Finding new and improved means for economically utilizing wood residues and inferior species is not only of importance from a utilization standpoint, but it is of importance from the broader standpoints of forest management and planning for a future balanced forestry budget. Finding uses for woods residues that would pay for clearing would help materially in reforestation forest management and fire control. For the present it would be preferable, however, to concentrate on the utilization of already accumulated wood residues that exist in large quantities at various wood processing plants.

Available Raw Material in the United States

Table 1 gives the amount of wood cut annually in the United States broken down into the amount used for the purpose for which it is cut, wood residue used for other purposes than those for which it is cut (largely as a fuel in the plants where the residue originates), and the residue that is totally unused (one quarter mill residue and three quarters woods residue), together with the standing timber lost due to fire, insects, and storm. The figures are given in tons of oven-dry wood so that they may be compared with figures for farm residues, fuel, and mineral resources. It is of interest that the total wood drain per year is practically equal to the total farm residue and not much smaller than the annual petroleum production. The amount of mill residue plus woods residue that is entirely unused is equal to the total iron and steel production. If valuable large scale uses could be found for wood residues
many plants would prefer to process all of their residue and use other fuels for power production. This, together with standing dead timber would double the amount of available raw material. The figures thus show that there is sufficient raw material for a tremendous new or expanded industry.

**Methods of Processing**

The various possible uses for wood residues may be divided into three different groups: (a) salvaging of solid wood cuttings for various established uses, (b) utilizing the fibers for various types of paper or synthetic boards, and (c) subjecting the wood substance to various types of chemical processes to remove naturally contained materials of value or to convert part or all of the wood components into different chemical products.

**Wood Cuttings**

The first utilization approach is the simplest and in general requires the smallest investment. Its chief shortcoming is that many of the potential products, such as short length lumber and dimension and cut stock can often be made cheaper from larger and higher grade timber. To offset the greater handling cost, products of greater monetary value might be made. One such application that falls in the chemical field is to make small resin-treated compressed products (compreg products) from normally wasted short pieces of wood \( (47, 48, 49, 50) \). Although such an operation might prove to be quite profitable it would use only a small fraction of available wood residue.

**Fiber Products**

The second approach to the problem of utilizing wood residues by processing them into fibers for the manufacture of paper, paperboard, and building board is now being practiced to some extent and shows promise of considerable expansion. As papermaking and better utilization of raw materials and byproducts is the subject matter of another report given at this meeting only the use of wood fibers in making of board and molding materials will be considered here. The problem of using more wood residues in paper, paperboard, and building board manufacture is largely an economic one. Slabs and edgings are suitable for processing in present equipment as evidenced by their increasing use in this way. In the Western States several integrated sawmills and pulpmills remove the bark from their logs with hydraulic barkers and use the slabs and edgings for pulp. Such cooperative and integrated operations are possible only when the lumber mills and pulpmills are relatively near each other. The more isolated small lumber mills have so far been unable to dispose of their residues in this way. Their only salvation is to use the residues themselves. In no case would they have sufficient wood residue to justify building a conventional pulp mill and only in cases where the readily available residue exceeded, say, 50 tons a day on a sustained basis, would it pay to build a conventional board mill. Efforts have hence been made to work out means of
processing wood residues on a considerably smaller scale for the production of coarse fibers and fiberboards (20, 21, 24, 39, 40, 53).

Investigations at the U. S. Forest Products Laboratory and elsewhere have shown that acceptable fiberboards can be made from almost any species of wood by mechanically processing either steamed or raw chips in an attrition mill and forming the boards from a dilute slurry of these pulps in water in a simple hand operated deckle box or suction box, followed by drying without pressure or under pressure (20, 21, 40). Relatively large amounts of sawdust can be used together with some longer fibered stock. In this case it is desirable to add 15 to 25 percent of a hydrated pulp or reprocessed newspaper (55). Appreciable amounts of bark can be included in the same way as sawdust if the color of the product is not considered critical. The inclusion of appreciable amounts of sawdust and bark does weaken the product, but the boards are, nevertheless, strong enough for a number of uses (20, 39).

Forming the boards in batch suction boxes followed by handling the boards by a vacuum lift device has proven successful in small-scale commercial operations of a western company, as well as in pilot plant operations at the U. S. Forest Products Laboratory (21). Making boards in this way will, of course, increase the manufacturing cost over that of the large existing plants that use continuous forming equipment. It is, however, only through simplification of the board forming steps that small-scale operations are possible. It is felt that the saving resulting from use of existing wood residues within the parent plant instead of buying expensive pulpwood will in a large measure offset the greater manufacturing cost. Another means of overcoming the differences in manufacturing costs between large mechanized and small batch operated plants is for the plant to make a board of a type that it can use in its own regular product, such as a plywood mill or furniture plant making core stock for panels or furniture. Recent tests at the U. S. Forest Products Laboratory have shown that wet felted fiberboards when press dried at a low pressure to give a specific gravity of about 0.5 show considerable promise for use as a core material (29).

The equipment needed for such a small-scale plant, together with approximate costs as of 1947, and approximate operating costs have been estimated by the U. S. Forest Products Laboratory for a plant processing 20 tons of wood residue per day for the production of insulating board (21). Equipment and payroll costs should be increased by about 50 percent to cover current increases. This would make the plant investment about $400,000. Existing plants that would not require additional ground, buildings, or steam facilities, would not have to make as large an investment. Placing a value of $4.00 per dry ton on the wood residue used and providing for the use of 20 percent of waste paper as a binder at $20 per ton, 18,000,000 square feet of one-half inch thick insulating board could be made per 300 working day year at a cost of $556,000 or about 3¢ per square foot. These figures, although only approximations, indicate that under present conditions insulating board could be made that will sell for a reasonable profit. Hardboards could be manufactured at about the same cost per unit weight. A hot press would cost more than a kiln, but it could be operated more efficiently.

There has been a great deal of interest in making board materials from wood residues by a dry or semidry process. This interest in dry forming is not...
surprising. Making up a pulp slurry in water containing 2 percent or less of fiber, removing the water by filtration, suction and evaporation, as is done in making wet felted fiberboards, does seem wasteful. This procedure, however, gives formation and strength properties at low specific gravities that have not as yet been attained by any dry forming process. The fact that no binder has to be used in wet felted boards more than makes up for the seemingly involved wet forming steps. Wet felted fiberboards containing no binder but about 2 percent of a rosin-alum or asphalt emulsion size stand up better in the Bureau of Standards weathering test (7) consisting of alternate soaking in water, steaming, freezing, and drying than do any of the dry formed boards so far tested, with the exception of those containing sizable amounts of expensive synthetic resins. Nevertheless, there is a demand for a good dry formed board.

Many binders have been tried in making dry or semidry formed boards. The most important of these which have found some commercial use are Portland cement (8) and magnesium oxichloride and oxisulfate (3h). The object of using wood residue rather than gravel or stone as the aggregate is to produce a cheap product that is considerably lighter in weight with better thermal insulation properties than normal concrete, and can also be readily sawn. Wood sawdust to cement ratios of 5:1 to 1:1 have been used giving densities ranging from 40 to 100 pounds per cubic foot in contrast to 140 pounds per cubic foot for normal cement. Blast furnace slag and pumice, however, give equally low densities and give a product that is less subject to cracking on freezing. Wood extractives tend to retard the setting of cement (8). This effect has been minimized by adding small amounts of calcium chloride or precipitating silica from a solution of sodium silicate on the wood particles prior to using. Products with reasonably good compressive strengths have been made but the flexural strength is only about one-tenth that of wet felted fiberboards of the same density. The use of coarse excelsior in place of sawdust gives a somewhat lighter board with a better flexural strength. The worst shortcoming of this type of board is that it tends to crack when absorbed water freezes within the structure. This has been overcome to some extent by coating the surface with water resistant bitumens.

Magnesium oxichloride and oxisulfate cements have the advantage over Portland cement in that they set up much more rapidly in the presence of wood. When the ratio of sawdust to cement is 1:1 or less and the product has a density of 70 pounds per cubic foot or more the product is harder than normal cement or brick (3h), and has fair weather resistance. A lighter product can be made with excelsior than with sawdust.

Many natural glues such as gelatin, casein, soya bean glues and rosin and by-products have been tried as binders. Even when binder contents as high as 40 percent are used, the product is considerably less strong for its weight than conventional wet felted fiberboards and the water resistance and weathering properties are generally poor except when appreciable amounts of the more expensive synthetic resins are used (2).

Urea resins in concentrations of 20 to 40 percent give boards with good dry strength properties but poor weathering resistance. Such boards, which are now being made to a limited extent, should be used only under dry conditions.
Phenolic resins give boards with considerably better weathering resistance than urea resins and with quite good strength properties. The amount of resin needed increases rapidly with a decrease in the specific gravity of the product. When the specific gravity is 0.9 or above as little as 10 percent of resin is needed. When the specific gravity is 0.5 about 30 percent of resin is needed to make a good board. One of the larger millwork companies is now making a dry formed board with a specific gravity of about 0.9 in this way from hammermilled ponderosa pine mill residues. It apparently is proving to be quite suitable for door and kitchen cabinet panels. Similar boards are reported to be made in England.

It is also possible by a steam (1, 5, 6, 22, 23, 27, 28, 38, 52), acid (11, 61), or alkaline hydrolysis to free the lignin from the cellulose of wood and remove the more hygroscopic hemicelluloses and obtain a product that has superior plastic properties to normal wood. When chipped wood is subjected to a very high pressure steam cook followed by passing through an attrition mill, a pulp is obtained that is suitable for making hardboards by the wet felting process without the use of a binder. Masonite is made in this way (5, 6, 52). When sawdust is used, preferably that from a hardwood, a molding powder can be made that requires only half the amount of phenolic resin that is normally used in high pressure phenolic molding powders with wood flour (11, 22, 41). Such molding powders were made to a limited extent during World War II. Although these molding powders give a product with properties comparable with normal phenolic molding powders they flow less readily and consequently cannot be molded with as great speed. If and when phenolic resins become less available such molding powders may again be made in the United States. In countries where phenolic resins have to be imported the use of hydrolyzed wood molding powders may prove profitable at the present time.

There has long been a need for a cheap handmolded product that does not require expensive presses for molding. Unfortunately most of the products of this type in which sawdust is the filler tend to shrink, distort, and crack due to the fact that water-borne binders are used. Solvents must be present for the material to become tacky enough to form. When the solvent evaporates shrinkage occurs. A liquid alkyd type of thermosetting resin, diethylene glycol maleate, has been found by the Forest Products Laboratory to give the desired tack and sets to give a good bond without the need of a solvent (9). Objects molded with this resin do not shrink as they set due to the fact that the liquid is converted on heating to an infusible solid without any evaporation occurring. Unfortunately as much resin as sawdust by weight must be used to give the desired tack and bond. The product, however, has high water resistance and strength properties approaching those of high pressure molding compositions. This sawdust binder mix appears suitable for making of objects in a small shop in quantities insufficient to make it profitable to use expensive high pressure molds.

There are thus quite a number of different types of products of a synthetic board or molded object nature that could under proper circumstances be made from wood residues. Wet felted fiberboards without a binder at present appear to be most promising.
Chemical Products

Using wood residues for the manufacture of various chemical products has a distinct advantage over the two previously described means of using wood residues in that for most processes the original form of the wood, the bark content, and frequently the species, are only of minor importance. Even the inclusion of fire-killed and partially decayed wood may not materially affect the yields of products.

Chemical processing methods may be divided into (a) extraction, (b) destructive distillation, (c) hydrolysis, in some cases followed by fermentation, (d) hydrogenation, (e) oxidation, and (f) miscellaneous methods.

Extraction Methods

Of these various processing methods, extraction is the most exacting as to the nature of the raw material for it involves removal of specific soluble materials naturally present in various species rather than a chemical conversion of cellulose and lignin to other products. Extractives, which are isolated from various species and parts of trees, vary in amount from a few tenths of a percent to about 30 percent of the weight of the raw material.

Essential oils are obtainable from the wood of eastern redcedar (Juniperus virginiana), the needles of various conifers, such as white spruce (Picea glauca), eastern hemlock (Tsuga canadensis), redcedar, the northern white-cedar (Thuja occidentalis) and western redcedar (Thuja plicata), the bark of such trees as sweet birch (Betula lenta), and the roots of the sassafras tree (Sassafras albidum) (10, 44). They are isolated by steam distillation. Sweet birch oil (similar to oil of wintergreen) is obtained in yields of only about 0.2 percent (10). The various conifer leaf oils are obtained in yields of only 0.2 to 1.0 percent (36). Cedar wood oil is obtained in the somewhat better yields of 1 to 3 percent while sassafras oil is obtained in yields of 6 to 9 percent from the bark of the roots, but only about 1 percent of the roots as a whole (10). Because of the collection problem the recovery of these essential oils from the various parts of trees has not been a very lucrative industry. If the extraction were followed by a hydrolysis of the residue to sugars as will be described later, the essential oil extraction might become a more lucrative, larger scale industry.

The most important extractive of wood from an industrial standpoint is the oleoresin obtained from old stumps of longleaf and slash pines. The wood as a whole contains only 4 to 6 percent of resin, while the stumps contain 15 to 30 percent of resin as a result of the less resinous sapwood having decayed or fallen away. Up to the present time it has been profitable to use only the old stumps. Present plants processing from 150 to 1,500 tons per day processed 1,550,000 tons of stumpwood in 1947 to produce 12,000,000 gallons of turpentine and 757,500 barrels of rosin (520 pounds each) (51). It has been estimated that at the present rate of production all accessible stumpwood will be used up in another 20 years. It is hoped that economical methods for extracting the mill residues of the resinous pines will be developed prior to that time. In order to make the handling of such large volumes of wood
profitable this extraction industry will very likely have to be combined with a hydrolysis of the extracted chips to produce sugars. Hydrolysis of the spent chips following extraction looks promising under present conditions and is being seriously considered by several naval stores plants.

Tannins are extracted with hot water from the wood or bark of several species (10). The most important source of tannin is the wood of the quebracho tree which grows in South America. The chief source in the United States has been from the wood of the chestnut tree from which 5 to 15 percent of tannin is extracted followed by pulping of the residual chips. This is an excellent illustration of integrated operations. Unfortunately, as a result of the chestnut blight this species is disappearing in the United States.

Tannin is also obtainable from the bark of such species as eastern and western hemlock (Tsuga canadensis and T. heterophylla), tan oak (Lithocarpus densiflora), swamp chestnut oak (Quercus prinus), and black oak (Quercus emoryi and Q. kelloggii). Of these, chestnut oak and eastern hemlock barks have been most extensively used for tannin production. The extraction of western hemlock bark looks promising for use in expanding the industry (15).

Several species of wood contain water soluble gums such as the arabo-galactan of tamarack (Larix occidentalis and L. laricina), and mesquite (Prosopis juliflora). A plant was in operation some years ago for a short period extracting the chips of old western larch stumps that contain 15 to 18 percent of arabo-galactan. The water extract was concentrated and then oxidized with nitric acid to mucic acid (37). Mucic acid was sold for use in baking powders for releasing the carbon dioxide. The process was not a financial success. It is conceivable, however, that an integrated process, in which the residual chips remaining after water extraction are hydrolyzed to sugars, could be made to operate profitably.

Destructive Distillation Methods

Charcoal production is the oldest of the chemical wood processing industries. For years charcoal burning was carried out in open pits without byproduct recovery. This is still done today to a limited extent in portable or semi-portable kilns (2, 3, 19).

Most of the charcoal produced in the United States is made in externally fired byproduct ovens in which the destructive distillation takes place in buggies which can be readily rolled into or out of the ovens (2, 19). Although the process is efficient from the standpoint of handling of the wood it is quite inefficient thermally because of the poor temperature control and low rate of heat transfer. Little effort has been made to correct these shortcomings in the United States due to the fact that destructive distillation of wood has not been a lucrative industry since the price of charcoal has been unstable and the volatile byproducts methyl alcohol, acetone, and acetic acid have been produced cheaper synthetically (14). The expanded demand for charcoal during and since World War II have again created an urge to improve the industry. There has been a great deal of interest lately in the German Reichert process (32) and the Belgian Lambiotte process (25) both of which involve the use of more efficient internal gas heated retorts (30).
These processes, like the oven process, use sizable pieces of wood. They are suitable for utilizing inferior species cut especially for the purpose, and possibly slabs, but not for mill residues as a whole. The most successful process in the United States for utilizing fines is the Stafford process. This process has been in successful operation for a number of years in a large plant that has sizable quantities of wood residue (2, 12). Warm dry hogged wood is fed continuously into the top of a well-insulated vertical cylinder at the bottom of which a heavy bed of charcoal is maintained. The exothermic distillation reaction furnishes the heat necessary for bringing the descending wood to the distillation temperature.

Another process for the continuous destructive distillation of subdivided wood, the Seaman process, involves passing the material through a slightly inclined, either externally or internally heated, rotating cylinder. Plants of this type are not in operation at present, but recent research on the process has again aroused interest in it (33). Research is under way on the development of other types of continuous feed destructive distillation methods, which should give more rapid controlled distillation and less decomposition of the volatile byproducts (30). If these are successful wood distillation may again become an important means of chemically processing inferior woods and mill residues.

Hydrolysis Methods

Wood hydrolysis at present appears to be the most promising means of chemically utilizing wood residues. The hydrolysis of the carbohydrate portion of wood to sugars followed by the fermentation of the sugars to alcohol was developed to a commercial stage in the United States prior to World War I. The process was successfully operated at Georgetown, S. C., and Fullerton, La., for a number of years (43). Exhaustion of readily available wood residue supplies near the plants and the introduction of cheap blackstrap molasses from Cuba finally caused the plants to close.

During the period between World Wars I and II research on wood hydrolysis in the United States was limited to tests on the production of plastic powders. The Germans, however, became very active during this period and developed the Bergius and Scholler processes which were in active operation up to the end of World War II. The Scholler process, the most successful of the two, used dilute sulfuric acid as a hydrolysis medium quite similar to the earlier American process, but carried on the digestion for considerably longer periods of time, thus increasing the completeness of hydrolysis. Research carried on during World War II at the Forest Products Laboratory under the sponsorship of the Office of Production Research and Development of the War Production Board showed that the Scholler process, although efficient from the standpoint of carbohydrate utilized was not so efficient as it should be from the standpoint of production of fermentable sugar, steam consumption, and time required. The long exposure of the charge to acid was causing the decomposition of part of the sugar that was produced.

The Madison wood sugar process was developed with this background in mind (13, 16). It gives a higher yield of fermentable sugar in 3 to 4 hours than the Scholler process does in 18 to 20 hours. Instead of subjecting subdivided
wood residue to the steeping action of a series of charges of dilute sulfuric acid at elevated steam pressures for about an hour each, the new process involves continuously flowing dilute sulfuric acid through the bed of hot chips after a short steeping with the original make-up acid under a gradually increasing temperature schedule. The increasing temperature schedule is designed to supply heat just as it is needed. The easily hydrolyzable hemicelluloses are hydrolyzed off first at a temperature which causes little decomposition followed only when needed by the more drastic hydrolyzing conditions to convert the more chemically resistant portions of the carbohydrate to sugar. The sugar content of the liquor leaving the digester is initially about 15 percent. When it drops to about 1 percent the cook is discontinued. The average sugar content of the liquor is then about 5 percent. The yield of sugar from various species of wood calculated on a dry, bark-free basis ranges from about 45 to 55 percent.

The hexose part of the wood sugars is readily fermentable to ethyl alcohol. Softwood species, such as Douglas-fir, that are low in pentose sugars will yield up to 65 gallons per ton of alcohol on a dry, bark-free basis (13, 16). Wood residues, such as slabs with bark contents up to 30 percent, give yields of 40 to 50 gallons of alcohol per dry ton (13).

This new hydrolysis procedure combined with continuous neutralization of the sugar solution under pressure is the basis for the large alcohol plant that was built with Government support at Springfield, Oreg., for processing 200 to 300 tons of wood residues per day. This plant operated one of its five digesters successfully in trial runs after a few mechanical modifications. The operators were not financially able to put the whole plant into proper operation and as a consequence the plant has been idle for a long time while a new operator was being sought. Indications are that after few changes are made in the plant it can produce alcohol quite profitably.

Although the original objective in hydrolyzing the carbohydrates in wood to sugars was for the production of alcohol (13, 16, 26) the wood sugar can be utilized in a number of other ways. It can be merely concentrated by evaporation to a molasses with a sugar concentration of 50 percent for animal feeding (11). It, as well as the still bottoms from an alcohol plant, can be used for growing yeast. A number of other fermentation products can be obtained under properly controlled growth conditions such as acetic, butyric, and lactic acids, acetone, butanol, butylene glycol, and glycerine. None of these has been developed as yet to the commercial production stage, but they all show distinct commercial possibilities.

Molasses production for animal feeding shows the greatest promise for utilizing large quantities of wood residue (11). If the feeding tests now under way prove that wood molasses is practically equal to blackstrap molasses in food value, very large amounts of it could be used. At present about 100 million gallons of molasses are used for feeding purposes annually in the United States. If it were fed only to cattle and dairy cows at the rate of 3 pounds per day per head, which can be done with blackstrap molasses, present consumption could be increased seventy-five-fold. This would require all mill residues and about two-thirds of all woods residues occurring in the United States to produce this amount. Such large amounts of wood residue would probably never be used in this way. The figures show, however, that the expansion of this
industry need not be curtailed by a limited demand for the product as would be the case for practically all other products.

Molasses production has another distinct advantage over the production of alcohol or yeast from wood residues in that it creates no pollution problem. Still bottoms from the Springfield alcohol plant would have the stream pollution equivalent of a city of about 100,000 people. Growing yeast on the still bottoms would reduce this value by about one-half. Molasses could also be made in a smaller plant than alcohol. According to present methods a plant making ethyl alcohol from wood residues would have to process about 200 tons of wood residue (dry weight basis) per day to operate profitably. A molasses plant, on the other hand, could process from 30 to 50 tons of wood residue (dry weight basis) profitably under present economic conditions. This makes possible many more plant sites. Research is now under way to try to simplify molasses production so that it could be profitably processed from 5 to 10 tons of wood a day. This would open the possibilities of farm cooperatives where a farmer could haul in a ton of low-quality wood lot wood to the plant and take home an equivalent amount of molasses containing 50 percent sugar.

Feeding tests are well under way in comparing wood molasses with blackstrap molasses, beet molasses, and other feeds (16). The results to date are quite favorable. A number of potential manufacturers are awaiting further pilot plant data as to manufacturing costs and confirmatory feeding data before starting to build plants.

Yeast grown on wood sugar is about half protein and is high in the vitamin riboflavin, which may help make it a valuable protein animal feed (31). It was made extensively from wood sugar in Germany during World War II both for human and animal consumption. Recent tests at the U. S. Forest Products Laboratory indicate that the Waldhof propagator developed in Germany, with slight modifications, appears the most suitable thus far developed for growing yeast with a minimum consumption of air. Yeast yields of 40 percent of the weight of the wood sugar are readily obtainable. When made from the total wood sugar a yield of about 100 pounds of yeast per ton of wood residue, calculated on a dry, bark-free basis, is obtainable. About 60 pounds of yeast can be made from the still bottom residue left after making ethyl alcohol from a ton of softwood residue, calculated on a dry, bark-free basis. When hardwoods are used the yield will be increased to about 100 pounds. Further feeding tests are needed to determine the value of wood sugar yeast in the United States.

**Hydrogenation Methods**

The problem of profitably utilizing the soluble lignin residue in pulp mill effluent and the solid lignin residue remaining when the carbohydrate portion of wood is hydrolyzed to sugar is an acute one. Lignin has higher fuel value than wood itself so it can in a number of cases be economically used as a fuel. In the isolated solid form it shows some promise as a soil conditioner. These, however, are low value uses. Lignin recovered from the waste liquor of the soda pulping process shows promise in plastics as a resin extender. The insoluble form of lignin obtained as a byproduct of wood hydrolysis has so far...
shown no promising plastic applications. Other proposed means of utilizing lignin do not at the present appear promising for large scale use with the exception of hydrogenation.

Lignin isolated by the various pulping methods or that remains as a solid residue after wood hydrolysis, when dissolved in a high boiling stable organic liquid or suspended in water containing an alkali, will react with hydrogen gas at elevated temperatures and pressure in the presence of a metallic or metallic oxide catalyst (12, 17, 18, 35, 42). Suitable catalysts are Raney nickel, copper chromite, and palladium oxide. Three types of liquid products, namely neutral oils, cyclic alcohols, and phenolics, together with a high boiling tar-like residue are obtained. The yields will vary with the type of lignin, the catalyst, and the reaction conditions. The cyclic alcohols have been shown to have high antiknock properties when added to gasoline for use in internal combustion engines, and they also have toxic and good solvent properties. The phenolics are mixtures of both resin forming and nonresin forming types. Possibilities of using them in plastics are still unknown. The neutral oils appear suitable for fuels and possibly the heavier fractions could be used for lubricating purposes. If and when petroleum shortages occur it would be possible to make 110 gallons of liquid fuel from a ton of wood residue calculated on a dry, bark-free basis by hydrolyzing the carbohydrates to sugars, followed by their fermentation to alcohol, and hydrogenation of the lignin residue under conditions to give an optimum yield of neutral oils.

When wood rather than lignin is subjected to hydrogenation under mild conditions the cellulose is left in the form of a pulp and the lignin is converted to the three types of liquid products. When the hydrogenation conditions are drastic, the cellulose is broken down into sugars and a mixture of various polyhydric alcohols, including glycerine.

Practically all the research on hydrogenation of lignin and wood up to the present time has been carried out in batch bombs. Continuous hydrogenation equipment has just been installed at the U. S. Forest Products Laboratory. Studies with this equipment will better indicate the commercial possibilities of this type of utilization.

Oxidation and Other Methods

A number of valuable partial oxidation products are obtainable from wood and wood components. For example, wood, cellulose, lignin, and isolated wood sugars can be oxidized to make oxalic acid. The manogalactan extract obtainable from western larch in high concentrations can be oxidized with nitric acid to mucic acid as was previously described (37). Other possibilities that have received little attention are the reaction of wood and wood components with chlorine and other halogens.

Bark Utilization

Bark until recent years has received little attention, both from a research and a utilization standpoint, except in the case of a few species for the extraction of tannins. The most extensive work on bark utilization in the United States
has been carried on by private enterprise. The work has been concentrated on the separation of Douglas-fir bark into different fractions containing varying proportions of fibrous and corky material. The most fibrous fraction finds use as an ingredient for increasing the impact strength of plastics. Intermediate fractions find use as glue extenders and reactant fillers for phenolic molding powders. A corky fraction will react with aldehydes as does phenol to form resins. One fraction is finding use in dusting insecticides. Still another fraction is being sold as a soil conditioner substitute for peat moss.

More extensive research on the chemical composition of bark from various species of wood should eventually lead to more extensive utilization of bark in general.

Conclusions

From this survey it may be concluded that there are a number of promising means of increasing the utilization of wood residues. No one approach can be expected alone to solve the problem. The nature of the residue as well as the economic conditions will in some cases indicate that making of dimension stock items is preferable, while in other fiber products or chemically derived products should be produced. Even in a single plant it appears that integrated utilization of the waste may be the most efficient. For example, the removal of valuable extractives may be economically followed by destructively distilling or hydrolyzing the residue. Hydrolysis may be profitably followed by hydrogenation of the lignin.

Although it is known how to make a great array of products from wood residues, there is little available information on production costs. A potential processor should carefully study his possible markets as well as determine manufacturing costs before making significant investments. There is still need for much more fundamental research, applied process research, pilot plant research, and economic surveys before it will be possible to decide on the best commercial way to utilize each type of wood residue occurring in each region. The amount of available raw material is so great and its economic use so important that such research and surveys should be greatly expanded all over the world to accomplish a high degree of utilization of wood residue.
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Rept. No. RL770
Table 1.—Annual drain or production of various commodities in the United States

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Weight in millions of tons</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest drain from cutting operations</td>
<td>1183</td>
<td></td>
</tr>
<tr>
<td>Wood used for purpose cut</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>Wood used for other purposes than those for which cut</td>
<td>230</td>
<td>(54, 56)</td>
</tr>
<tr>
<td>Cut wood totally unused</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Standing timber lost due to fire, insects, and storm</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Farm residue</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Farm residue not needed for return to the soil</td>
<td>100</td>
<td>(46)</td>
</tr>
<tr>
<td>Petroleum</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>Iron and steel.</td>
<td>60</td>
<td>(51)</td>
</tr>
<tr>
<td>Copper</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

1—Based on oven-dry weight and average density of 30 pounds per cubic foot.
2—90 percent mill residue, 10 percent woods residue.
3—25 percent mill residue, 75 percent woods residue.