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Report
FPL-GTR-86

Recycling Research Progress at the Forest Products Laboratory

Abstract

This document summarizes accomplishments of USDA Forest Service researchers in the area of recycling. Specifically, it describes work in economic assessment, paper recycling, recycled housing and industrial applications of recycled materials, other recycling applications, and technology transfer. The literature list includes the references cited in the text and additional publications regarding Forest Service recycling research.

Keywords: Recycling, waste resource assessment, recycling legislation, economic modeling, paper recycling, contaminant removal, structural products, recycled plastics, composites, preservative-treated wood, bioremediation, panel products, wood pallet recycling, geotextiles, technology transfer

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The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

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Introduction

The United States faces the difficult challenge of meeting society's growing appetite for wood and fiber products while conserving the forests. Americans use only half as much wood per person as they did in 1900 (Fig. 1), but the country has three times as many people now and it is to reach 346 million by 2050 (Brownridge 1992). That growth portends a need for more wood, even as people increasingly call for an end to cutting trees in old-growth forests and smaller harvests from public lands.

Recycling offers one key to satisfying these paradoxical demands and to achieving environmental and economic sustainability in the forest products industry. Reprocessing wood-based waste directly contributes to reducing the volume of timber harvested annually to meet the needs of the American public (USDA 1993). Recycling can also greatly reduce the amount of wood-based waste that Americans send to the landfills. At the same time, recycling can improve the volume and value of material produced from each tree, create jobs, and increase economic growth.

However, realizing these benefits depends on having the technologies and market conditions to allow and encourage companies to recycle. Currently, recycling technology is limited to narrow product niches and serves only limited U.S. geographical areas. Unless the situation changes, by the year 2000, Americans will throw out more than a quarter of a million tons per day of potentially useful wood-based material.

The USDA Forest Service has launched a research and development initiative to help stem that tide of waste by developing the technologies that can create new markets and expand existing ones for products made from recovered paper and wood wastes. One unit of the Forest Service, the Forest Products Laboratory (FPL) in Madison, Wisconsin, played an important role in planning this initiative (Hamilton and Laufenberg 1992; Laufenberg and others 1992) and is now leading research in this effort. The FPL is uniquely qualified and positioned to lead this research. It can draw upon its 85 years of expertise in harnessing science and technology to most efficiently use every tree that is cut and to improve the wood products people use. FPL research has already significantly advanced recycling technology and expanded markets for recycled wood-based products. In broad terms, FPL has accomplished the following in the areas of recycling wood-based material:

- Launched programs to assemble and analyze information about available supplies of wood-based wastes and recycling trends so that industry can better evaluate whether to invest in recycling technology.
- Created technologies that cost effectively convert wood-based wastes into raw materials to be fed into manufacturing processes.
- Developed technologies that change raw wood-based materials into value-added products.
- Tested prototype products to ensure good performance and safety.

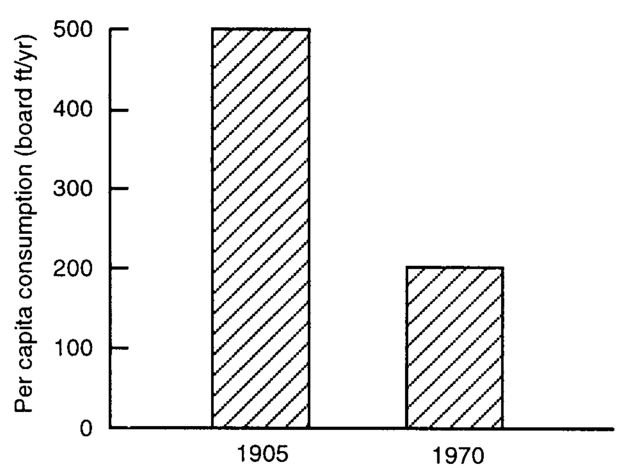

Figure 1–Per capita consumption rate of wood has decreased dramatically this century, as a result of improved efficiency of wood use and substitution of fossil fuels for wood fuel (MacCleery 1992).

- Analyzed the economic feasibility of the technologies for commercial production.
- Started laying the groundwork for the standards and codes that will eventually govern the manufacture and quality of recycled products.

Raw Material Assessment

Inventing a technology and applying it commercially are entirely separate matters. Companies will not adopt technology unless it is economically feasible. For companies to make that economic evaluation, they must have a comprehensive and accurate picture of the raw material supply and an understanding of the external factors that drive recycling markets. In the same manner, Government officials must have the information and understanding to craft recycling, waste disposal, and timber policy. Economists at the FPL have provided the necessary information and analyses. They have initiated a Waste Resource Assessment Program, analyzed legislative trends, and conducted economic modeling.

Waste Resource Assessment

Adequate near- and long-term raw material supplies must be available at reasonable costs for companies to adopt and implement recycling technology. The amount and type of wood-based wastes generated, their condition and quality, and whether they can be effectively sorted are factors that determine if a raw material is reasonably priced. Additional economic factors include the kind of contaminants present in the recovered materials; the geographic location of the material; and the cost of buying, stockpiling, and transporting.

At this time, no organization has a good grasp of this information at the national, state, and regional levels. The U.S. Environmental Protection Agency (EPA) collects national statistics for the types and quantities of municipal solid waste generated in the United States each year, but the agency does not provide regional or state estimates (U.S. EPA 1992). The EPA also does not include urban demolition waste, new construction waste, and other categories in its estimates. These data gaps mean companies and governments may not have all the information they need to make sound decisions.

Scientists at the FPL are working to fill in these information gaps. They have launched a program to assemble and maintain a computer database of all publicly available local, state, regional, and national information on waste generation. Economists will use the information to develop national and regional supply estimates. Government and industry can use this information to better assess waste wood, fiber, and non-wood materials as a raw material and develop markets for these materials.

Researchers have quantified the amount of waste wood and paper generated in the municipal solid-waste stream, from new residential and nonresidential constructions and remodeling, urban demolition projects, other lesser sources of waste such as old railroad ties, and solid-wood residues from primary timber processing industries. Recoverable supplies of this material were then estimated on a national basis. This information was used to accomplish the following:

- Evaluate potential impacts of this recoverable waste for use as furnish by the Nation's nonstructural panel industries (McKeever and others 1995). This information may enable manufacturers to exploit the waste resource.
- Estimate current and potential levels of recovery of paper and solid wood for recycling of specific products and industries (Ince and McKeever 1995a). This analysis indicated that wood and wood fiber recycling technology could exploit a large resource base if efficient technology were developed to fully utilize the resource.
- Quantify current and evaluate potential recycling activities in the United States as part of a global evaluation of recycling for the United Nation's Economic Commission for Europe Timber Committee (Ince and McKeever 1995b). This information will help the international community better understand the role of recycling in the United States and the world.
- Estimate the resource potential of solid-wood waste in the United States as a biomass resource (McKeever 1995). Total amounts of waste generated, amounts of wood waste generated by type, and amounts of wood waste potentially available for recycling were quantified. Possible uses for each source of wood waste were identified, and recommendations for better utilizing this resource were made. This information will help highlight waste wood as a potentially valuable biomass resource and may help promote its use.

Legislative Trends

One of the forces driving recycling has been legislation. Federal and state legislatures increased their lawmaking pace as public concern increased during the country's garbage crisis (Fig. 2). Americans were throwing out more garbage as the number of places to dump the waste was shrinking. About 14,000 of the 20,000 landfills operating in the United States in the late 1970s were closed by 1990 (U.S. EPA 1992), because landfill owners sought to avoid more stringent EPA regulations and site requirements. The strengthened standards were intended to reduce the risk of landfill leachate seeping into groundwater and methane gas explosion.

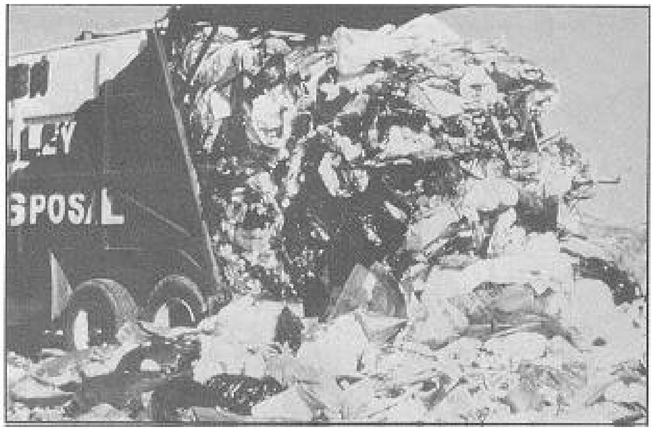

Figure 2–Forest Service recycling research can help reduce the nearly 50 percent of U.S. municipal solid waste that is wood based.

As a result of the closings, some regions faced shortages of landfill capacity. Nationwide, the fees people paid to dump their trash in landfills soared an average of 386 percent during the same period (U.S. EPA 1992).

Citizens and government officials began calling for action. Legislators began to pass recycling legislation to reduce the waste going to landfills, spurring a rapid increase in the paper collected for recycling. The supply of recovered paper soon exceeded the demand, and prices for the recovered materials slumped.

That market glut demonstrated the need for a better understanding of how legislative action affects pulp and paper markets, The following shows how researchers at FPL supplied that understanding.

- Tracked and analyzed national and state recycling legislation to discover that lawmaker actions to reduce the amount of recyclable material going into landfills (Fig. 3) were important factors in recycling markets (Alig 1993a). This understanding will help governments and industry better project the results of recycling legislation.

- Tracked national and state recycling legislation to discover that tax incentives, and requirements that government agencies buy paper with minimum levels of recycled content, were important factors in a company's decision to invest in recycling technology (Alig 1993b, 1994). Establishing that critical link between technology and legislation can help government craft recycling and disposal policies that will encourage markets.

- Provided updated analyses of current recycling legislation in a monthly column appearing in *Recycled Paper News.* This effort gives business and government decisionmakers valuable current information.

In addition, these research efforts reveal how legislation corresponds with technology and market changes provide a sound basis for examining the effects of external forces on markets. The analysis has also lent credibility to assumptions made about recycling and provided accurate forecasts of changes in recovery and use of recovered paper. In turn, these improved abilities have led to accurate forecasts of how recycling affects pulp, paper, and timber markets.

Economic Modeling

Recycling is the most significant technological change in the forest products sector in the 1900s because of the potential economic impact of recycling, its effect on forest resources, and the magnitude of capital investment that recycling requires. Similarly, recycling is the most significant social change in forest products technology in the 1990s because of its hold on the American conscience and its potential to reduce timber harvests and save landfill space. With so much at stake, industry and government decisionmakers need access to information that predicts how recycling will evolve and affect the American economy, environment, and society.

Researchers at the FPL have helped develop that analytic capability by the following:

- Organized a team of FPL, academic, and industry collaborators who developed an economic model that predicts how recycling rates, legislation, and technological advances will affect and be affected by markets for the 13 grades of the North American pulp and paper sector (Ince and others 1992, 1994; Ince 1993). Such modeling abilities will be key for the pulp and paper industry to make production decisions and government officials to draft their recycling, timber harvest, and waste disposal policies.

- Used the economic model to help the Forest Service develop its 1993 RPA Update, a long-range assessment of timber supply and demand (Ince 1994a,b; USDA 1993). The analysis indicated that recycling is a trend, not a fad, and that it can extend the Nation's forest resources and reduce its landfill burden (Fig. 4). This effort gives the Forest Service direction in setting its timber harvest goals on national forests.

- Used the economic model to help the EPA analyze potential effects of various scenarios under different recycling policies. This effort allows the agency to predict how government recycling policies (e.g., Federal procurement standards) and stricter landfill regulations affect recycling rates and how forest resources are used (Marcin and others 1994).

- EPA used the Forest Service projections in the Climate Change Action Plan of the President to show how recycling affects timber harvest levels and global carbon cycling (Clinton and Gore 1993; Marcin and others 1994).

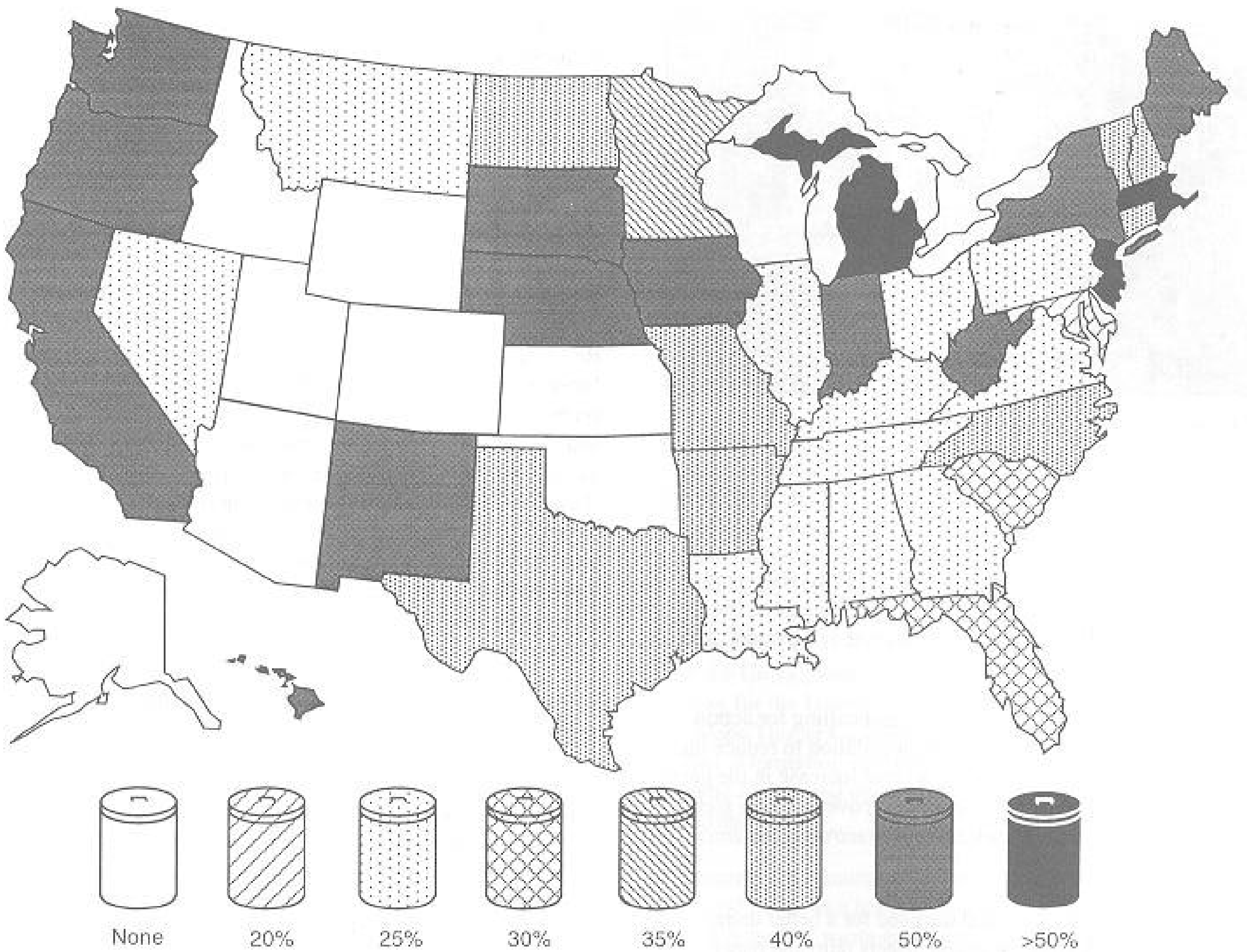

Figure 3–Tracking states that have set waste-stream recovery goals helps FPL researchers determine the effects of legislative action on pulp and paper markets.

This effort allowed the Action Plan to propose targets for reducing national carbon dioxide emission levels.

- Started to improve and update the economic model, known as the North American Pulp and Paper (NAPAP) Model, for the 1997 RPA Update. This effort gives the Forest Service an even more accurate tool to generate predictions to help direct timber policy.

- Initiated efforts to use the FPL-developed economic framework, which is the heart of the NAPAP model (Zhang and others 1993), to develop a similar model for the solid-wood product industry. This effort will provide the same forecasting abilities that the paper sector has for the solid-wood product sector.

Paper Recycling

Paper recycling is at the same time a recycling success and an unfulfilled promise. In 1990, paper and paperboard accounted for more than 66% of the municipal waste diverted from landfills for recycling. In 1993, companies used wastepaper to provide 30% of the fiber used in paper and paperboard production, a 24% increase from 1990 (U.S. EPA 1992).

However, the recycling success has been achieved largely through the recycling of tissue, newsprint, and paper board-all low value, low grade papers (Fig. 5). However, recovery and utilization rates for printing and writing paper, the highest grade of paper, lag significantly. This occurs largely because the industry has relatively limited capacity to

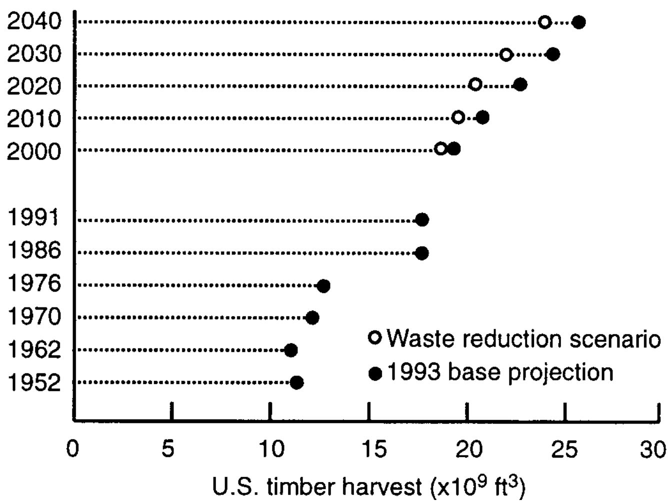

Figure 4–Increased recycling will reduce the rate at which future timber harvests grow, according to projections from an economic model developed by Forest Service researchers.

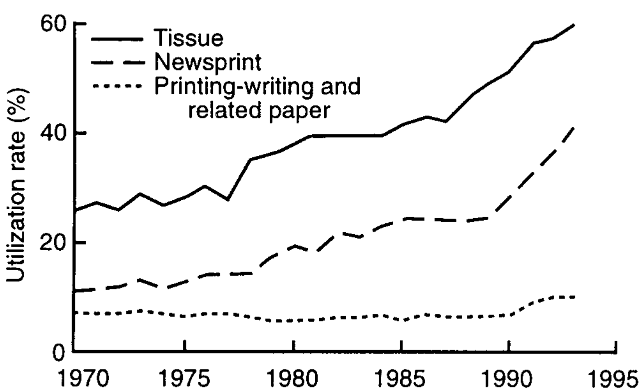

Figure 5—Various grades of paper are being recovered and recycled at different rates. One goal of Forest Service research is to develop better technology for reusing the lesser used grades.

remove ink from such papers, and the existing removal processes are inefficient. Research from the pulp and paper unit at FPL has improved fiber strength, ink removal, and contaminant removal processes. Researchers at FPL have also created structural products from recycled fibers and explored landfill alternatives.

Improved Fiber Strength

Recycled fiber is weaker than virgin fiber, the result of changes that occur during the drying phase when the fiber is first made into paper. Drying hardens the fiber surfaces and shrinks the pores that allow water to pass back and forth between fibers. These changes reduce the flexibility of the fibers and their ability to bond to one another, leaving a recycled pulp of shorter, stiffer fibers that produce weaker paper.

The recycled fiber is also dirtier than virgin pulp because ink or other contaminants have not been completely eliminated from the pulp. Research at FPL in this area includes the following:

- Developed technology to restore the bonding potential of the dried fibers by soaking wastepaper fibers in various chemical treatments before disintegration (Scott and Abubakr 1994). This technology gives papermakers another option to increase recycled paper strength.

- Developed methods for using screens to successfully fractionate, or separate, wastepaper fibers that are shorter and stiffer from those that are longer, more flexible to form stronger paper (Abubakr and others 1994). The technology, tested on a laboratory scale but easily adapted to commercial scale using conventional papermaking equipment, gives companies a way to increase paper strength without investing in expensive new equipment and creating a toxic effluent.

- Developed a technology that allows an inexpensive, inorganic filler to be substituted for some fiber in paper pulps so that the resulting paper is stronger and less costly to produce (Klungness and others 1994). This “fiberloading” technology, successfully tested on a commercial scale, creates a reaction that causes the filler to form within the fiber walls where it will not interfere with the ability of the fibers to bond (Fig. 6). Fiberloading gives companies a way to improve paper strength while it streamlines production processes and cuts the amount of sludge and emissions generated using conventional methods to add filler.

- Received a U.S. patent for the fiberloading technology. This step allows the technology to be licensed for commercial applications.

- Added to the technical literature by publishing results of experiments showing that adding certain chemical treatments to recovered linerboard pulps failed to improve strength (Springer and others 1993a). Linerboard forms the smooth layer on the outside of corrugated cardboard. This published finding can help researchers direct their efforts down other avenues for improving paper strength.

Improved Ink Removal

Committing words to paper is much easier than reclaiming them. The photocopiers and laser printers that are invaluable office time-savers use inks, actually nylon- or plastic-based toners, that are difficult to remove from wastepaper. These toners are bonded to laser-printed and photocopier paper under high levels of heat instead of being painted on fiber surfaces like the traditional ink used in pens and typewriters.

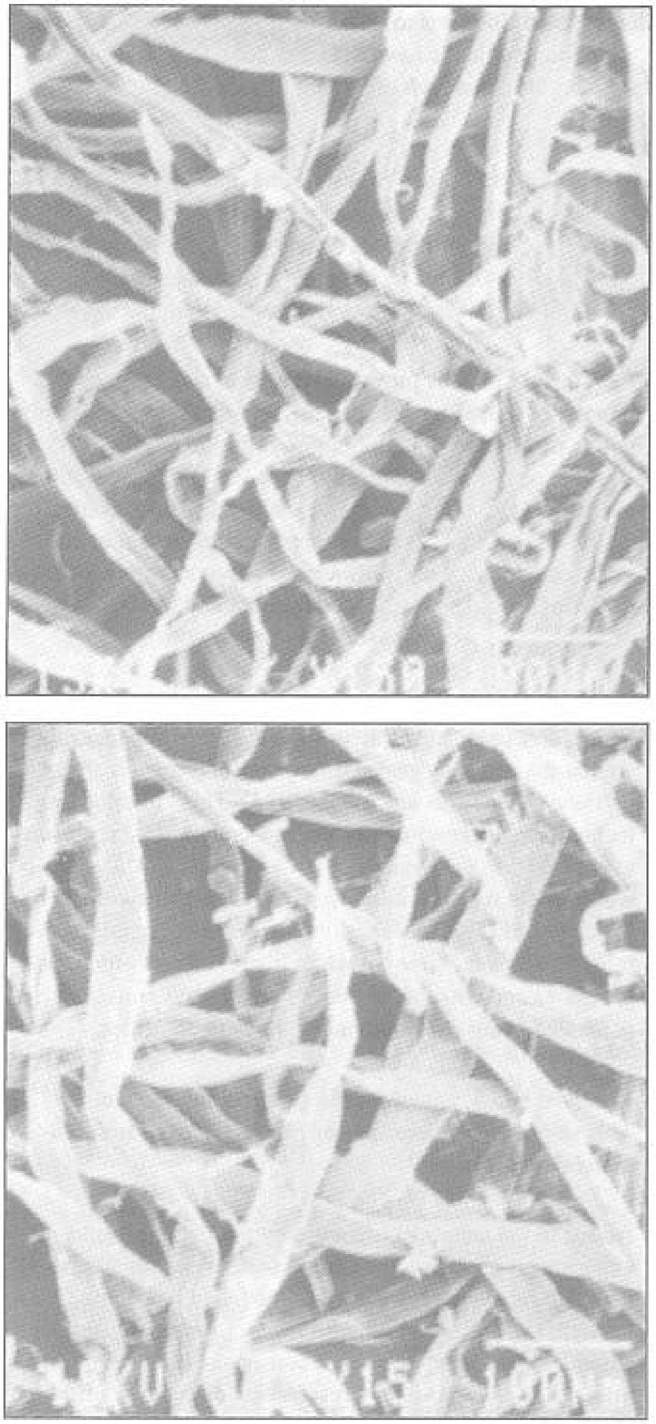

Figure 6—Recycled fibers (top-dried and rewetted three times) are shorter and stiffer than virgin fibers (bottom-never dried). Researchers are developing ways to restore the fiber strength and papermaking properties of recycled fiber.

Traditional ink can be rather easily washed out of wastepaper fibers, but removing toner requires strong, relatively expensive solvents that soften and separate the toner from the fibers. Current processes to deink, or remove toners, are not effective, a problem that has dampened recycling rates for photocopied and laser-printed paper.

The following indicates the research that FPL scientists have completed for better deinking methods and upgrading the quality of recycled fiber to produce printing and writing papers.

- Developed and laboratory tested a technology that uses commercially available biodegradable enzymes to enhance the effectiveness of conventional processes to separate and wash toners from fibers (Jeffries and others 1994). Laboratory tests demonstrate the promise of an enzymatic treatment that would give papermakers an environmentally friendly and effective way to remove toners.
- Demonstrated the enzymatic deinking technology on an industrial scale and planning a series of additional deinking trials with industrial collaborators (Fig. 7). These steps will generate industry interest in the technology, verify its feasibility for commercial scale production, and help direct development of that commercialization.
- Applied for a U.S. patent for the enzymatic deinking technology. This step will allow companies to license the technology for commercialization.
- Pursued discussions with seven companies that have expressed interest in forming a cooperative research partnership with FPL to focus on better understanding of how enzymes work to deink wastepaper fibers. This partnership would create a basic understanding of the removal mechanism so that the technology could be effectively transferred to industry.
- Developed a method to use ultrafiltration screens to recapture the fiber that escapes from the pulp as water is used to wash ink from the pulp (Upton and others 1994). This technology, tested on a laboratory scale but readily adapted to commercial scale, gives papermakers a way to improve their recovery of fiber, reduce the wastes they have to dispose, and consequently produce paper less expensively.
- Developed technology to improve the brightness of wastepaper fibers without using chlorine (Springer and others 1993b). This technology would give companies a bleaching agent whose effectiveness compares with that of chlorine, but does not carry the same environmental risk.
- Added to the technical literature by publishing results about an unsuccessful test on a semi-commercial scale to brighten pulp from wastepaper with a chlorine-free bleaching process (Adams and others 1993). This work adds to the body of recycling and bleaching knowledge and can help direct researchers to technologies that show more promise.
- Launched a program to test whether old-corrugated containers, which are recycled relatively easily and are a good

Figure 7—Enzymatic treatments being developed at the Forest Products Laboratory could give papermakers an effective and environmentally friendly way to remove toners from recycled paper.

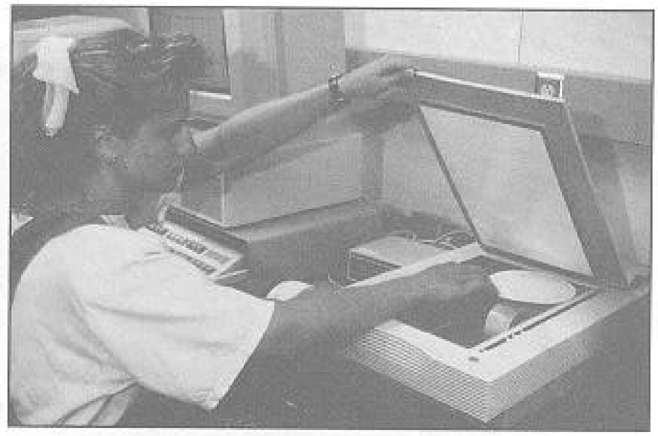

Figure *8—Contaminants are a major problem for papermakers using recycled fiber. Technology developed at the Forest Products Laboratory can easily and quickly measure the level of adhesive contaminants left in a recycled pulp.*

source of fiber, can be upgraded and used to make printing and writing papers (Sykes 1993). This program will test whether using enzymes improves processes to remove lignin, the glue that holds wood fibers together, and to bleach the pulp. Success in this area would give companies a source of less expensive, easily recycled fiber for printing and writing paper.

Improved Contaminant Removal

Another modern office convenience, the ubiquitous office "stickie," also proves the bane of recyclers. Adhesives such as on the backs of envelopes and sealing tapes are a source of contaminants complicating wastepaper recycling. The contaminant needs to be removed or masked to produce a clean pulp for papermaking, but current methods of separating contaminants from fibers in paper pulps are often ineffective and can damage the fibers.

The following indicates how scientists at FPL have conducted research to better understand how adhesives and other contaminants affect recycled fibers and have devised more effective ways to remove them.

- Determined that the processes used to remove contaminants, and not the contaminants themselves, caused recycled paper to lose strength and proposed specific chemical treatments to improve strength properties (Klungness 1993). This information adds to the body of knowledge about the effects of contaminants and steers work to improve the removal processes. This work also provides an improved option for contaminant removal.

- Invented equipment to separate fiber from contaminants by placing pulp in a high-speed disk that spins out the large, dense, hydrophobic contaminants, while the hydrophilic fibers travel at the same speed as the water and remain in the disk longer (Klungness and others 1994). Researchers are now testing the technology to determine whether it can be scaled up for commercial production. If commercially feasible, the disk separator would give papermakers another effective way to remove contaminants without using chemicals.

- Conducted studies to better understand how the adhesive and fiber particles separate while in the disk separator (Saliklis and others 1988) and to verify the optimum operating conditions of the equipment (Klungness and Evans 1989). This work will help to advance efforts to commercialize the technology.

- Developed technology to easily and quickly measure the level of adhesive contaminants left in a recycled pulp (Klungness and others 1989). This quality-control tool is now widely used by papermakers to determine whether recycled pulp is clean enough to place on paper machines for further processing (Fig. 8).

Structural Products

Some contaminants, such as adhesives, inks, and groundwood fibers, may be so difficult and costly to remove that trying to recycle wastepaper into printing and writing paper does not make economic sense. However, that does not mean that the wastepaper is destined for the dump. The FPL researchers have created the following technologies that turn this hard-to-recycle waste into value-added products:

- Introduced new pressing technologies for enhancing the performance of containerboard made from recovered fibers

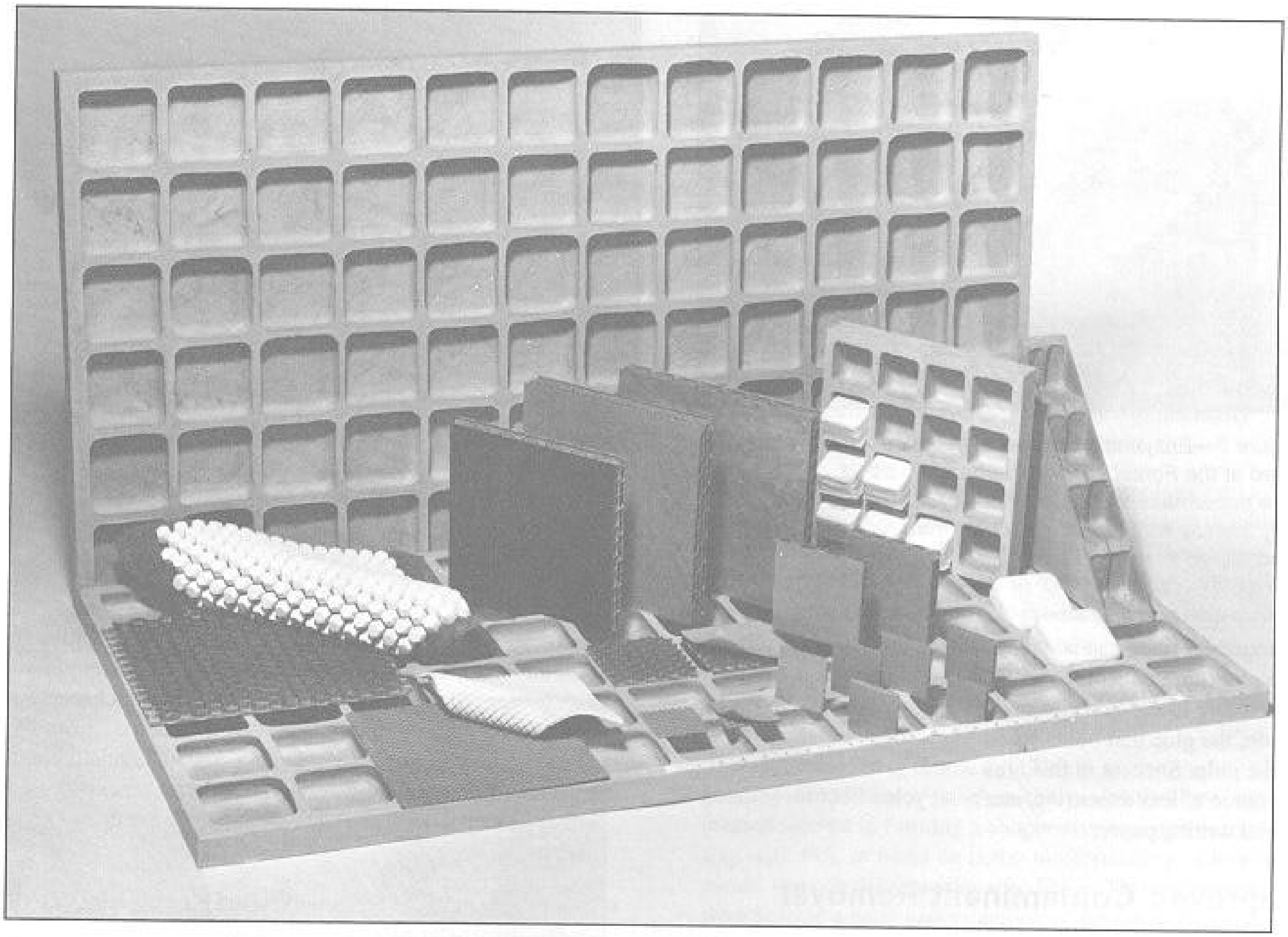

Figure 9—Companies have already licensed this patented FPL Spaceboard technology for molding recycled fiber into a three-dimensional structural product. Its high strength-to-weight ratio shows potential for use in sound stages, office systems, packaging applications, and building products.

(Laufenberg and Hunt 1992). These approaches improved paperboard compression strength, dimensional stability, and creep resistance, thus providing the incentives for the structural papers industry to use mixed wastepaper as a feedstock without sacrificing performance.

- Developed technology to mold recycled fiber into a three-dimensional structural product called Spaceboard, which shows potential as a structural panel (Hunt and Gunderson 1988) to be used in sound stages, office systems, packaging applications, and prototype products (Hunt and Scott 1988; Scott and Laufenberg 1994). In 1993, Spaceboard was named by *Popular Science* magazine as one of the year's 100 most significant developments in science and technology. This technology gives companies a low-cost raw material for producing panels that perform similar to conventional panels of the same weight (Fig. 9).

- Received five U.S. patents related to Spaceboard technology and its applications. This action helped to secure three licensees to develop commercial applications using this technology.

- Assisted companies that have licensed Spaceboard to adapt the technology for industrial-scale production and test prototype products. A California licensee is currently producing and marketing panels made with Spaceboard technology.

- Initiated tests to determine the mechanical properties of fiberboards made from magazine paper that were recycled up to 10 times. Results after two cycles suggest that fiberboards made from subsequent recyclings do not necessarily decrease in mechanical properties. Fiberboards recycled a second time had greater stiffness and bending strength than fiberboards made from the first recycling and swelled in water at a slower rate. This testing helps answer questions regarding how many times a fiber can be recycled without decreasing its mechanical properties.

Landfill Alternatives

Recycling creates wastes; among them is a sludge composed of the toners and other contaminants removed from wastepaper pulp during recycling. Disposing of this sludge has become increasingly costly and difficult as some communities move to restrict the waste in their landfills, thus forcing companies to haul their waste greater distances. Researchers at FPL are finding ways to better handle these wastes so they do not end up adding to the landfill burden. In some cases, they have found a way to benefit in a small way from these wastes. In this area, researchers at FPL have completed the following:

- Analyzed the energy and environmental costs associated with several disposal processes and how those methods compare with a number of alternative incineration technologies, including applying the sludge to forest or agricultural lands (Scott and others 1995). The published literature gives papermakers valuable information about options for disposing sludge from papermaking.
- Developed technology to convert discarded disposable diapers into paper by using conventional separation equipment to remove the contaminants (Klungness and Siegfried 1992). Researchers conclude that more work is needed to evaluate the economic viability of the process, but the technology provides an avenue for tackling the diaper disposal problem.

Recycled Housing and Industrial Applications

Wood wastes from construction and demolition sites are in large supply (Fig. 10). They can potentially substitute for expensive virgin construction materials and be incorporated into new molded products. Composite materials made from recovered wood and paper wastes provide ample opportunity for engineers and architects to design products that are optimized for performance. Unlike conventional lumber products, which are constrained by standard rectilinear geometries and processes that whittle the wood to size, products of composite processes are molded to finished dimension, curved or edged as needed, and can incorporate performance enhancing treatments during their processing (Laufenberg 1993).

However, wood wastes have largely been ignored as a raw material for a variety of reasons. Many of these wastes are difficult to process because they contain nails, glass, dirt, and contaminants that concern health issues, including lead-based paints and some preservative treatments. These wastes also come in a variety of sizes and conditions and from different tree species, factors that pose processing problems. Companies are also concerned about the difficulty of securing a constant supply. Construction wastes are seasonal, and predicting the amounts of other available solid-wood wastes is

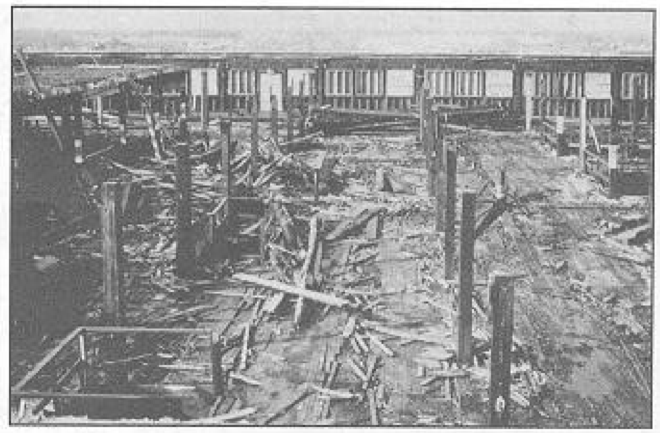

Figure 10—Demolition debris and construction waste represent a large untapped source of wood fiber.

difficult because wood wastes have a less predictable life span than paper wastes.

As a result of these and other challenges, few products are made from these wastes. What few there are tend to be relatively low-value, low-volume goods such as mulch or burned as boiler fuel. However, the FPL has launched a recycled building products program to mine these wastes to produce high-value products that can be used in housing and other structural uses (Falk 1994) (Fig. 11). Researchers have already developed board panels from post-industrial waste, made plastic feedstock from carton film, converted feedstock from paper fiber and plastic, and used conventional wood composites from recycled wood wastes.

Board Panels From Post-Industrial Waste

As wood wastes from demolition and construction sites are increasingly being restricted from landfills, so are other wooden materials conventionally used in home construction. The FPL has developed methods to give a second life to these wood wastes and other post-industrial wastes. Researchers have initiated studies to develop technology to mix fibers from urban wood waste with fiberglass waste from sheet molding to produce subflooring panels. The technology can give companies a stronger, less expensive panel, while it diverts two wastes from landfills.

Feedstock From Carton Film

Juice boxes are joining bologna sandwiches and potato chips as staple items in children's school lunch boxes. Recyclers like the low-cost, high-quality fiber that these boxes, milk cartons, and other food packages contain. However, separating the fibers from plastic film (low-density polyethylene, LDPE), which is used to coat the fibers, presents problems.

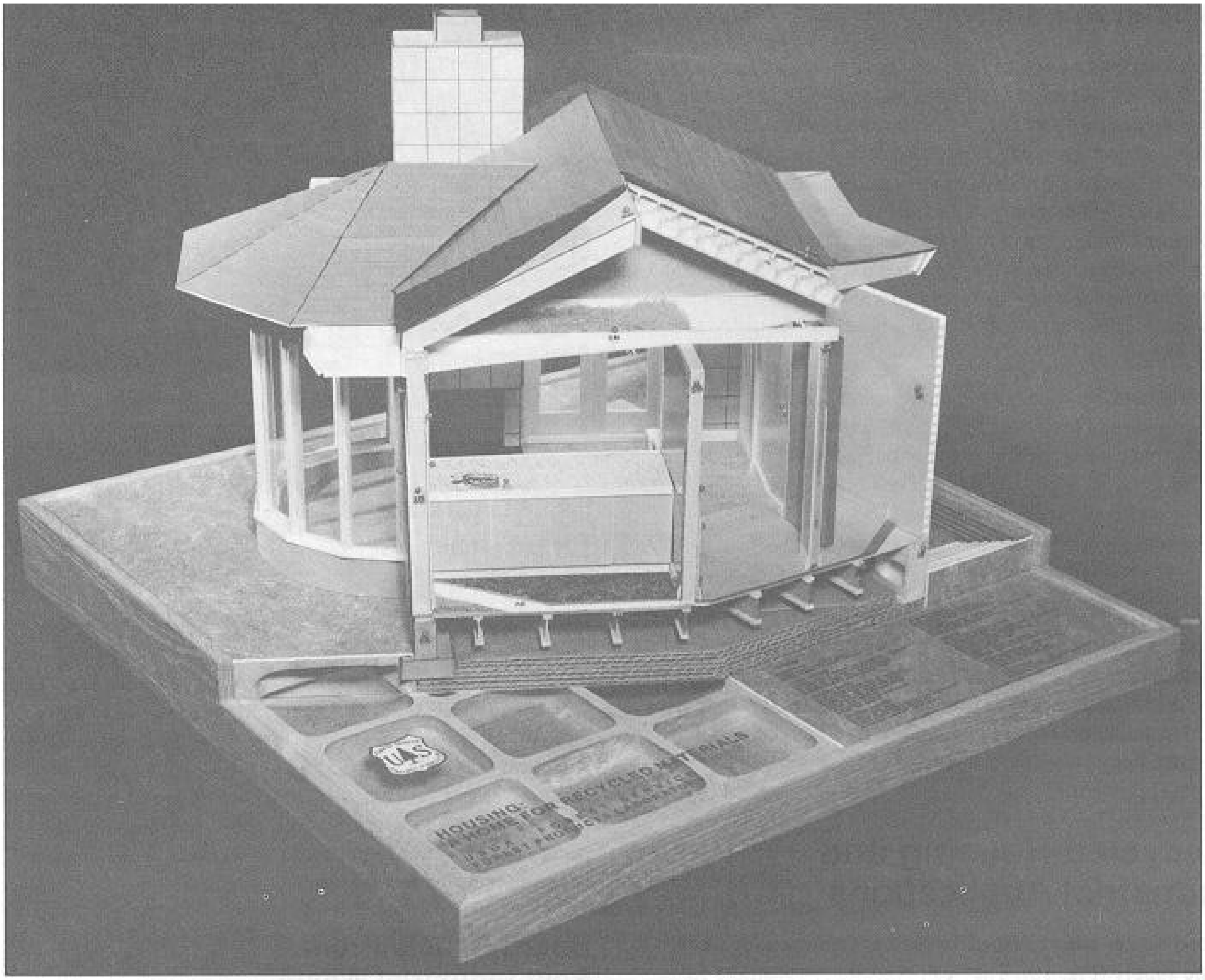

Figure 11—This model house demonstrates some potential uses for recycled materials in building products of the future. Recovered paper and wood could be used in everything from shingles and roof panels to wall studs and floor joists

Up to 50 percent of the paper fiber is lost in the waxy slurry during the separation process. A single mill that recycles these coated boxes can generate up to 40 tons a day in wet-film wastes. The Wisconsin Department of Natural Resources turned to FPL for help in finding a means to reduce this waste. In this area, FPL researchers have completed the following:

- Developed technology with private industry and a Wisconsin university that thickens the film waste and creates pellets that can be used in typical plastic processing equipment (English and Schneider 1994). An Ohio company has successfully used the material in its plastic lumber. This technology gives recyclers another way to benefit from post-consumer material and reduce disposal of waste (Fig. 12).
- Completed a full-scale analysis of the cost of setting up a recycling operation for the wet-film waste and published those results in technical journals and the popular press. This information gives companies a means to determine the feasibility of this technology.

Feedstock From Paper Fiber and Plastic

If recycling one waste material is good, recycling two materials at the same time is even better. The FPL scientists are advancing research to allow waste fibers and post-consumer

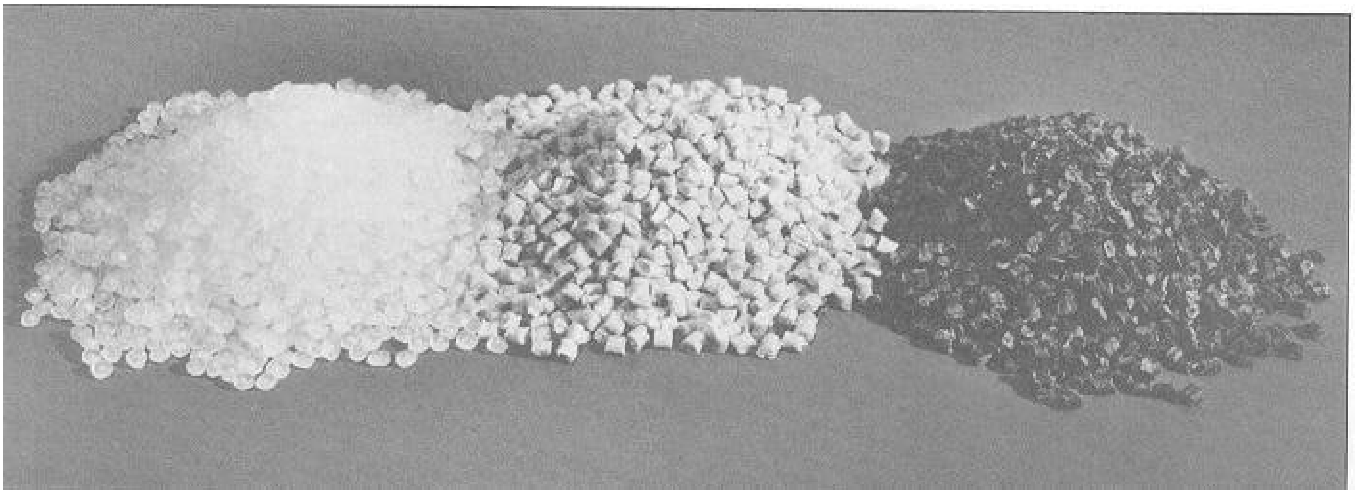

Figure 12—Putting recovered fiber into a form that manufacturers can readily use is a key step in recycling. FPL researchers have found a way to recombine plastic pellets (left) with wood fiber (center) or old newspapers (right) into a wood-plastic pellet that is readily used in existing plastics equipment.

plastics to be converted into a composite from which a wide array of themoplastic goods can be produced. This research will not only help provide additional markets for various waste fibers and post-consumer plastics, but will enable plastic manufacturers to cut their costs and increase their products' performance by giving them a feedstock that can be less expensive but stronger than virgin plastic.

A key to achieving these goals will be learning more about the surface interactions between fibers, which are hydrophilic, and polyolefins, which are hydrophobic. These contrasting affinities make it difficult for the materials to compound and result in inefficient composites. In work to overcome these difficulties and produce composites from lignocellulosic fibers and thermoplastics, FPL researchers have completed the following:

- Demonstrated that recycled fiber and various agricultural fibers such as kenaf can be substituted for wood flour in fiber/thermoplastic compounds and can greatly improve the mechanical properties of fiber/thermoplastic composites. This work has shown the promise and challenge associated with composites from lignocellulosic fibers and thermoplastics (Fig. 13).
- Initiated studies critical to improving the compounding ability of lignocellulosic fibers and thermoplastics. Researchers have concentrated on developing the compounding agents and modifying the fiber to improve the interaction and adhesion between the fiber and plastic surfaces. Such work will help improve the mechanical properties of fiber/thermoplastics compounds and ultimately encourage their use.
- Initiated studies critical to inexpensively producing the length and quality of wastepaper fibers necessary for the fiber-plastic mix. They also are working to improve and optimize the mixing methods and developing ways to adapt compounding equipment and composite formulations to produce specific products. This work helps lay the groundwork for the outreach and future commercialization of the technology.
- Developed technology to allow wood wastes to be mixed with plastic and fed into plastic production processes and successfully collaborated with a Wisconsin plastics manufacturer to thermoform interior car door panels from the wood wastes (Myers and Clemons 1993). This research shows the promise of this composite as a feedstock and indicates potential commercial applications.
- Launched an outreach program that will culminate with 300 to 500 plastic product manufacturers within 250 miles of the FPL receiving a mix of wastepaper fiber and plastic to test in their manufacturing processes. The FPL will document the project and make results available to all companies interested in commercializing the composite. This effort will help further demonstrate the technology's commercial feasibility and potential applications (Fig. 14).

Composites From Recycled Wood Wastes

The composite products that are ubiquitous in American homes, such as furniture, cabinets, and flooring, are made by gluing wood particles with adhesives or resins. Many companies produce these goods using wood wastes-the kinds of waste that come from mills and other industrial sites, not the kind that people throw away, post-consumer waste.

Figure 13—Composites that combine recycled wood fiber and plastic show great potential for a variety of uses, such as car door liners, decorative moldings, and other molded or sheet products.

Industrial wood wastes, including sawdust, planer and millwork shavings, and plywood manufacturing trimmings, are generally clean, dry, of a known species, and available in a large and consistent quantity. In short, these materials are everything that demolition and construction wood wastes are not. As shown in the following, FPL researchers have conducted studies to answer critical questions of how differences in post-consumer wood wastes will affect the processing and end use and how to adjust for those differences in production processes.

- Developed the technology to use demolition waste to form a hardboard that performs as well as hardboards made from virgin hemlock. This provides hardboard manufacturers with a readily available fiber source.
- Studies demonstrated that the type of contaminant present in wood wastes may dictate the kind of composite products wastes are used in. For example, scientists found that differences in pH levels in the different tree species found in wood waste also affects its bonding ability. This information will help researchers and eventually industry to direct various wastes to those production processes that best suit them and help identify the technical barriers that need to be overcome.
- Developed specialized gluing methods to allow the use of preservative-treated wood waste in a structural composite.
- Investigated the use of demolition wood as a major ingredient in a cement-bonded durable wood composite.

Other Recycling Applications

Recycled wood and paper fiber is a new resource with a colorful past. Because recycled fibers have only recently been used to create an array of new products, little is known about their basic qualities. These recovered raw materials boast individual histories and characteristics. For instance, recycled fiber destined for paper may come from unsorted wastepaper that includes several grades of paper. Each grade was likely made from a different tree species and produced with a variety of processes and additives. Each grade was also regenerated using a range of techniques.

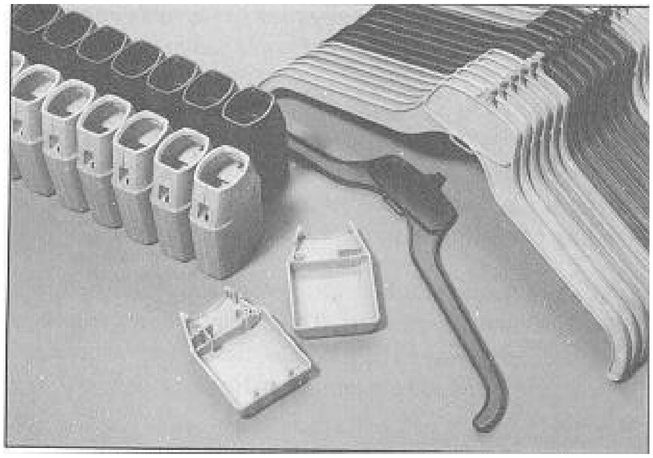

Figure 14—Flashlight casings and clothes hangers are examples of the multitude of products that could be produced by meltblending wood and plastic.

Collectively, these histories impart to the waste unique qualities. In some cases, these qualities are technical barriers that hamper recycling. In other cases, the qualities can allow the recycled wastes to be used in plastics and other products outside the traditional forest products industry.

The FPL and other Forest Service researchers are helping to define the properties of this new biologically based resource. They have launched a program to identify these basic waste qualities, provided options for managing preservative-treated wood, and applied bioremediation of treated wood. Researchers have also investigated topics related to recycling wood pallets and incorporating bio-based geotextiles from recycled wood.

Identification of Waste Characteristics

The FPL scientists will draw on the work of fellow Forest Service researchers as they seek to turn treated-wood wastes into new products. Researchers at the Southern Forest Experiment Station in Pineville, Louisiana, are focusing on defining the basic characteristics of recycled wood and paper wastes so that researchers can work to exploit them. Researchers are seeking the following ways in which recovered wastes can be put to benefit outside traditional forest industry markets.

- Started studies to determine physical and mechanical properties of virgin and recycled pulps from corrugated cardboard, newsprint, mixed office waste, and tissue. These characterization studies will help reveal how many times a fiber can be recycled and suggest ways in which waste fiber, as a result of how it was used or regenerated, can be use to produce fiber-reinforced plastics and other products outside the realm of traditional forest products.
- Developed a powerful new electron microscopy technique that allows additional understanding of how wood fibers fail, an integral piece in answering the question of how many times a fiber can be recycled. This understanding allows researchers to logically develop new approaches to improve and engineer the mechanical properties of wood fibers.
- Tested various formulations of polystyrene and fibers to create composites and found that contaminants adsorbed onto the fiber surface dramatically reduce the strength of the fiber/polymer interaction. This finding is particularly significant in helping researchers understand the technical challenges to using recycled fibers in composites.
- Formulated composites with various ratios of wood or recycled paper fiber to synthetic polyols and analyzed these composites. They found that how fiber is pulped, whether it is mechanically ground or chemically pulped, dramatically influences how composites made from that fiber perform. This information can help researchers, and ultimately companies, engineer composites to obtain the desired performance characteristics.

Preservative-Treated Wood Options

Americans are asking for protection from some preservatives that have long protected their favorite wood products from pests and decay. These particular preservatives may contain chemical compounds that are toxic. Public concern about health effects on humans has spurred government officials to tighten regulations for disposing preservative-treated materials and has limited progress in developing technology to recycle such materials.

The trend to tightly control the fate of this wood waste is occurring, even as the country continues generating more of this waste. Utility poles and railroad ties are continually being removed from service and more than half the Southern Pine lumber produced in the United States is pressure treated with preservatives.

The FPL has responded to this acute need. Scientists have launched a research program aimed at providing more options for reusing or recycling this group of material. Researchers are identifying technology that could be developed to achieve that goal. They are also surveying and identifying currently available technologies, such as bioremediation, that might be used to recycle preservative-treated wood products generated by the U.S. Department of Defense.

The FPL is also conducting research that will allow treated-wood wastes, especially those from demolition sites to be burned as fuel. Researchers have investigated the economic feasibility of different ways to break down these wastes to be used in wood combustion systems and looked at the economics of using variously sized combustion systems. They found that burning particleboard made with a urea-formaldehyde resin produced emission levels that did not differ greatly from those released during the burning of clean wood. This information, along with information about optimal combustion conditions, will help allow treated wood to be diverted from landfills to boilers and furnaces without risking human health.

Wood products treated with pentachlorophenol (PCP) to increase durability may soon be added to the EPA list of wastes banned from ordinary sanitary landfills. PCP has been shown to cause cancer in laboratory animals, but wood treated with the chemical is now disposed as ordinary solid waste because tests have shown that PCP concentrations in extracts from treated wood fall within EPA standards. However, growing scientific evidence and public concern about the potential health hazards of PCP may spur government officials to reclassify PCP-treated wood products, so that they will be required to be disposed in a hazardous-waste landfill.

The FPL has developed a cost-effective and environmentally benign alternative. Researchers have developed technology to put the degradative abilities of a fungus to work breaking down PCP-treated wood products that have been chipped and injected with the fungus. This effort expands the applications for an FPL-developed bioremediation technology that successfully remedied soil at two PCP-contaminated sites. The FPL has also launched a program to use this technology to degrade stockpiled U.S. Department of Defense PCP-treated ammunition boxes. This effort could prove to be a natural, low-cost way to dispose of huge accumulation of treated-wood products in the United States (Fig. 15).

Bio-Based Geotextiles From Recycled Wood

Geotextiles, the textile-like material placed over soil to help prevent erosion and serve other engineering purposes, are increasingly common. People are demanding that such materials be biodegradable. The researchers at FPL and others in the Forest Service are cooperating with private industry and the USDA Agricultural Research Service to meet this market demand. In this area, FPL researchers have completed the following:

- Conducted research to use recycled wood and agricultural materials to produce biodegradable geotextiles for a variety of uses. This work gives engineers a more environmentally friendly option with a variety of applications.
- Developed and field demonstrated sheet mulches that help seeds take root and increase the rate of survival. This work could eventually provide business and government a non-chemical way to boost seedling survival, hence saving re-planting costs (Fig. 16).
- Developed geotextiles to control erosion and allow soil to better filter and absorb water. This research offers engineers a biodegradable way to help keep sediment from entering lakes and streams and contaminants from seeping into groundwater.
- Found that kenaf fibers can be treated with soy oil and successfully used as a staple fiber in bio-based geotextiles. This research expands the fiber sources for geotextiles, not only benefiting textile producers because they have a source that can be rapidly replenished, but farmers who could grow kenaf as a cash crop.
- Demonstrated that seeds, fertilizers, and herbicides can be incorporated into bio-based geotextiles and that these geotextiles can be effectively used to control erosion while plant growth is established. This work could give geotextile users a way to use chemicals to enhance plant growth while sequestering them so they do not seep into groundwater, lakes, or streams.

Technology Transfer

The technology FPL scientists develop is only as good as their ability to get it into use. If the public is to benefit, the inventions and information that researchers discover in the laboratory must be successfully applied on the much larger industrial scale and then transferred to private industry.

The FPL has a good record in transferring their research results. It is poised to make even more impressive progress in forging the crucial link between laboratory invention and commercial use. The following highlights many examples of FPL's strong commitment to technology transfer:

- Committed organizational and financial resources to a State & Private Forestry technology marketing unit that was recently transferred to the FPL to give a higher profile to technology transfer activities. The marketing unit's mission is to work with interested parties to uncover the problems and needs facing local governments, private landowners, and forest industries, and then work to provide technological answers to solve those needs.

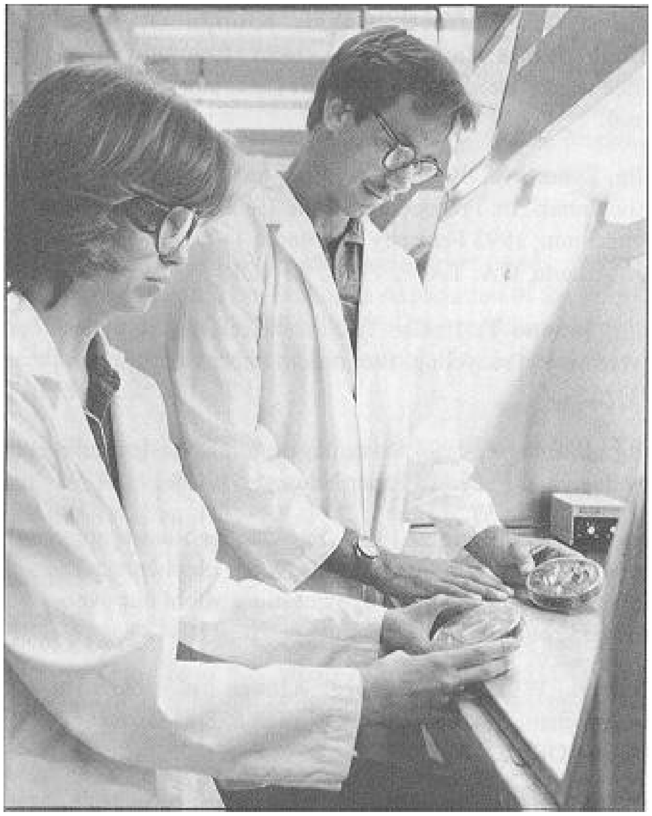

Figure 15—FPL researchers screened many species of wood-decay fungi to find strains that will break down wood preservatives in contaminated soil. This bioremediation technology could prove to be a cost-effective, environmentally friendly way to dispose of treated wood products.

- Supported Forest Service researchers in their efforts to patent and license new recycling technologies. Since 1980, FPL scientists have received 21 patents for technology related to recycling; 16 additional patent applications are pending for recycling technologies. These activities lay the groundwork for securing licensees to develop the technology for commercial applications.

- Offered expertise to companies interested in licensing and commercializing Forest Service inventions. Such work helped benefit the California licensee of FPL's Spaceboard technology, enabling the company to open a production plant in 1994. The FPL activities thus helped add jobs to the California economy while assisting one community find a market for its wastepaper.

- Hosted and conducted a national conference on technology transfer in 1994. This conference familiarized industry and other government agencies with FPL technology, a critical step in commercializing the technology and putting it to use for the public good.

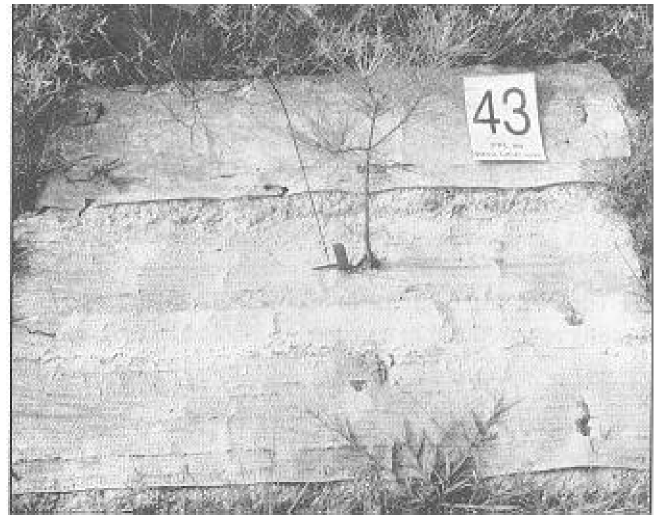

Figure 16—FPL researchers produced mats made from old corrugated containers and cotton to nurture young tree seedlings in reforestation projects. The mat reduces competition from weeds, conserves water, and degrades naturally within 3 years.

- Presented papers at Focus '95, TAPPI's Landmark Paper Recycling Symposium and in ensuing years at TAPPI Recycling conferences in 1992 in New Orleans, 1994 in Boston, and 1995 in New Orleans. Also, papers were presented at the Materials Research Society Symposium on Recycled Materials. These efforts help to disseminate information about FPL technologies and interest industry in collaborative work with the FPL. Such partnerships can help develop FPL technologies on a commercial scale and speed their transfer to industry.

- Provided an Internet connection for the FPL to allow public access to research findings (http://www.fs.fed.us).

- Continued monthly mail distribution of a publication that discusses new forest products technology, coming meetings, and emerging issues. The publication serves Forest Service personnel, USDA Extension system employees, state marketing and forest products utilization specialists, and any program interested in developing markets for forest products.

- Published an overview of FPL's pulp and paper pilot plant capabilities, specifically highlighting opportunities for private companies and research organizations to collaborate with FPL researchers on recycling studies (Abubakr and others 1994).

Extending the Recycling Frontier

As this publication illustrates, FPL researchers are pushing the frontiers of recycling and laying the groundwork for greater utilization of America's vast supply of wood-based wastes. Extensive research and development efforts by the FPL have generated an important body of technical literature and new technologies that have helped expand recycling markets. The FPL will continue to be an international leader in recycling research and in transferring innovation to industry.

Researchers at FPL will continue to seek a better understanding of the available wood-based wastes and their characteristics and abilities to predict recycling markets and their driving forces. They will fine-tune the technology to convert wood-based wastes into economically priced raw materials for manufacturing and turn those raw materials into a wide array of recycled products to be produced on a commercial scale. Then, they will test the technologies and prototypes and help develop standards for them so that the American public can be assured of the performance and safety of the processes and products.

Research at FPL will help the United States seize the opportunity that recycling presents to allow the country to extend its timber resources, cut its landfill burden, and bring jobs and economic growth to the rural and urban communities.

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