NREL Advances in Technology at the National Renewable Energy Laboratory

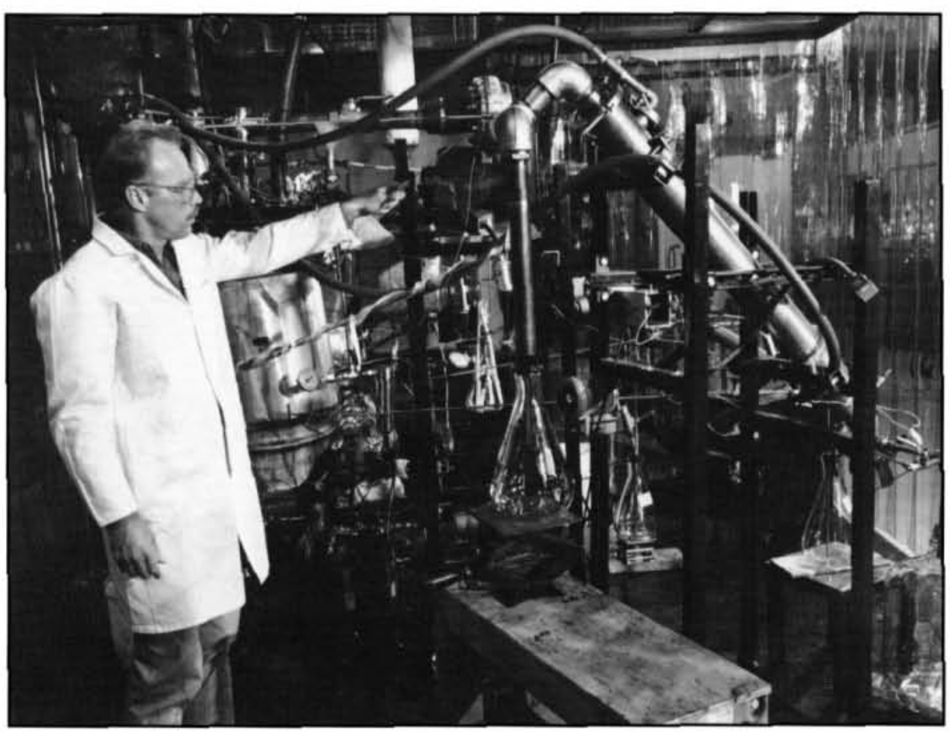
Technology Brief

NREL Turning Biomass into Adhesives and Plastics

Chemicals to Make Adhesives for Composite Wood Products Produced from Wood Wastes Instead of Petroleum

With the increasing use of composite materials such as strand board, flake board, and composite lumber, the wood products industry is moving toward the "everything but the squeal" model of pork processing. But the adhesives used for these composite wood products are currently made from petroleum and natural gas. The U.S. Department of Energy (DOE) and its National Renewable Energy Laboratory (NREL) are developing technology to make wood adhesives from sawdust, bark, or other biomass (plant materials or wastes derived from them).

The United States used 556 million kilograms (1.2 billion pounds) of phenol to make phenolic resins in 1992. NREL technology can replace half of that with phenolics made from biomass instead of oil, and at a substantially lower cost.



For the first step in making phenol-formaldehyde resin from biomass, NREL's fast-pyrolysis vortex reactor converts biomass particles to an oil.

Phenol (C_6H_5OH), the primary component of the resin used for the wood adhesives, is made from petroleum. NREL is producing phenol-like extracts from biomass that can substitute for about 50% of the phenol in the resin. Researchers expect to be able to make these phenolics for about 50% of the cost of phenol, so net savings for the cost of the resins will be about 25%. Resins made with the biomass extracts can also substitute in producing certain molded plastics and foam insulation, with similar savings.

Huge Potential Market

The United States used 556 million kilograms (kg) (1.2 billion pounds [lb]) of phenol to make phenolic resins in 1992. About 80% of this was for phenol-formaldehyde (PF) resin used by the wood products industry to glue together plywood, particle board, strand board, and other composite products. Wood composites use will undoubtedly grow rapidly as rising lumber prices and reduced availability of old-growth trees further accelerate the trend away from solid-wood products. A visit to any home construction site will verify this trend toward wood composite products.

To replace the phenol in the PF resins, NREL uses its fast-pyrolysis vortex reactor. This unique technology turns wood waste or other biomass into oils that are rich in phenol-like compounds. NREL scientists are extracting from these oils a phenolics and neutrals fraction that substitutes well for 50% of the phenol in PF resin.

The vortex reactor can make good use of materials that have the least value as wood sources. Sawdust and other wood particles too small to be useful for wood composites or other uses can go directly into the vortex reactor without further milling. About 20% of the resulting vortex oil can be extracted as a phenolics and neutrals fraction for resin production. Bark must be chipped before being pyrolyzed but yields more phenolics because of its higher content of lignin and other phenolic extractives. Bagasse (sugar cane waste) and other biomass sources also work well.

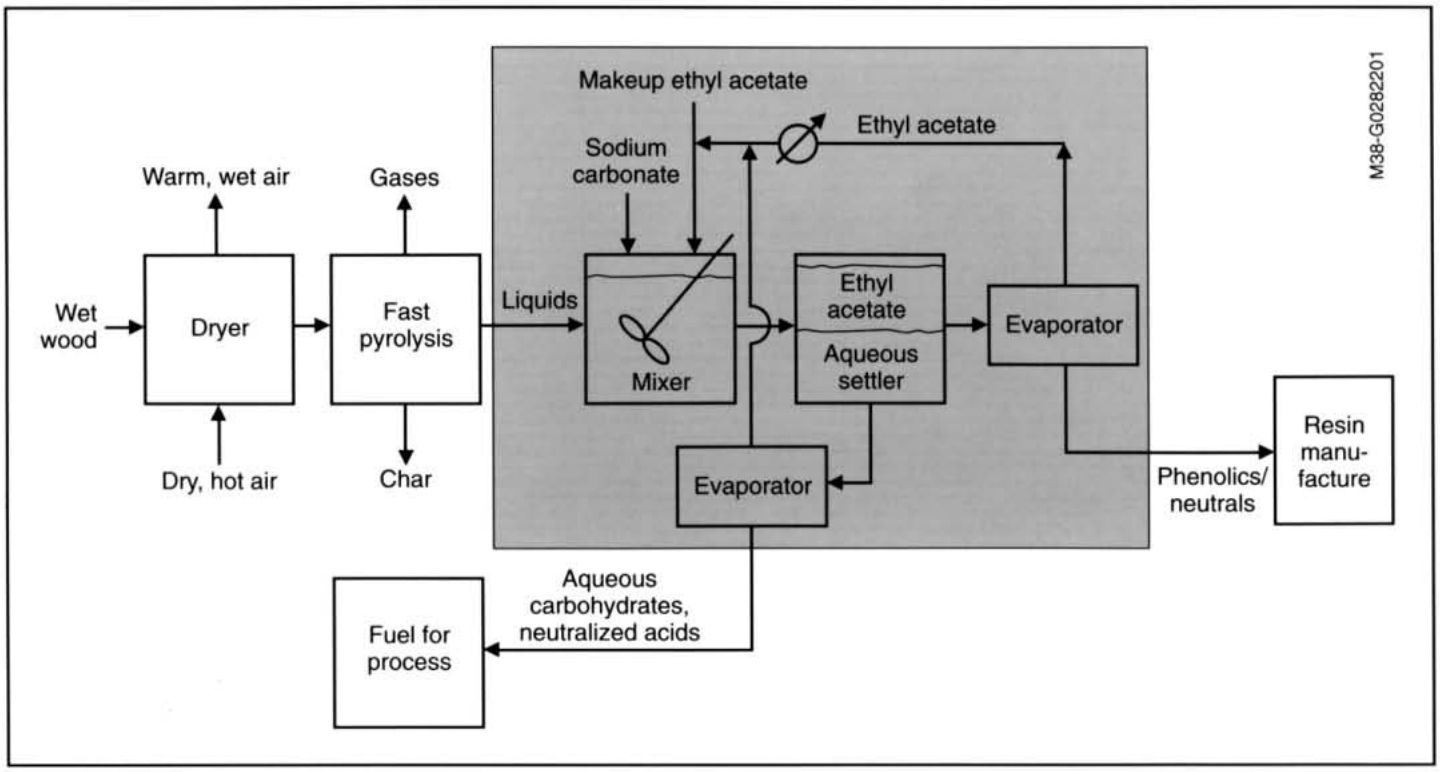
The phenolic-rich extracts from vortex pyrolysis oil can also replace 50% of the phenol used to make resins for Bakelite plastics. Bakelite plastics or novolacs, the first synthetic plastics made (1909), are used for molded plastic parts and foam insulation. They account for about 20% of the U.S. use of phenol to make phenolic resins.

Three Steps All Nearing Readiness

Producing phenolic resin from biomass requires three distinct processing steps. First, vortex fast pyrolysis depolymerizes the biomass to break it down into simpler compounds. Next, extraction separates out the phenolics from the vortex oil. Finally, resin synthesis mixes these phenolics with traditional phenol and formaldehyde to produce the resin. NREL is leading the optimization and demonstration of the first two steps. Commercial phenolic-resin producers have joined in a consortium with NREL for the third. Their years of experience in resin formulation will help ensure production of adhesives and plastics that meet commercial standards.

In collaboration with DOE, NREL has joined with four industrial corporations to form a consortium to develop pyrolysis resins for commercial use.

The vortex reactor portion of the technology (see sidebar on next page) is well developed, having been used by NREL at the laboratory scale (23 kg or 50 lb per hour) for more than 10 years. In cooperation with a



The second step (highlighted in red) in making adhesives and plastics from wood waste or other biomass uses solvent to extract and concentrate a phenolics and neutrals fraction from the pyrolysis oil.

The Fast-Pyrolysis Vortex Reactor

One way to break down complex organic materials such as wood into simpler compounds is pyrolysis, the use of high heat flux without oxygen. By transferring heat to the material very rapidly, NREL's vortex reactor is able to use relatively moderate temperatures—625°C instead of 900°C—and shorter residence times than can other pyrolysis systems. This enables NREL scientists, by carefully controlling the temperature and residence time, to generate more desirable products with little loss to char or breakdown of vapors into nonvaluable gases.

Specifically, biomass pyrolyzed in the vortex reactor and then condensed yields a highly useful oil. This pyrolysis oil differs from petroleum primarily because it is oxygenated. It can, however, be refined in ways similar to those of refining crude oil. NREL researchers have already identified several valuable uses for pyrolysis oil. The oil can be burned for electrical generation or phenolics can be extracted from it to produce resins for plastics or for adhesives for the wood products industry.

Biomass particles are fed into the reactor by a superheated, high-velocity stream of steam or inert gas. That carrier gas accelerates the particles to speeds of more than 200 meters per second. Entering the vortex tube at a tangent to its 625°C walls, the fast-moving biomass is thrown to the wall of the reactor by centrifugal force and slides along those walls in a helical pattern. Rapid heat transfer of as much as 1000 watts per square centimeter from the wall to the entrained material causes that material to depolymerize and vaporize.

Large particles of char and material that has not yet vaporized exit on a tangent from the bottom and are recycled back through the system until they are completely pyrolyzed. The vaporized material and fine char leave the system (along with the original carrier gas) through a central tube, pass through a baghouse filter to remove fine char particles, and then, depending on the desired end product, are either condensed directly to form pyrolysis oil or are catalytically treated to form other products.

subsidiary of Interchem Industries, NREL is working to build a scaled-up version of the reactor that will be able to process 32 tonnes (35 tons) of biomass per day.

The second step of the process uses solvent to extract a phenolics and neutrals fraction from the pyrolysis oil. This fraction also includes aldehydes that may be able to substitute for some of the formaldehyde (otherwise derived from natural gas) used to make the resins. NREL researchers have already proven this extraction technology in the laboratory and obtained patents for it. Now they are collaborating with neighbor Hazen Research, Inc., of Golden, Colorado, to scale up the continuous extraction process to be able to handle 300 kg (660 lb) of pyrolysis oil per hour.

The final step substitutes the pyrolysis-derived phenolics into the formulation of PF resins. Plastics Engineering Company and a recognized expert industry consultant on PF resin adhesives are demonstrating the feasibility of using the pyrolysis-derived phenolics in making PF resin. Determining that the neutrals fraction did not have to be removed allowed major cost savings for the phenolic extraction process.

Consortium to Bring Biomass Resins into Commercial Use

In collaboration with DOE, NREL and its managing company, the Midwest Research Institute, have joined with industrial partners in a consortium to develop phenolic substitutes from vortex pyrolysis oil for commercial use in PF resins. Members of the Pyrolysis Materials Research Consortium (PMRC) include Interchem Industries—which is developing biomass pyrolysis, AlliedSignal Corp., and Aristech Chemical Corp.—which produce phenol, and Plastics Engineering Company—which produces PF resins for molded plastics.

The PMRC is directing the research and engineering still necessary to bring NREL's technology and the pyrolysis adhesives to market. Two remaining challenges to gaining industry acceptance of the reformulated resins are addressing a wood smoke odor and reducing curing time requirements. Technical solutions have been found and are being verified by industry.

The Federal Laboratory Consortium (FLC), a national organization of more than 500 government laboratories, has twice recognized NREL's work with private industry in the development of phenolic substitutes from biomass. In 1990, the FLC recognized the PMRC for its cooperative involvement of private companies in the development of vortex-pyrolysis oil products. DOE has since set up a program of cooperative research and development agreements (CRADAs), to encourage such government-industry collaboration.

In 1994, the FLC gave an Excellence in Technology Transfer Award to three NREL researchers for connecting Interchem with ARES, Inc., a defense contractor affected by cutbacks. A manufacturer of wide-bore gun barrels, ARES had the expertise necessary to make the precision-engineered steel tube—with helical ribs inside—needed to make the scaled-up vortex reactor. The pyrolysis adhesives process itself also received a prestigious R&D 100 award from *R&D Magazine* for being a most technologically significant product.

With the increased use of composite materials, the wood products industry is making more efficient use of American forest resources. DOE and NREL are pleased to develop technology that can save the industry money in making those materials, while reducing reliance on fossil fuels.

Publications and Patents

Chum, H.; Black, S., Inventors (July 1990). "Process for Fractionating Fast-Pyrolysis Oils, and Products Derived Therefrom." U.S. Patent No. 4,942,269. Assignee: MRI Ventures, Inc.

Chum, H.; Diebold, J.; Black, S.; Kreibich, R., Inventors (August 1993). "Resole Resin Products Derived for Fractionated Organic and Aqueous Condensates made by Fast Pyrolysis of Biomass Materials." U.S. Patent No. 5,235,021. Assignee: MRI Ventures, Inc.

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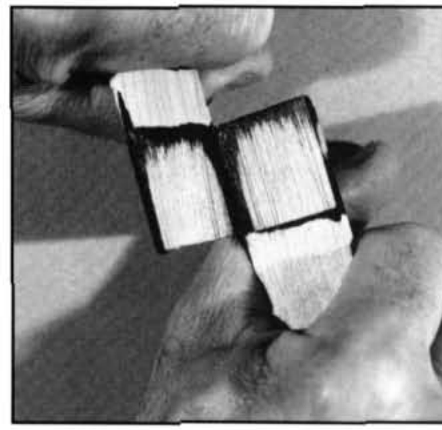

The third step in the process incorporates the biomass phenolics in formulation of PF resins used to make plastics and wood adhesives. As shown here, the reformulated adhesives outperformed conventional adhesive in tests of bond strength on maple wood strips.

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