realized, although even yet the resins do not promise that their bond with wood will be spontaneous, for the production of a good joint generally requires high pressure, with or without added heat.

Phenol-formaldehyde and urea-formaldehyde are the most widely used synthetic-resin glues. Melamine and resorcinol glues, among the discoveries during the Second World War, promise good performance, the resorcinols particularly so because highly durable bonds can be obtained without hot pressing. The resins are available as powders, solutions, or prepared films. Their special advantage is that they reduce surface swelling and the other changes caused by the water in the less concentrated adhesives, particularly in furniture and other fine veneer work in which they are being adopted.

THE GLUING OF WOOD is not a simple, infallible procedure, because wood species vary chemically and physically, and glues vary in source, methods of preparation, and use.

Findings at the Forest Products Laboratory after years of research lead to five general recommendations for applying glue.

It is usually unnecessary, and often detrimental, to roughen the wood surface; in fact, the mating surfaces should be machined to a smooth, true fit.

Animal glue must not be overheat ed. Heating the wood is generally unnecessary or detrimental.

Glue should be thick, rather than thin, in consistency when it is pressed.

A relatively heavy pressure should be applied to bring the surfaces to be joined into firm contact until at least partial setting has occurred.

Minor details of procedure can be varied in any way that will assure a proper jellylike consistency of the glue at time of pressing.

DON BROUSE, a native of Indiana, joined the Forest Products Laboratory in 1923 and was assigned to work on the problems connected with the application of wood-working adhesives. He is assistant to the chief of the Division of Wood Preservation at the Laboratory and has general supervision over investigations on adhesives, veneer and plywood production, and sandwich panel fabrication. Dr. Brouse has degrees from Purdue University and the University of Wisconsin.

CHEMICALS FROM WOOD

ALFRED J. STAMM

Chemical processing of wood, up to the present time, has been limited to (1) destructive distillation, whereby charcoal, wood alcohol, acetic acid, turpentine, and tars are produced, and (2) extraction processes with water or petroleum solvents that remove the extraneous materials, such as tannins, turpentine, rosin, and essential oils.

The destructive-distillation process in recent years has not proved to be very profitable, because many of the products formerly produced exclusively by the process are now made more cheaply by synthetic methods.

The extraction process, although highly profitable when applied to a few species, is not suitable for all woods and actually utilizes only from 1 to 20 percent of the weight of the wood.

Two rather new processing methods, hydrolysis and hydrogenation, show promise of broader application. Hydrolysis changes the cellulose and other carbohydrate material into sugars. Hydrogenation causes hydrogen gas to react with the wood components at high temperatures and pressure to form liquid products.

The new procedures, together with
the old, provide a practical approach to the chemical utilization of wood residues.

Wood residues are especially adapted for chemical processing because wood of any form or size or quality can be used. Sawdust, shavings, slabs, trimming, cordwood, and cull logs are all suitable. Further, the presence in the residue of relatively large amounts of knots, bark, and even wood in the early stages of decay does not interfere with most of the processes, although it may reduce the yield of chemical products. Even though it would usually pay to process the hardwoods (broadleaved species) separately from the softwoods (cone-bearing species) for the reason that the products and yields from those two general classes of wood differ, it is not necessary generally to separate them.

The amounts of wood residues available indicate the possible magnitude of a chemical industry based on their full utilization. Naturally, the first wood residues to be considered for such an industry would be those that occur at sawmills, veneer mills, and secondary manufacturing plants, because the material is already at hand and a large part (in the form of sawdust and shavings) is already reduced sufficiently in size for use. Some 16 million tons of such material now remain unused each year. An additional 27 million tons are burned to generate steam for plant operations. As soon as its chemical-processing value becomes greater than its fuel value, which at present averages about $4 a ton, this material, too, will be available for chemical processing.

The total mill residue is equal in weight to one-fifth of the national petroleum production. Left unused in the woods each year, because their removal is considered unprofitable, are 44 million tons more of cut wood, chiefly crooked, split, and partly decayed material unsuitable for lumber but admirably suited for chemical use. Still another 23 million tons of standing timber are killed by fire, lightning, or insects each year and left in the woods; a large part of that would also be suitable. Altogether, those residues equal in weight about half the present petroleum production. Enough wood residues are available, then, to supply a great new chemical industry.

Such a large industry would not be warranted unless its products were in sufficient demand at a price for which they could be profitably produced. The nature and uses of the products obtained by the various methods of chemically processing wood can be a measure of this demand and value.

Extraction differs from the other chemical-processing methods in that it is highly dependent upon species and alters the wood substance only slightly. The only extensive wood-extraction industry is the naval stores industry of the South, which extracts turpentine and rosin from old stumps of longleaf and slash pines from which the sapwood has decayed. Only the heartwood stumps of those species are used because of their high extractive content. The industry processes about 6,000 tons of stump wood daily to obtain 12,500,000 gallons of turpentine and 750,000 drums (520 pounds to the drum) of rosin a year. Turpentine is used chiefly as a paint thinner, a medicinal, and a raw material for making synthetic camphor and other valuable synthetic products. The rosin is used chiefly in soaps, paper size, paints, varnishes, sealing waxes, cements, and plastics. Large amounts of cymene and a rosin residue are also obtained. The latter is used in plastics and as a binder for sand in foundry cores.

Chestnut wood chips and hemlock bark are extracted to obtain tannin for tanning leather. In no case is the tannin content of wood sufficient to make extraction profitable for it alone. In the case of chestnut, the extracted chips have been used to form pulp for paper making. The chip residue might also be used for further chemical processing.

Years ago a small industry existed in the Northwestern States in which the
butt logs of western larch were extracted with water to remove the large amount of water-soluble gum that they contain. The gum was chemically converted to mucic acid, which is used as the gas-liberating acid in some brands of baking powder. The process was not a financial success because the large amount of chip residue was unused.

A number of small plants scattered about the country extract essential oils, medicinals, and flavoring materials from needles, bark, roots, or wood of various species. Those plants, like all other extraction plants, could profit by chemical refining of their residues.

**DESTRUCTIVE DISTILLATION** is by far the oldest wood-chemical-processing industry. For years the charcoal residue was the only product sought. Charcoal is used as a domestic and picnic fuel; in smelting and reducing various ores; in making such chemicals as carbon bisulfide, which, in turn, is used in making viscose, rayon, and cellophane, and also sodium cyanide, a powerful disinfectant.

Now a number of valuable volatile products are also obtained by condensing the vapors from destructive distillation. In the case of hardwoods, methyl alcohol (wood alcohol), acetone, and acetic acid are obtained as a water-soluble distillate, together with the water-insoluble tars and pitches. Methyl alcohol is used as an antifreeze agent in the radiators of automobiles, for denaturing grain alcohol, as a solvent in many industries, and for making formaldehyde, which, in turn, is used as a disinfectant and in making plastics. Acetone is used as a solvent in the rayon and plastic industries, and acetic acid in making white lead paint and acetate rayon and films. Yields of methyl alcohol, acetone, and acetic acid are lower from softwoods than from hardwoods.

The pines, however, yield considerable turpentine and softwood tar. Softwood tar is used in the compounding of rubber, to some extent in manufacturing oakum for calking ships, in cordage, and also in medicinals. Both softwood and hardwood tars find use as flotation oils in mineral separation and as gasoline gum inhibitors. The heavier fractions are used as preservatives, disinfectants, and stains. The pitch finds use as a waterproofing and insulating agent and as a binder for briquets.

Although the products obtained by the two older wood-processing methods named are of considerable industrial importance and could perhaps be used in larger amounts than are now produced, a large expansion in their production does not now seem warranted. Any real increase in the chemical utilization of wood will thus have to be by the processes which produce products that are in greater demand.

**HYDROLYSIS** of wood to sugars, followed in some cases by their conversion to other products, is a most promising chemical approach to large-scale utilization of wood residues.

At the Forest Products Laboratory it was found that sugars can be produced to the extent of about half the weight of the wood by a simple process of heating wood chips or sawdust with a dilute solution of acid in water under moderate steam pressure. These sugars, which are a mixture of glucose and several different pentose sugars, would be difficult to purify and crystallize, but can be evaporated easily to a molasses that contains 50 percent sugar.

Experiments now under way are using this molasses as an animal feed. The tests have been sufficient to indicate that it is palatable to cattle and sheep. If its nutrient value proves equal to that of cane molasses, which it resembles closely, it could find extensive use as a livestock feed. Pilot-plant studies indicate that about 180 gallons of molasses can be produced from a ton of dry wood at a cost that should not exceed 10 cents a gallon. Cane molasses sold on quantity basis at 25 to 40 cents a gallon in different parts of the country in 1948. If its
price could be made as attractive as the pilot-plant studies indicate, the demand for feed molasses from wood could be tremendous. If livestock feeding could be built up to the level already demonstrated as possible with cane molasses (about 3 pounds per day per head for cows, somewhat more for beef cattle, and somewhat less for sheep), the amount of molasses used for feeding could be increased at least 75 times. In theory, such a goal could utilize the equivalent of about two-thirds of all available wood residues. Here, then, is a potential use for wood residue that could consume large quantities of it.

The sugar solution resulting from hydrolysis can also be fermented to ethyl alcohol (grain alcohol). Bark-free softwoods yield up to 60 gallons of alcohol per ton of dry wood, and hardwoods about 50 gallons. Bark may be present up to 50 percent, but its presence somewhat decreases the yield. This alcohol is suitable for many industrial purposes. A large commercial plant capable of processing 200 to 300 tons of wood residue a day in the manufacture of ethyl alcohol has been built on the Pacific coast. The short time in which it has operated has demonstrated the commercial possibilities of the process. When shortages of petroleum products occur, the ethyl alcohol produced at such plants could become one of our chief motor fuels. It can, under present conditions, be produced from wood at about one-fifth of the cost of producing it from grain.

Only the hexose sugars are used in making alcohol. The pentoses remain in the stills after distillation. They may be used for growing yeast or for conversion to furfural, which is a chemical used as a solvent in oil and rosin refining, in certain plastics, and recently as a starting material in making nylon.

Tests are under way to determine the food value of wood yeast. It is rich in riboflavin, a vitamin, and consequently should have greater food value than is indicated by its high protein content alone. The production of wood yeast thus also shows promise of developing into a sizable industry that could use up large amounts of wood residue.

Different cultures and fermentation conditions make possible the manufacture of acetic, butyric, and lactic acid from wood sugars and also acetone, butyl alcohol, and butylene glycol. Butyric acid is used in making cellulose-butyrate plastics. Lactic acid is used as a food preservative. Butyl alcohol and butylene glycol can be used in making artificial rubber. Butylene glycol would be a good antifreeze agent for use in automobile radiators.

When sugars are formed by the hydrolysis of wood, a residue of fine solid lignin remains. This material, a substance that binds the wood fibers together in a tree, has a higher fuel value than wood itself and may be burned as a fuel in the processing plant. It shows promise as a soil conditioner. When agricultural crop residues decay, the remaining humus is largely lignin, so it is natural that lignin should have soil-conditioning value. Lignin from wood hydrolysis has not shown the value in plastics found in other forms of lignin recovered from paper manufacture.

Hydrogenation has been most extensively studied on isolated lignin, but it may also be applied to all parts of wood. In the process, the lignin is suspended, or preferably dissolved, in an organic liquid that itself does not react with hydrogen and that will not decompose at the high temperatures used. Most of the work to date has been done on batch lots placed in small bombs. A metallic or metallic-oxide catalyst is used to promote the reaction. A complex mixture of liquid products and a tarlike residue are produced.

The liquid consists of a mixture of complex cyclic alcohols, phenolics, and neutral oils. The cyclic alcohols, when added to gasoline, show good anti-knock properties. They are also good solvents, and some of them have toxic properties. The phenolics are a mix-
turing of those suitable for plastics and some that are not. Means of separating them have not yet been found.

The neutral oils are of the hydrocarbon type. Part of them may prove suitable for lubricating purposes, and all as fuels.

The proportions of these three types of chemicals formed in the process may be varied with the hydrogenating conditions.

Wood may also be hydrogenated in aqueous alkaline suspension. The lignin forms compounds of the types just described. When the hydrogenation conditions are mild, the cellulose left is a pulp residue; when severe, the cellulose is broken down into sugars and glycerine. The industrial possibilities of such a glycerine-forming process must await further research.

Before the hydrogenation of either lignin or cellulose can become an industrial reality, methods for carrying on the process in continuous-flow equipment will have to be developed. The possibilities of commercial hydrogenation, however, are promising. One is to hydrogenate the lignin residue from a wood-hydrolysis ethyl-alcohol plant to obtain an optimum yield of neutral oils. Such a plant, it is estimated, could produce, by the combined methods, from a ton of dry wood about 110 gallons of liquid fuel consisting chiefly of ethyl alcohol and neutral oils, together with some methyl alcohol and furfural.

With all these possibilities, the chemical processing of wood residues may well be expected to expand rapidly in the next few years.

Alfred J. Stamm, a Californian, joined the Forest Products Laboratory in 1925 and at present is chief of the Division of Derived Products. He has published a number of research papers on such subjects as particle size in emulsions, capillary structure of wood, wood and cellulose-liquid relationships, swelling and its prevention, electrical properties of wood, and molecular properties of cellulose and lignin. Dr. Stamm has degrees in chemistry from the California Institute of Technology and the University of Wisconsin. In 1928 he studied in the University of Upsala, Sweden, in order to apply the ultracentrifuge technique to the study of the molecular weight of cellulose.

**PUTTING UNUSED WOOD TO WORK**

C. V. SWEET

Every time a saw chews through a log, it spits aside sawdust. Whenever a planer dresses the roughness off a board, it throws off shavings. Square-edged lumber is made only at the cost of slabs, edgings, and trims. For every log put through the sawmill a considerable tonnage of wood fiber is left in the forest. Even the digesters of pulp mills disgorge as unusable sizable quantities of the wood fed into them. And so it goes with nearly every operation concerned with harvesting and converting trees into useful things.

Those unused materials generally have been called waste, not in the sense that they signify neglect or carelessness but in the sense that they are not economically usable. If there is use for them, the margin of profit may be discouragingly narrow, the necessary investment for equipment may be prohibitive, or the expense of handling and hauling the raw material to one point may be excessive.

Theoretically, there is a use to which practically every type of unused wood is or can be put. The problem is in finding profitable ways of doing it on an adequate basis.

Only in relatively recent years have we come to regard those unused forms