OPPORTUNITIES FOR COMPOSITES FROM RECYCLED WOOD BASED RESOURCES

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ABSTRACT

A reduction is urgently needed in the quantities of industrial and municipal solid waste materials that are currently being landfilled. Major components of municipal solid waste include waste wood, paper, agriculture wastes, and other biomass fibers. In 1990, there were approximately 80 million tons of 6,000 different paper end paperboard products and 5.8 million tons of wood in the municipal solid waste stream. There are also potential millions of tons of wood fiber in timber thinnings, industrial wood waste, demolition waste, pallets, end pulp mill sludges. These materials offer great opportunities es recycled ingredients in wood-based composites. This paper discusses possibilities for manufacturing selected composites from these materials es well as materials which coexist with the wood-based resources such as plastics, fly ash, end gypsum.

INTRODUCTION

The word "waste" projects a vision of a material with no value or useful purpose. However, technology is evolving that holds promise for using waste or recycled wood and, in some cases, even plastics to make en array of high-performance composite products that are in themselves potentially recyclable.

When fibers, resins, and other materials are used as raw materials for products such as paper, they require extensive cleaning and refinement. When recovered fibers, resins, end other materials are used for the manufacture of composites, these materials do not require extensive preparation. This greatly reduces the potential cost of manufacturing.

A case-in-point is the making of composites from recycled paper. In the United States, nearly 80 million tons of 6,000 different paper end paperboard products are produced and over 70 million tons are discarded each year. Few of the paper products found in the municipal solid waste (MSW) stream are produced solely from fiber end water. Each product consists of a fiber matrix to which some mineral or chemical compound is added to enhance the utility of the product. Thus, many forms of wastepaper contain contaminants (extraneous materials). Whether they are adhesives, inks, dyes, metal foils, plastics, or ordinary household wastes, these contaminants may need to be separated from the wastepaper before the fiber can be recycled into another useful paper product. This is not the case with wood-based composites. In many uses, wood fiber composites of varying types are opaque, colored, painted, or overlaid. Consequently, recovered fibers, resins, or other materials used for composites do not require extensive cleaning and refinement. Thus, composites provide an unusually favorable option for the recycling of
several highly visible and troublesome classes of MSW--paper of various types, waste wood, plastic bottles, fly ash, gypsum, and other biobased fibers.

This paper focuses on wood-based resources that either presently enter or could enter the recycling stream, both commercially and residentially. This includes newspaper, packaging, and other forms of wood-based fiber products, as well as all forms of industrial and residential solid-wood and wood-based composite waste. The use of resources that coexist with wood-based resources is also considered, including a variety of plastics and other resources that "contaminate" the wood-based resource.

A comprehensive waste management program must rely on the aggregate impact of several courses of action: waste reduction, recycling, waste-to-energy schemes, and landfill [1]. The greatest impact that is likely to result from further research is in the area of recycling. Increased use of recycled biobased resources will allow the markets for fiber composites to grow without increasing the use of virgin timber. Therefore, forest products industries will benefit from such research because less expensive raw materials will be available for producing value-added composites.

The purpose of this paper is to describe the potential for producing selected composites from waste wood, paper, plastics, fly ash, gypsum, and other forms of waste biomass. We first discuss the availability of waste materials from the MSW stream and the desirability of developing ways to recycle these materials into useful, high-performing value-added composites. We then briefly describe methods for making selected composites and discuss product properties and attributes. Next, we briefly review composites made from combinations of wood with other biobased fibers. Finally, we outline research and development needs for maximizing the benefits of using recovered waste materials for composite products.

MUNICIPAL SOLID WASTE AS SOURCE OF MATERIALS FOR COMPOSITES

A considerable amount of data is available regarding the inventory of the U.S. MSW stream (Table I). In 1988, paper and paperboard, wood, and plastics in the MSW stream accounted for approximately 71.8, 6.5, and 14.4 million tons respectively. By the year 2000, these figures are expected to increase to 96.1, 8.4, and 21.1 million tons annually [2]. In addition to the wood fiber in the MSW stream, vast quantities of low-grade wood, wood residues, and industry-generated wood waste in the form of sawdust, planer shavings, and chips are now being burned or otherwise disposed of.

The data in Table I include all the residential waste products but not all the industrial waste materials. Data are available for the total volume or weight of certain wood-based products in the MSW stream, such as paper, packaging, and pallets, but only incomplete information is available for timber thinnings, leaves, industrial production wastes, bark, and sawdust. These latter categories of wood waste also represent potentially valuable sources of raw materials.
<table>
<thead>
<tr>
<th>Source</th>
<th>Percent</th>
<th>Weight (x10$^6$ tons)</th>
</tr>
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<tbody>
<tr>
<td>Paper and paperboard</td>
<td>40.0</td>
<td>71.8</td>
</tr>
<tr>
<td>Yard waste</td>
<td>17.6</td>
<td>31.6</td>
</tr>
<tr>
<td>Metals</td>
<td>8.5</td>
<td>15.3</td>
</tr>
<tr>
<td>Food waste</td>
<td>7.3</td>
<td>13.2</td>
</tr>
<tr>
<td>Glass</td>
<td>7.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Plastics</td>
<td>8.0</td>
<td>14.4</td>
</tr>
<tr>
<td>Textiles</td>
<td>2.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Wood</td>
<td>3.6</td>
<td>6.5</td>
</tr>
<tr>
<td>Rubber-leather</td>
<td>2.6</td>
<td>4.6</td>
</tr>
<tr>
<td>Miscellaneous inorganic</td>
<td>1.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Other</td>
<td>1.7</td>
<td>3.1</td>
</tr>
<tr>
<td>(Total)</td>
<td>100.0</td>
<td>179.6</td>
</tr>
</tbody>
</table>

Many problems are associated with the use of waste materials, including collection, analysis, separation, clean up, uniformity, form, and costs. Assuming that these problems can be overcome on a cost-effective basis, some of the resultant reclaimed materials should be useful ingredients for a range of valuable composites, from low-cost, high-volume materials to high-cost, low-volume materials for a wide range of end uses.

Source separation and recycling not only extend the life of landfills by removing materials from the MSW stream but also make available large volumes of valuable raw materials for use by industry in place of virgin resources. Industrial use of such materials reduces both costs for raw materials and the energy it takes to make a finished product [3]. The main requirement is that the recycled ingredients meet the quality and quantity requirements of the consuming production operation.

COMPOSITES FROM WASTEPAPER, WOOD FIBER, PLASTICS, AND INORGANIC MATERIALS

Wastepaper, wood, plastics, fly ash, gypsum, and other biomass fibers can be reclaimed from industrial and MSW streams and used for several kinds of composite products: wood fiber-plastic composites, dry-formed wood fiber-based composites, inorganic bonded wood composites, and composites that combine wood fibers with other lignocellulosic fibers, metals, and glass.

Thermoformable Wood-Plastic Fiber Composites

Thermoformable composites are classified into two general types on the basis of the manufacturing process. Both processes—melt blending and nonwoven mat formation—allow and require differences in composition and in the lignocellulosic component.
A typical composition for a melt-blended composite is 40 to 60 weight percent wood flour or cellulose pulp fiber with a powdered or pelletized thermoplastic such as polypropylene or polyethylene. In the melt-blending process, the wood-based fiber or flour is blended with the melted thermoplastic matrix by shearing or kneading. Currently, the primary commercial process employs twin screw extruders for melting and mixing; the mixture is extruded as sheets that are subsequently shaped by thermoforming into the final product. Limits on the melt viscosity of the mixture restrict the amount of fiber or flour (to about 50 weight percent) as well as the length of the fibers that can be used. Fiber length is also limited by fiber breakage as a result of the high shear forces during melt mixing.

In contrast, nonwoven mat technology involves room temperature air mixing of lignocellulosic fibers (or even fiber bundles) with thermoplastic fibers. The resultant mixture passes through a needling step that produces a low-density mat in which the fibers are mechanically entangled. The mat is then shaped and densified by a thermoforming step. With this technology, the amount of lignocellulosic fiber can be greater than 90 weight percent. In addition, the lignocellulosic fiber can be precoated with a thermosetting resin, for example, phenol-formaldehyde. After thermoforming, the product possesses good temperature resistance. Because longer fibers are required, this product can achieve better mechanical properties than that obtained with the melt-blending process. However, high wood fiber contents lead to increased moisture sensitivity.

It is virtually certain that virgin ingredients can be replaced by some recycled ingredients in melt blending and nonwoven mat formation for many applications. For example, the thermoplastic polymer might be totally or partially replaced by high-density polyethylene (HDPE) from milk bottles, polyethylene terephthalate (PET) from beverage bottles, or even nonsegregated plastic mixtures from MSW. Large quantities of a variety of industrial waste plastics are also available and should be considered. The virgin lignocellulosic component might be replaced by fibers from wastepaper or waste wood. These substitutions offer potential benefits in reducing both MSW and the cost of the composite processes. In some cases, the properties of the composite will probably be improved, for example, by substituting wastepaper fibers for wood flour in the melt-blending process.

Currently, the primary application of thermoformed composites, both melt blended and air laid, is for interior door panels and trunk liners in automobiles. Additional large-volume, low-to-moderate cost applications are expected in areas such as packaging (trays, cartons), interior building panels, and door skins.

The following sections are not intended to be a comprehensive review of recent research on wood fiber-thermoplastic composites. We describe the effects of some important composition and processing variables in the composite processes, including preliminary indications of the effects of recycled ingredients.

**Melt-Blended Composites**

The 1980s brought a resurgence of research into various aspects of melt-blended composites made from wood-based flour or fiber in virgin thermoplastic matrices. For example, Kokta and colleagues published many papers in this area, emphasizing improvements in the filler-matrix bond through coupling agents and grafting of polymers on cellululosic fiber surfaces [4-6]. Klason and colleagues carried out extensive
investigations on the effects of several polymer and fiber types and the influence of a variety of processing aids and coupling agents [7-8]. Woodhams and others examined several types of pulp fiber in composites made with polypropylene and HDPE [9-10]. Shiraishi and colleagues showed improvements in mechanical properties as a consequence of using high-molecular-weight maleated polypropylene instead of normal polypropylene [11-12]. Finally, Maiti and Hassan measured the effects of wood flour on the melt rheology of polypropylene [13].

At the Forest Products Laboratory (FPL) in Madison, Wisconsin, and the University of Wisconsin, Myers and others investigated in some detail the influence of a low-molecular-weight maleated polypropylene (Eastman's Epoline E-43) on the mechanical and physical properties of wood flour and polypropylene-extruded composites [14]. Experiments by Kolosick and others [unpublished data] indicated that the E-43 probably is not acting as a true coupling agent but instead has some effectiveness as a dispersing agent.

Publications are beginning to appear on the effect of recycled ingredients on the behavior of melt-blended lignocellulosic-polyolefin composites. Selke and colleagues showed that composites from aspen fiber and once-recycled blow-molding HDPE from milk bottles possessed essentially equivalent strength and modulus properties as those of composites made from virgin HDPE; however, impact energy was reduced [15-16]. Woodhams and others found that composites made from polypropylene and pulp fibers or fiberized old newspaper possessed strength and impact properties superior to those of composites made from wood flour-polypropylene systems [10]. In preliminary work at the FPL, we compared the properties of wood flour-polypropylene and wood flour-HDPE systems with properties of a fiberized old newspaper-HDPE composite. The differences between wood flour-polypropylene and wood flour-HDPE systems were qualitatively consistent with expectations based on the lower strength and greater flexibility of HDPE relative to polypropylene. Strength was also improved by substituting fiberized old newspaper for wood flour.

Nonwoven Web Composites

Numerous articles and technical papers have been written and several patents have been issued on both the manufacture and use of nonwoven fiber webs containing combinations of textile and cellulosic fibers. This technology is particularly well-known in the consumer products industry. For example, Sciaraffa and others were issued a patent for producing a nonwoven web that has both fused spot bonds and patterned embossments for use as a liner material for disposable diapers [17]. Others found that polyolefin pulps can serve as effective binders in nonwoven products [18]. Many additional references could be cited in this area.

Brooks published a review of the history of technological development for the production and use of moldable wood products and air-laid, nonwoven, moldable mat processes and products [19]. The first moldable wood product using the wet slurry process was developed by Deutche Fibrit during 1945 to 1946 in Krefeld, West Germany [19]. A moldable cellulose composition containing pine wood resin was patented by Roberts as well as a process for producing molded products from this composition [20-21]. The composition consisted of a mixture of comminuted cellulose material and at least 10 percent of a thermoplastic pine wood resin derived from the solvent refining of crude resin. From 1966 to 1968, a series of patents were issued on the use of a wood fiber-thermoplastic resin system in conjunction with a thermosetting
resin system [22-26]. In the early 1970s, Brooks developed a process that produced a very flexible mat using a thermoplastic Vinyon fiber in combination with a thermosetting resin system [19]. The mat was fed through an oven to melt and set the Vinyon fiber without affecting the setting of the thermosetting resin component. This process was patented in 1984 by Doerer and Karpik [27].

Brooks also developed an interesting method of recycling waste cellulosic materials for the production of medium-density fiberboard and paper [28]. After being shredded, sorted from other waste materials like plastic and metal, and steamed, the cellulosic fibers end fiber bundles are abraded under heat and pressure to break down any hydrogen bonds and to soften any lignin and other resins. The resultant cellulose fibers are then mixed with resin, formed into a mat, and consolidated under pressure to form flat fiberboard and paper products.

Youngquist and Rowell reviewed opportunities for combining wood with nonwood materials [29]. This review included a discussion of the materials and properties of composites consisting of wood fibers and biomass, metal, plastic, glass, or synthetic fibers. In a recently published paper, Youngquist and others reported on the mechanical and physical properties of wood-plastic fiber composites made with air-formed dry-process technology [30]. This paper reported the effect of species, wood flour to polypropylene ratio, and type of plastic fiber or plastic fiber-thermosetting resin blends on mechanical and dimensional stability properties of pressed panels having a density of 1 g/cubic cm. Krzysik and Youngquist reported on the bonding of air-formed wood-polypropylene fiber composites using maleated polypropylene as a coupling agent between the hydrophilic wood and the hydrophobic polyolefin materials [31].

A number of preliminary trials were conducted at the FPL using recycled mixed office wastepaper, magazines, shredded old newspapers, dry fiberized old newspaper, and fiberized demolition waste wood. The raw paper materials, which did not have the ink removed, were reduced to a suitable form using several reduction methods. The demolition waste was first sorted mechanically and then manually to remove nonwood materials, washed, and fiberized using a pressurized refiner. The recycled wood-based fibers were then air mixed with virgin polyester or polypropylene, transferred by an air stream to a moving support bed, needled, and subsequently formed into a continuous, low-density mat of intertwined fibers. When polyester fibers were used, the wood fibers were sprayed with a liquid phenolic resin prior to web formation. The use of a thermoplastic polyolefine such as polypropylene greatly improved the dimensional stability of the composite compared to that of the polyester copolymer-containing composite. These results can probably be explained by the fact that the polypropylene melts and, to some extent, partially encapsulates the wood fibers. In all cases, the ability of the polyester copolymer-containing composite to absorb impact energy was superior to that of the polypropylene-containing composite. This can be attributed to the fact that the polyester maintains a fibrous matrix whereas the polypropylene fibers melt and flow under heat and pressure. Phenolic resin, in combination with wood and polyester homopolymer fibers, formed a composite with greatly improved mechanical properties compared to that of the other two composite formulations tested.

Wood-Plastic Fiber Mat Composites

Wood and plastic fibers can be formed into a web using nonwoven web technology. The fibers are introduced into a turbulent air stream, transferred via this air stream to a moving support bed, and subsequently
formed into a continuous mat with low or high density. This mat of intertwined fibers is then passed through a needling operation where fish-hook-type needles further intertwine and strengthen the fibers. The ratio of wood to plastic in this matrix can be in the 95/5 weight percent range. The plastic material (5 percent) can also be replaced with a long wood fiber like jute or kenaf.

One interesting application for low-density fiber mats is for mulch around newly planted seedlings. The mats provide the benefits of natural mulch; in addition, controlled-release fertilizers, repellents, insecticides, and herbicides can be added to the mats as needed. Research results on the combination of mulch and pesticides in agronomic crops have been promising [32]. The addition of such chemicals could be based on silvicultural prescriptions to ensure seedling survival and early development on planting sites where severe nutritional deficiencies, animal damage, insect attack, and weed problems are anticipated. The Forest Service is conducting preliminary research on using fiber mats to improve the survival of loblolly pine seedlings in southern Louisiana.

Low-density fiber mats can also be used to replace dirt or sod for grass seeding around new homesites or along highway embankments. The grass seed can be incorporated in a wood or jute fiber mat. Fiber mats promote seed germination and good moisture retention. High-density fiber mats can be used for air filters or other types of filters. The density of the mats can be varied, depending on the material being filtered and the volume of material that passes through the mat per unit of time. The FPL is conducting preliminary work on developing wood fiber mats for filters.

All of these applications for wood fiber mats provide excellent outlets for recycled wood fiber.

**Dry-Formed Wood-Fiber-Based Composites**

Wood fiber-based composites are made from reconstituted wood: the wood is first reduced to fibers or fiber bundles and then put back together by special manufacturing processes into panels of relatively large size and moderate thickness. In final form, the panel materials retain some properties of the original wood, but because of the manufacturing methods, the materials also gain some different properties. Because these products are manufactured, they can be and are tailored to satisfy a particular end-use or group of end-uses.

Wood fiber-based composites are essentially made by breaking down wood to fibers through thermal-mechanical or mechanical processes. The fibers are interfelted in the reconstitution process end are characterized by a bond produced by the interfelting. The composites are frequently classified as fibrous-felted board products. At certain densities under controlled conditions of hot pressing, rebonding of the lignin effects a further bond in the resultant panel product. Binding agents and other materials may be added during manufacture to increase strength or resistance to fire, moisture, or decay. These materials include rosin, alum, asphalt, paraffin, synthetic and natural resins, preservative end fire-resistant chemicals, and drying oils. Wax sizing is commonly added to improve water resistance.

There is a great opportunity to produce fiber-based composites of varying densities from recycled wood fibers. One family of products, called Homasote, was first produced in 1916 and is made from old newspapers and other groundwood paper [33]. Other fiberboard-type products now on the market also use all or partly recycled wood fiber as the raw material base stock. Uses for these types of products include
insulating acoustical board; carpet board; wall, ceiling, and floor acoustical insulation panels; nail baseboard; and floor and roof insulation boards. We anticipate that many other uses for wood fiber-based products will be developed as collection, separation, and clean-up processes are further refined and developed.

Research is now being conducted at FP1 to determine the dimensional stability, moisture resistance, stiffness, and strength properties of dry-process hardboards made from varying blends of virgin wood fiber and old newsprint fiber.

Inorganic Bonded Wood Composites

Wood particles or fibers held together with an inorganic matrix, such as Portland cement or gypsum, form a composite that can be used in a variety of structural and industrial applications [34]. These composites have a unique advantage over some conventional building materials because they combine the characteristics of both the wood fiber and mineral matrix. Some of these composites are water resistant and can withstand the rigors of outdoor applications, and almost all are either fireproof or highly fire-resistant and are very resistant to attack by decay fungi.

These types of composites, which provide another major future recycling opportunity to utilize waste wood and other postconsumer wastes, are made by blending proportionate amounts of the wastes with inorganic materials. The most apparent and widely used example is cement. Portland cement, when combined with water, immediately begins to react in a process called hydration to eventually solidify into a solid stonelike mass. When fine sand and coarse stone, the traditional aggregates, are blended with the cement and water paste, the materials are bound together to form concrete. The strong bond between the paste and the aggregate occurs as each cement particle establishes a type of surface growth that spreads by linking with other cement particles and the aggregate.

A special category of concrete is structural lightweight concrete. Because lightweight concrete is made entirely or partially with lightweight aggregates, such as burnt clay, pumice, expanded blast furnace slag, and expanded vermiculite, its principal unique property is its lower density compared to normal-weight concrete. This makes lightweight concrete attractive for reducing dead loads in structures with concrete floor or roof fills. Generally, lightweight concrete also has superior insulating properties. Concrete made with waste wood will also be lightweight and have high insulating value.

As an aggregate for concrete, wood can be used in many forms. The wood aggregate may be a gradation of wood chunks, wood chips (typical of the chips used by the pulp and paper industry), shredded fiber bundles, sawdust, and even individual wood fibers (such as in a pulp slurry or that produced from recycled wastepaper). For example, the North Central Forest Experiment Station of the USDA Forest Service in Houghton, Michigan, is developing a product called Chunkrete, which uses wood chunks, particles, or fibers to substitute for or partially replace gravel or stone aggregate. The type or character of bulky wood waste material to be recycled will somewhat dictate the type of size-reduction or comminution equipment selected to process the waste wood. The type of equipment in turn will determine the final size and character of the resulting aggregate. For example, certain types of size-reduction equipment (shredders, pulverizers, hammermills, augers) might be best suited to convert waste wooden pallets, wood reels, stumps, and housing demolition material into shredded fiber bundles for use as concrete aggregate. On the other hand, a completely different kind of machine (wood chipper or
chunker) might be preferred for reducing unmerchantable trees and tree trimmings into chips or chunks.

Besides wood waste, other postconsumer wastes such as glass and plastic can also be used as concrete aggregate. Depending on the type or types of aggregate used and the proportionate blend of materials in the resulting concrete, the end properties may differ somewhat but the product would generally be classified as low- to medium-strength concrete, for which there are many potential applications.

Other inorganic waste materials that can be added to the concrete mix or used independently to produce a different kind of composite material are fly ash and flue gas gypsum. The extremely finely grained fly ash, which is produced during the combustion process and especially during the incineration of coal fuels, is collected by mechanical or electrostatic precipitators. Flue gas gypsum, now being produced in very large quantities because of Clean Air Act regulations, is the result of introducing lime into the combustion process to reduce sulphur dioxide emissions. By 1995, more than 100 power plants throughout the United States will be producing gypsum. Flue gas gypsum can be used in lieu of mined gypsum.

Gypsum-bonded wood-fiber panels are used as replacements for gypsum wallboard and are reported to have strong nail- and screw-holding properties, high moisture and fire resistance, and improved impact, mold, and mildew resistance [35]. Other reported advantages include improved anti-sag properties (for ceiling boards), better sound insulation, and easy installation (joints do not require taping).

The combination of wood fibers with inorganic binders provides a unique opportunity to utilize recycled, waste, and low-grade wood fiber. Research has clearly indicated that inorganic bonded wood composites can meet structural and industrial needs.

**Wood-Biomass Fiber Composites**

Wood is only one biobased resource in the waste stream. Other biobased resources include yard waste, water plants, and agricultural residues. Yard waste is a major co-mingled source of biobased fiber that is now considered only for composting. This is a vast resource that could be combined with the wood-based resource to produce composites of many different types. Many lakes and waterways suffer from an overproduction of water plants. These unwanted plants create another large waste stream that could also be considered as a valuable source of industrial fiber if they could be collected and processed economically and combined with the wood-based resource to produce composites. Because most recycling plans call for the composting or burning of this portion of the waste stream, very little thought has been given to using yard waste and water plants for composites.

Agricultural residues, such as straw, rice hulls, bagasse, and corn stalks, also represent a vast resource that can be used to make composites of many different types. In some parts of the world, these products are already being used to produce composites for various applications—such as furniture to structural wall panels.
RESEARCH AND DEVELOPMENT NEEDS

The USDA Forest Service, by virtue of its role as steward of the National Forests, its research mission, and its longstanding expertise in wood-based composites and recycling research at the FPL, is actively engaged in a high-priority research program on alternative uses for recovered materials from the MSW stream. The FPL research program is focusing on developing value-added composites from waste materials, including wood-plastic fiber composites, dry-formed wood fiber-based composites, and composites fabricated with inorganic binders. For each of these program areas, we are:

1. developing methods for converting recovered fibers into forms suitable for subsequent processing into alternative end-use applications,
2. optimizing laboratory methods for making prototype products,
3. developing a performance data base, including determining mechanical and physical properties of wood-based products and conducting analytical tests,
4. determining the potential for recycling composites with minimal loss of properties, and
5. studying product applications and economic viability of alternative end-use applications.

In each of these research areas, economic and laboratory studies are being conducted on an iterative basis as a means of setting research priorities and guiding process development. The research will focus on the components of successful recycling systems through determining the supply and availability of waste wood fiber, analyzing the economic efficiency of processing concepts, and studying the market potential for products made from recovered fiber. Studies will examine the effect of new technologies on the environment, such as the projected impact on the landfill burden and on the quality of the air, forests, soil, and water. They will also examine the broader economic impact of these technologies on timber markets and trade.

CONCLUSIONS

Recycling is a critical element in the long-term management of renewable resources. A successful approach to recycling requires full cooperation between the government and the private sector. Government cannot logically mandate the increased use of recyclable materials without the involvement of industry—the industrial sector has the technical knowledge and equipment to separate and process solid waste and to make useful, economically viable products from waste materials. Industry provides the market for recycled resources, and it must be a full partner in all aspects of the process. We believe that using recovered wood and fiber for wood-based composites presents tremendous opportunities for growth, for progress, and for further industry competitiveness in a world that is rapidly consuming many nonrenewable resources at an ever increasing rate.
ACKNOWLEDGMENT

The USDA Forest Service is developing a comprehensive wastepaper and waste wood fiber recycling program. As part of this effort, the FPL has formed a multidisciplinary team of government, university, and industry specialists to prepare a detailed problem analysis to focus research on composites from recycled materials. Some material in this problem analysis was used in the preparation of this paper. We wish to acknowledge the following individuals who are participating in this effort.

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