SOURCES AND AVAILABILITY OF RECOVERED WOOD AND FIBER FOR COMPOSITE PRODUCTS

DAVID B. McKEEVER
Forest Products Laboratory
Madison, WI

JOHN A. YOUNGQUIST
Forest Products Laboratory
Madison, WI

BRENT W. ENGLISH
Forest Products Laboratory
Madison, WI

McKeever, David B.; Younquist, John A.; English, Brent W. 1995. Sources and availability of recovered wood and fiber for composite products. In: Proceedings of the 29th international particleboard/composite materials symposium; 1995 April 4-6; Pullman, WA. Pullman, WA: Washington State University: 197-214.

ABSTRACT

Waste is becoming a valuable resource. Although wood is usually thought of as a renewable resource, applications for recycled wood waste are growing. This paper provides information on the sources and availability of recovered wood and fiber in the United States, presents options for using these materials to produce various wood-based composites, and discusses the potential impact of increased recovery of wood wastes. Total amount of wood waste generated, amount of waste generated by type, and amount of waste available for recovery are quantified for three major sources of wood waste: municipal solid waste, new construction and demolition waste, and wood residues from primary timber manufacturing facilities. A combination of mill residues, municipal solid waste, wood and paper waste, and construction and demolition waste may provide the resource of the future for the panel industry based on fiber and small particles for furnish.

INTRODUCTION

A significant environmental challenge facing most developed nations is finding disposal and recycling methods for an enormous and ever-increasing amount of waste materials. Although nearly half the municipal solid waste stream consists of wood waste and waste paper. the lack of developed collection. sorting. cleaning. and marketing systems continues to be a major barrier to keeping these items out of landfills. One promising use for waste wood is in the manufacture of new and improved products from recovered wood, which can be marketed as being produced from “green” materials and technolo-

gies. This alone may provide incentives to entrepreneurs to accelerate the development of collection and distribution systems for recovered wood materials. Once distribution systems are in place, it is predicted that many different composite products containing recovered materials will soon be available in the marketplace.

The U.S. forest products industry is both a major consumer and manager of the Nation's forests. The industry includes nearly 52,000 plants that produce wood products, pulp and paper, and furniture. In 1991, total shipments of forest products were valued at $215,000 million, a 26% share of all industries. Forest products industries provide 1 in 10 manufacturing jobs, most of which are located in rural America, an area traditionally plagued with high unemployment. These industries also contribute four percent to the gross domestic product and provide essential products to all sectors of industry, from basic construction through all professional services. The use of recovered waste wood and fiber in products made by the forest products industry will contribute greatly to long-term sustainable development and forest ecosystem management, and it will allow markets for wood-based composites to grow while minimizing the use of virgin timber.

Examples of conventional wood composites currently on the market, some of which already use recovered materials and which have a high degree of customer acceptance, include particleboard, hardboard, fiberboard, and various types of flakeboard. Other "nonconventional" wood composites-such as products made from a blend of wood fiber and thermoplastic resins, as well as inorganic bonded wood and fiber composites-also provide opportunities to utilize significant quantities of recovered wood waste.

WASTE RESOURCE

Large amounts of waste are generated in the United States annually. Although much of this material is, indeed, waste, an increasing share has become a valuable resource. In the past, recycling was limited to a few commodity items such as metal, glass, and old newspapers. Today, such diverse items as plastic containers and film, used oil and oil filters, fluorescent lighting tubes, and aerosol spray cans are being recycled. One can only speculate as to what materials will be included on the recycling list of the future.

Wood, although usually not considered as a recycled commodity, is recyclable. Residues from primary timber processing facilities have been recycled into usable products for decades. Today, wooden pallets are being recycled into new pallets or other wood products at an increasing rate, and wood waste from construction and demolition sites is now becoming an important commodity. Perhaps in the near future wood from urban waste collection will also prove to be a valuable resource.

The first step in developing waste wood into a resource is to quantify the amounts of waste wood available by source and me of material. Before time and money are invested in technologies for using a new resource, information is needed about the location and form of the resource. Three principal sources of wood waste in the United States are examined in the following text: municipal solid waste, new construction and demolition waste, and wood residues from primary timber processing facilities. " For each source, estimates were derived for total amounts of waste generated, amounts of wood waste generated by type, and amounts of wood waste available for recovery. Wood waste from other sources was identified, but not included in this analysis because of their relatively small volumes compared to those examined here. In addition, the analysis did not include residues remaining in the woods after logging or cultural operations, and nonwoody agricultural biomass that could be used as a wood fiber substitute.

Municipal Solid Waste

Municipal solid waste (MSW) is waste from residential, commercial, institutional, and industrial sources and includes such things as durable goods, nondurable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic waste (Figure 1) (U.S. Environmental Protection Agency [EPA] 1994).

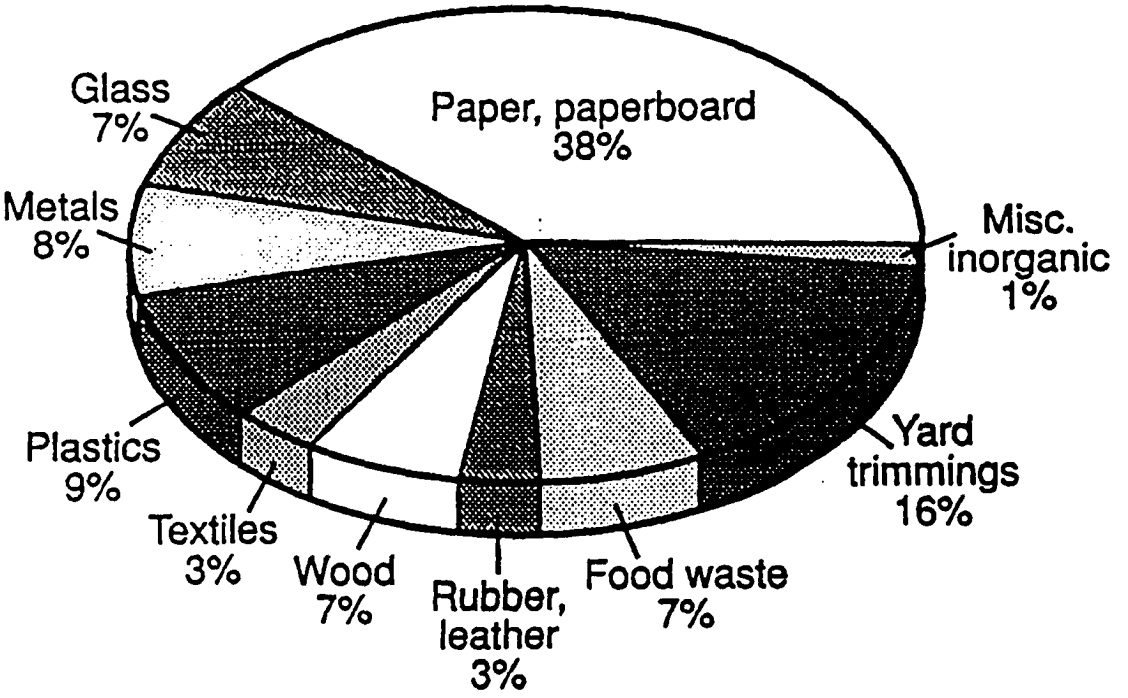

Figure 1. —*Materials in municipal solid waste (MSW), 1993*

Examples include appliances, automobile tires, newspapers, clothing, boxes, disposable tableware, office and classroom paper, wooden pallets, and cafeteria waste. Not included are waste from other sources-such as new construction and demolition waste, automobile bodies, municipal sludges, combustion ash-and industrial process wastes that may or may not be disposed of in municipal waste landfills or incinerators.

An estimated 206.9 × 10^6 short tons (187.7 × 10^6 metric tonnes [t]) of MSW was generated in the United States in 1993 (Figure 2). Throughout this report, the term ton refers to a short ton (2,000 lb); this measurement is followed by the metric equivalent (referred to in tonnes, abbreviated t). In 1960, 87.8 × 10^6 tons (79.7 × 10^6 t) was generated; since then (with the exception of 1991), MSW generation has increased steadily. (Note: MSW generation is sensitive to overall economic conditions. Periods of economic recession, such as in 1991, cause deviations in MSW generation from !ong-term trends.) Between 1960 and 1993, MSW generation increased at an average rate of 2.6% per year. Since 1990, the rate has been only 1.5% per year compared to 2.8% per year for the period 1960 through 1990. The EPA projects that overall MSW will be 218 × 10^6 tons (197.8 × 10^6 t) by the year 2000. This represents an average annual increase of just 0.7% per year for the period 1993 through 2000. Thus, although total MSW is increasing, it is increasing at a decreasing rate, and it is expected to do so into the foreseeable future.

Per capita MSW generation averaged 4.39 lb (1.99 kg) per person per day in 1993, an increase from 4.35 lb (1.97 kg) in 1990 and 2.66 lb (1.21 kg) in 1960. Trends in per capita generation closely followed total MSW generation from 1960 through 1990. By 1990, source reduction and recycling programs initiated in the late 1980s began to influence waste generation. Per capita generation began to plateau in the early 1990s; in 2000, it is expected to decrease (to 4.32 lb [1.96 kg]), for the first time since 1960.

A wide variety of products are included in the overall MSW generation figures. It is the wood waste, yard trimmings, and paper and paperboard waste portion of MSW that may pro-

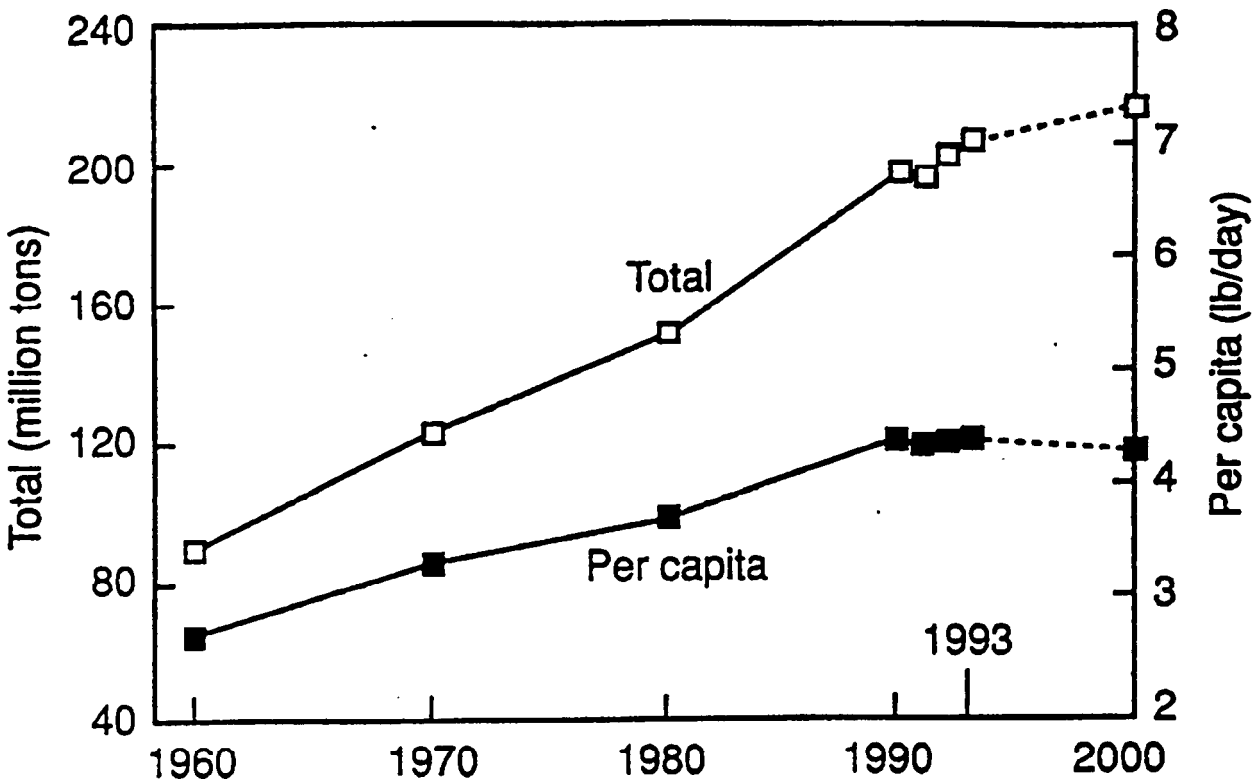

Figure *2.—Total and per capita MSW generation, 1960-2000. 1 lb* = 0.45 *kg*

vide a resource from which to produce wood-based panels and composite products. 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, waste from manufacturing facilities, and a variety of other rniscellaneous products. Wood waste does not include roundwood or unprocessed wood. Yard trimmings include leaves and grass clippings, brush, and tree trimmings and removals. The amounts and types generated, currently recovered for recycling, composting, or combustion, and discarded determine the physical supply of this material.

Wood

In 1993, 13.7 × 10^6 tons (12.4 × 10^6 t) of wood waste was generated in the United States as part of MSW (Table 1, Figure 3). This amounted to nearly 7% of all MSW generated (Figure 1). Of this wood waste, 1.3 × 10^6 tons (1.2 × 10^6 t) was recovered for recycling or comporting, and 12.4 × 10^6 tons (11.2 × 10^6 t) was discarded-either combusted or sent to landfills. The exact proportion of discarded waste that was combusted is available only for overall MSW, not for specific materials within the waste stream. In 1993, 32.9 × 10^6 tons (29.8 × 10^6 t) of MSW was combusted. Approximately 95% of this material was unprocessed mixed waste or processed mixed waste (refuse-derived fuel), both of which include wood. Since wood waste accounts for about 10% of all combustible mixed MSW, about 3.3 × 10^6 tons (3.0 × 10^6 t) of wood waste was probably burned in 1993. In addition, some discarded wood waste was too contaminated, commingled with other waste, or otherwise unacceptable for recovery. Overall, about 60% of all discarded wood waste was considered to be recoverable (Ince and McKeever 1995a, 1995b). In 1993, 7.4 × 10^6 tons (6.7 × 10^6 t) of wood waste was recoverable from MSW (Table 1).

Table 1.—Solid wood, paper, and paperboard waste generated and recoverable from various sources, 1993*

Source and Material	Generated		Recoverable		
	10^6 tons	(10^6 t)	10^6 tons	(10^6 t)	%
Municipal solid waste					
Solid wood					
Wood waste	13.7	(12.4)	7.4	(6.7)	54
Woody yard trimmings	31.1	(28.2)	15.1	(13.6)	48
Total	44.8	(40.6)	22.5	(20.3)	50
Paper and paperboard	77.8	(70.6)	30.8	(28.0)	40
Total MSW	122.6	(111.2)	53.3	(48.3)	43
Construction and demolition					
New construction waste					
Solid wood	6.7	(6.1)	5.9	(5.4)	88
Paper and paperboard	0.2	(0.2)	0.2	(0.2)	89
Total	6.9	(6.3)	6.1	(5.5)	88
Demolition waste					
Solid wood	25.0	(22.7)	7.5	(6.8)	30
Paper and paperboard	0.3	(0.3)	0**	(0**)	2
Total	25.3	(23.0)	7.5	(6.8)	30
Total C&D					
Solid wood	31.7	(28.8)	13.4	(12.2)	42
Paper and paperboard	0.5	(0.5)	0.2	(0.2)	40
Total	32.2	(29.2)	13.6	(12.3)	42
Primary timber processing					
Solid wood residues	82.1	(74.5)	4.7	(4.3)	6
Total, all sources					
Solid wood	158.6	(143.9)	40.6	(36.8)	26
Paper and paperboard	78.3	(71.1)	31.0	(28.2)	40
Total	236. 9	(215.0)	71.6	(65.0)	30

* Data reported as short tons (1 short ton = 2000 lb); metric tonnes (t) are in parentheses (1 t = 1000 kg)
** $<50.0 \times 10^3$ tons

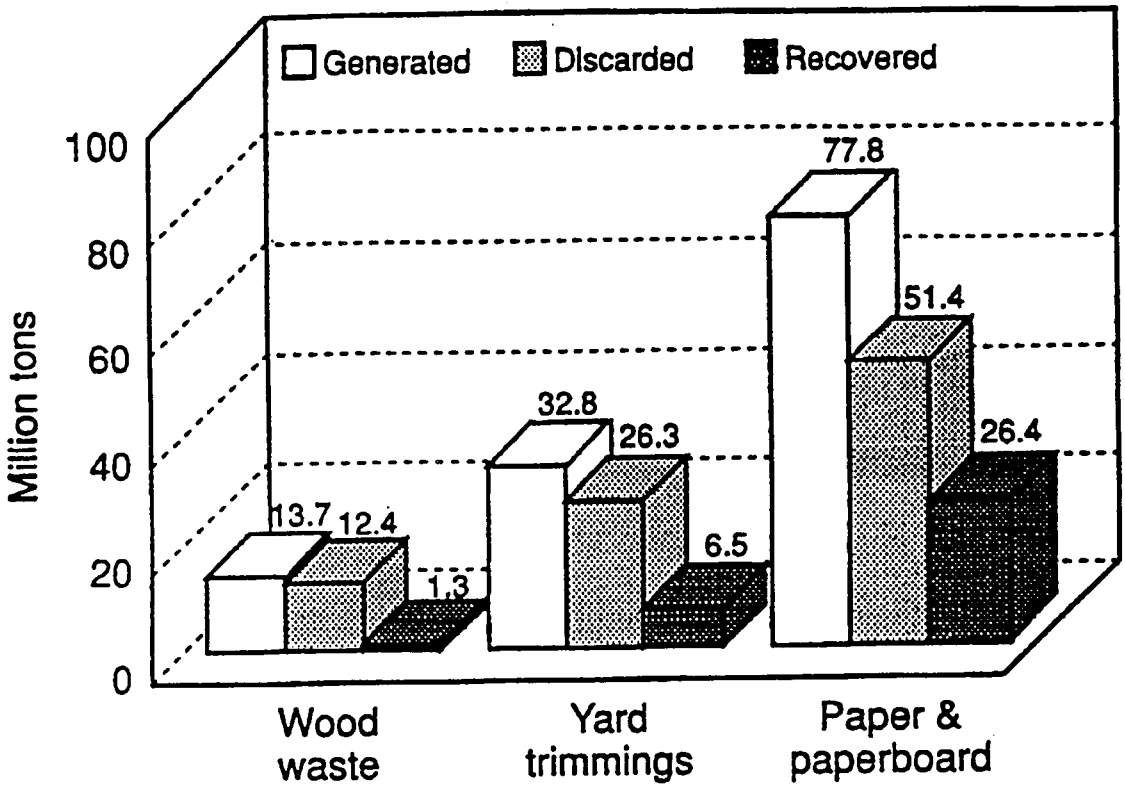

Figure 3.—*Generation, recovery, and discards of wood waste, yard trimmings, paper, and paperboard, 1993*

Yard Trimmings

Yard trimmings constituted the second largest single component of MSW in 1993—32.8 × 10^6 tons (29.8 × 10^6 t) (16%) (Figures 1 and 3). Of this, 6.5 × 10^6 tons (5.9 × 10^6 t) was recovered for recycling or composting; 26.3 × 10^6 tons (23.9 × 10^6 t) was discarded. A recent report by the NEOS Corporation (1995) provides details on the generation and disposition of all urban tree and landscape residues, not just the proportion in MSW. The authors estimated that in 1993, 95% of all urban tree and landscape residues, by volume, was wood residues; 5% was leaf and grass clipping residues. Application of these percentages to MSW yard trimmings resulted in an estimated 31.1 × 10^6 tons (28.2 × 10^6 t) of woody residue being generated and 25.0 × 10^6 tons (22.7 × 10^6 t) being discarded in 1993. After combustion and allowance for unrecoverable material resulting from contamination, size, commingling with other materials, and cost of collection, about 15.1 × 10^6 tons (13.6 × 10^6 t) was available for recovery (60% of total amount discarded) (Table 1).

Paper and Paperboard

Paper and paperboard constitute the single largest component of MSW by far. In 1993, 77.8 × 10^6 tons (70.6 × 10^6 t) of paper and paperboard entered the MSW stream (38% of all MSW) (Table 1, Figures 1 and 3). Paper and paperboard was the most recovered component—34.0% of all paper and paperboard generated, and 58.8% of all recovered MSW. In total, 26.5 × 10^6 tons (24.0 × 10^6 t) was recovered for recycling and comporting; 51.4 × 10^6 tons (46.6 × 10^6 t) was discarded. Using the same assumptions used to estimate the recoverable proportion of discarded wood waste and yard trimmings, about 30.8 × 10^6 tons (28.0 × 10^6 t) of paper and paperboard was available for recovery in 1993 (Table 1).

Total Waste Wood, Paper, and Paperboard

Overall, 122.6 × 10^6 tons (111.2 × 10^6 t) of solid wood (wood waste and woody yard trimmings) and paper and paperboard waste was generated in MSW in 1993 (Table 1). Of this, 53.3 × 10^6 tons (48.3 × 10^6 t) was available for recovery. It should be emphasized that although these amounts were potentially available, many factors affected their availability and usability. These factors included condition of the material, extent of commingling with other types of waste, contamination, physical location, and costs associated with acquiring, transporting, and processing the material into a usable form. Overall economic conditions and changing recovery rates will affect future supplies of recyclable materials. The amounts estimated for 1993 should be viewed as upper bounds on overall supply, not exact amounts available.

New Construction and Demolition Waste

New construction and demolition (C&D) waste materials, although usually considered to be a single form of waste material, originate from distinctly different sources, have different characteristics, and differ in their ease of separation and recoverability. New construction waste, particularly wood waste, originates from the construction, repair, and remodeling of new single-family and multifamily houses and new low-rise nonresidential buildings. Lesser amounts of wood waste are generated by the construction of high-rise residential and nonresidential buildings and other nonresidential structures. Demolition waste originates at any site where a building or other structure is being demolished. New construction waste consists of contemporary types of materials and tends to be much cleaner than demolition waste. In contrast, demolition waste typically contains a more diverse mix of materials and is usually more contaminated with foreign materials such as paints, fasteners, wall covering materials, and insulation. Many materials in demolition waste are no longer being widely used in new construction, which makes them potentially more difficult to recycle. New construction waste can be separated on the job site with little additional effort by the builder, whereas source separation of waste at the demolition site can be very time-consuming and costly. Demolition practices would have to be altered radically to achieve adequate source separation. For these reasons, new construction and demolition wastes were evaluated separately.

Although some C&D waste is now being recovered, little consistent information is available nationally for developing overall estimates of materials generation and recovery potential. Available data are limited to specific case studies that vary widely and that may or may not reflect overall national trends. The C&D waste generation rates published over the past 25 years are summarized in Figure 4. Rates ranged from a low of 0.12 lb (0.05 kg) per person per day (43.8 lb [19.9 kg] per year) to 3.52 lb (1.60 kg) per person per day (1,284.4 lb [582.6 kg] per year). Factors that affect C&D generation rates include the level of new construction activity, types of structures built, types of materials used, level of demolition activity, type and age of structures demolished, and extent to which materials are recovered from structures prior to demolition. Because of variability in reported C&D waste generation rates and the many factors that affect them, information from specific case studies that could be linked to national levels of construction activity was used to estimate amounts of C&D waste generated in 1993. The resulting generation and recovery estimates, although not precise estimates of the size or extent of the waste stream, particularly on a regional or local level, provided a good overall view of the C&D waste resource available in 1993.

New Construction Waste

The construction of new residential and nonresidential buildings, together with new nonbuilding construction, generates considerable amounts of waste material annually. Information on the types and amounts of waste generated is sketchy and limited to anecdotes or a handful of case studies. Since nearly all new single-family and low-rise multifamily residential structures are based on traditional wood-frame building

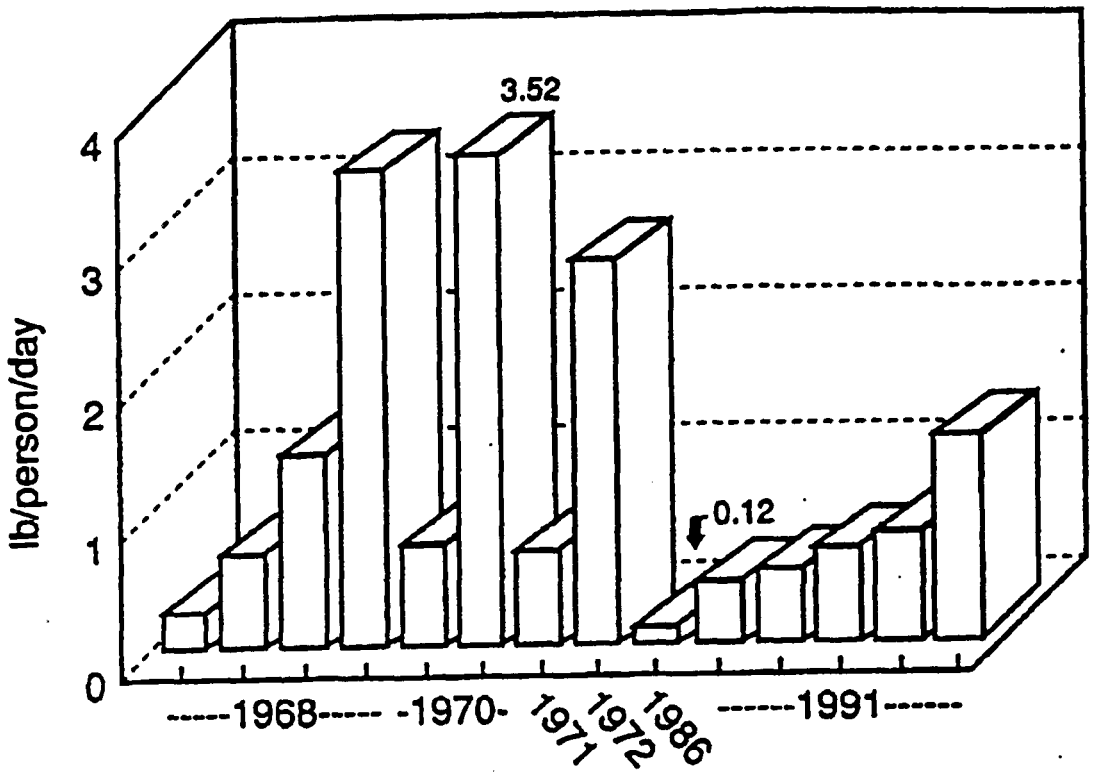

Figure *4.—Published construction and demolition (C&D) waste generation rates*

technology, information on this type of construction was used to develop estimates of wood waste generated and recoverable for new construction. Specific waste generation rates were obtained from a case study conducted by McGregor and others (1993) in the Portland, Oregon metropolitan area.

Although specific to the individual structures examined, the waste generation rates were typical of all new residential construction in 1993 because the individual structures examined showed physical characteristics typical of all new residential construction. Information from the Portland area was used to develop weighted average waste generation rates based on the square feet (meters) of floor area built for new single-family and multifamily houses. These rates were then applied to the total floor area of each type of structure built in the United States in 1993 to develop estimates of total waste generated for residential construction. These estimates were then adjusted to account for new nonresidential construction and for residential repair and remodeling. Waste from mobile home and manufactured housing production was not included; waste from these sources was accounted for in the MSW estimates.

An estimated 4,931 lb (2,237 kg) of solid wood waste, 130 lb (59.0 kg) of paper and paperboard waste, and 2,548 lb (1,156 kg) of other nonwood, nonpaper waste were generated for the average 2,027-ft^2 (188.3-m^2) single-family house built in the Portland metropolitan area in 1993 (McGregor and others 1993). These amounts were equivalent to 2.43, 0.06, and 1.26 lb per ft^2 (11.86, 0.29, and 6.15 kg/m^2) of finished floor area, respectively. Overall, an estimated 88% of this material was considered to be recoverable. New multifamily construction generated 1,365 lb (619 kg) of wood waste, 37 lb (16.8 kg) of paper and paperboard waste, and 823 lb (373 kg) of nonwood, nonpaper waste per living (apartment) unit. These amounts included not only materials generated from each living

unit, but also pro-rated amounts generated for common areas such as laundry rooms, lobbies, and recreational areas; the amounts were equivalent to 1.52,0.04, and 0.92 lb per ft^2 (7.42, 0.20, and 4.49 kg/m^2) of finished floor area, respectively. Eighty-eight percent of this material was considered to be recoverable.

In 1993,1,126,000 new single-family houses with an average of 2,095 ft^2 (195 m^2) of floor area and 153,000 multifamily living units with an average of 1,065 ft^2 (99 m^2) of floor area were built nationally (U.S. Department of Commerce, Bureau of the Census 1994a). Applying the average waste generation rates per square foot (square meter) of floor area resulted in the generation of an estimated 2,994 × 10^3 tons (2,716 × 10^3 t) of wood 79 × 10^3 tons (72 × 10^3 t) of paper and paperboard, and 1,558 × 10^3 tons (1,413 × 10^3 t) of nonwood, nonpaper waste for new residential construction in 1993 (Figure 5). Based on materials use factors (amount of a given building material required per unit of finished floor area) for new residential construction published by Anderson and McKeever (1991) and McKeever and Phelps (1994), an estimated 29.9 × 10^6 tons (27.1 × 10^6 t) of wood products was required for new residential construction in 1993. (Paper and paperboard consumption estimates for new single-family construction were not available.) Waste wood generated was, therefore, about 10% of the wood used to build the structures.

Large amounts of wood products are required for residential repair and remodeling and new, nonresidential construction annually, and these activities, therefore, generate large amounts of wood waste. Reliable information on the amounts of waste generated by these types of construction was not available. However, the types of materials and constriction techniques typically used for residential repair and remodeling are used for new single-family residential construction as well. Therefore, it was possible to estimate waste generation for residential re-

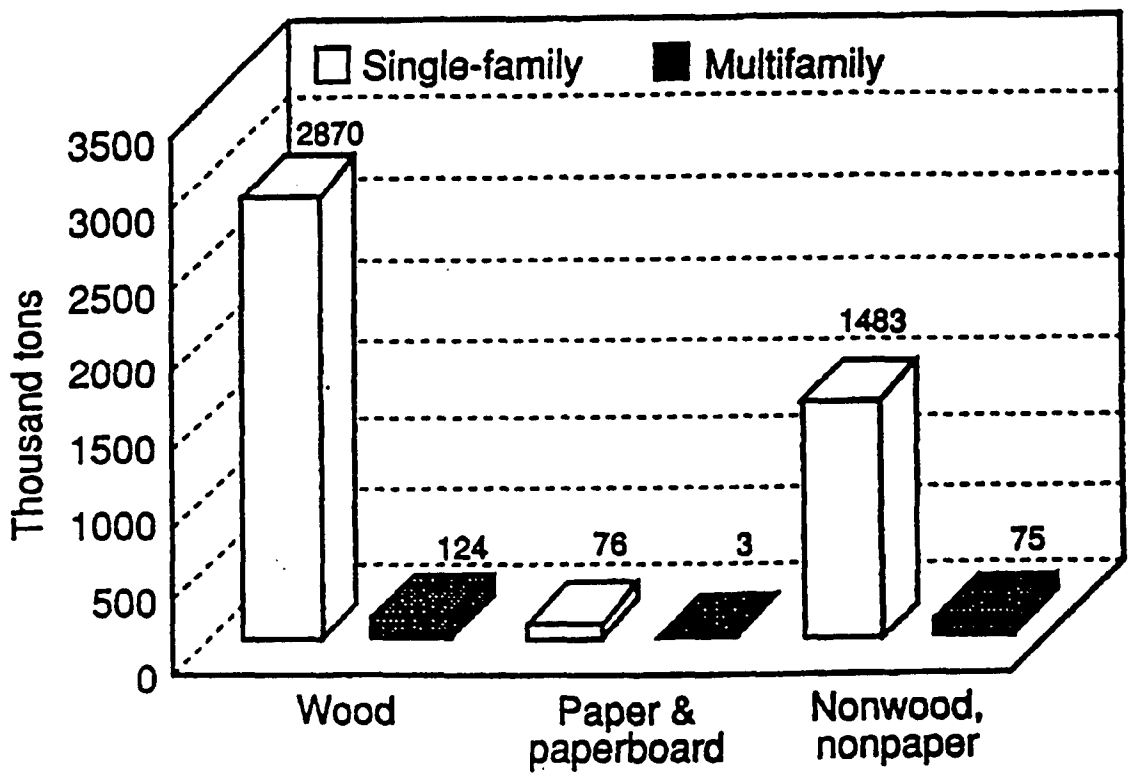

Figure 5.—*Estimated waste generated by new residential construction, 1993*

pair and remodeling based on waste generation rates for new single-family construction.

Data from McKeever and Anderson (1993) on wood products use in 1991 for residential repair and remodeling were updated to 1993 using expenditures data from the U.S. Department of Commerce (1994b) and converted to tons. Total wood products use for residential repair and remodeling was estimated to be 28.4 × 10^6 tons (25.8 × 10^6 t), slightly less than that for new single-family construction. Based on the ratio of waste generated to total materials used for new single-family construction, an estimated 2,858 × 10^3 tons (2,593 × 10^3 t) of wood waste and 76 × 10^3 tons (69 × 10^3 t) of paper and paperboard 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 that used in 1993. In 1993, about 9.5 × 10^6 tons (8.6 × 10^6 t) of wood products was used for new nonresidential construction, one-third of that used for new single-family construction. The wood products and construction techniques typically used to build low-rise, light-frame nonresidential buildings such as stores and office buildings are similar to that used for new residential construction. Waste generation is also expected to be similar. Typically, wood is not used as the primary construction material for larger nonresidential projects such as warehouses, factories, high-rise buildings, public buildings, and highways. Also, the building techniques are very different from that used for wood-based construction. Information needed to estimate waste generated from larger nonresidential projects was not available. However, since wood was not the primary building material, it was assumed that most of the wood waste generated was accounted for by low-rise, light-frame nonresidential construction. (Only an unknown portion of the nonwood waste generated by new nonresidential construction was accounted for.) In 1993, the combined use of wood products for residential repair and remodeling and for new nonresidential construction was about 27% greater than that for new residential construction (single-family and multifamily combined) and generated 25% more wood waste.

Waste generation for all new construction (new single- and multifamily residential, residential repair and remodeling, and new nonresidential) was estimated to be 6.7 × 10^6 tons (6.1 × 10^6 t) of wood and 0.2 × 10^6 tons (0.2 × 10^6 t) of paper and paperboard in 1993 (Table 1). Nearly 5.9 × 10^6 tons (5.4 × 10^6 t) of solid wood and 0.2 × 10^6 tons (0.2 × 10^6 t) of paper and paperboard waste were considered to recoverable.

Demolition Waste

Demolition waste is the heterogeneous mixture of buiIding materials generated by demolishing a building or other structure. It, typically, contains aggregate, concrete, wood, paper, metal, insulation, glass, and other contemporary building materials. Depending on the age and type of structure, it may also contain asbestos, lead-based finishes, mercury, polychlorinated biphenyl (PCB) compounds, or other contaminates. Estimates on the amounts of demolition waste generated have been made over the years. Usually, these figures have been estimated for specific localities, have typically included construction waste, and have been based on the size of the resident population. (Urban areas tend to generate more C&D waste per capita than suburban or rural areas.) The Solid Waste Association of North America (1993) reported C&D waste generation rates made by the California Waste Management Board and the New York Solid Waste Management Board for 1968 and 1991, respectively (Figure 6). Because of the consistency between the New York and California rates, and the relationship between community size and waste generation, the New York C&D generation rates were used to estimate demolition waste generated in the United States in 1993.

To estimate national levels of demolition waste in 1993, generation rates from the 1991 New York study for areas with <10,000 and 10,000-100,000 people were first weighted to

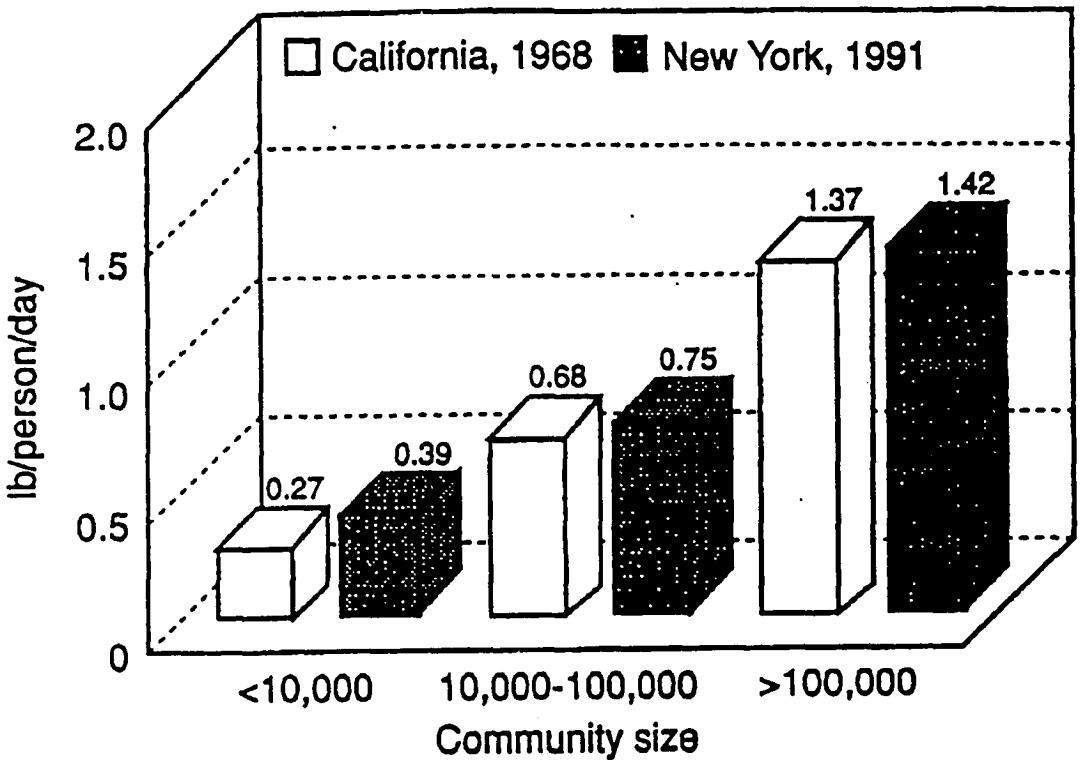

Figure 6.—*Reported C&D generation rates for California and New York*

form a single rate. Next, the daily rate for communities with population in excess of 100,000 was annualized and multiplied by the 1993 U.S. resident population in Metropolitan Statistical Areas (MSAs). The weighted daily rate for communities of <100,000 was annualized and multiplied by the resident population of the United States in non-MSAs. The products were summed, resulting in an estimate of the total amount of C&D waste generated in the United States in 1993. The estimated amount of new construction waste was then subtracted, leaving an estimated 48.3 × 10^6 tons (43.8 × 10^6 t) of demolition waste generated in 1993. Final figures were calculated using information from a 1991 Metropolitan Toronto *waste* composition study (Solid Waste Association of North America 1993), which indicated that 52% of demolition waste being disposed of in metropolitan Toronto landfills was wood, 1% paper and paperboard, and 48% other materials. Application of these percentages resulted in an estimated 25.0 × 10^6 tons (22.7 × 10^6 t) of wood, 0.3 × 10^6 tons (0.3 × 10^6 t) of paper and paperboard, and 22.9 × 10^6 tons (20.8 × 10^6 t) of other materials in demolition waste in the United States in 1993 (Table 1).

Recoverability of demolition waste is difficult to determine. The characteristics of demolition waste make it more difficult to recover than construction waste. Recovery operations are very sensitive to contamination. Typically, entire loads of demolition waste are rejected if contaminated. According to James McElvenny (1995), about 15% of the wood, by weight (38% by volume), received at his facility is usable. Little, if any, of the paper and paperboard is usable. These percentages are for one specific operation producing a single product and are based on primary crushing of the incoming demolition waste to achieve uniform material size. Differences in treatment technology, products manufactured, and source of demolition waste affect the utilization rate. Based on an assumed overall 30% utilization rate, approximately 7.5 × 10^6 tons (6.8 × 10^6 t) of wood,

paper, and paperboard demolition waste was considered to be recoverable in 1993 (Table 1).

Primary Timber Processing Mill Residues

Primary timber processing facilities in the United States generate large amounts of residues in such forms as bark sawmill slabs and edging, sawdust, and peeler log cores. In 1991, an estimated 28.7 × 10^6 dry tons (26.0 × 10^6 t) of bark and 82.1 × 10^6 dry tons (74.5 × 10^6 t) of wood residues were generated (Table 1) (Powell and others 1993). Of these wood residues, 61% was coarse materials and 39% fines. Many residues were used to produce other products, primarily fiber products, or fuel. Only 5% of the bark (1.5 × 10^6 tons [1.4 × 10^6 t]) and 6% of the wood residue (4.7 × 10^6 tons [4.3 × 10^6 t]) were not used. Regionally, most of the unused wood residue was in the North (3.0 × 10^6 tons [2.7 × 10^6 t]) (Table 2).

Unused wood residue is a potentially valuable source of wood. However, the proximity of unused residue to mills is a major obstacle limiting future use. Unused bark residue, although potentially valuable as fuel or for mulch-type products, is probably not a viable alternative for wood-based products. Table 2 shows the amount of wood residues generated, used, and recoverable from primary timber processing facilities in 1991, by region and type of use. Since overall lumber and plywood production changed little between 1991 and 1993, the 1991 mill residue data were used as an estimate for 1993.

Other Sources

There are many other sources of waste wood, paper, and paperboard, including chemically treated wood used for railroad crossties, switch ties and bridge timbers, telephone and utility poles, and pier and dock timbers, and untreated wood in the form of logging residues left in the woods, chipped brush and limbs resulting from maintenance of utility right-of-ways, and industrial waste wood and paper outside the MSW stream. Some of this material is being reused, burned, and disposed of in hazardous waste landfills, and much is being left on site. Chemical treatments and cost of collection render much of this material unusable.

The amounts of wood, paper, and paperboard available from these other sources (except logging residues) were fairly small compared to that from the three major sources of material previously discussed. For example, information provided by Clyde Crimmel of the Association of American Railroads (1995) indicated that a

Table 2.—Wood residues generated, used, and recoverable from U.S. primary timber processing facilities, 1991*

	Type of Wood Residue Use										
	Generated		Fiber Products		Fuel		Other		Recoverable		
Region	10^6 tons	(10^6 t)	10^6 tons	(10^6 t)	10^6 tons	(10^6 t)	10^6 tons	(10^6 t)	10^6 tons	(10^6 t)	%
North	21.9	(19.9)	7.0	(6.4)	6.3	(5.7)	5.7	(5.2)	3.0	(2.7)	13
South	36.5	(33.1)	21.2	(19.2)	10.6	(6.9)	3.8	(3.4)	1.0	(0.9)	3
West	23.6	(21.4)	13.5	(12.2)	7.7	(7.0)	1.8	(1.6)	0.7	(0.6)	3
U.S.	82.1	(74.5)	41.6	(37.7)	24.6	(22.3)	11.2	(10.2)	4.7	(4.3)	6

* SOURCE: Powell, Douglas S.; Faulkner, Joanne L.; Darr, David R.; Zhu, Zhiliang; and MacCleery, Douglas W. 1993. *Forest Resources of the United States*, 1992. USDA Forest Service General Technical Report RM-234. U.S. Department of Agriculture, Forest Service. Rocky Mt. Forest and Range Experiment Station. Ft. Collins, CO.

total of 12.3 × 10^6 railroad crossties was replaced in 1993. The replacement ties were all treated wood and had an estimated volume of 491 × 10^6 board feet (MMBF) (1.2 × 10^6 m^3). Bridge and switch tie replacements added an additional 44 MMBF (0.1 × 10^6 m^3). The combined volume of 535 MMBF (1.3 × 10^6 m^3) was equivalent to nearly 0.9 × 10^6 tons (0.8 × 10^6 t) of ties replaced. If half the wood in the removed ties were sound, then <0.5 × 10^6 tons (<0.5 × 10^6 t) of wood would have been recoverable from all railroad tie replacements. This volume was only about 10% of the wood residue potentially available from primary timber processing mills, the smallest of the three major sources of wood waste.

Although wood from other sources may become a valuable resource in the future, these sources were not examined in the volume estimates presented here because of their smaller volumes or obstacles to recovery.

Summary of Waste Resource

In 1993, an estimated 237 × 10^6 tons (215 × 10^6 t) of waste wood, paper, and paperboard was generated in the United States from three principal waste sources: MSW, C&D waste, and primary timber processing facilities (Table 1). Two-thirds of this material was wood and the remainder, paper and paperboard. Much waste wood, paper, and paperboard was being used for new products and for fuel, or was not suitable for other uses because of contamination or other physical characteristics. Of the total amount generated, an estimated 72 × 10^6 tons (65 × 10^6 t) was recoverable. This volume consisted of 41 × 10^6 tons (37 × 10^6 t) of wood and 31 × 10^6 tons (28 × 10^6 t) of paper and paperboard. Overall, 30% of the waste generated was considered to be recoverable; 26% of wood waste and 40% of paper and paperboard waste generated were recoverable. Although technical and economic obstacles have hindered the use of much of this material, it is nevertheless a valuable resource that will play a major role in satisfying the demand for wood-based products in the future.

THE WOOD-BASED COMPOSITES OF PARTICLEBOARD, MDF, HARDBOARD, INSULATION BOARD, AND HARDWOOD PLYWOOD

Many currently manufactured products contain wood in the form of flour, fiber, or particles. The largest category of wood-based products, in terms of wood used and type of product, is that of wood composites used primarily as substrates for various covering applications. Wood fiber-plastic composite products are a recent innovation, and markets are just beginning to develop for these materials. Inorganic-bonded wood composites are used in large quantities in many different parts of the world, but they are just beginning to be used by the construction industry in the United States.

Five types of panels: particleboard, medium-density fiberboard (MDF), hardboard, insulation board, and hardwood plywood are the subjects of this discussion. With the exception of hardwood plywood, all of these products are produced from reconstituted wood in the form of chips or fibers, and are, therefore, potential candidates for the use of recovered wood, paper, and paperboard in the production process. To varying extents, recovered wood from primary timber processing mill residues is currently used in particleboard, MDF, hardboard, and insulation board.

Using wood fiber blended with thermoplastic resins to make products previously made with pure plastics is gaining in popularity. The use of wood-based materials to reduce the cost of thermoset plastics dates to the beginning of the century. A recent innovation is using recovered wood or paper fiber as a reinforcing filler in thermoplastics. Most commodity thermoplastics --such as low- and high-density polyethylene (LDPE and HDPE), polypropylene, and polystyrene---can be blended with waste wood or paper. Using wood and paper fiber as reinforcing fillers decreases raw material costs and significantly increases product rigidity and strength.

The manufacture of wood fiber-plastic composites represents a very small portion of the total composites industry at present. This technology lends itself to the use of recycled fiber in the form of waste wood or paper, and production facilities can be located in urban settings where recovered fibers from MSW are prevalent. Although commercial activity is beginning, many production and optimization studies remain to be done. Research at the Forest Products Laboratory of the USDA Forest Service is addressing issues relating to using recovered wood fibers in composites and to improving mechanical properties through the use of compatibilizers, coupling agents, and lubricants.

Inorganic-bonded wood composites contain different forms of wood bonded with either magnesiurn oxide, gypsum, or portland cement. Both magnesium oxide and gypsum are moisture sensitive, and composite products made with them are used primarily for interior applications. Portland-cement-bonded products are more durable than products bonded with magnesium oxide or gypsum and are used for both exterior and interior applications.

All inorganic-bonded wood products are highly resistant to fire, insect, and pest damage. All of these products are either made from a slurry of wood, water, and binder or at least have a high moisture content during manufacturing. These products are particularly interesting from the standpoint of wood fiber recycling. Many paper mill wastes consist of short wood fibers with high moisture content and contamination with undesirable materials, like plastic shreds. At present, these wastes are either landfilled or burned, but potentially they could be used in the manufacture of inorganic-bonded products for many different applications. Another advantage to this technology is the fact that these products can be made using a range of manufacturing techniques-from low cost labor-intensive operations to sophisticated, high production volume technology. Research in all of these areas is ongoing.

Because data were readily available, production trends for particleboard, MDF, hardboard, and insulation board were examined and used to estimate overall raw material requirements for each panel type based on current production technologies. The potential impact of increased use of waste wood, paper, and paperboard by the composites industry where possible was evaluated in terms of overall raw material requirements and amount recoverable. Because the vast majority of wood particles and fibers for manufacturing commercial products is used by the aforementioned panel manufacturing facilities, this product category was emphasized.

Production

Combined production of particleboard, MDF, hardboard, and insulation board, totaled 15,947 × 10^6 ft^2, 3/8 in. basis (14.1 × 10^6 m^3) in 1993 (Anonymous 1994). This volume was equivalent to approximately 10.5 × 10^6 tons (9.5 × 10^6 t) or 498 × 10^6 ft^3 (14.1 × 10^6 m^3) of panels. Particleboard production accounted for more than half of total production—an all-time high of 8,482 × 10^6 ft^2, 3/8 in. basis (7.5 × 10^6 m^3) (Figure 7). Medium-density fiberboard also achieved record production: 2,322 × 10^6 ft^2, 3/8 in. basis (2.1 × 10^6 m^3), 15% of total production. Hardboard and insulation board constituted 11 and 21% of total production, respectively.

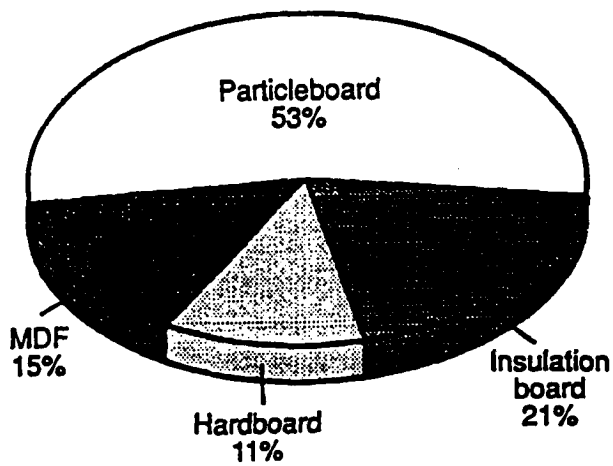

Figure *7.—Particleboard, MDF, hardboard, and insulation board panel production in the United States, 1993*

Raw Material Requirements

The composite products mentioned above are produced from a variety of raw materials. Mill residues from primary timber processing facilities are the preferred material and account for a large majority of the raw material used. Roundwood and waste paper are used also, but to much smaller and varying extents. Precise estimates of the proportions of mill residues, roundwood, and waste paper used were not available. However, in general, producers in the western half of the United States traditionally have used nearly 100% mill residues for furnish, whereas producers in the east and south have used larger amounts of roundwood. Insulation board producers have used waste paper to augment their residue and roundwood furnish.

The types and amount of raw material furnish used to produce such panels are dictated, in part, by the types and amount locally available. In the past, producers in the west traditionally have had a large sawmill and planer mill industry from which to obtain mill residues. Recent changes in both the availability and size of the timber resource in the west and improvements in processing technologies in general are tending to reduce the amount of primary timber processing mill residues available to the panel industry. Shortfalls in mill residues necessitate the increased use of roundwood and other types of furnish to maintain production levels.

Based on factors of raw material volume to volume of product produced (Jackson 1990), an estimated 622×10^6 ft^3 (17.6×10^6 m^3) of residues, roundwood, and waste paper were consumed in 1993 to produce 498×10^6 ft^3 (14.1×10^6 m^3) of three types of panels (Figure 8). In 1993, the ratio of the volume of raw material required per unit volume of output, weighted by production, was 1.25. This ratio has been increasing steadily over time as a result of increases, in particleboard and MDF production relative to that of hardboard and insulation board. An assumed overall mix of 90% mill residues, 9% roundwood, and 1% waste paper and paperboard resulted in an estimated consumption of 560×10^6 ft^3 (15.8×10^6 m^3) of residues, 56×10^6 ft^3 (1.6×10^6 m^3) of roundwood, and 6×10^6 ft^3 (0.2×10^6 m^3) of waste paper by the this part of the panel industry in 1993.

Potential Impact of Increased Recovery

Increased use of waste wood, paper, and paperboard by the composites industry using fiber and small particles appears to be inevitable. Sustainability and ecosystem management issues, timber supply reductions, decreasing log sizes, improvements in processing technologies, and increased production of reconstituted wood products are all working to reduce the amount of primary timber processing mill residues available to the panel industry.

Timber supply restrictions and price increases may also limit the use of roundwood timber. The 56×10^6 ft^3 (1.6×10^6 m^3) of roundwood used by the fiber/small particle panel industry in 1993 was equivalent to nearly 1×10^6 tons (0.9×10^6 t). Local and regional reductions in available roundwood and mill residues may necessitate the acquisition of an additional 0.5×10^6 tons (0.5×10^6 t) of furnish from alternative sources.

The most likely source of raw material is wood, paper, and paperboard waste. A total of 71.6×10^6 tons (65.0×10^6 t) of waste wood, paper, and paperboard was considered to be recoverable in 1993 (Figure 9). Nearly two-thirds of this was waste wood. There seems to be littte reason to believe that 1.5×10^6 tons (1.4×10^6 t) of this material could not be diverted from the waste stream to this part of the panel industry. The extent and speed by which this waste material is diverted from the landfill to individual composite products plants depends to a great extent on the economics of using the waste material.

Long-term costs of using the existing mix of furnish must be evaluated against the costs of acquiring and transporting the waste material, costs of acquiring and maintaining specialized equipment needed to use the waste material, and anticipated revenues from products to be manufactured. The resource of the future may well be a combination of mill residues and waste wood

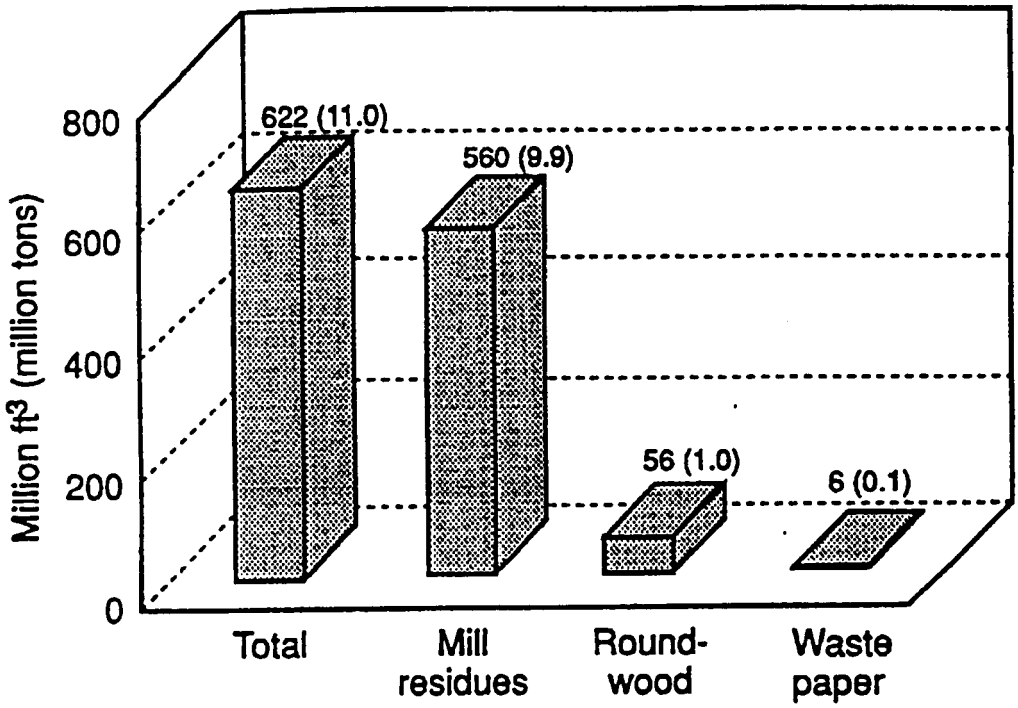

Figure *8.—Raw materials consumed, by type, for particleboard, MDF, hardboard, and insulation board production, 1993*

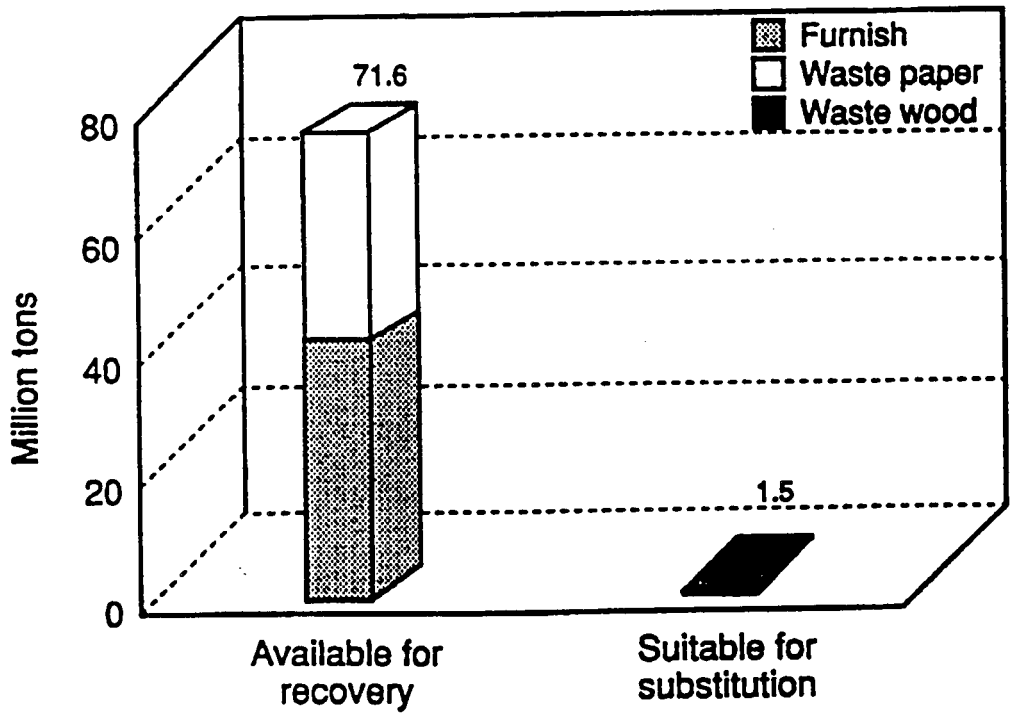

Figure *9.—Recoverable waste wood, paper, and paperboard, and furnish suitable for substitution by recovered waste, 1993*

and paper from MSW, new construction waste, demolition waste, and other waste sources.

In fact, the future has arrived. One particleboard plant in Eugene, Oregon reports using furnish consisting of up to half recovered wood, consisting of construction site waste, pallets, crating, and other waste wood. (This plant is being converted to MDF production.) Funding and siting for a planned MDF plant in Toronto, Canada, is currently underway. The plant will use exclusively urban and industrial waste in such forms as demolition waste and pallets. Paper waste is also being considered as a raw material. This plant is also considering the establishment of six MDF plants in large metropolitan areas in the United States and Canada.

Summary of the Wood-Based Composites Industry Based on Fibers and Small Particles for Furnish

Timber supply reductions, decreasing log sizes, improved processing technologies, and increased production of reconstituted wood products are reducing the amount of primary timber processing mill residues available to this part of the composites industry in general and to individual plants and manufacturing facilities in particular. Timber supply restrictions and price increases may also limit the use of roundwood timber. The most likely source of alternative material for these composites is waste wood and paper. The resource of the future may well be a combination of mill residues and waste wood and paper from municipal solid waste, new construction and demolition waste, and other waste sources.

REFERENCES CITED

Anderson, Robert G. and McKeever, David B. 1991. Wood used in new residential construction in the United States, 1988. Market research report. American Plywood Association. Tacoma, WA.

Anonymous. 1994. Panel capacity growth occurring worldwide. *Wood Technol.* 121: 4(7/8):34-35.

Crimmel, Clyde. 1995. Personal communication, March 28, 1995. Association of American Railroads, Washington, DC.

Ince, Peter J. and McKeever, David B. 1995a. Quantities of paper and wood recovered for recycling and potential for additional recovery in the United States. Report to United Nations Economic Commission for Europe Timber Committee, team of specialists on new products, recycling, markets, and applications for forest products. USDA Forest Service, Forest Products Laboratory. Madison, Wisconsin.

Ince, Peter J. and McKeever. David B. 1995b. Estimates of paper and wood recovery for recycling and potential recovery in the United States. Proceedings, Wood Fiber-Plastic Composites Conference; May 1-3, 1995. Forest Products Society. Madison, Wisconsin.

Jackson, Kristine C. 1990. Appendix B. Conversion factors for forestry and the timber products industry. In An Analysis of the Timber Situation in the United States 1952-2040, R.W. Haynes, coordinator. USDA Forest Service General Technical Report RM-199. U.S. Department of Agriculture, Forest Service. Rocky Mt. Forest and Range Experiment Station. Ft. Collins, CO. pp. 255-266.

McElvenny, James. 1995. Personal communication, March 27, 1995. Wood Recycling, Inc. Woburn, MA.

McGregor, Mark; Washburn, Howard; and Palermini, Debbi. 1993. Characterization of construction site waste. Final report presented to METRO, Solid Waste Department. Portland, OR.

McKeever, David B. and Anderson, Robert G. 1993. Wood products used for residential repair and remodeling in the United States, 1991. Resource Bulletin FPL-RB-19. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, WI.

McKeever, David B. and Phelps, Robert B. 1994. Wood products used in new single-family house construction: 1950 to 1992. *Forest Prod. J.* 44:(11/12):66-74.

NEOS Corp. 1995. Urban tree residues: results of the first national inventory. Final report prepared for: International Society of Arboriculture Research Trust, Allegheny Power Service Corp. and National Arborists Foundation. NEOS Corp. Lakewood, CO.

Phelps, Robert B. and McKeever, David B. 1990. Recent trends in the consumption of timber products. In An analysis of the timber situation in the United States 1952-2040, Chapter 2, R.W. Haynes, coordinator. USDA Forest Service General Technical Report RM-199. U.S. Department of Agriculture, Forest Service. Rocky Mt. Forest and Range Experiment Station. Ft. Collins, CO. pp. 8-42.

Powell, Douglas S.; Faulkner, Joanne L.; Darr, David R.; Zhu, Zhiliang; and MacCleery, Douglas W. 1993. Forest resources of the United States, 1992. USDA Forest Service General Technical Report RM-234. U.S. Department of Agriculture, Forest Service. Rocky Mt. Forest and Range Experiment Station. Ft. Collins, CO.

Solid Waste Association of North America. 1993. Construction waste & demolition debris recycling. A primer. Pub. # GR-REC 300. Solid Waste Association of North America. Silver Spring, MD.

U.S. Department of Commerce, Bureau of the Census. 1994a. Characteristics of new housing: 1993. Current Construction Report C25/93-A. Washington, DC.

U.S. Department of Commerce, Bureau of the Census. 1994b. Expenditures for residential improvements and repair. Current Construction Report C50/94-Q2. Washington, DC.

U.S. Environmental Protection Agency. 1994. Characterization of municipal solid waste in the United States: 1994 update. EPA530-R-94-042. Washington, DC.