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USES FOR SAWDUST, SHAVINGS, AND WASTE CHIPS

Abstract

Although many outlets are available for the utilization of wood fines, economical disposal of sawdust, shavings, and waste chips remains a problem of growing concern to the wood industry. This report summarizes current uses for wood residues and provides sources of further information on available outlets, processing methods, and economic considerations.

USES FOR SAWDUST, SHAVINGS, AND WASTE CHIPS[1]

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Introduction

This report attempts to review and summarize the best information currently available (1969) on uses for wood fines. The information at hand on some uses is reasonably complete and applicable nationwide; on others, where the use is small and localized, the information is fragmentary and may not be currently applicable elsewhere or under other conditions.

Numerous references are given to indicate recent sources of detailed useful information. Many articles cited contain cost analyses or other economic information. Publications that record only general information or recommendations have been largely omitted. Older publications generally can be traced through the references in the papers cited here and through bibliographies of the Institute of Paper Chemistry, Appleton, Wis. (40, 210, 211).[2]

Major emphasis in this report is placed upon established or developing uses rather than upon potential uses. Potential uses may seem more important to many inquirers, but for the most part such uses are still largely a matter for further research and economic investigation. This report aims to cover normal trade outlets and makes little attempt to report on the status or results of fundamental research projects. The information should help wood processors decide which outlet is now best for their fine mill residues. A parallel publication on bark utilization (88) also may be helpful.

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[1] This is a major revision of FPL Rep. 1666-1, "Uses for Sawdust and Shavings," originally issued in 1947 and revised in 1961.

[2] Underlined numbers in parentheses refer to the Literature Cited at the end of this report.

Scope of the Problem

Economical disposal of sawdust and shavings is a problem of growing concern to the wood industries. Enormous quantities of sawdust are produced annually by sawmills. The sawdust produced in cutting a thousand board feet of 1 inch hardwood lumber with a saw cutting a 1/4 inch kerf is at least (0.25 ÷ 12) x 1000 = 20.8 cubic feet of solid wood. At a typical green weight of 52 pounds per cubic foot for solid hardwood, this amount of sawdust would weigh 1,085 pounds. The same air-dry wood (12 pct. moisture content) would weigh 36 pounds per cubic foot, hence the sawdust would weigh 750 pounds when dried to 12 percent moisture content. Planing and machining of lumber and other manufacture from wood leads to further residues. A planer mill produces about 600 pounds of dry residue per thousand board feet. Thus, the total amount of air-dry wood fines originating in U.S. industries alone exceeds 15 million tons a year--enough to make a (triangular cross section) pile 50 feet high, 100 feet wide, and over 150 miles long!

Sources of Utilization Information

Several good publications provide brief information on many of the possible outlets for wood wastes and mill residues and the problems associated with the marketing of wood waste products (16,17,36,55,66,75-77,90,115,127,132,152, 183). A bibliography covers the uses other than board uses, including foreign and patent literature up to about 1961 (40). Use of wood wastes in boards is covered comprehensively in general bibliographies on boards (210,211).

Frequently, meetings are held at which waste utilization problems are discussed, and reports of the transactions are recorded in the literature. For example, transactions of the annual meetings of the Northwest Wood Products Clinic in Spokane, Wash., can be purchased for $5 a copy from the Extension Service, Washington State University, Pullman, Wash. Many local surveys of amounts of wood wastes produced have been made, for example, for North Carolina (187) New Hampshire (86), Minnesota (97), West Virginia (77), Georgia (152), Indiana (158), Oregon (45,47), and Western Mountain areas (43,110).

Residue Estimation and Marketing

There are several publications that give tables or graphs that are useful in measuring or estimating amounts and weights of sawdust and shavings produced from various kinds and sizes of trees being converted to lumber of different dimensions (29,45,52,55,86,99,107,112,127,152,180,187,192,216).

Quantity estimates of wood fines based on volume depend on the degree of compaction and the particle sizes of the material and are not very reliable. Since compacting occurs during transportation, the weight of a small sample taken in a measuring box from the surface is often in no way characteristic of a whole load: weighing the entire delivery is better. Since the moisture content is important for measuring amounts of true wood substance present in weighed batches, representative samples of sawdust or shavings must be taken and their moisture content determined (2,169,209). The moisture content of chips may be monitored continuously (25,170).

The search for profitable outlets for sawdust, shavings, and similar wood wastes is often instigated by the need for reducing costs of disposal of materials that clog production, or by the desire to get some return from material that in the log form has represented a considerable outlay of money. Of late, the drive against pollution of air, lakes, and streams has added greater urgency (35,36, 138). Frequently, installations based on inefficient steam power plants that once used wood waste for fuel at the point of its production have been replaced by oil, gas, or electric equipment, so that many major outlets for sawdust as fuel have been closed. On the other hand, certain uses for sawdust and shavings have been extended.

Many uses for sawdust and shavings are open to the individual producers of such waste. Many call for retailing special qualities of material or relatively small lots of material, demands for which are customarily supplied by centralized dealers who specialize in sawdust and shavings. Most large cities have such dealers, whose names are carried in classified directories and similar lists. An economic analysis of the feasibility of packing and shipping small lots of sawdust and shavings is available (126). Recent development in England of an automatic baling machine for wood waste is of interest in this connection (3). Another baling press for woodworking waste is made by Lake Engineering Co., P.O. Box 784, Hammond, Ind. Conventional farm baling machinery can be modified for baling wood wastes, but it generally requires one or two operators (126).

On an industry-wide basis most sawdust is green. Green sawdust has limited uses, for example, as fuel at the producing plant or for pulping. Green hardwood sawdust is also used in fairly large amounts for meat smoking. In some localities green softwood sawdust, and to a less extent hardwood sawdust, is also used in special sawdust furnaces for domestic heating. Thus far it has seldom been considered economically feasible to dry sawdust artificially (6,46,63,169).

Shavings ordinarily come from air-dried or kiln-dried wood. Shavings and sawdust produced from machining dry wood of a single species afford their producer the best prospects for marketing waste material. Uniform particle sizes (achieved by screening) are needed for some uses. For most uses only fresh material is acceptable. Sawdust and shavings, when exposed to the weather, deteriorate very rapidly and lose much of their value. Mixed dry sawdusts are good for briquetting for fuel (44,165).

As in other fields of wood use, it is often better to prevent the waste or to minimize its occurrence than to salvage it after it occurs. Frequently, however, companies may now find it profitable to amend their production practices to create a different kind of waste--perhaps even in larger volume--but one that can be marketed more readily. In any case, after waste is produced, economical disposal depends more upon the initiative and salesmanship of the producer than upon almost anything else.

Large-scale use of sawdust and shavings still remains a major problem for which only partial solutions have developed. Geographic separation of sources and markets and transportation problems arising from bulkiness severely limit profitable outlets for these materials. In-plant use still has the most desirable features--an existing handling system plus synchronization between waste production and consumption plus a captive source of supply. Next to in-plant consumption, local markets are advantageous from the materials handling standpoint but may be limited in consumption. Longer shipping distances can generally be tolerated only for high-value products, for example, the best quality wood flour. Low-grade products, such as sawdust/shavings for agricul-ural use, must be marketed close to the point of origin.

Use Classifications

Brief information on various uses of sawdust and shavings is tabulated in tables 1, 2, 3, and 4 of this report under four general classifications:

(1) Uses based on special physical qualities.

(2) Fuel uses,

(3) Fiber and wood-base board uses.

(4) Chemical uses.

This classification is not entirely satisfactory because some uses may be classed in more than one group. Producers seeking outlets are advised to look at all categories.

Physical Qualities

In seeking markets, it is well to recognize that intrinsic physical qualities (table 1) of sawdust and shavings, as well as their cheapness and availability, govern certain types of use. Recognition of this may help the producer to find local markets not specifically listed in table 1. Sawdust and shavings sometimes are chosen for use because they are (1) absorbent, as for liquid spill cleanup, mud control, floor coverings, sweeping compounds (201), or as a carrier of liquid manure: (2) abrasive, as in hand soaps, metal polishes, fur cleaners, or sweeping compounds; (3) bulky and fibrous, as for wood flour, cushioning, packaging, or lightweight cement aggregate; (4) nonconductive, as for insulation; and (5) granular, as for textured surfaces, for example, in oatmeal wallpaper.

Wood flour, a long-established important wood residue product (63,166,188), is really fibrous, but its use is classified in this report under uses based on special physical qualities. It is used mainly as a filler for thermosetting resins: in moldings it confers impact resistance, shrinkage control, and good electrical insulating characteristics at low cost.

Absorbency, bulk, and chemical composition combine to make sawdust and shavings (11,19,30,33,54,68,75,105,120-122,171,208)--or chipped wood and bark (21,33,88,121,122)--of value in improving the physical condition of soil especially after the material is used as bedding for animals or poultry (9,21,73,75, 212) before application to the land. The economics of this outlet have been examined (19). Although wood itself contains no appreciable fertilizer chemicals, wood particles used as bedding can absorb liquid manure, which contains 90 percent of the total nitrogen in manure, in addition to carrying the solid manure. By adding about 50 pounds of superphosphate per ton before spreading on the fields, the nitrogen in the liquid manure can be “fixed” in a form that does not evaporate and is not readily leached out. When wood fines are mixed into the soil, bacterial action decomposes the cellulosic portion of the wood within 2 months to a year, depending on soil structure and consistency, temperature, and moisture (10). The modified but largely undecomposed lignin Of the wood remains as a fertile humus to improve soil tilth and increase the permeability and water retention of the soil, especially on sandy or clay soils. Well-rotted sawdust can be applied directly to the soil, but fresh sawdust not Used as bedding first should be fortified with nitrogen (10,34,88,128) before being placed on soil that is to be cropped the same year. The bacteria that decompose the wood require more nitrogen than can be supplied by the wood alone, hence will Compete with the crop plants for soil nitrogen unless sufficient nitrogen is added to the wood. The amounts that have to be added depend upon the species, age, and bark content of the wood waste, three factors that affect its rate of decomposition (10). Suggested average levels lie around 25 pounds of fertilizer ammonia, or 80 pounds of urea, or 100 pounds of ammonium nitrate, or 200 pounds of ammonium sulfate per ton of wood fines. This added nitrogen eventually becomes available to crops when the decomposition cycle is complete. The effects of wood wastes on the acidity of soil are discussed extensively in a parallel paper (88).

Wood particles are also of value when applied above ground as a mulch (11,19, 33,68,80,105,150,203,208). In strawberry and blueberry raising, and in orchards, a 4- to 6-inch layer of wood particles conserves moisture, prevents high soil temperatures, and reduces the number of weeds. Old sawdust is also beneficial in establishing turf grasses (15,106,140,148,204), for example, for landscaping, in graveyards, or on golf courses, and in counteracting aftereffects of pesticides in soils (137). Beneficial effects on soils when pests or diseases are a problem are also frequently observed (10,88,143).

Composted wood particles are frequently used by nurserymen and gardeners instead of peat moss, which is more difficult to mix into the soil. Wood particles, including bark, can be composted slowly like other vegetable matter (59,80,172), but some half-dozen methods have been developed that reduce the composting time considerably (65,66,100,108,172,213,214). Some methods may involve inoculation with a bacterial culture (100,213,214), with or without the addition of fortifying chemicals. The most rapid systems involve inoculation, addition of chemicals, and control of heat and moisture content as the material passes through multistage continuous processors. Other vegetable and animal (packing house) wastes may be included with the wood. Supplemental chemicals are added to most composts. Sawdust compost can be used advantageously for growing edible mushrooms (28). Champignons are grown commercially on enriched beech sawdust in Germany.

Mulching and soil-conditioning can utilize large quantites of sawdust and shavings, but require sawmill locations in agricultural areas. Profit possibilities are normally low, but costlier waste disposal by other means may be avoided.

Another agricultural outlet for sawdust and shavings may be developing in the field of animal feedstuffs. Cattle raised on high energy grain diets in pens or feedlots require a certain amount of roughage in their food in order to promote adequate salivation and digestion. Sawdust appears to fulfill this need for a roughage ingredient admirably (20,177,189). Mild treatment of certain kinds of wood with alkali--a common practice for upgrading poor quality hay--may even make some of the fiber in the wood digestible: thus such wood would serve both as a roughage and as partial nutrient (177). Further articles on this subject will appear in a forthcoming book (221).

Highway uses may absorb appreciable quantites of wood and bark particles even in nonagricultural areas (15). Mulching is used on fresh road embankments to prevent erosion and to aid the establishment of a permanent vegetative cover. Winter logging roads of compacted snow are much improved in bearing capacity by the addition of sawdusts. Tests have shown that the tensile strength of ice with sawdust in it is thrice its normal strength; sawdust additions make it possible to increase the load-bearing capacity of lake or pond ice. In constructing logging roads in bog areas, a thick submerged layer of coarse sawdust provides a satisfactory foundation to support the earth that forms the road. Sawdust and shavings are also useful for a base for practice ski slopes in dry areas (161); extensive amounts are also used for bridle paths, mud control around building sites, in livestock showrooms and arenas, stables, kennels, and laboratory animal pens and cages.

Sawdust and shavings are used as aggregate in lightweight concrete (89,98), but extractives or incipient decay in the wood sometimes interfere with the setting of cements (206,207). Results of using sawdust in concretes or plasters have been erratic, but studies of the chemistry involved have made possible a better control of such products. High humidities and freezing-thawing cycles cause such materials to disintegrate, but indoor use is normally quite safe. Medical plaster casts have been reduced in weight by use of sawdust as a filler. One proprietary flooring material combines sawdust with asbestos as filler material for the cement.

Fuel

Four main classes of fuel uses (table 2) for sawdust and shavings (167,168) are recognized: (1) for power and heat at the producing plant (with other wood waste) (5,6,195); (2) in public buildings and power plants (with hogged waste) (18,129); with special domestic sawdust burners (sawdust only); and (4) as briquets (dry sawdust and shavings) (44,165). The first class is country-wide and large in volume, although decreasing; bark is now replacing wood in this role (88). In some localities, sawdust and shavings are becoming too valuable to expend on this low-grade outlet. The last three classes are of special significance, mostly in the Pacific Northwest, but interest in the fourth class (briquets) has extended to all parts of the United States and to other nations. The most common products in this category are artificial logs for household fireplaces, barbecues, or stoker furnaces. These are usually made by molding fine wood particles at high temperatures and pressures without a binder, relying upon plasticization of the wood to hold the particles together. Good markets for these products are usually to be found only in large metropolitan areas. Most are made in the "Pres-to-log" machines[3] (two sizes) manufactured and sold or leased by Wood Briquettes, Lewiston, Idaho. Both machines have a throughput of some 12 to 15 tons of kiln-dried (8 to 10 pct. moisture content) hammermilled wood fines per day. The operating crew can run two machines simultaneously. Some American briquet manufacturers use equipment produced by a Swiss firm (Glomera, Basel) or the Swedish Soderhamn machine (Talladega, Ala.). A more recent development can use green sawdust (37), but it takes 10 machines to process 12 to 15 tons in an 8-hour shift. Since investment and production costs are thus rather high, special markets for these logs are needed. However, unlike Pres-to-logs, these logs do not swell or disintegrate if they become wet. The P 192 Log Machine recently developed by Western Research (and Scientific Laboratories), Inc., 699 Second Street, San Francisco, Calif. 94107, is also said to convert 6 to 12 tons of any sawdust per day to 6-pound high-flaming logs by compressing it with an equal amount of wax (136). Some manufacturers add inorganic salts to their logs to give them gaily colored flames. Typical compressed fuel logs burn about 2-1/2 to 3-1/2 hours. Fuel logs cut straight from the tree seem to form the best outlet for wood from small holdings (74), unless it can be chipped or shredded and put to some of the agricultural uses mentioned earlier in this report.

The fuel value of wood (144,217) depends upon its density, and lignin and extractives contents. Since softwoods contain more lignin and terpenes than hardwoods, their calorific values are higher. Kiln-dried hardwoods produce some 8500±200 B.t.u. per pound, softwoods give about 9300±300 B.t.u. per pound. This is about half the amount of heat from fuel oil or three-quarters of that from mineral coal. Some major lumbering companies claim that wood waste actually has a fuel value in large installations of about $4 to $6 a ton, a price which competes quite favorably with its value as a source of fiber. Information on the preparation and firing of wood fuels is available (167,168).

In-plant use of sawdust/shavings as fuel for process steam or electric power has advantages that warrant close scrutiny before it is abandoned (5,18,53,175, 217). In cost comparisons with competing fuel systems, the capital investment and standby charges for the replacement fuel must be considered together with the additional charges required to dispose of the wood residue by other means. Such other means may require additional investment for extension of the handling system, storage, and processing equipment. Processing and marketing costs and overhead must be charged against the new utilization system. Since the profit level for any salvage product is always lower than that for the principal product, the overall picture often favors in-plant fuel use. However, the bulkiness of sawdust and its tendency toward incomplete combustion are disadvantanges in its use as a fuel. The moisture content is also important (217).

[3] Use of trade names is for information only, and does not imply endorsement by the U.S. Department Of Agriculture to the exclusion of others which may be equally suitable.

In the past few years sawdust and shavings have been used more and more widely for charcoal briquet production. This expansion came about after the development of rather large capacity continuous carbonization equipment (50). Two manufacturers of such equipment are the Nichols Engineering Research Corporation, 150 William St., New York 10038, and the BSP Corporation, Box 8158, San Francisco 94128. Other recent developments are a fluidized bed process (104) and a continuous, vertical entrainment drying and carbonization technique (32). Detailed guides to charcoal manufacturing equipment, charcoal production, and marketing are available (83,103,185,193,202); a survey gives a list of U.S. producers (197).

Fiber and Wood-Base Board Uses

Other uses offering possibilities of increasingly large volume consumption are fiber uses (table 3), for example, in roofing felts (42), building fiberboards (71,72,116,117,210), and paper. Particleboard (71,72,117,145,211) provides another market for sawdust and shavings.

Use of sawdust and shavings for pulp began in the west and has attracted much attention of late in other regions; sizable amounts of southern pine coarse sawdust, for example, are now going into pulp products. However, it must be stated clearly here that fine sawdust cannot be used for pulping. Even coarse sawdust and shavings alone do not give satisfactory pulps using the sulfite method. Nevertheless, some mills with batch digesters add up to 20 percent sawdust and shavings to the wood chips used for kraft pulping. For example, in the southern pine area, "saw kerf chips," produced under controlled conditions, are mixed with standard pulp chips to make kraft paper (for example, by Buckeye Cellulose and Westvaco). The kerf chips comprise about 15 percent of the digester charge. Kerf chips are coarse sawdust particles large enough to be retained on a screen with 3/16-inch round openings, and are made by sawing at a constant feed rate of about 1/4 inch per tooth to yield particles that are 1/4 inch long in the direction of the fibers. Frequently, because the wood waste chips are smaller and thinner than the regular chips, the pulping cycle has to be modified; even so, the smaller wood particles are degraded severely, despite the modified conditions, while the regular chips are not optimally pulped. This may make this approach to the use of wood wastes in pulping too expensive (151).

Before the advent of continuous digesters, there were no efficient systems to convert fine wood residues alone into usable pulps. In recent years, however, sawdust and shavings have come to be regarded as a good low-cost furnish source for some paper stocks. Pulping systems developed within the past 10 to 15 years permit coarse sawdust and shavings to be delignified on a continuous basis using short (approximately 30 min.) cooking cycles, in contrast to the

2.5- to 6-hour cycles used for cooking normal chips. This has opened up the field for the conversion of wood wastes to paper products. As late as the 1950's, less than 35,000 ovendry tons of wood residues were processed into Paper products, compared to the present (1969) usage of approximately 2.3 million ovendry tons annually. Now pulp produced by separate cooking and washing in the normal chip delignification process is blended with smaller amounts of sawdust Pulps from continuous digesters and used in a variety of products, ranging from newsprint and tissue to bag and business papers. The western states have the major outlets for the material. However, utilization of sawdust pulps in southern states is also beginning to develop. The finer fibers from the sawdust pulps are used instead of the hardwood pulps that have been found to improve the printing characteristics of papers. In the future, it is likely that this fiber source will be utilized in all pulping regions of the United States with ever increasing amounts of wood residue being converted to fiber products. This will satisfy one requirement of whole tree utilization demanded by the ever increasing stumpage prices for pulpwood and the diminishing pulpwood resource. A list (arranged alphabetically by states) giving the locations of North American mills preparing pulps from sawdust is presented in table 5. About 4 tons of green sawdust (moisture content 50 pct., 14 to 16 pounds per cubic foot) are required per ton of kraft pulp. Mills buy on a weight basis (ovendry 2,000 pound units) (2,22,23,196).

As mentioned previously, fine sawdust is unsuitable for pulping. The "sawdust" for pulping is really a fine chip or shaving (see photographs in 133,182,215). Special machinery for sawing lumber that simultaneously produces large chips suitable for pulping has been developed (4,47,51,133-135,147,182). Some machines, like the Chip-N-Saw units (from Irvington Machine Works, Portland, Greg.), for example, chip and saw lumber simultaneously and are used in several mills (4,96). Others, like the Selectric Beaver (from Stetson-Ross, 3200 First Ave., S., Seattle, Wash. 98134), carry out these operations in sequence (7,157). Several sawmill equipment manufacturers now make similar machines that apply the chipping/sawing principle. The Griffsaw (from Frick Company, Waynesboro, Pa.) is another machine with several blades on multiple spindles that gouges out shavings suitable for pulping or use in boards (154). Strojimport in Czechoslovakia has recently developed a similar 10 spindle multisawing unit that is said to Produce virtually no waste. The Utilizer machines (from Nicholson Manufacturing Company, Seattle, Wash.) bark and chip wood that is too small for lumber production, such as forest thinnings and crowns (4) Journals such as Forest Industries, B. C. Lumberman, and Southern Lumberman describe plants where such machinery is in operation. Normally, only chips from debarked logs are suitable for Pulping (22,23,88), although minor amounts of bark can sometimes be tolerated (174). Unbarked chips can, of course, be used for fiberboard production (13), but the higher value of bark-free chips for pulping makes it worthwhile for mills to install barking equipment (39,67,181). The requirements concerning chip size and quality have been enumerated by several authors (22, 23,159,182,215). Some papers discuss sawing technology in this connection (85, 131,134,135,194). Freight costs tend to limit the longest distance that chips or shavings can profitably be supplied to a mill for pulping to about 100 to 200 miles. Several papers have dealt with the topics of bulk chip handling and rail or truck transportation and their costs (57,69,70,119,156,160,209).

Mills with good pulpmill outlets for wood fines generally find it worthwhile also to reduce their bulkier wastes to chips for pulping. Many publications deal with the policy of reducing slabs, trims, and edgings to l waste chips" for pulp production (16,17,49,107,109,112,113,156,158,180,181,196) and the economics involved (39,52,56,57,67,70,95,147,191,219). Many sawmills now have debarker-chipper systems or chipper headrigs, descriptions of which are given in the. trade journals. Others, especially mills in the New England States, send their residues to centralized chipping plants (181). Abundant information is available on machinery for converting solid wood residues to chips for pulping (16,69,93, 94,198). Experience reports on the latest equipment and trends can generally be obtained from the American Pulpwood Association, 605 Third Avenue, New York 10016.

The situation in this field has now matured to the state that one pulp and paperboard producer is actually manufacturing lumber in conjunction with a chipping operation (157). This company found that solid wood in the form of lumber is more valuable than pulp chips produced from roundwood and started producing cants from its larger pulpwood sticks while still maintaining its supply of pulp chips. Replacement of some obsolete stone grinders for groundwood pulp by modern refiners also allows waste chips to be used instead of roundwood, so that canter chips can be used for pulp production and the cores for lumber. Many pulp companies have recognized this development and are either planning to install sawmills with chipping headrigs or already have them, Consequently, there has been a dramatic increase in the amount of pulp chips produced from sawmill residuals in recent years. The size of the sawdust particles, shavings, or chips determines the kind of fiber uses to which wood fines can be put. If the waste chips produced from solid residues are just as large as those produced by normal pulpwood chipping, naturally the waste chips can be used in any conventional refiner groundwood, kraft, or chemimechanical installation to give pulps suitable for newsprint, bag, linerboard, hardboard, cardboard, or corrugating medium production. For the last purpose, the wood waste converted to waste chips can even be unbarked. However, only mills making newsprint or printing papers can advantageously use finer grain sizes of sawdust and shavings in groundwood because of the smaller length of fibers.

Although they may be of less interest to the wood processor seeking outlets for his residues, there are numerous technical reports in the literature describing methods and equipment used to produce pulp from sawdust/shavings and enumerating the properties of the pulps produced: dissolving pulps (111), groundwood pulps (14,24,42,79,87,130,146,149,176,178,179,220), and kraft pulps (8,27, 48,60-62,64,81,82,101,118,135,139,164,173,186,190,215,218). A capital cost estimate for setting up a unit for producing 100 air-dry tons of unbleached kraft pulp per day from sawdust has also appeared recently (48).

It is important to note that sawdust and shavings can also be used in addition to chips for making refiner groundwood (24,146,149,176,178,179), which finds uses in newsprint, tissue, towels, etc. (149,178) and fiberboards (42,130). Sawdust and shavings should be an interesting raw material for refiner groundwood manufacturers, because of their low cost and ready availability, and because a little of the energy needed to reduce logs to pulp fibers has been put into this material during sawing and machining. There are now over 40 refiner groundwood installations in North America making about 1-1/2 million tons of mechanical pulp a year and 15 other such installations making half a million tons of chemimechanical pulp a year. Many of these could use some sawdust/shavings or waste chips. The use of such methods is likely to expand. It, therefore, should be worthwhile for anyone seeking potential markets for wood wastes to inquire about possible outlets at local pulpmills (39). The locations (by states) of all pulpmills in North America can be found in either Lockwood's Directory of the Paper and Allied Trades (Lockwood Publishing Co., 551 Fifth Ave., New York 10017) or Post's Pulp and Paper Directory (Miller Freeman Publications, 500 Howard St., San Francisco 94105), each of which is revised yearly.

The Forest Service has estimated that for sawdust alone, an amount equal to over 7.5 million cords is now being burned annually. Theoretically, 4 million tons of bleached kraft pulp could be made from this waste. The total quantity of unused sawdust and shavings available in the U.S. from both hardwood and softwood in 1962 was put at 742 million cubic feet (solid wood equivalent). Currently, only about 5,000 tons per day of kraft pulp are being made from sawdust/shavings. Present utilization is thus only about 10 percent of the total softwood fines residue available in the U.S.

Mills in the Northwest have very little control of the relative amounts of sawdust and shavings in the residues delivered to them Sawdust is the denser material (10 to 12 pounds per cubic foot for dry material as compared to 4 to 6 pounds per cubic foot for shavings). Shavings supplied to mills usually have a longer, more uniform fiber and contribute to stronger pulp products. Moisture content and compaction are important variables in trying to assay the relative proportions of the two forms from the weight of a shipment. The fiber length in wood fines depends on the particle geometry and on the adjustment and speed of the wood cutting machine (feed rate, depth of cut in planing, bite per tooth in sawing): softwood dimension planing machines, for example, operate with about 4 to 6 cuts per inch while high speed band mills use 12 to 20 cuts per inch (1/16-in. bite per sawtooth). Most high speed circular sawmills, however, use a 1/8-inch bite.

Uses of sawdust and shavings as fiber (table 3) have thus received considerable attention, and are still being developed to an important degree. Sawdust and shavings have now become generally acceptable for pulping, so that this may now represent the best long-term outlet for such residues.

Coarse sawdust and shavings, as particles or fiber, have been much used in recent years for board products of various densities, adapted to various special uses (1,12,13,71,72,102,114,116,117,130,145,210,211). By definition, particleboards are usually boards of medium density (40 to 45 pounds per cubic foot) made in panel shape from dry wood particles that have been coated with a binder (usually 6 to 8 pct. urea resin), and formed and bonded by pressure and heat (114,117,145). Particleboard can be made from almost any type of wood whole or residue, and wood of any species, but generally low-density woods are preferred (71,72). However, because of unfavorable particle geometry, plain sawdust is seldom used in particleboard and must often be sifted out of shavings. Good boards cannot be made from ordinary sawdust alone. To obtain specific board properties, careful selection of residue and species is important. Special machinery has been used experimentally for surfacing lumber in order to upgrade the wastes: instead of small planer shavings, flakelike particles are produced that are of higher value for particleboard production (91,92,125).

Major uses of particleboards are for furniture core stock, floor underlayment, door cores, cores for kitchen cabinet tops, and wall paneling. At present, uses are mainly for interior applications; but much research is under way to develop particleboard suitable for exterior applications, such as house siding, soffits, and signboards. A recent change in mat laying technology has produced a process (German Bison process) well suited to the use of milled planer shavings for raw material. The particles are felted while thrown by an air blast; this causes segregation according to particle size, A graded density board is obtained with longer, stronger, splinter-like shavings at the core and fines at the surface (145). More than half of the world production is now made using this method. Several millwork companies are producing boards containing some sawdust bonded with 5 to 8 percent phenolic resin. These are used in panels for millwork. A Swiss process is being used extensively in the United States for making boards of various densities with a sawdust-and-shavings core faced with selected shavings to provide an attractive appearance. Particleboard with veneer or treated paper facings is also being manufactured (142). A typical economically feasible particleboard plant currently has a production rate of at least 200 tons per day; therefore, if a plant is to utilize planer shavings, there must be at least 200 tons available within economical shipping distance (usually assumed to be 100 miles radius). A recent article places these figures even higher (114).

Since 1967, annual symposia on particleboard have been held in Spokane, Wash. The transactions of these meetings can be purchased for $15 per copy from the Wood Technology Section, Engineering Division, Technical Extension Service, Washington State University, Pullman, Wash. Information on the latest trends in particleboard production and machinery can be obtained from the National Particleboard Association, Suite 720, 711 14th St., NW, Washington, D.C. 20005.

The production of fibers for fiberboard production has been discussed earlier under fiber uses of wood residues. No matter which type of forming process is used for making fiberboard (12,13,71,72,116,130,210), dry, semidry, or wet, either coarse residue or material such as pulp chips is usually required. Chips made from unbarked slabs or thinnings can be tolerated (13). Insulation board or hardboard cannot, however, be produced from ordinary, fine-grained sawdust, because the fiber length is too short. A typical fiberboard plant now must make at least 60 tons per day for economic production.

Each July issue of the journal Forest Industries (Miller Freeman Publications, 500 Howard St., San Francisco 94105) contains an annual directory of North American board producers (listed alphabetically by states) indicating the location and output of each manufacturer and indicating the raw materials used as furnish This list provides a key to potential markets for wood residues, For instance, recently constructed particleboard plants in Louisville, Miss., Malvern, Ark., Medford, Oreg., Springfield, Oreg., and Bend, Oreg., use planer shavings as raw material for their products; another plant recently built in Gassaway, W. Va, uses slabwood as starting material (1).

In addition to uses in boards, sawdust and shavings bonded with new and improved resins are molded into chair backs, toilet seats, furniture parts, croquet balls, pool balls, shuffleboard discs, containers with molded-in depressions for tools such as tap and die sets, and articles of various other types (31,38,41,78, 141,153,155,199,205). More recently a nucleonic barrier-type of sawdust plastic has been developed. A list of some plants making molded products from wood fines is available (200).

Reducing the Amount of Residue

The reduction of byproduct sawdust during lumber cutting and surfacing has always been a difficult problem (85). The Forest Products Laboratory has developed a new circular log saw which reduces the kerf by about 3/32 inch (84). It is partially self-tensioning through its unique compound taper grind of the saw plate. A single tensioning formula makes possible its operation through a wide range of speeds. It is recommended for mills that produce mostly boards or boards and single cants on the headrig. Its sawing accuracy, although not quite equaling conventional 7-8 gage saws, is much superior to conventional saws with similar narrow (7/32 in.) kerf. Considering that for each reduction of 1/32 inch of kerf width, the production of sawdust is reduced by 2.5 percent for 1-inch lumber, this saw should be of interest to companies facing severe sawdust disposal problems. The prototype saw blade was manufactured by the Minor Saw Works, P.O. Box 6725, Columbia, S.C. 29206. Another thin small-diameter saw for resawing cants also seems to be advantageous in reducing sawing waste economically (58). In addition to decreasing waste sawdust, thin saws may also reduce losses in trims, edgings, etc. (26).

Sawdust production can be eliminated entirely by slicing hot wood (123,124). Slicers made in Germany (by Industrie Companie, Krefeld, and RFR, Hamburg 33) are used extensively in industry for making low-grade slicewood products up to 4/10 inch thick, for example, shooks for packaging crates or baling. Machinery for cutting high-grade materials in thicknesses up to 1 inch has now been developed (162,163). This material can be used to produce packing crates, pallets, laminated hardwood flooring, or laminated siding with a low-grade backing and high-grade exterior. However, slicewood has some distinct shortcomings that limit its applicability; for example, checks along the grain reduce its strength slightly and make surface finishes less attractive, and the slices have a tendency to curl over the roller bar and toward the core during drying. The latter faults can be corrected by drying under constraint, but springback may occur if the material becomes wet.

In general, however, wood fines generation is expected to continue at its present or even a higher level, so that profitable, non-polluting outlets must be found. Besides mill location, the main factors determining the type of use to which fine wood residue from a specific mill can be put are the volume and makeup of the residues. For pulp uses, softwoods are preferable and the mill must be able to supply the pulpmill with regular daily shipments of at least 100 tons. For particleboard, 200 tons per day is the lower limit, but both hardwoods and softwoods can be used, For charcoal production by the continuous process, 80 to 90 tons of any kind of wood fines per day are needed in order to

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Thus, smaller mills must either pool their wood fines or rely on some of the small volume, lower value outlets mentioned in the tables, markets for which are of course much more difficult to find. Good salesmanship and intense efforts to ensure customer satisfaction will be found necessary in order to make a success of any wood fines disposal program.

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Table 1.--Uses of sawdust and shavings based on special physical qualities

Use	Sawdust	Shavings	Species	Specifications	Users or purchasers	Market location	Economical shipping distance	Annual consumption	Remarks (references)
FOR ABSORBENT QUALITIES:									
Bedding									
Stables and cattle pens	Green, Dry	Green, Dry	White pine, basswood, ponderosa pine, and other softwoods and hardwoods	Soft, absorbent, nonresinous woods preferred. Woods containing tannins not desired	Chiefly farmers and dairies	Countrywide	Ca. 50 miles	Large	Use subject to expansion to utilize valuable liquid stable manure commonly lost (9,21,73,75,212)
Laboratory animal cages	Dry	Dry	Southern pine, true firs, birch, maple, beech	Fine shavings; as above	Hygiene and clinical laboratories via dealers	Countrywide	Nationwide	Small	May need sterilization. Particle smaller than 20 mesh cause infan mortality in rats.
Kennels		Dry	Eastern redcedar	Dry shavings	Sawdust dealers			Small	
Floor Covering Factories Fish markets Garages Hotel kitchens Machine shops Meat markets Packing plants Tanneries Taverns Vegetable markets Warehouses	Principally dry sawdust used. Some shavings accepted.		"Box Shop," a mixture of hardwoods and softwoods as produced at box factories, furniture factories, and other woodworking plants	Dry, nonresinous, lightweight species preferred.	Purchased through sawdust dealers or directly from producer.	Many urban centers	Local	Relatively large	Absorbents are perhaps the greatest single outlet for dry sawdust from small mills. Green sawdust should be acceptable in some cases.
Grasshopper Bait	Green, Dry		Ponderosa pine, cottonwood	Weathered pine (2 years), green or dry cottonwood.	Government and local authorities	Northern Plains States	500 miles or less	Small	Poisoned with arsenic. Used only in critical years.
Leather Working	Dry		White pine or other lightweight, light-colored, nonstaining woods	Soft, clean, nonstaining species	Tanneries		Local		
Mulch/Soil Conditioner	Green, Dry	Green, Dry	Mixed; may include bark	Low extractive content preferable	Farmers and nurserymen, landscapers, architectural firms	Rural areas for agricultural uses; municipalities for turfgrass uses	Local	Medium, expanding	Should be combined with or used as a carrier of fertilizing matter; improved by composting (10,11,15,19,21,30,33,34,54,59,65,66,68,75,80,88,100,105,106,108,120-122,128,137,140,143,148,150,171,172,203,204,208,213,214)
Signal Rockets and Fireworks	Dry			Sifted, fine, for impregnating with chemicals			Local	Small	
Mud Control	Green, Dry	Green, Dry	Mixed softwoods and hardwoods		Construction companies	Countrywide	Local	Small	

Table [illegible].--Uses of sawdust and shavings based on special physical qualities (Continued)

Use	Sawdust	Shavings	Species	Specifications	Users or purchasers	Market location	Economical shipping distance	Annual	Remarks (references)
FOR ABRASIVE QUALITIES:									
Cleansing Soaps	Dry		Sapwoods preferred	Screened to 36 mesh	Specialty manufacturers, paint works, garages, machine shops, factories	Country-wide	Local	Small	Absorbent qualities also beneficial in removing grime from hands
Floor Sweeping Compounds									
Commercial	Dry		Hardwoods and softwoods	Dry stock sifted to 16 to 20 mesh or finer. Light-colored, lightweight woods preferred.	Made and distributed by numerous oil, chemical, and janitor supply companies for use in schools, stores, office buildings, and the like	Many urban centers	Up to about 300 miles	Moderate amounts	Green sawdust used in one type now being tried (201)
Household	Green		Any species	Same as commercial	Householders	Country-wide	Local	Small	As a dust retardant for sweeping basement floors; as a material for sprinkling on icy steps; domestic outlets in small but numerous lots are possible
Fur Working Cleaning	Dry		Kiln-dried sugar maple, a little birch, and a small amount of softwood	40 mesh maple (cleaning), 16 to 36 mesh for dressing and dyeing	The fur manufacturing trade concentrated in New York City; also numerous cleaners elsewhere. Users usually supplied by sawdust dealers	Dressing and dyeing industry, chiefly in New York City; cleaning in all cities	1,000 to 2,000 miles	Moderate amounts	Stock coming largely from maple flooring plants
Metal Finishing Cleaning Drying Polishing (from pickling bath, plating solution, lathes, machines, and the like)	Dry	Dry	For cleaning, drying and polishing plated ware, kiln-dried sugar maple is preferred. For other cleaning and drying, light soft woods are desirable. Species of high tannin, resin or acid content not acceptable	Platers' sawdust is dry hard maple 16 mesh and finer; white pine dust 8 mesh and finer. Often screened to get uniform size and free of chips	Sawdust dealers	Industrial centers	Usually supplied from local plants	Moderate amounts	Used chiefly in tumbling drums
Poultry Picking	Dry		Lightweight species	Sifted, fine					Believed to be only occasional use
Synthetic Abrasives									
Carborundum	Green				Manufacturers of abrasives	Eastern cities, New York, New England, Niagara Falls		Small	

Table 1.--Uses of sawdust and shavings based on special physical qualities (Continued)

Use	Sawdust	Shavings	Species	Specifications	Users or purchasers	Market location	Economical shipping distance	Annual consumption	Remarks (references)
FOR BULK QUALITIES:									
Circus Rings and Riding Stables	Green, Dry	Dry	Mixed		Regular dealers and riding stables	Circus towns	Local	Medium	
Clay Products-Special Porous brick and tile	Green, Dry		Species not important	Often sifted for uniform size	Specialty manufacturers			Relatively small	For reducing density and weight
Composition Flooring	Dry	Dry	Hardwoods or mixed hardwoods and softwoods	Varied, usually dry, soft species, nonstaining, nonacid, 4 to 50% as filler. Coarse softwood base. Fine hardwood top. Usually sifted for size.	Limited commercial experimentation			Small	Used with various cements to give insulating and resilient properties
Molded Novelties	Dry	Dry	Lightweight hardwoods and softwoods	Dry stock, ground to proper fineness. Must be clean	Furniture parts and novelty producers		Ca. 100 miles	Moderate	Plaques, novelty jewel cases, furniture ornaments, etc. (31, 38, 41, 78, 141, 153, 155, 199, 200, 205)
Packing									
Glass, china, canned and bottled goods, metal ware	Dry	Dry	Various species, but low density preferred	Nontannic or nonacidic species for packing metal ware. Light-colored, lightweight, soft, absorptive stock preferred. All stock dry and clean	Shippers of liquids, glass, china, and other fragile items	Widely dispersed	Local	Moderate	Wood flour used for plateglass to protect surface from scratches
Building stone		Dry	White pine, basswood, ponderosa pine	Light-colored, lightweight, nonstaining stock	Shippers of building stone	Indiana, New York, and other quarrying regions		Small	Packed between finished stone on flat cars, and the like
Grapes, fruit	Dry		Spruce, Douglas-fir, white fir	Cubical stock, air-dried, clean, sifted	California grape growers	Central and southern California		Few thousand tons	Often made specially by cutting
Nursery stock		Dry	Cedar, white pine, ponderosa pine, basswood	Soft, absorbent woods, chiefly shavings and shingle tow	Nurseries	Countrywide			Packing about roots of plants, shrubs, and the like, in shipping
Plaster Board	Dry	Dry	White pine, ponderosa pine and other light-colored, lightweight woods	Medium-coarse stock of species listed. Must be nonstaining and nonacid	Certain plants making plaster board			Several thousand tons	Usual mix 4-5% by weight. Is being replaced by foaming compounds

Table 1.--Uses of sawdust and shavings based on special physical qualities (Continued)

Use	Sawdust		Shavings		Species	Specifications	Users or purchasers	Market location	Economical shipping distance	Annual	Remarks (references)
	Green	Dry	Green	Dry							
Sawdust-Cement Concrete											
Cast blocks and panels	Green	Dry			Permissible species not definitely established. Spruce, red pine, jack pine, and aspen reported satisfactory. Leached stock of other species may be satisfactory. Woods said to be avoided: cottonwood, oak, birch, maple, Douglas-fir, western redcedar	Large, coarse, hard particles of woods having no detrimental extractives. (Extractive content and decay are factors affecting setting of the cement (206,207))	Building contractors				For interior use only (89,98). Includes certain patented formulas and special trade names.
Wood Flour											
Special types For burn-out mesh in ceramics	Green		Green		Southern pine		Some manufacturers of firebrick and ceramics	A few limited locations		Relatively small	
Usual types		Dry		Dry	White pine, ponderosa pine, Douglas-fir, maple, aspen, birch, hemlock	Dry stock (9% moisture content and lower); softwood preferred; any size. Southern pine if low in resin	Specialized plants drawing waste from planing mills, box factories, millwork plants	Scattered in different sections in East, Midwest, and West	Up to approximately 500 miles	Approximately 80,000 tons	Gradually increasing use in manufacture of plastics, and the like (63,166,188). Use for linoleum now decreasing.
FOR NONCONDUCTIVE QUALITIES:											
Concrete Protection	Green			Dry	Mixed	Nonstaining species	Building contractors	South		Small	Coverage to prevent too rapid drying; now largely replaced by chemical additives to mix
Thermal Insulation		Dry		Dry	All species	Dry sawdust and shavings; any kind but lightweight and light color (clean) preferred	Builders			Moderate	Used formerly more than now. Replaced by foam plastics, mineral fiber, and glass wool.
FOR GRANULAR QUALITIES:											
Display-Window Decoration				Dry	Mostly specially cut; light color	Suitable for dyeing or for staining to different colors		Urban stores		Small, occasional	
Texturing Oatmeal Wallpaper, Paints		Dry			Any species	Screened for size	Specialty paper/paint manufacturers			Small	

Table 2.--Fuel uses of sawdust and shavings

Use	Sawdust		Shavings		Species	Specifications	Users or purchasers	Market location	Economical shipping distance	Annual consumption	Remarks (references)
Briquets		Dry		Dry	Hardwoods and softwoods	Stock preferably of low moisture content (9 pct. or less)	Special briquetting plants where several tons are available per day	Metropolitan areas, especially on West Coast	Local	200,000 tons	Expanding use (44, 163). Market for products made from green wastes may be developing (37, 136).
Industrial Fuel Producing plants and local utilities	Green	Dry	Green	Dry	All	Any size and moisture content	Originating and nearby plants	Country-wide except utilities mainly in Northwest	Local	Large	Usually with Dutch ovens or special feeders (5, 6, 18, 36, 53, 88, 129, 144, 167, 168, 175, 217)
Lime Burning				Dry	Any, pine preferred	Dry shavings	Burners near source of shavings	Local			Loose shavings delivered by truck

Table 3.--Fiber uses of sawdust, shavings, and waste chips

Use	Sawdust	Shavings	Species	Specifications	Users or purchasers	Annual consumption (1968)	Remarks (references)
	(relative proportions)						
Liner and container pulp	70-90	30-10	Softwoods and hardwoods; major softwoods: fir and pine	Uniform screened particle size	Kraft pulpmills	1,534,300 O.D. tons	Mainly waste chips Rapidly expanding (8,27,48,60-62,64,81,82,101,118,135,139,164,173,186,190,215,218)
Paper pulp	70-90	30-10	Softwoods; major species: western fir and mixed	Uniform screened particle size	Kraft pulpmills	660,000 O.D. tons	
Groundwood	70-90	30-10	Softwoods, mixed	Uniform screened particle size	News and book grade pulpmills	35,000 O.D. tons	Expanding (14,24,42,79,87,130,146,149,176,178,179)
Building fiberboards	70-90	30-10	Western softwoods, mixed	Screened	Five at present	Ca. 6,000 O.D. tons	Industrial application not yet fully developed (12,13,71,72,115,130,210)

Table 4.-- Chemical uses of sawdust and shavings

Use	Sawdust		Shavings		Species	Specifications	Users or purchasers	Market location	Annual consumption	Remarks (references)
Distillation										
Cedars oils	Green	Dry	Green	Dry	Eastern redcedar	Heart stock	Several plants in Southern States	Most plants located in Tennessee		Fresh chips only can be used
Charcoal	Green	Dry	Green	Dry	Softwoods and hardwoods, bark		Several plants		Over 100,000 ton/yr.	Expanding (32,50,83, 103,104,185,193,197, 202)
Dyes	Green	Dry	Green	Dry	Osage-orange, sumac	Heart stock	Not known			Little current importance

Table 5.--Locations and capacities of North American pulpmills using sawdust/shavings as part of charge

State or province	Company/Mill location	Pulp type/digester*	Daily pulp output (tons)	Description of process
Alabama	Marathon Southern/Naheola	kraft/M & D	100	
Idaho	Potlatch/Lewiston	kraft/BC	150	(118)
		M & D	220	
Louisiana	Crown-Zellerbach/Bogalusa	kraft/BC	100	
	International Paper/Springhill	kraft/Kamyr	100	
	Olin Corporation/West Monroe	kraft/M & D	125	
Montana	Hoerner-Waldorf/Missoula	kraft/Kamyr	150	
Oregon	American Can/Halsey	kraft/2 M & D	350	
	Boise-Cascade/St. Helens	kraft/BC, Kamyr	575	(62)
	Crown-Zellerbach/Wauna	kraft/M & D	175	
		groundwood/BR	200	
	Georgia-Pacific/Toledo	kraft/M & D	100	
	International Paper/Gardiner	kraft/BC	60	
	Publishers' Paper/Oregon City	groundwood/BR	200	(220)
	/Newberg	groundwood/BR	320	(220)
Michigan	Packaging Corporation of America/Filer City	kraft/ESCO	--	(64)
Texas	Eastex/Silsbee	kraft/Kamyr	230	
Virginia	Union Bag-Camp/Franklin	kraft/M & D	50	(61)
		Kamyr	150	
Washington	Boise-Cascade/Wallula	kraft/M & D	150	(27)
	Crown-Zellerbach/Camas	kraft/2 BC	200	
	/Port Angeles	groundwood/BR	100	(220)
	/Port Townsend	kraft/M & D	100	
	Inland Empire Paper/Millwood	groundwood/S-W	80	(14)
	Longview Fiber/Longview	kraft/2 BC	400	(8,82,186)
		groundwood/BR and B-J	200	
	Pacific Pulp Molding/Wenatchee	groundwood/S-W	40	(87)
Canada				
British Columbia	Canadian Forest Products, Ltd./Port Mellon	kraft/Kamyr	400	(81)
	Crown Zellerbach/Campbell River	kraft/AD	150	(60)
	Eurocan P & P/Kitimat	kraft/M & D	100	(215)
	Kamloops/Weyerhaeuser/Mission Flats	kraft/ESCO	250	(164)
	MacMillan-Bloedel/Port Alberni	groundwood/BR	90	(179)
	/Powell River	kraft/Kamyr	150	
		groundwood/BR	15	(220)
Quebec	Consolidated Paper/Grand' Mère	groundwood/S-W	--	(220)
	International Paper/La Tuque	kraft/Kamyr	150	

*Abbreviation: AD = American Defibrator Continuous Digester from American Defibrator Inc., Chrysler Building, 405 West Lexington Ave., New York, N.Y. 10017.
BC = Black Clawson Pandia Continuous Digester, from the Black Clawson Co., P.O. Box 1028, Everett, Wash. 98201.
B-J = Beloit-Jones Refiner, from Jones Division, Beloit Corp., Pittsfield, Mass. 01201.
BR = Bauer refiner, from Bauer Bros. Co., P.O. Box 968, Springfield, Ohio 45501.
ESCO = Esco Continuous Digester from ESCO Corp., 2141 N.W. 25th St., Portland, Oreg. 97210.
Kamyr = Kamyr Continuous Digester from Kamyr, Inc., Allen St., Hudson Falls, N.Y. 12839.
M & D = Bauer M & D Continuous Digester, from Bauer Bros. Co., P.O. Box 968, Springfield, Ohio 45501.
S-W = Sprout-Waldron Refiner, from Sprout, Waldron & Co., 32 Logan St., Muncy, Pa. 17756.

Information about refiner groundwood installations not listed here and sawdust pulping installations projected after 1970 can probably best be obtained from the above equipment manufacturers.