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Recovery of Paper and Wood for Recycling: Actual and Potential

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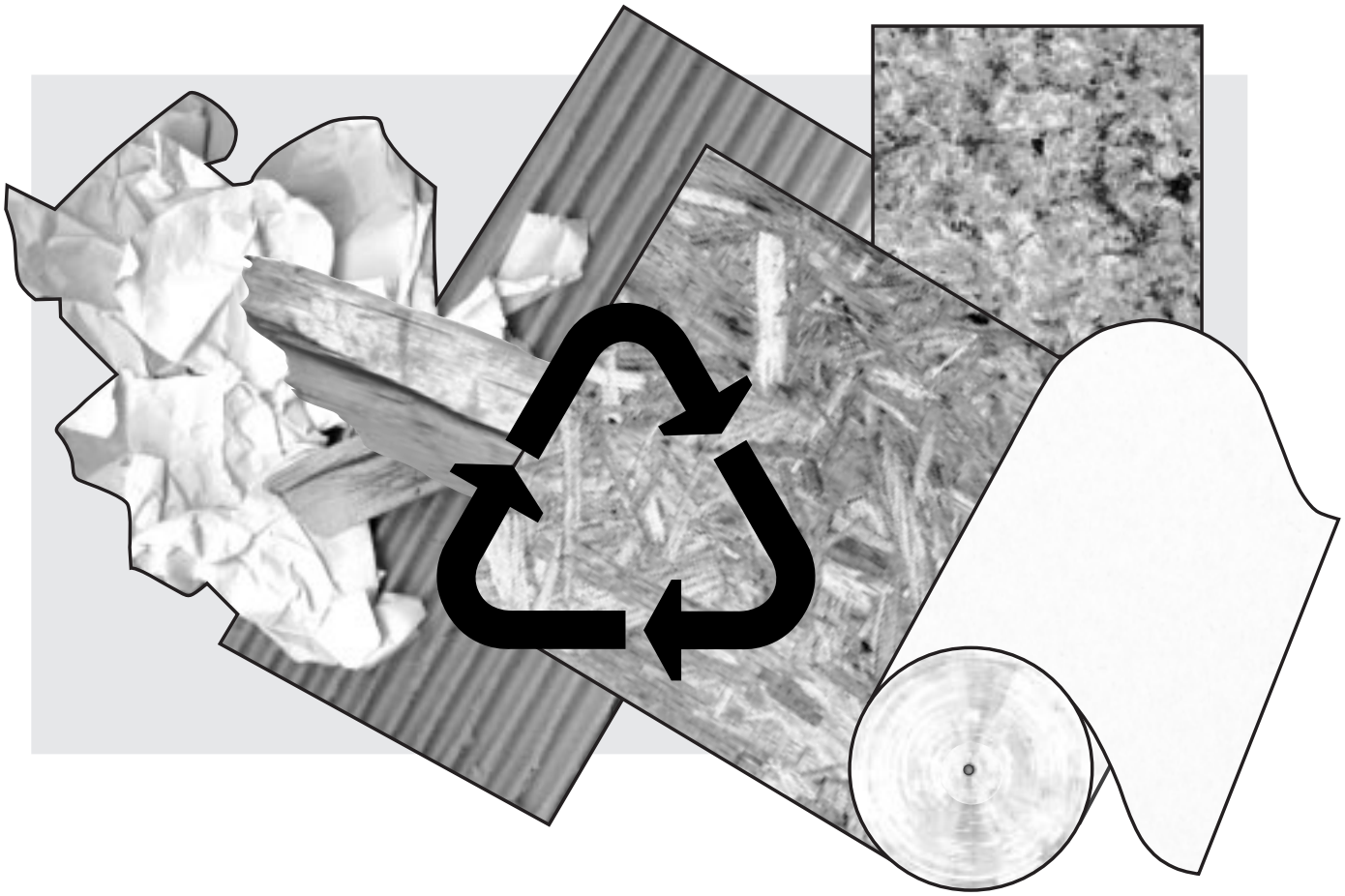

Abstract

Quantities of paper and wood recovered annually for recycling were estimated for all principal commercial uses in the United States, based on material consumption and end-use data. Principal categories of commercial uses were identified and relative quantities were compared. Some innovative or novel commercial product developments were identified. The potential for additional recovery from municipal solid waste, construction and demolition debris, primary timber processing residues, and other sources was also identified.

Keywords: Recycling, paper, wood, recovery potential

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Recovery of Paper and Wood for Recycling: Actual and Potential

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Recovery of Paper and Wood in 1994

In the United States, around 37 million tonnes of paper and wood materials were recovered for recycling into new products in 1994. These products included paper and paperboard, insulation and related products, molded pulp products, fiberboard products, wooden pallets and containers, animal bedding, cellulose mulch, particleboard and hardboard, reclaimed lumber and flooring, roof systems and siding, "plastic lumber" and plastic panels, and novel products such as foam-core panels.

Paper and Paperboard

Paper and paperboard has remained the largest single use for recycled wood fiber in the United States. More than 470 individual pulp, paper, and paperboard production facilities consumed recovered paper by 1994 (AF&PA 1994a). Industry data for the United States indicated the following recovered paper utilization rates by product category in 1993 (percentage ratios of recovered paper consumption to production of products) (AF&PA 1994b):

Newsprint	41.6
Printing, writing, and related paper	9.9
Packaging and industrial converting paper	14.6
Tissue	59.9
Kraft paperboard, bleached and unbleached	15.1
Semichemical paperboard	39.6
Recycled paperboard	106.3
Construction paper and board	55.0

By 1994, 28 million tonnes of recovered paper were consumed in production of paper, paperboard, and related products in the United States (AF&PA 1995). In 1994, the average utilization rate for recovered paper for the entire industry was around 34 percent. This was a gain of seven percentage points since 1990, with more than 8 million tonnes of added recovered paper consumption in just 4 years. In addition to domestic consumption, 7 million tonnes of recovered paper were exported in 1994 for recycling in other countries. Thus, in total, 35 million tonnes of paper and paperboard were recovered for use in production of recycled paper and paperboard products in 1994, representing by far the largest single element of all wood and wood fiber recovered for recycling in the United States (about 95 percent of the total quantity).

It should be noted that consumption of wood residues in the pulp and paper sector were excluded from the previous estimates (wood residues include sawmill and plywood mill byproducts such as chips). Wood residues have generally not been considered as "recycled" material in the United States, since they are byproducts and are not recovered from finished products. Residues were estimated to be 27 percent of pulpwood consumption in the pulp and paper sector of the United States by 1994 (AF&PA 1995), or roughly 30 million tonnes of a total pulpwood consumption of more than 100 million tonnes (dry weight basis).

In 1994, growing demand for recovered paper finally caught up with supply. During the year, recovered paper prices increased substantially in the United States, abruptly ending the so-called glut in wastepaper markets, which had prevailed in the early 1990s. By late 1994, real prices for most recovered paper commodities had returned to the high end of their long-run historical range, and prices continued to increase in 1995. Boosted by record product demands in domestic and global markets and by higher prices for most paper and paperboard products, producers in the United States were able to maintain higher rates of recycling despite increased prices for recovered paper. However, it was anticipated that growth in paper recycling would likely be slower in the late 1990s than in recent years, as higher recovered paper prices would tend to reduce incentives for new investment in recycling capacity.

Insulation and Related Products

The cellulose insulation industry was estimated to be the second largest recycler of wood fiber in the United States in 1994, using mainly recovered paper as raw material. Cellulose insulation consists chiefly of pulverized or fiberized paper, treated with fire retardants (inexpensive inorganic chemicals such as borax). Cellulose insulation is produced mainly as a dry bulk product. It is used as a loose fill for insulation of attics and walls, where it is usually poured or blown into place. It is also sometimes mixed with water and adhesives for application as a wet spray. Cellulose insulation constitutes only a small fraction of the entire building insulation market in the United States, holding a market share of around 4 percent according to recent industry estimates (API 1991). The building insulation market in the United States has been dominated by fiberglass insulation and plastic foam panel products for many years.

The number of cellulose insulation producers declined from a peak in the late 1970s. By 1995, there were reportedly 55 separate producers of cellulose insulation (Harris Directory 1995) with about 70 plants operating in the United States, using primarily old newspapers and other recycled paper as raw material (Apotheker 1994). Average plant output was 7,000 tonnes in 1994. More than twice as many plants had been in operation 10 years earlier. In 1994, estimated annual production of the entire industry was around 500,000 tonnes (Apotheker 1994).

In addition to cellulose insulation, a small group of other insulation products was produced from recycled paper or paperboard in 1995, such as insulation blocks, barriers, or insulation baffles (Harris Directory 1995). These were produced by a small number of manufacturers (about half a dozen) in the United States, representing a relatively small market.

Molded Pulp Products

The molded pulp products industry was estimated to be the third largest recycler of wood or wood fiber in the United States. There were reportedly 13 producers of molded pulp products in the United States by the early 1990s, with annual consumption of recovered paper estimated at upwards of 300,000 tonnes (API 1991). Molded pulp products were used chiefly in packaging (protective packaging in shipping containers, food packaging, such as food service trays, and egg cartons), horticulture (plant pots), and furniture. However, the large protective packaging market has long been dominated by polystyrene and other plastic foam packaging materials.

Fiberboard Products

The fiberboard products industry was estimated to be the fourth largest consumer of recycled wood fiber in the United States. Several producers of fiberboard products were reportedly using recycled wood fiber exclusively in 1995 (Harris Directory 1995). Two large producers used recycled paper; both producers had manufactured fiberboard products from recycled paper for many decades at facilities located in the Northeast. Another producer located in the Pacific Northwest was reportedly using waste wood diverted from landfills. Several other fiberboard producers used smaller proportions of recycled paper as fiber input (typically 10 to 30 percent; the remainder of fiber inputs derived from virgin wood fiber via defibrated or groundwood pulping processes). Fiberboard products have been used traditionally for subflooring, light sheathing, structures for deadening noise, insulating, and other applications. One furniture manufacturer also introduced a new product: children's chairs fabricated from fiberboard made with 100 percent recycled paper.

Acoustical ceiling panels were another category of fiberboard product that was reportedly manufactured in part from recycled paper. Such panels have been used for many years, mainly as a component of suspended ceiling systems designed to provide acoustical insulation. In 1995, two major producers in the United States reportedly used varying amounts of recycled paper; recycled fiber ranged from 20 to 90 percent, depending on market availability and type of product being produced (Harris Directory 1995).

For many years, wood fiber strips have been used for concrete expansion joints. Fiber expansion strips have been used to fill expansion joints between sections of poured concrete in roadway and walkway construction. In 1995, two large U.S. producers of fiberboard products were reportedly using some recycled wood fiber in the production of fiber strips for concrete expansion joints (Harris Directory 1995).

Several producers reportedly were manufacturing rigid composite fiberboard panel products with inorganic minerals such as perlite or Portland cement, using varying proportions of cellulose fiber from recycled paper (reportedly 2 to 35 percent). Such panels were used as fire barriers or fire protection board (in fire doors, for example), as subflooring for ceramic tile floors, and for roofing systems (Harris Directory 1995).

In addition to traditional fiberboard products, by 1995 there were several producers of less traditional lightweight fiberboard panels reportedly made from recycled paper. These included two producers of lightweight honeycomb or molded hollow core fiber panels made from recycled paper. These panels were designed for use as veneer cores for lightweight doors and furniture, or for portable walls and partitions, and as pallet slips. In addition, another producer made a range of lightweight panels using laminates of paper (made in part from recycled paper) and plastic or foil; the panels were designed mainly for display applications. The quantity of material use in these products was quite small relative to other fiberboard products (probably less than 1 percent).

Precise data on tonnage of recovered paper consumed in fiberboard and related products were not available. A review of

reported mill capacities for all producers of fiberboard and medium density fiberboard (MDF) in the United States suggested that the annual consumption of recovered paper in fiberboard and MDF production was probably around 275,000 tonnes in 1994.

Wooden Pallets and Containers

According to recent studies at Virginia Polytechnic Institute (Bush and others 1994), the wood pallet and container industry recovered the equivalent of 15 percent of annual pallet production for repair or recycling into pallets or other uses. With use of wood in pallets and containers at roughly 10 million tonnes in 1994, the tonnage of wood recovered in pallets was estimated to be approximately 1.5 million tonnes.

According to the report by Bush and others (1994), 15 percent of recovered pallets were inspected and reused without need for repair, 62 percent were repaired and reused, 14 percent were disassembled to recover lumber for reuse in pallets, and about 9 percent were ground, chipped, hogged, or otherwise reduced to particles. About half (53 percent) of ground pallet material was used as fuel, 18 percent was used as mulch and plant bedding material, and 29 percent was used for other purposes, including furnish for particleboard and hardboard, fuel pellets, compost, molded wood products, and landfilling. The report noted that pallet recovery has been increasing by about 20 percent per year, as has been the use of ground pallet material for particleboard, hardboard, and mulch.

Pallets that were simply inspected or repaired and reused might not be technically regarded as "recycled" inasmuch as they were not used to produce new recycled products. Also, the term "recycled" would not apply to wood used as fuel, landfilled, or composted. In addition, in the report by Bush and others (1994), the quantities of wood used for particleboard, hardboard, and molded pulp products were accounted for separately under those product categories. Thus, considering only the quantities of pallets that were actually disassembled for recycling of lumber, along with quantities used for mulch and plant bedding, it was estimated that perhaps 250,000 tonnes of pallet wood was recycled into pallets and mulch in 1994.

Animal Bedding

The use of shredded paper (chiefly old newspapers) for animal bedding has become increasingly popular in the United States since the early 1980s. Paper bedding has been found to be most useful for dairy cows, particularly in northern regions where it can provide additional insulation in winter months. Precise national data on consumption were not available, but an estimate of roughly 100,000 tonnes was made for the United States in the early 1990s based on available state and local data (API 1991).

Cellulose Mulch

By 1995, there were reportedly 24 producers of cellulose mulch and ground cover products, used chiefly for soil protection, erosion, and moisture control in lawn seeding, and landscaping applications (Harris Directory 1995). Cellulose mulch was made mainly from old newspapers, telephone directories, and other grades of wastepaper. Most producers were small business enterprises. One producer in the Northeast reportedly used recycled wood (such as demolition waste and used pallets) in addition to recycled paper. In application, mulch was often mixed with grass seed and water, and sprayed with a water cannon in a process called "hydromulching." Precise national data were not available on the tonnage of recycled wood or paper used in cellulose mulch; in the early 1990s, the quantity was estimated to be 100,000 tonnes (API 1991).

Particleboard and Hardboard

One major producer of particleboard in the United States was reportedly using recycled wood by 1995. Located in the Pacific Northwest, this producer used wood recovered from used wooden pallets for a fraction of wood raw material requirements (reportedly up to 20 percent). Another U.S. producer in the Pacific Northwest reportedly used recycled wood recovered from pallets, crates, and demolition waste for approximately 50 to 75 percent of the wood fiber required for manufacturing hardboard. However, in the United States generally most of the wood raw material for particleboard and hardboard has consisted of virgin wood fiber (chiefly wood residues from sawmills and plywood mills along with smaller amounts of roundwood). Assuming that roughly 1 percent of the wood used in particleboard and hardboard was recycled wood in 1994, the annual quantity recycled was perhaps around 50,000 tonnes.

Reclaimed Lumber and Flooring

By 1995, there were reportedly 26 producers of reclaimed lumber and 18 producers of reclaimed wood flooring in the United States (Harris Directory 1995). All were generally small business enterprises, established since the early 1970s. They used wood salvaged from various sources, chiefly old wooden structures, old factories and mills, and abandoned railroad cars; other sources included riverbeds, docks, farm buildings, used pallets, shipping crates, and wine vats.

Producers of reclaimed lumber and flooring were dispersed geographically across the United States. The products consisted of various species, ranging from hardwoods to softwoods. There were no available data on total production or consumption of recycled lumber and flooring in 1994, but the quantity was thought to be less than 50,000 tonnes (assuming that the average producer had the capacity of a small micro-sawmill).

By 1995, there were also at least four producers of furniture made exclusively with reclaimed or recycled wood, reportedly using wood from old buildings, pallets, shipping crates, and other salvage sources (Harris Directory 1995). Some salvage firms also specialized in reclaiming unique artifacts, such as old fireplace mantles from demolition sites.

Roof Systems and Siding

At least eight producers of roof shingles, roof tiles, and siding products were reportedly using various proportions of recycled wood fiber to produce composite products in 1995 (Harris Directory 1995). Four producers of asphalt roof shingles were using dry felt paper fiber in their products in 1995, although most leading producers of roof shingles had shifted to use of fiberglass instead of paper fiber. In addition, some newer types of wood fiber and inorganic composite roofing and siding products were being produced in 1995. Four producers reportedly made composite roof tiles, shakes, or siding products using wood fiber and Portland cement or diatomaceous earth (Harris Directory 1995). Three of those producers reportedly used recycled paper, with ratios of 10 to 20 percent recycled fiber in the finished products. The fourth producer used wood residues, in a ratio of 33 percent. The inorganic composite siding products occupied only a small share of the siding market in 1995, a market dominated by other forms of siding such as vinyl siding, vinyl clad siding, and wood panel siding.

"Plastic Lumber" and Plastic Panels

In addition to reclaimed lumber (consisting of solid wood), by 1995 there were reportedly 40 producers of recycled "plastic lumber" and posts in the United States (Harris Directory 1995). Recycled plastic lumber was made primarily with an extrusion molding process, and most producers reportedly used recycled plastic as the only raw material. However, two producers reportedly made a composite product using up to 50 percent wood residues combined with plastic, and at least two others made a plastic and fiberglass composite. There was also reportedly at least one producer of an extruded composite material for door and window fabrications, made from 50 percent recycled plastic and 50 percent industrial wood residues.

Most plastic lumber producers were small enterprises serving specialized markets. All were established since the early 1970s, and most since the early 1980s. The output of the average producer was quite small—just a tiny fraction of the output of a large conventional sawmill, for example. A common application for plastic lumber was in waterfront docks, piers, and decking, where it was substituted for conventional treated lumber. In addition, there were also reportedly several dozen producers of outdoor furnishings made from plastic lumber-type materials, including items such as benches and picnic tables (Harris Directory 1995). Recycled plastic was reportedly used as the only raw material in most cases. However, in several cases a composite of 50 percent recycled wood and recycled plastic was reportedly used in outdoor furnishings.

In addition to plastic lumber and related products, there were reportedly 15 producers of recycled plastic panels in the United States by 1995. Panels were produced in dimensions similar or identical to those of conventional nonstructural wood panels (for example, hardboard panels), and in some cases they were marketed for similar applications (such as sheathing and subflooring). Variations in color, thickness, and density allowed for different applications by plastic fabricators. Only one producer reportedly had developed a composite wood and plastic panel product, using 50 percent wood residues and recycled plastic. As with producers of plastic lumber, the average output of recycled plastic panel producers was relatively small. Most were small business enterprises established since the early 1980s.

The total quantity of recycled wood used in plastic lumber and panels was estimated to be very small or negligible, as the few producers who were actually using wood in composites were reportedly using wood residues (virgin wood fiber) rather than recycled or reclaimed wood.

Other "Recycled" Products Using Wood

There were several producers of structural "stress skin" or foam-core panels in the United States who reportedly were capable of using recycled materials in 1995 (Harris Directory 1995). Structural stress-skin panels have a thick inner layer of expanded polystyrene foam bonded to surfaces of structural wood panels (for example, oriented strandboard [OSB]). The plastic foam core is the component of stress-skin panels that can be made from recycled materials (for example, recycled plastic). Traditionally, producers of foam-core panels have not utilized recycled wood per se, as OSB panels are made from virgin timber. Polystyrene foam can also be bonded to other panel substrates such as gypsum wallboard for interior walls and ceilings. Structural foam-core panels have been designed for exterior walls, roofs, floors, and ceilings. Such stress-skin panels can reportedly economize on wood use. Their use can reduce structural lumber requirements in conventional housing construction by 30 percent by reducing lumber framing requirements. However, the proportion of U.S. construction that actually utilized stress-skin panels by 1994 was thought to be very small (much less than 1 percent).

Several other miscellaneous construction products were produced in the United States in 1995 using recycled wood or wood fiber. One producer of permanent concrete formwork reportedly produced a permanent type of wall system using a composite of reinforced concrete and reclaimed wood fiber.

Table 1—Approximate quantities of wood and wood fiber materials recovered for recycling among all principal categories in the United States, 1994

Use category	Approximate quantity recycled[a] (tonnes)
Paper and paperboard	28,100,000 (paper)
Recovered paper export	7,000,000 (paper)
Insulation and related	500,000 (mostly paper)
Molded pulp products	300,000 (mostly paper)
Fiberboard products	275,000 (mostly paper)
Wooden pallets	250,000 (wood)
Animal bedding	100,000 (paper)
Mulch	100,000 (paper)
Particleboard, hardboard	50,000 (?) (wood)
Reclaimed lumber	50,000 (?) (wood)
Roof systems, siding	50,000 (?) (paper)
"Plastic lumber" and other	10,000 (?) (wood)

[a]Question mark indicates educated guess—data not based on actual survey.

The structural components of the wall system reportedly contained 85 to 90 percent reclaimed wood fiber, filled with concrete and reinforced with rebars (Harris Directory 1995). This composite wall was reportedly designed with good insulative and load-bearing properties. Similar products have been reportedly manufactured in Europe for decades.

Another novel category of recycled product was a molded resin composite that resembled quarry stone but contained recycled wood fiber. One producer reportedly has manufactured "molded stone" composites since 1989 using recycled fiber (Harris Directory 1995). The product was designed to simulate quarry stone and is a composite of 15 percent recycled paper, gypsum, resin, and natural coloring compounds. Reportedly, the product could be cut with an ordinary saw and installed with nails or glue. The product has been used for wall veneer systems and decorative interior moldings. Another producer was also reportedly planning to produce a "granite-like" resin composite in 1995, which would reportedly contain up to 40 percent recycled fiber.

As has been the case for many years, various recycled paper and paperboard products were also used in construction products in 1995, chiefly gypsum wallboard panels and roofing felts. Gypsum wallboard panels were made principally from solid natural or synthetic gypsum (obtained by concentration of fly ash from power boilers), surfaced with 100 percent recycled paperboard. One producer also made a novel type of gypsum wallboard that was a rigid composite of blended gypsum and cellulose fibers from recycled old newspapers (15 percent cellulose fiber). Except for the latter product, paper industry data for recycled paperboard have subsumed data on the recycled fiber used in gypsum wallboard facing. Likewise, paper industry data on construction paper and board production have subsumed data on roofing felts and other construction paper and board.

Summary of Recovery and Use

Table 1 summarizes estimated quantities of wood and wood fiber recovered for recycling in the United States by commercial use category in 1994. The paper and paperboard sector, including exports, was by far the leading category in total tonnage. As discussed, a number of innovative commercial products have appeared in recent years, including various composite products using wood and inorganic materials or wood and plastics. However, the actual quantity of wood or wood fiber recycled in such products was estimated to be relatively small.

In summary, we estimated that in 1994 approximately 37 million tonnes of paper and wood materials was being recovered annually in the United States for use in recycled products, of which roughly 99 percent was recovered paper and about 1 percent was recycled solid wood. The bulk of these recycled materials, about 95 percent, was used to produce recycled paper products, four fifths being used in the United States and one-fifth exported to other countries for that purpose.

Potential for Additional Recovery

In addition to the 37 million tonnes of paper and wood recovered for use in recycled products in 1994, quantities of waste-paper and wood waste remained unrecovered in the United States. Although much of this material was low quality or perhaps unrecoverable, some could be potentially recovered and used in recycled products.

Three principal sources offered significant potential for additional recovery of paper and waste wood: (1) municipal solid waste, (2) new construction and demolition waste, and (3) wood residues from primary timber processing facilities. Total quantities of waste generated, disposal burdens following recovery for recycling and composting, and maximum amounts potentially recoverable were evaluated for each source. Wood waste from other smaller sources was identified, but these sources were not included in this analysis. Wood residues from harvest operations and non-woody agricultural biomass were also not examined.

Municipal Solid Waste

Municipal solid waste (MSW) is waste from residential, commercial, institutional, and industrial sources. It includes discarded durable goods, nondurable goods, containers and

packaging, food scraps, yard trimmings, and miscellaneous inorganic waste. Figure 1 illustrates estimated proportions of various types of materials generated in MSW within the United States in 1993 (EPA 1994). MSW typically includes such things as discarded packaging, appliances, automobile tires, newspapers, clothing, boxes, disposable food service items, office and classroom paper, wooden pallets, and cafeteria waste. However, MSW does not include waste from certain other sources, such as new construction and demolition waste, automobile bodies, municipal sludges, combustion ash, sewage waste, and industrial process wastes that may or may not be discarded in municipal waste landfills or incinerators.

An estimated 188 million tonnes of MSW were generated in the United States in 1993 (EPA 1994). Except for brief periods of economic recession, MSW quantities have increased steadily in recent decades, rising from 80 million tonnes in 1960. Between 1960 and 1990, MSW quantities increased at an average annual rate of 2.8 percent per year. However, since 1990 the rate of increase has been just 1.5 percent per year. Projections indicate that the quantities of MSW generated annually in the United States will approach 200 million tonnes by the year 2000. This would represent an average annual increase of just 0.7 percent per year for the period 1993 through 2000. Thus, although total MSW is increasing, it appears to be increasing at a declining rate, and it is expected to do so in the near future. Per capita MSW generation averaged 1.99 kg per day in 1993, compared to 1.97 kg in 1990 and 1.21 kg in 1960. Source reduction policies and other environmental concerns have perhaps been moderating the per capita generation of MSW; it was expected to decrease to 1.96 kg per person by the year 2000 (EPA 1994).

A wide variety of wood and wood fiber materials were included in estimated MSW quantities, including significant quantities of paper and paperboard, wood waste, and yard trimmings (which include some wood). These materials are the main elements of MSW that provide a potential resource for additional recovery of wood or wood fiber for future commercial uses. Wood waste includes such items as wooden furniture and cabinets, pallets and containers, scrap lumber and panels from other than new construction or demolition activities, wood waste from manufacturing facilities, and a variety of miscellaneous products. The wood waste category of MSW does not include roundwood or unprocessed timber. However, yard trimmings do include tree trimmings and removals, as well as leaves, grass clippings, and brush.

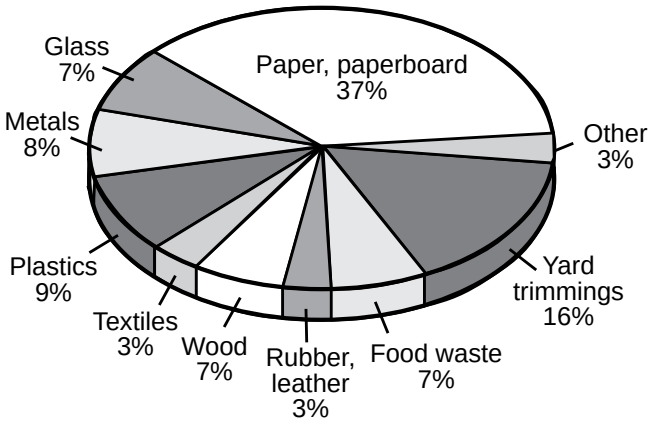

Figure 1—Municipal solid waste (MSW) generated in the United States, by weight, 1993.

Paper and Paperboard

In the United States, paper and paperboard has long remained the largest single component of material generated in MSW. In 1993, 71 million tonnes of paper and paperboard were reportedly generated in MSW, representing about 38 percent of all MSW generated in the United States (EPA 1994). Paper and paperboard was also the most heavily recovered and recycled component of MSW, accounting for 59 percent of all MSW materials recovered for recycling or composting in 1993. Nevertheless, we estimated that a gross disposal burden of nearly 47 million tonnes of wastepaper remained in 1993, after MSW recovery for recycling and composting. Most of this wastepaper was destined for disposal via landfilling, combustion, or other means. Precise data on landfill and combustion quantities for wastepaper were not available, but estimates were available for all MSW.

The total disposal burden for all MSW following recovery for recycling or composting was estimated to be 147 million tonnes in 1993, and combustion accounted for an estimated 30 million tonnes or about 20 percent of that total quantity (EPA 1994). In most cases, energy was recovered either from combustion of unprocessed mixed waste (mass burn) or processed mixed waste (refuse-derived fuel). The latter generally contained more concentrated proportions of organic wastes such as paper, wood, or plastic, so it was likely that the incinerated proportions of wastepaper and wood waste were greater than the average proportion for all MSW. Therefore, it was reasonable to assume that a maximum of 60 percent of the wastepaper and wood waste disposal burden could potentially have been recovered for recycling, given that somewhat more than 20 percent was probably burned for energy recovery and that other amounts might not be physically recoverable. Thus, for the United States, we estimated that the maximum paper recovery potential for recycling from MSW was about 28 million tonnes in 1993 (that is, 60 percent of the 47 million tonne disposal burden). This quantity was in addition to quantities already being recovered for recycling, composting, or energy. However, again it should be noted that some of this material may have been very low quality (for example, contaminated with food or industrial wastes, or mixed with other waste materials) such that it could be very costly or difficult to recycle into commercial products that are safe and acceptable to consumers.

Yard Trimmings

Yard trimmings were the second largest material component of MSW, with 30 million tonnes generated in 1993, representing about 16 percent of all MSW (EPA 1994). Approximately 6 million tonnes of yard trimmings were recovered for recycling or composting, leaving a burden of about 24 million tonnes for disposal via landfilling, incineration, or other means. A recently completed report on urban tree residues (NEOS Corp. 1995) estimated that in 1993, 95 percent of all urban tree and landscape residues were wood residues, by volume, and 5 percent were leaf and grass clipping residues. This suggests that the disposal burden for woody residues alone amounted to roughly 23 million tonnes in 1993 (for example, more than 95 percent by weight of the 24 million tonne disposal burden from yard trimmings in MSW).

As mentioned, precise estimates of proportions landfilled and incinerated were available for all MSW, but not specifically for woody residues from yard trimmings. Assuming, as for paper and paperboard, that about 60 percent of the woody residue disposal burden would be potentially available (beyond energy recovery), the recovery potential for woody residues from yard trimmings in MSW would have been roughly 14 million tonnes in 1993 (60 percent of 23 million tonnes).

However, it should be noted that three-fourths of this material was estimated to be in the form of chips, which were often commingled with twigs and leafy materials from tree trimmings, and the remainder was in the form of randomly sized tree trunks and limbs (NEOS Corp. 1995). Such material was generally undifferentiated by tree species and was not graded or harvested according to any standard logging practices. Thus, at best, the yard trimmings material might be similar in quality to "whole-tree chips," which have been used conventionally for fuel in the pulp and paper industry, and some of the material would likely be much lower quality (mixed with twigs, leaves, grass clippings, dirt, or other debris). Thus, yard trimmings from MSW would generally yield material that was inferior in quality to conventional pulpwood chips, and certainly much lower in quality and uniformity than most wood obtained commercially for industrial uses.

Wood Waste

In 1993, MSW was estimated to contain a total of 12.4 million tonnes of wood waste (nearly 7 percent of all MSW) (EPA 1994). Of this total, 1.2 million tonnes were reportedly composted or recovered for recycling, leaving a burden of 11.2 million tonnes for disposal via landfilling, incineration, or other means. Again, precise estimates of proportions landfilled and incinerated were available for MSW in total, but not specifically for wood waste. Assuming, as for paper and paperboard, that about 60 percent of wood waste disposal burden was potentially recoverable for recycling, it was estimated that the annual recovery potential for wood waste from MSW was roughly 7 million tonnes in 1993 (that is, around 60 percent of 11.2 million tonnes).

New Construction and Demolition Waste

New construction and demolition waste originates from two distinctly different sources in the United States, with different characteristics and different potential for separation and recycling. Wood waste from new construction originates principally from the construction of new single-family and multifamily houses. Smaller amounts of wood waste are generated at new nonresidential building and construction sites. Demolition waste originates at any site where a building or other structure is being demolished.

Wood waste from new construction tends to be much cleaner than demolition waste and is more uniformly derived from contemporary wood products. Demolition waste contains wood that is usually contaminated with other materials such as paints, nails, fasteners, wall covering materials, and insulation, and typically contains a more diverse mix of materials, which often includes old wood and unconventional materials. New construction waste can also be more readily separated on the job site with some additional effort by the builder; source separation of waste at a demolition site is usually more costly and less efficient. Conventional demolition practices in the United States would have to be radically altered to achieve efficient source separation. For these reasons, new construction waste and demolition waste were evaluated separately.

New Construction Waste

Statistical information on types and amounts of waste generated in new construction in the United States are sketchy, limited to anecdotal information or a few local case studies. However, since nearly all single-family and low-rise multifamily residential structures built in the United States in recent decades have used traditional wood-frame building technology, information on this type of construction was used to extrapolate local data to national estimates of wood waste generated in new construction.

Specific waste generation rates were obtained from a recent case study conducted in the Portland, Oregon, metropolitan area (McGregor and others 1993). Although specific to individual construction sites in this area, the waste generation rates were regarded as typical of new residential construction in general because the structures had characteristics that were typical of most new residential construction in the United States in 1993. Information from the Portland study was used to develop weighted average waste generation rates per unit of floor area for new single-family and new multifamily houses. These rates were applied to the total floor area of each type of structure built in the United States in 1993 to develop

estimates of total wood waste generated in new residential construction. Total waste generated was then adjusted to account for new nonresidential construction and for residential repair and remodeling. Waste from the production of mobile homes and manufactured housing was not included. Waste from these sources was included in the MSW wood waste estimates.

It was estimated that 2,237 kg of solid wood waste, 59 kg of paper and paperboard waste, and 1,156 kg of nonwood, nonpaper waste were generated for the average single-family house built in the Portland, Oregon, metropolitan area in 1993 (McGregor and others 1993). The average single-family house was estimated to have 190 square meters of floor area. New multifamily construction generated 619 kg of wood waste, 16.8 kg of paper and paperboard waste, and 373 kg of nonwood, nonpaper waste per living unit. These amounts included not only materials generated from each living unit, but also prorated amounts generated for common areas such as laundry rooms, lobbies, and recreational areas. For both single-family and multifamily construction sites, 88 percent of the waste material was considered to be potentially recoverable and recyclable.

In 1993, 1,126,000 new single-family houses were built in the United States, with an average floor area of 195 square meters; 153,000 multifamily living units were also built in 1993, which averaged nearly 100 square meters of floor area per unit (U.S. Department of Commerce, Bureau of the Census 1994a). Applying average waste generation rates from the Portland study, we estimated that approximately 2.7 million tonnes of wood waste, 72,000 tonnes of paper and paperboard waste, and 1.4 million tonnes of nonwood, nonpaper waste were generated in 1993 for all new residential construction in the United States. Based on studies of total material use in new residential construction (Anderson and McKeever 1991, McKeever and Phelps 1994), we estimated that 27.1 million tonnes of wood products were required in 1993 for new residential construction. Thus, waste wood generated in new residential construction was about 10 percent of the wood used in new residential construction.

Residential repair, residential remodeling, and new nonresidential construction also require large amounts of wood products annually, and they therefore generate large amounts of wood waste. Reliable information on amounts of waste generated by these types of construction was not available. However, residential repair and remodeling activities typically use the same types of materials and construction techniques as those used for new single-family residential construction. Therefore, we extrapolated waste generation for new single-family construction to residential repair and remodeling. Data on wood products used in 1991 for residential repair and remodeling (McKeever and Anderson 1993) were updated to 1993 using expenditures data from the U.S. Department of Commerce (1994b) and converted to tonnes. Total wood products use in residential repair and remodeling was estimated to be 25.8 million tonnes, just slightly less than the figure for new single-family construction. Thus, based on the 10-percent figure for new residential construction, we estimated that 2.6 million tonnes of wood waste were generated in 1993 by residential repair and remodeling activities.

Estimated amounts of wood products used for new nonresidential construction in 1986 (Phelps and McKeever 1990) were used to estimate amounts used in 1993. About 8.6 million tonnes of wood products were used for new nonresidential construction in 1993, about one-third of the amount required for new single-family construction. Wood products and construction techniques typically used for low-rise, light-frame nonresidential buildings such as stores and office buildings are similar to those used for new residential construction. Therefore, the waste generation rates for this kind of nonresidential construction would probably be similar to the waste generation rates for new residential construction. However, a large share of nonresidential construction consists of larger nonresidential building projects such as warehouses, factories, high-rise buildings, and public buildings, as well as projects such as highways. Wood is not typically used as the primary construction material for this kind of nonresidential construction or the building techniques are very different from those used for residential construction. Information needed to accurately estimate waste generation in nonresidential construction was unavailable. However, lacking empirical data, we assumed that waste generation rates in nonresidential construction were similar to those of residential construction.

We estimated that wastes generated in all new construction in the United States in 1993 (new single-family and multifamily residential, residential repair and remodeling, and new nonresidential) included 6.1 million tonnes of wood and roughly 0.2 million tonnes of paper and paperboard. Based on data from the new residential construction study in Portland, approximately 88 percent of this material would be potentially recyclable, or 5.4 million tonnes. Using these estimates, we estimated that new construction in the United States generated a disposal burden amounting to roughly 6 million tonnes of wood waste, with a recovery potential for recycling of roughly 5 million tonnes of wood.

Demolition Waste

Demolition waste is the heterogeneous mixture of waste materials generated by demolishing buildings or other structures. It typically contains aggregate stone and brick, concrete, wood, paper, metal, insulation, glass, and other contemporary building materials. Depending on the age and type of structure, demolition waste may also contain hazardous materials such as asbestos, lead-based paints and finishes, mercury, polychlorobiphenyl (PCB) compounds or other contaminants. The amount of demolition waste generated in the United States has been estimated over the years, usually for specific localities. The estimates have also typically included construction waste, since in many cases buildings are

demolished and replaced by new construction, resulting in commingling of demolition and construction waste. Also, available estimates have been correlated to local population density. In general, urban areas tend to generate more construction and demolition waste per capita than do suburban or rural areas. The construction and demolition (C&D) waste generation rates estimated by the New York Solid Waste Management Board for 1991 (Solid Waste Association of North America 1993) were used here to estimate demolition waste quantities for the entire United States in 1993.

Based on the New York data, we estimated total C&D waste quantities for the United States by extrapolating waste generation rates across resident population estimates by community size in 1993. Amounts of new construction waste (estimated above) were then subtracted from total C&D waste, resulting in an estimate of demolition waste generated in the United States in 1993. We then used data from a demolition waste composition study (Solid Waste Association of North America 1993) to estimate proportions of waste wood and paper & paperboard in the demolition waste. This resulted in estimates of 23 million tonnes of wood and 0.3 million tonnes of paper and paperboard generated in demolition waste in the United States in 1993.

Potential recoverability of wood from demolition waste was difficult to estimate, lacking any real economic experience or data on which to base our estimates. However, we could assume that poor physical characteristics, heterogeneous sourcing, and contamination of wood would certainly make demolition waste more difficult to recover and recycle than wood in construction waste, for example. Therefore, we assumed that less than one-third of the wood materials in demolition debris would be potentially recoverable for recycling, and none of the paper and paperboard would be recoverable. Thus, we estimated that approximately 7 million tonnes of wood materials in demolition waste were potentially recoverable for recycling in 1993.

Mill Residues From Primary Timber Processing

Primary timber processing facilities (for example, sawmills and plywood mills) in the United States generate large quantities of wood residues in many forms, such as bark, chips, sawmill slabs and edgings, sawdust, and peeler log cores. In 1991, it was estimated that 26 million tonnes of bark and 74.5 million tonnes of wood residues were generated by primary timber processing facilities in the United States (Powell and others 1993). However, most of these wood residues were already being used as fuel or as fiber raw material to produce other products, primarily pulp and paper products. Only 6 percent of the wood residues and 5 percent of the bark residues were not being used in 1991, creating a disposal burden of only 4.3 million tonnes of wood waste and 1.4 million tonnes of bark waste.

The proximity of the unused residue supplies to production facilities that could use the material was a major obstacle that limited its use. Much of the unused wood residue was generated in remote rural sawmills, such as in the intermountain West. Unused bark residue, although potentially valuable as a fuel or as a mulch-type material, has generally low utility for wood-based products. Since U.S. lumber and plywood production quantity has changed very little between 1991 and 1993, we used the 1991 mill residue data as an approximation of residue quantities available in 1993. We assumed that all of the wood and bark wastes were potentially recoverable as raw material for wood products, although it must be recognized that transportation logistics and costs likely limit the recoverability of this material.

Other Sources

Various other sources of wood waste and wastepaper were in the U.S. economy in 1993. These sources included wood that was chemically treated with preservatives, such as old railroad crossties, switch ties, bridge timbers, telephone poles, utility poles, pier timbers, and dock timbers. Other sources of wood waste included trees, brush and limbs resulting from maintenance of utility right-of-ways, industrial wood waste and waste paper generated outside of the MSW stream, and logging residues left in the woods. Some of this material was recovered and used, some was burned, and some was disposed of in hazardous waste landfills. However, much of this material was simply left on site. Chemical treatments and costs of collection make recovery and utilization of much of this material very difficult.

The total amount of wood plus paper and paperboard available from these other sources (except logging residues) was fairly small compared to that of major sources of material. For example, a total of 12.3 million railroad crossties were replaced in 1993, representing an estimated volume of 1.2 million cubic meters. Replacement ties were all chemically treated wood. Replacement wooden bridges and switch ties added 0.1 million cubic meters of material. The combined total was equivalent to nearly 0.8 million tonnes. Thus, even if half of the original ties were sound and recoverable, then only approximately 0.4 million tonnes of wood would have been available for recycling from all railroad tie replacements in the United States in 1993. Although wood from such sources may become a more useful resource in the future, these sources were not included in our estimates because of their relatively small quantities and their relative difficulty of recycling.

Summary of Disposal Burden and Recovery Potential

Table 2 summarizes estimated wood waste and wastepaper disposal burdens from MSW, new construction and demolition waste, and material from primary wood processing

facilities. The table also summarizes the estimated recovery potential for recycling and raw material use beyond the quantities already recovered for wood raw material, recycling, composting, or energy.

It should be emphasized that although large quantities were estimated to be potentially recoverable, many factors would affect economic availability and commercial utility of these materials. Those factors would include physical quality and condition of materials, commingling of wastepaper and wood wastes with other types of waste, mixing of wood species and types, contamination of waste materials, physical location of the materials, lack of grading standards for wood wastes, lack of uniformity of material, costs associated with acquiring, transporting, and processing the materials into recyclable raw materials, and product quality standards. Thus, the potential recovery estimates should be regarded only as upper bounds or maximum recovery values for recycling; the estimates should not be regarded as quantities that might actually have been used efficiently or economically.

Concluding Remarks

In the United States, around 37 million tonnes of paper and wood materials was recovered for recycling into new products in 1994. About 95 percent of this material was used to produce recycled paper products—four-fifths used in the United States and one-fifth exported to other countries for that purpose. Much of the remainder was recovered paper used for other purposes such as cellulose insulation, molded pulp products, and fiberboard. Only about 1 percent of the total recovery for recycling was solid wood, mostly consisting of recycled wooden pallets. The relative magnitudes of recovery by product or use category in 1994, shown by the estimates in Table 1, clearly show the dominance of the pulp and paper sector in the spectrum of wood and wood fiber recycling in the United States.

Although more than 36 million tonnes of paper products and less than 1 million tonnes of solid wood materials were recovered for recycling in the United States in 1994, there was nevertheless a substantial potential for additional recovery, especially for solid wood materials and for paper. Although demand caught up with supply in recovered paper markets during 1994, with much higher prices for recovered paper, potentially recoverable volumes of wood for recycling remained vastly in excess of current demands for such material. The potential for additional recovery of solid wood materials for recycling was estimated to be roughly 39 million tonnes annually from MSW, new construction and demolition wastes, and primary timber processing facilities, based on data for the year 1993. The potential for additional recovery of paper from MSW was estimated to be around 28 million tonnes annually.

The potential for additional recovery of wood and wood fiber materials for recycling, which totaled 67 million tonnes in 1993, was considerably greater than the actual recovery of such materials (37 million tonnes by 1994). Because much unrecovered material—especially material from sources such as demolition debris and yard wastes—was low quality, lacking in uniformity, difficult to recover, and commingled with other wastes and contaminants, it would be difficult to utilize in commercial product applications. However, the combined recovery potential, including current recovery and additional potential, was estimated to be more than 100 million tonnes annually. This combined figure is roughly equivalent to nearly half of the total annual timber harvest in the United States, suggesting that wood and wood fiber recycling technology could exploit a large resource base if efficient technology could be developed to fully utilize this resource.

Table 2—Annual disposal of wood and wastepaper materials derived from principal waste sources in the United States in 1993 and recovery potential for recycling or raw material use, millions of tonnes[a]

	Waste wood		Wastepaper	
Material	Disposal burden	Recovery potential	Disposal burden	Recovery potential
MSW	34	21	47	28
New construction	6	5	0.2	(negligible)
Demolition	23	7	0.3	(negligible)
Primary timber	4.3 (wood)	4.3 (wood)	—	—
processing	1.4 (bark)	1.4 (bark)	—	—
Total	69	39	47.5	28

[a]Disposal after recovery for raw material, recycling, or composting. Recovery potential refers to recovery for recycling or raw material use beyond conventional energy recovery.

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