Products from Recycled Fibers - A U.S. Perspective

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Abstract

The issue of sustainability underlies most concerns surrounding forests and their use in the 21st century. Recycling offers a rational way to conserve forest resources, reduce demands on other natural resources and ecosystems. and still meet human needs for wood-based materials. However. markets for recovered raw materials constitute a major barrier to successful recycling. The USDA Forest Service, Forest Products Laboratory, is researching and developing new technologies that efficiently turn recovered wood and paper fiber into higher value products. Such research includes assessing the available recovered fiber supply, developing technologies to produce wood-based products suitable for housing and other industrial applications. developing technologies to improve the utilization of recovered paper fibers. conducting economic analyses. and ensuring that products made from recycled fiber meet accepted performance standards. From a U.S. perspective. creating and implementing these new technologies is best accomplished through effective partnerships between government. academia. and industry.

Keywords: Recycling. waste. recovery. reuse.

Introduction

Forests contribute in many ways to our well being: Forests play a crucial role in watersheds by providing slope stability: aid in climate regulation: furnish habitat for wildlife: provide human leisure and recreation: render nontimber resources such as floral greens and edible mushrooms: and supply timber resources for producing fuel. making furniture. constructing homes. building bridges. and making paper. In short. the demands on our forests are numerous. and we need to ensure that we are using them wisely and in a sustainable manner.

When the concept of sustainable development was presented in the 1987 United Nations report. “Our Common Future,” it clearly contained the message that the environment and economics cannot be treated separately and that material needs must be met in ways that preserve the biosphere. In 1992. a report of the National Commission on the Environment. “Choosing a Sustainable Future” (World Wildlife Fund 1992), endorsed the 1987 United Nations report and went one step further. The Commission stated that “long-term growth depends on a sound environment. and resources to protect the environment will come from economic strength.” The point here is important - it is a circular relationship: a strong economy depends on a healthy environment and a healthy environment depends on a strong economy.

The U.S. forest products industry contributes positively to the U.S. economy. In nearly every U.S. state, the forest products industry is one of the top ten manufacturing employers. In total. nearly 1.4 x 10^6 people are employed in lumber and wood products and the paper and allied products industries in the United States (U.S. Bureau of Census 1994). Together. these industries produce nearly US$200 x 10^9 in shipments every year. making up more than 7% of all manufacturing in the United States (US. Department of Commerce 1993).

Our dependency on forest products is growing. Nearly half (by weight) of all industrial raw materials used in the United States (steel. concrete. plastics) is wood based. Residential construction is the dominant market for most timber products in the United States. and a 13% increase in lumber consumption per housing unit is projected in the next 45 years. In total. lumber consumption is projected to grow approximately 30%, to 74.0 x 10^9 board feet (260 x 10^6 m^3) in 2040. Consumption of structural panels (softwood plywood, oriented strandboard. and waferboard) is expected to reach 42.3 x 10^9 ft^2 (3.9 x 10^9 m^2) by 2040, an increase of 70% above 1990 consumption levels. Consumption of nonstructural panels (hardwood plywood. insulating board. hardboard, and particle board) is also projected to increase to

28.4×10^9 ft^2 (2.6×10^9 m^2) by 2040, an increase of 28% above 1990 levels. Finally, pulpwood consumption is expected to grow more than 53% in the next 45 years. In total, U.S. timber consumption in terms of roundwood volume is expected to reach 16.5×10^9 ft^3 (750×10^6 m^3) in 2040, more than 40% above 1990 consumption levels (Haynes et al. 1995).

In the past. growing demand for products translated into greater emphasis on timber harvesting. Although we acknowledge that great strides in conserving resources can he made by reducing our material use. we must be realistic in recognizing .that the demand for products will not diminish. Population in the United States is expected to increase from 262 to 338×10^6 by 2025; world population is expected to increase from 5.6 to 8.9×10^9 by 2025. On a worldwide basis, this means that we face the need to find new ways to conserve our forest resources. In addition. in the United States we are facing increasing restrictions on harvesting of forest lands. This raises the question of how to meet growing demand for wood-based products while still meeting our sustainability goals. Recycling of wood fibers provides an opportunity to meet both objectives - to provide the raw material used in making wood-based products and to conserve forest resources. Assuming recycled paper products can be substituted for virgin wood material when producing paper and paperboard. it has been estimated that accelerated recycling has the potential to offset the need to harvest 400×10^6 ft^3 (11.3×10^6 m^3) of sawtimber and pulpwood (Haynes et al. 1995).

U.S. Recycling

Most industrialized nations have been actively pursuing new technologies to recover more materials from postconsumer and postindustrial waste streams. In the United States. this effort gained momentum in the late 1980s when the growing volumes of material disposed in landtills resulted in public pressure to reduce the availability of land for new dump sites. In 1993, 44% of the municipal solid waste generated in the United States consisted of paper. paperboard. and wood products (U.S. EPA 1994). Because of this large percentage of municipal solid waste, U.S. state and local laws and regulations were passed that required recovery and reuse of many wood-bused products.

Currently. every U.S. state regulates recycling or solid waste management. State governments encourage reuse of recovered material through demand-side mandates such as minimum content standards. tax incentives. green labeling, and procurement standards. State legislators have also pursued mandates to increase the supply of recovered materials. They have prohibited products from being disposed in landfills and adopted recycling goals that specify a percentage of the waste stream to be recovered for recycling, reduced at the source, composted, or otherwise diverted from landfills.

The U.S. pulp and paper industry has also adopted recovery goals to increase the amount of paper material recovered from the municipal solid waste stream. In 1990, the U.S. paper industry proposed a 40% recovery goal by 1995. That goal was met in 1994 when 38.6×10^6 tons of paper were recovered in the United States - just over 40% of all paper used. The U.S. paper industry has since set a new goal to recover for recycling and reuse half of all paper used by the year 2000.

In addition to conserving our resources. recycling offers many societal benefits. Recovery of materials can extend the life of existing landfills and offset the need to find new landfills. Cities throughout the United States are finding that recycling offers employment and. when successful. brings in revenues to help lower the cost of refuse collection. Further. processing recovered paper fiber requires less energy than processing virgin materials. thus generating less carbon emissions (Skog 1995) and helping the U.S. government meet its objective of keeping net emissions of carbon to levels no greater than those in 1990.

The USDA Forest Service. Forest Products Laboratory (FPL), recognizes the benefits of recycling and is researching and developing new technologies that efficiently turn recovered wood and paper fiber into higher value products. Such research includes assessing the available recovered fiber supply. developing technologies to produce wood-based products suitable for housing and other industrial applications. developing technologies to improve the utilization of recovered paper fibers. conducting economic analyses. and ensuring that products made from recycled fiber meet accepted performance standards,

Waste Resource Supply Information

Success in developing technologies to produce value-added products from recycled wood waste is dependent upon many factors. including the availability of a consistent and relatively uniform raw material source. Detailed raw material resource information is a necessary first step in developing any new technology or system to convert a raw material into a usable product. Adequate short- and long-term raw material supplies must be available at reasonable costs for a technology to be commercially adopted and implemented. Factors affecting the economic supply of recyclable raw materials include amounts and types of material generated. condition and quality of the material, extent of commingling of materials, separability of materials, types of contaminants present, physical location of the material, and costs of acquisition. concentration. and transportation. Likely changes in these factors must be evaluated to determine possible effects on raw material supply.

The capability to economically assemble a continuous supply of raw material requires innovations in collection. sorting, and distribution of waste materials. Directing materials to the highest value use is essential. In addition. a manufacturing firm must have some assurance of long-term supply. which includes both a continuous flow of suitable raw materials and the ability to compete economically in the raw material market place.

Recycled Wood-Based Composite Products

There are many opportunities to develop the technology needed to make composite products from recycled wood-based fiber. The fiber can be used alone to make low cost/high performance composites. Alternatively, recycled fiber can be combined with other recycled materials. such as plastics, to produce mixtures, compatibilized blends. and alloys. Finally, wood-based fiber can be combined with inorpanic materials. Researchers at FPL lead the formation of a task force composed of government. industry and academia to provide a framework for research to develop composite products using recycled fiber (Rowell et al. 1993).

Several essential issues need to be addressed to fully utilize post-consumer wood and paper wastes in composite products. First, characterization of the recyclable materials and their levels of contamination are needed. Secondly, the raw material needs to be converted into a form suitable for the manufacturing process. Also, any effect of existing residual contamination on the manufacturing process needs to be quantified. Most importantly, the link between raw material characteristics and final product performance must be established. Finally. evaluation. testing. and design standards must be developed to use these products.

In this paper, we discuss several existing and developing technologies that have the potential to produce recycled wood-based products suitable for use in housing and other industrial applications. One benefit of these technologies is that they provide an outlet for recycling other materials, such as some grades of plastic, or using agricultural fibers for which there is currently no economic use.

Dry-Formed Wood Composites

Dry-formed wood composites can be made from recovered wood fiber in much the same way as conventionally produced particle-based composites (e.g., particleboard, hardboard, medium-density fiberboard). Dry-formed processing involves breaking wood waste into strands. flakes. particles. or fibers and reassembling them into new forms with the aid of an adhesive. An important part of particle-based composite panel manufacture from virgin wood is a consistent and homogeneous raw material source to ensure uniform panel properties. Because the raw materials being considered here are derived from waste. the many forms and sources of wood waste will likely pose special processing considerations. For example. waste wood from demolition sites may be contaminated with lead-based paint. nails, stones, plastic, gypsum, and concrete. In addition to this surface contamination, the wood waste may contain preservative or fire-retardant chemicals. Research and development to efficiently process these raw materials will result in new, value-added products.

Wet-Formed Structural Fiber Products

Wet-formed structural Fiber products can be produced from basic papermaking technologies (pulp slurry). Using a three-dimensional pulp-molding process, researchers at the FPL have produced a structural component called Spaceboard. It is anticipated that the Spaceboard technology will be used to produce a variety of housing components. This process can readily accept recycled wood fibers. and although now limited to rectangular panels. has the potential for both curvilinear and three-dimensional solid-formed products. This molding potential could greatly enhance design flexibility for architects and engineers.

The FPL is also considering two potential technologies to utilize recycled wood fiber using wet-formed processes. One technology is a pulp extrusion process that has the potential to produce products with various dimensions and cross sections. Potential products developed with this process might include decorative molding and trim products and lumber substitute products.

Another technology is a wet-formed fiber-based process that involves shaping structural components through the winding of paper sheet stock. This laminating process incorporates existing paper sheet-forming technology and is familiar to most builders that have used paper tubes for concrete formwork. This type of process has the potential to utilize low-grade recycled paper stock. Because circular. rectangular. and other efficient cross-sectional shapes can be formed. a number of potential housing components can be produced with this laminating process.

Wood-Plastic Composites

Wood-plastic composites include those made by binding recycled wood fibers with recycled plastics. synthetic fibers. and resins. These combinations can produce a variety of composite building products.

Recycled wood-based fiber and plastics can be combined to make a wide spectrum of products. ranging from very inexpensive, low-performance composites to espensive, high-performance materials. Fiber technology, bonding performance, and fiber modification can be used to manufacture wood-plastic composites that have uniform density, durability in adverse environments. and a high level of strength.

The primary application for fiber-thermoplastic composites is in extrusion molding. The natural fiber improves the rigidity and strength of the plastic and lowers the cost of the final products.

Utilizing thermoplastics in composites has been limited to nonstructural uses by creep. which results from thermal or long-term loading deformation. However. thermoplastics (which melt when heated) can be converted to thermosetting materials (which are cross-linked and unable to melt). so that it would be possible to make creep-resistive structural products using recycled thermoplastics. Research and development to overcome such limitations can greatly increase the use of wood-plastic composites.

Wood-Inorganic Composites

Another recycling opportunity is to bond recovered wood and other postconsumer materials with inorganic materials. Recycled particles or fibers of wood held together with an inorganic binder. such as Portland cement and gypsum. form a composite that can be used in a variety of structural and architectural applications. such as lightweight concrete. Virgin-based wood and cement composites have found wide use in Europe. although their use is scarce in North America.

Compared with conventional wood-building materials. wood-inorganic composites offer unique advantages in that these composites combine the advantageous characteristics of both the wood fiber and mineral matrix. These composites have good fire. noise. decay fungi. and insect resistance.

The use of inorganic materials to bind recovered wood fiber. chips. and particles has proven to be technically feasible in commercial products such as sound insulation board. gypsum. fiberboard. and low-density cement-bonded wood building blocks. This range of products can be extended if means are developed to convert waste wood into optimal particle sizes.

Recycled Solid-Wood Products

One source of lumber that has great potential for reutilization is the “old” lumber and timbers from dismantled structures. In addition to the millions of single-family residential buildings in the United States, thousands of World War II military buildings that contain millions of board feet of usable lumber and timbers are slated for demolition. This demolition material is an attractive recyclable because it takes little energy to put it in reusable form.

The lumber and timbers salvaged from the demolition of existing wood structures are becoming a building material with increased value. This is because large-sized virgin timbers are not readily available from contemporary forests. Also. salvaged timbers. while sometimes containing bolt holes and other defects. are usually well seasoned.

The potential for utilizing old lumber or timbers depends not only on the economic feasibility of recovery compared with disposal, but the acceptance of used products in new construction. Because the grade of lumber is correlated to its structural performance and building officials require some measure of assured performance (typically given by the grade stamp on virgin lumber), a system is needed to grade old lumber.

Recovered Paper Technologies

The use of recovered paper fiber to make new paper products has increased steadily over the past several years. However, there are several technical barriers to recovery and reuse of high grade paper materials. Research is needed to improve the ability to remove toners and other Contaminants from recovered paper. improve fiber strength. and improve the bleaching process of recovered fiber. Furthermore, making paper with recycled fiber generates more sludge than making paper from virgin fiber. Research is needed to examine new uses for this sludge and develop new technologies that produce fewer byproducts.

Improving Toner and Contaminant Removal

Few paper products found in municipal solid waste contain only fiber. Recovered paper can contain toners. adhesives. fillers. dyes. metal foils. plastics. and dirt. Use of fibers from recovered paper to produce new paper products requires separating fibers from Contaminants and cleaning. Success in developing technologies to improve toner and contaminant removal can greatly increase the raw inaterial potential of municipal solid waste.

One problem is that photocopiers and laser printers use nylon or plastic-based toners that, under high heat, bond to xerographic and photocopier paper. Recycling xerographic and photocopier paper into printing and writing paper is difficult and costly. FPL is examining the use of commercially available biodegradable enzymes to enhance conventional removal processes. This enzymatic deinking process uses a low amount of chemicals. resulting in a cleaner process water with effluent that is lower in oxygen demand and less toxic. Further, enzymes are readily biodegraded and do not cause problems in environmental cleanup. This technology separates toner from fibers more effectively. improves pulp brightness and drainage, thus allowing for greater production.

Increasing Fiber Strength

Recycled fiber is weaker than virgin fiber as a result of the changes that occur during the drying phase when the fiber is first made into paper. The drying dehydrates the fibers under high temperatures and pressure. This hardens the fiber surfaces and shrinks the pores that allow water to pass back and forth between fibers. These changes reduce the flexibility and the ability of the fibers to bond to one another. leaving short. stiff fibers that produce weak paper.

Three technologies have the ability to improve the strength of recovered fiber. One technology involves soaking recovered paper fibers in various chemical treatments before disintegration. This technology restores the bonding potential of the dried fibers.

A second technology involves using screens to separate the shorter and stiffer recovered paper fibers from those that are longer and more flexible. This technology allows for the use of the longer more flexible fibers to enhance paper strength, without creating a toxic effluent. A third technology 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. This process, called fiberloading, creates a reaction that causes the filler to form within the fiber walls where it will not interfere with the bonding ability of the fiber. Technologies to increase fiber strength of recovered paper will ensure that recycled paper is comparable with paper made from virgin materials. This will enhance consumer acceptance and use of recycled paper products.

Bleaching Recovered Fibers

One primary concern in using recovered fiber to make new paper products has been the brightness of the end product. In the past. the most commonly used aid for repulping and bleaching recovered paper was sodium hypochlorite. However. increased environmental concerns regarding the use of chlorine compounds in paper mills have resulted in the need to find alternative repulping aides (Kapadia 1992).

The FPL research is examining other compounds (such as peroxymonosulfuric acid and its salts) that show promise as bleaching agents for recovered paper fiber. Some of these compare in effectiveness to using chlorine. but do not produce the same byproducts.

Research is also underway to test the potential for using enzymes to remove lignin and bleach the pulp. If successful. this technology may be used in converting old corrugated containers (or fiberboard). which have a high recovery rate, into higher valued printing and writing papers.

Decreasing Sludge

Making paper from recovered fiber generates more sludge than making paper from virgin fiber. Sludge. a byproduct of pulp and papermaking. is a heterogeneous mixture of water. short or damaged wood cellulose fibers. and other contaminants. In a recent study by Scott et al. (1995), the energy and environmental costs associated with several disposal processes were analyzed. The study considered alternative incineration technologies. including applying the sludge to forest or agricultural lands. Results from this study provide valuable information about options for disposing of sludge from papermaking.

In addition to finding new uses for sludge. new technologies can result in a decrease in the amount of sludge generated. One technology uses ultrafiltration screens to recapture fiber that escapes from the pulp as water is used to wash ink from the pulp. This technology improves the recovery of fiber and reduces the waste. In addition. the fiberloading technology discussed previously not only improves paper strength. but reduces the amount of sludge and emissions generated over conventional methods.

Economic Analysis

Economic analysis of current and future trends in recycling technology and markets provides important information for researchers and policymakers. Forest Service economists are studying long-term recycling trends and their broad economic. environmental. and energy impacts. The FPL researchers have collaborated with academic and industry partners to develop an economic model called the North American Pulp and Paper Model (NAPAP Model). This model provides long-range economic assessments of the North American pulp and paper sector. It has been used to examine the effects of recycling on pulp and paper markets by simulating technology for using recovered fiber and virgin wood fiber and makes projections of timber supply and demand. growth, inventory. and prices. A similar model for the solid wood sectors of the U.S. and Canadian economies is under development.

Performance Evaluations and Standards

Although there is great opportunity to utilize recycled wood-based materials using the described processing technologies, the products produced from them must perform satisfactorily. For building and paper products. performance standards ensure a product's acceptability.

Each of the 6,000 grades of paper and paperboard products has established performance and quality standards that determine acceptability in the marketplace. These U.S. standards are set by manufacturing associations for each paper grade. A systematic analysis is needed to prioritize and target those grades of paper that are best suited to accept recycled fibers. This will mean assessing the effect of recycled content on paper performance in products made from recycled fibers.

Recycled products used in housing and other industrial applications must also meet performance standards. Standards for building products result in an assurance of public safety as well as the facilitation of regulatory acceptance of the developed products and building systems. Therefore. evaluations of structural performance. fire performance. environmental performance (including moisture effects and durability), insulative and acoustical properties, and toxicity hazards are needed. The establishment of testing, design, and evaluation standards to measure and maintain this performance is also required.

Standards organizations. such as the American Society for Testing and Material (ASTM). the American National Standards Institute (ANSI), and the International Standards Organization (ISO), develop test standards and performance criteria for comparing properties across a range of products intended for a specific application. The development of such "consensus" standards is the keystone to equitable treatment of properties across product lines and provides the consumer confidence in product performance and safety.

Partnerships - Making Recycling a Reality

Cooperative partnerships are essential for the timely implementation of new technologies. The FPL has already experienced many successes in creating partnerships for recycling technologies. Partners include individual companies, universities, and government agencies such as the U.S. Army and the U.S. Department of Energy. In addition, government research labs, such as the FPL. often work with state and local government agencies whose primary goal is to achieve increased recycling. State and local governments implement programs to ensure a steady supply of recovered materials. Researchers provide technical expertise to industry and can help facilitate the development of new technologies to utilize these recovered materials. Industry can then use these new technologies to process recovered materials into high value products with performance standards that ensure acceptability and use in the marketplace. By working together to recover. reprocess, and reuse recyclable materials. we can make great strides in ensuring the success of recycling efforts and conserving our resources for future generations.

Concluding Remarks

In the United States, we are making rapid strides in recycling wood fibers. In fact, we are ahead of schedule if we look at past goals and the timetables to reach them. However, much remains to be done. We have outlined the following six areas where technology is needed to make expanded recycling a reality:

- Available supply assessment
- Composites from wood and paper
- Solid wood product reuse
- Paper-to-paper technology
- Economics research
- Performance evaluations and standards development

We believe that science is the key to expanding recycling. We also believe that a close science/manufacturing partnership is needed to make further recycling a reality: science to provide the technology and industry to implement it. If successful. the public will benefit through a broader array of products and conservation of forest resources.

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