Nevada, and southern Idaho.
California Region 630 Sansome St. San Francisco, Calif. 94111	Covers California and Hawaii.

Pacific Northwest Region
319 S.W. Pine St.
P.O. Box 3623
Portland, Oreg. 97208

Covers Oregon and Washington

Alaska Region
Federal Office Building
P.O. Box 1628
Juneau, Alaska 99801

Covers Alaska

Institute of Tropical Forestry
P.O. Box AQ
Rio Pedras, Puerto Rico 00928

A list of state foresters and U.S. Forest Service officials appeared in Forest Industries 97(7): 74-78 (1970).