Chapter II

Solid Wood and Panel Products

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Summary and Conclusions

Research and development (R&D) in lumber and panel products manufacture has enabled the use of a variety of wood raw materials: smaller logs, hardwoods, and wastes. Spurred by rapidly rising prices of high-quality softwood timber, Government and the industry have developed ways to increase the use of harvested timber for both products and energy.

Nearly half the industrial timber harvested in the United States—over 6 billion cubic feet (ft^3)—is delivered to lumber mills, and about 40 percent emerges as lumber. The volume of lumber produced is nearly 2.5 times the plywood and particleboard manufactured. Therefore, even small increases in the efficiency of lumber manufacture can have major impacts on the amount and type of timber demanded from U.S. forests.

Advances in computer automation in lumber mills have made it possible to increase the amount of lumber recoverable from "roundwood," or logs. The Best Opening Face (BOF) program, developed by the U.S. Forest Service, Forest Products Laboratory (FPL), has produced average increases in recovery of 20 percent under laboratory conditions, though these results have yet to be matched in the field. Evaluation of the use of the BOF program in sawmills nationwide has shown only a 4 percent average increase in lumber recovery.

Changes in sawmilling practices can increase lumber yield and expand the range of raw material suitable for lumber manufacture. A system known as edge-glue and rip (EGAR) can increase yields by an estimated 10 to 13 percent by reducing edging loss.* Another sawmilling system, saw-dry-rip (SDR), enables expanded use of hardwoods in lumber manufacture by reducing the amount of defect in hardwood lumber.

Lumber products made from thin wood veneers laminated together may be stronger than conventional solid lumber, and can be manufactured from small logs or hardwoods. Known as parallel laminated veneer (PLV) lumber, these products can be manufactured in a variety of lengths and widths that are not limited by log size, making the process suitable for production of larger wood framing members such as joists, beams, or girders.

Efforts are under way to increase the efficiency of lumber use in housing and other light frame construction. Improvements in lumber grading systems, which classify lumber according to its strength and stiffness, could enable builders to reduce the amount of high-quality lumber used in critical applications and more closely match lumber grades to construction needs. Machine Stress Rating (MSR), for example, is a mechanical grading technology that measures lumber stiffness by nondestructive testing and produces lumber that has a narrower range of variability in important mechanical properties than does visually graded lumber.

*The amount of wood wasted when lumber is trimmed to specific widths.

Introduction

Panels have been replacing lumber in construction for the past three decades. Plywood has been produced commercially in the United States since the turn of the century, but plywood manufacture, like lumber manufacture, relies on large-diameter, high-quality softwood timber, which is becoming increasingly scarce. As a result, technologies for panel manufacture have concentrated on expanding the resource base, Newer panels, made from wood wafers or strands, can be made from small logs, residues, and hardwoods and can substitute for plywood in construction applications, Two new panel products, waferboard and oriented strand board (OSB), already have captured some plywood markets and are expected to continue expanding. Most new, planned panel manufacturing capacity in the United States is in OSB or waferboard. Because these products can be made from hardwoods and from lower quality softwoods than can plywood, production facilities are located in the Great Lakes States and Northeast, closer to construction markets and suitable wood supplies.

Advances in plywood manufacture also have expanded small log utilization through improvements in log peeling technology. Other changes in plywood production include increasing automation and improving drying processes to reduce energy use, accelerate drying, and produce more stable panels.

These improvements in primary manufacturing have been aimed principally at expanding the usable resource base: increasing the ability t o use hardwoods and a greater proportion of the tree. Increasing the efficiency of wood use in construction also has potential to reduce the pressure on domestic timber resources, particularly the softwoods. Engineering analyses have shown that many houses are overbuilt, or capable of withstanding far greater stresses than required by housing codes. More careful matching of construction members—framing and sheathing—to the engineering requirements of the structure could help reduce the amount of wood required to build a home.

New construction technologies also have shown some promise in reducing wood requirements. In particular, the use of factory-made wood trusses for floor, wall, ceiling, and roof framing reduces lumber requirements and, at the same time, speeds up housing construction and reduces labor costs. Factory-made housing components, such as wall panels that combine framing and sheathing, also can reduce wood waste and construction labor requirements. Construction technologies, however, are slow to change, and the impact of these technologies on wood utilization is unlikely to be significant in the short run,

Profile of the Lumber and Panel Products Industry

As the world's largest consumer of industrial wood[1] (including pulp), the United States uses over one-fourth of the world's timber products, more than half of which is lumber, plywood, and veneer, In 1979, the United States consumed approximately 50 million air-dry tons of lumber, 12 million tons of plywood, and 10 million tons of panel products, accounting for nearly half the U.S. consumption of industrial roundwood.[2] In addition, the United States produces over 20 percent of the world's softwood lumber, 15 percent of its hardwood lumber, nearly 45 percent of its plywood, 1.5 percent of its particle board, and 40 percent of its fiberboard,'

[1] Industrial wood includes all commercial roundwood products except fuelwood

[2] U S DA Forest Service, U.S. *Timber Production, Trade, Consumption, and Price Statistics*, 1950-1980, Miscellaneous Publication No, 1408, 1981.

[3] Roger A. Sedjo and Samuel J. Radcliffe, *Postwar Trends in U.S. Forest products Trade: A Global, National, and Regional View*, Research Paper R-22 (Washington, D.C. ,: Resources For the Future, 1980).

Despite its role as a major producer, the United States is a net importer of lumber and panel products, except particleboard, It imports nearly 35 percent of the world's total softwood lumber imports, over 5 percent of world hardwood lumber imports, 30 percent of world plywood and veneer imports, and over 10 percent of world fiberboard imports (fig. 7). The U.S. trade pattern is dominated by imports of softwood lumber and plywood from Canada, imports of hardwood veneer and plywood from Asia, exports of softwood products (including logs) from Alaska and the Pacific Northwest to Japan, and some export of panel products from the west coast and the South to Japan, Europe, and Central and South America.

Raw Materials

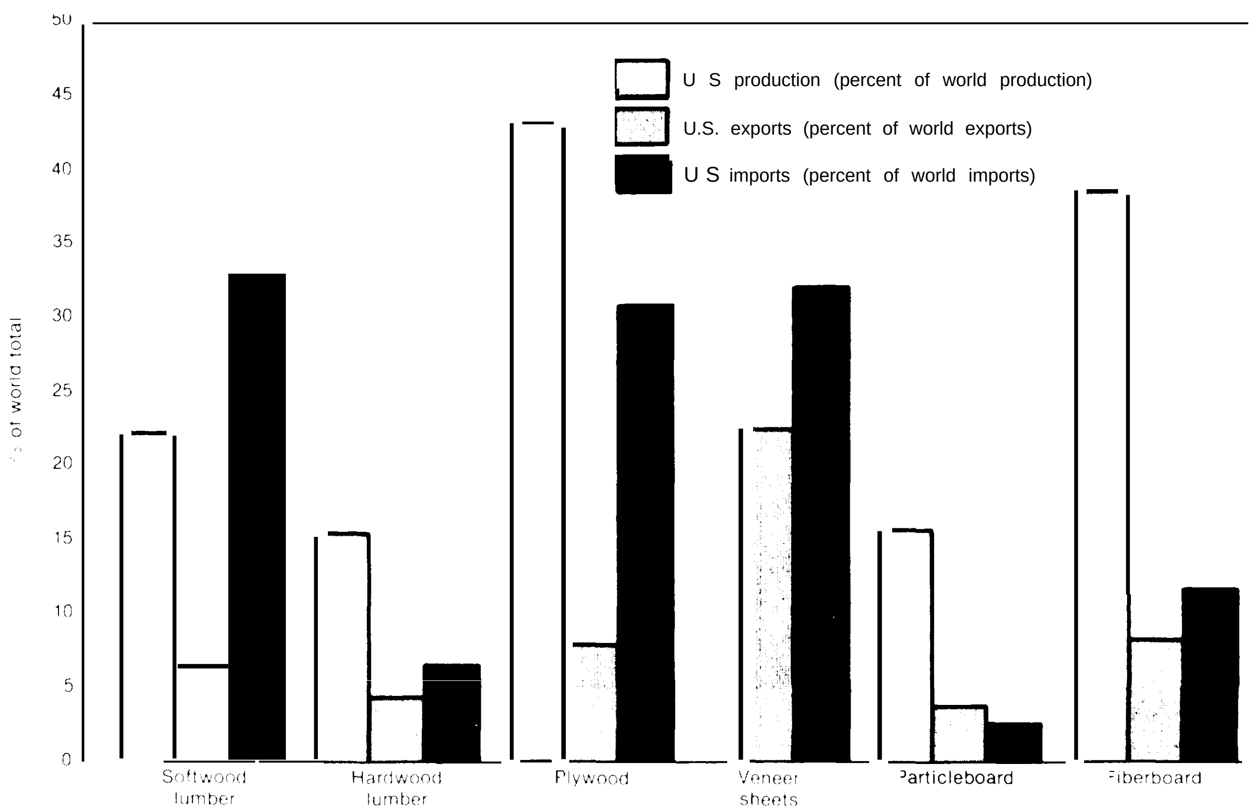
In addition to the various timber used as raw materials, plywood and panel products manufacture is a major consumer of adhesives. The largest single adhesives market today is in plywood manufacture.[4] Production of composite panel products consumes significant amounts of phenol and urea formaldehyde resins. Other chemicals used by the industry include fire retardants and wood preservatives. Preservatives may become even more important in the future if wood use for foundations in housing construction continues to expand. All of these chemicals—adhesives, preservatives, and fire retardants—are largely derived from petroleum.

Product Demand

Because demand for lumber and panel products is linked closely to the homebuilding in-

[4]Peter Gwynne, "Adhesives: Bound for Boundless Growth, " *Technology*, January/February 1982, p. 43.

Figure 7.—U.S. Trade in Lumber and Panel Products, 1976



SOURCE Roger A Sedjo and Samuel J Radcliffe, *Postwar Trends In U S Forest Products Trade: A Global National and Regional View,* Resources for the Future, Research Paper R.22, 1980 dustry, production of lumber and panel products follows the general pattern of housing starts. In 1976, construction-related activity accounted for three-fifths of the lumber and two-thirds of the plywood consumed in the United States.[5] New home construction is the major market for lumber and plywood, although residential upkeep and improvement and nonresidential construction also consume significant amounts. Periodic depressions in the housing industry create soft markets that greatly affect lumber, plywood, and panel demand, resulting in mill closures and curtailments in production.

Other major uses of wood—manufacturing and shipping—account for **18** percent of the lumber and 10 percent of the plywood consumed in the United States. Furniture making accounts for the bulk of the wood used in manufacturing, and pallet manufacturing is the major market for wood in shipping. A summary of lumber and panel products use is shown in table 11.

Industry Size and Distribution of Production

The lumber and forest products industry consists of 35,000 establishments and employs nearly 700,000 workers, or nearly 4 percent of those employed in U.S. manufacturing.[6] Major wood products manufacturing sectors of the lumber and wood products group employed 219,000 people in 1981 (table 12).

Although the industry is dominated by a few large firms, some segments are made up of small, competitive firms (table 13). The lumber industry is the most competitive component of the lumber and wood products sector. Of its 8,184 establishments, 80 percent employ fewer than 21 people, ' Over 50 percent of the U.S. lumber output is produced by 10 percent of the mills (table 14).

Lumber production is concentrated in the South and the West, where most of the softwood, sawtimber growing stock is located. While the South contains more sawmills than the West, its mills generally are much smaller. The West produces over two-thirds of the lumber output (table 15). Mills in the North and East produce only 6 percent of the annual lumber output.

The plywood and panel products industries are more concentrated than the lumber industry and have fewer mills. Their 232 softwood veneer and plywood mills, 366 hardwood veneer and plywood mills, and 68 particleboard mills employ about 77,000 people,

Because construction, like lumber, depends on high-value, large softwood logs, the South and West are major plywood-producing regions. In 1979, the South and West produced 42 percent and nearly 47 percent, respectively, of [J. S. plywood manufactured; the remainder was produced in the northern Rocky Mountain States. Plywood production has been shifting to the South since the early 1960's, primarily because of its lower wood prices.

In 1979,96 percent of the panel manufacturing capacity was in plywood. A few plywood plants also produced corn-ply, a structural panel with veneer faces and a particle core. Only two waferboard plants existed in the United States in 1980, although there were plans to add several more plants between 1981 and 1983 in the Great Lakes States or Maine.[8] Unlike the plywood and lumber industries, which require sawtimber-quality trees, composite structural panels use hardwoods; small, lower quality trees; and, occasionally, mill waste. The nonplywood panel products industry, therefore, probably will continue to be concentrated in the East, particularly in the Great Lakes States, and the Northeast, where major construction markets are located,

[5] USDA Forest Service, *An Analysis of the Timber Situation in the United States 1952-2030,* review draft, 1980.

[6] U.S. Department of Commerce, Bureau of Industrial Economics, *1982 U.S. Industrial Outlook for* 200 *Industries With Projections for 1986* (Washington, D. C.: U.S. Government Printing Office, January 1982].

[7] See note 6.

[8] Kidder, Peabody and Co., 1 nc., "Corn-ply, Waferboard, Oriented Strand Board: Revolution in the Structural Panel Market?", Dec. 24, 1980.

Table 11.—Domestic Consumption of Lumber and Panel Products, 1976

End-use	Lumber			Plywood			Other panel products				
	Million board feet	Tons (million)	Percent of total lumber	Million ft² (3/8" basis)	Tons (million)	Percent of otal plywood	Million ft² (3/8" basis)	Tons (million)	Percent of total panels	Total tons (million)	Percent of total wood use
Construction	25,246	26.8	59.4	13,580	7.6	66.1	6,795	4.5	50.6	38.9	59.4
New residential	16,555	17.6	39.0	8,410	4.7	40.9	3,540	2.3	25.8	24.6	37.6
New nonresidential	3,001	3.2	7.1	1,825	1.0	9.7	2,160	1.4	15.7	5.6	8.5
Upkeep, repair, and maintenance	5,690	6.0	13.3	3,350	1.9	16.5	1,095	0.7	7.9	8.6	13.1
Railroad and other ties	1,220	1.3	2.9	—	—	—	—	—	—	1.3	2.0
Manufacturing	4,300	4.6	10.2	1,550	0.9	7.8	3,480	2.3	25.8	7.8	11.9
Household furniture	2,540	2.7	5.9	700	0.4	3.4	—	—	—	—	—
Commercial furniture	260	0.3	0.7	220	0.1	0.9	—	—	—	—	—
Other	1,500	1.6	3.5	630	0.4	3.4	—	—	—	—	—
Shipping	6,900	7.3	16.2	738	0.4	3.4	—	—	—	7.7	11.8
Containers	1,140	1.2	2.7	318	0.2	1.7	—	—	—	—	—
Pallets	4,900	5.2	11.5	400	0.2	1.7	—	—	—	—	—
Dunnage, blocking bracing	860	0.9	2.0	20	<0.1	<0.1	—	—	—	—	—
Other	4,785	5	3	4,638	2.6	22.6	3,248[a]	2.1	23.6	9.8	15.0
Total	42,451	45.1	100.0	20,511	11.5	100	13,523	8.9	100	65.5	100

[a]Includes shipping

SOURCE: Adapted from *An Analysis of the Timber Situation in the United States 1952-2030*, USDA Forest Service (1979), review draft.

Table 12.—Selected Statistics on the Lumber and Panel Products Industry, 1981

Establishment	Value of product shipments (millions of dollars)	Value added (millions of dollars)	Number of establishments	Number of employees (thousand)
Sawmills and planing mills (SIC 2421)	$11,765.7	$5,552.2	7,544	151.0
Softwood veneer and plywood (SIC 2436) .	3,270	1,460	256	40.8
Hardwood veneer and plywood (SIC 2435)	1,200	430	321	21,3
Particleboard ., ...	545	225	63	6.2

SOURCE: U.S. Department of Commerce, *1982 U.S. Industrial Outlook for 200 Industries With Projections for 1986*

Table 13.—Number of Primary Timber-Processing Establishments in the United States, by Industry and Type of Organization, 1972

Industry	Single-unit companies		Multi unit companics		Total	
	Number	Percent	Number	Percent	Number	Percent
Lumber manufacturing.	21,554	95	1,132	5	22,686	100
Plywood and veneer manufacturing	332	54	276	46	598	100
Woodpulp manufacturing	82	25	249	75	331	100
Other primary timber manufacturing	4,081	86	679	14	4,760	100
Total establishments	26,039	92	2,336	8	28,375	100

[a]Single-unit companies operate at only one location
[b]Forest Sew Ice estimate based on Bureau of the Census data

SOURCE U S Department of Commerce, Bureau of the Census, Census of *Manufactures, 1972 Volume/ Subject and Special Statistics* (Washington, D C U S Government Printing Office, 1976)

Table 14.— Lumber Production by Mill Size, 1979

Mill size (Million board feet)	Number of mills	percent	Production (million board feet)	Percent
Over 50	151	10	17,920	55
25-50, ...	189	13	6,691	21
10 - 25 ...., ...	288	20	4,588	14
5 - 10 ...., ...	272	18	1,908	6
3- 5	233		911	3
Other.	334	23	478	1
Total	1,467	100	32,496	100

SOURCE 1981 Directory of Forest Products Industry

Table 15.— Large Mills and Production by Region and Size

Production range (million board ft)	Number of mills		
	West	South	North and East
Over 50. . . . .".	115	32	4
25-50	118	66	5
10-25	114	136	38
5-10	42	158	72
3- 5	27	112	94
Other	57	100	177
Total	473	604	390
Total production	22,131	8,287	2,078
Percent of total output	68	26	6

SOURCE 1981 Directory of the Forest Products Industry

Use of Solid Wood and Panel Products

Three sectors of the lumber and wood products industry group are among the 45 rapid-growth industries whose compound annual growth rates ranged from 6 to 20 percent between 1972 and 1978: 1) wood pallets and skids; 2) wood kitchen cabinets; and 3) structural wood members, such as laminated or fabricated trusses, arches, and other structural members of lumber (not including standard softwood or hardwood dimension lumber). Although three-fourths of the rapid-growth industries attributed their success to new product development, of the three rapid-growth, wood-using industries, only "structural wood members" listed new products as a key growth factor.[9] Two of these new products, laminated beams and roof trusses, actually were introduced into the market during the 1950's.

Two new developments, however, are trusses that can be used to frame entire houses and techniques for producing laminated beams, joists, and girders of many sizes and shapes. Such large, laminated beams and arches, frequently bent into specified shapes, have penetrated new markets, including the construction of large indoor sports arenas, convention centers, and domes. Trusses, on the other hand, have not opened many new markets for wood products but have replaced larger dimension lumber in light frame construction.

Other new products recently introduced include various types of fiberboard and particleboard. A medium-density fiberboard (MDF), first produced in the mid-1970's, has rapidly expanded into furniture corestock markets formerly held by particleboard and other panels. New types of particleboard include panels made from strands (thin shavings or slivers of wood), flakes, or wafers, sometimes with veneer faces. These panels, first introduced in Canada and the United States in the mid-1970's, now strongly compete with softwood plywood for structural use.

The amount of lumber used in homes has remained fairly constant for several decades, while the amount of plywood and structural panels has increased. Panels for sheathing (walls) have replaced sheathing lumber. Now, however, plastic-foam sheathing is replacing wood-based sheathing in some markets owing to its superior insulation properties. New pane] products are expected to replace plywood for sheathing and underpayment (floors). The same trend seems to have occurred in furniture manufacturing, where plywood and particleboard have replaced lumber as furniture corestock and have themselves been replaced by MDF.

Shipping pallets have been replacing wood boxes and containers for materials handling. New types of pallets, made with plywood decking, particleboard, or MDF, are expected to replace some of the existing hardwood lumber pallets in the future.

In general, new products introduced by the lumber and panel industries replace other wood products already in use, rather than compete with other materials. If the forest industry hopes to expand the uses of wood, it probably will have to develop new products that can compete with steel, aluminum, plastics, and other structural materials, rather than products that simply replace other wood products. This probably will require greater interaction of other professions involved in the construction industry: building code offices and testing organizations, architects, and building contractors.

[9] U.S. Department of Commerce, op. cit.

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Industry Trends and Potentials

Most of the wood (over *96* percent in 1976) entering mills for primary processing is used as products or as an energy source. Wastes from lumber and veneer or plywood mills are used for fuel or for manufacturing particleboard, composite panels, pulp, or paper.[10] While the wood products industry as a whole is quite resource-efficient, opportunities for increasing efficiency still exist in three areas: 1) increasing the recovery of high-value primary products (lumber, plywood, particleboard); 2) expanding the use of underutilized species, wood residues, and defective materials now left in the woods after harvest; and 3) increasing the efficiency of the end use of wood products.

Product Recovery

The efficiency of product recovery in lumber mills, described as the “lumber recovery factor” (LRF), is measured by the number of board feet (12 inches by 12 inches by 1 inch) of lumber recovered from a cubic foot of log. Because the nominal dimensions of finished lumber are larger than the actual dimensions (a standard finished 2- by 4-inch stud, for instance, measures approximately 1½ by 3½ inches), there are actually 16, rather than 12, board feet of lumber in a cubic foot of solid wood,

Lumber recovery efficiencies in the United States currently average about 41 percent (LRF of 6.5). With new technologies and processes, the product recovery in lumber mills could reach 60 to 88 percent (LRF of 10.0 to 13.0) for medium-sized logs.[11] The product recovery in plywood mills averages around 50 percent. New processes may improve efficiency slightly by enabling the use of materials which at one time were rejected as veneer stock. Finally, product recovery in particleboard, composite panel, and fiberboard mills approaches 75 percent on a weight basis.[12] Improvements are aimed at reducing processing time, improving panel quality, and increasing automation.

Since 53 percent of the wood entering sawmills is used to manufacture particleboard, fiberboard, paper, or energy, any increase in lumber output for one use tends to reduce the amount of wood available for other uses. These tradeoffs can be important in balancing lumber recovery efficiency with other production processes, including the need for energy.

Forest Resource Use

The forest products industry continually seeks ways to use a larger proportion of the woody biomass left in the forest after the marketable material is removed, Softwoods, which are intensively utilized, could provide even more wood material if the tops, limbs, branches, and dead, dying, or defective timber were used. The volume of dead and dying timber in 1977 was estimated to be 21 ft^3—almost double the amount harvested—and the volume of residues left from logging came to 8 billion ft^3 in 1976. New products and technologies, particularly in composite panel manufacture, could use these materials, although the amount that would be economically recoverable is unknown. As second-growth timber replaced old growth and utilization standards changed, the lumber and panel industries adjusted their processes to use smaller logs. This trend probably will continue, Moreover, as the price of high-quality softwood stumpage increases, advances in lumber processing and the development of composite panel products have increased the industry's ability to use the vast and largely untapped U.S. hardwood species.

[10]Mill wastes are no longer viewed as acceptable sources of wood for structural panel manufacture, Engineered panel products require roundwood to produce high-quality flakes of specified dimensions.

[11]Jerome Saeman, “Solving Resource and Environment Problems by the More Efficient Utilization of Timber, ” *Report of the President's Advisory Panel on Timber and the Environment,* April 1973.

[12]Personal communication with John Haygreen and Jay Johnson with OTA staff member Julie K, Gorte.

Efficient End Use of Wood Products

The greatest opportunity to increase the efficiency of wood use may be in construction. Current techniques could reduce substantially the amount of wood used for home construction—particularly in single-family detached dwellings–without reducing the quality of the structure. Two developments are particularly noteworthy: 1) truss framing and 2) engineered panel assemblies, which combine sheathing and framing. Increased use of single trusses to frame floors, walls, ceilings, and roofs together could yield greater wood savings. Some analysts estimate that truss framing could achieve as much as 30 percent reduction in lumber use over conventional construction practices.

Engineered assemblies or stressed-skin panels used for floors, walls, or ceilings, which combine sheathing and framing in sandwich panels or with adhesives, also may increase efficiency of wood use. Such assemblies are factory-built, as are trusses, and their use could reduce the wood wastes on construction sites from cutting and custom fitting, resulting in less wood use while providing structural strength and stiffness.

Improvements in wood use in manufacturing and shipping are more limited. Major improvements probably exist in the manufacture of particleboard pallets or of pallets with plywood or composite-panel decking. Although construction techniques now being used may produce a more durable and versatile pallet, they probably will not replace traditional pallets to any significant extent. Conventional pallet manufacture requires lower capital investment than particleboard facilities.

Lumber Products

Lumber products are of three basic types: 1] dimension lumber, 2) boards and finish lumber, and 3) timbers. Boards* and finish lumber are less than 2 inches thick and 1 inch or more in width. Dimension lumber is between 2 and 5 inches thick and at least 2 inches wide. Lumber that is 5 inches or more is classified as a timber.

Softwood dimension lumber, the mainstay of the lumber industrv, is manufactured in five types of sawmills: 1)small-log mill; 2) stud mill; 3) large, common-log mill; 4) large, grade-log mill; and 5) high-deduct, 1arge-log mill. Distinguishing factors among these sawmill types are log diameter and type of lumber product (table 16). The most common mill is the small-log mill, which produces dimension lumber for light frame construction.

* For purposes of this report, the term "hoard" is used only in reference to panel products. One-inch lumber will be referred to as "finish lumber."

Table 16.—Types of Softwood Sawmills and Their Primary Products

Sawmill type	Typical log diameter	Primary products produced
Small-log dimension mill ., .. .	5" to 16"	Random length dimension lumber
Stud mills, ... , ... ,	4" to 9"	Studs 2" x 4" X 8' nominal
Large, common-log mill ... ,	16" to 30"	Random length dimension lumber
Large, grade-log mill ., ...	15" and larger	Common, shop, and clear lumber
High-deduct, large-log mill . .	Large logs with greater than 30 percent deduct[a]	Clears and high-grade commons

Adapted from Williston 1976.

[a]Deduction in recoverable lumber volume due to defects in the logs

SOURCE Envirosphere Co Wood *Its Present* and *Potential Uses* contractor report to OTA 1982

Lumber Manufacture

The basic processing steps for lumber manufacturing are shown in figure 8. Materials and energy flows of a typical sawmill are shown in figure 9. The efficiency of lumber recovery tends to vary with mill size, with larger mills achieving higher recoveries.

Potential Improvements in Milling Efficiencies and Lumber Manufacture

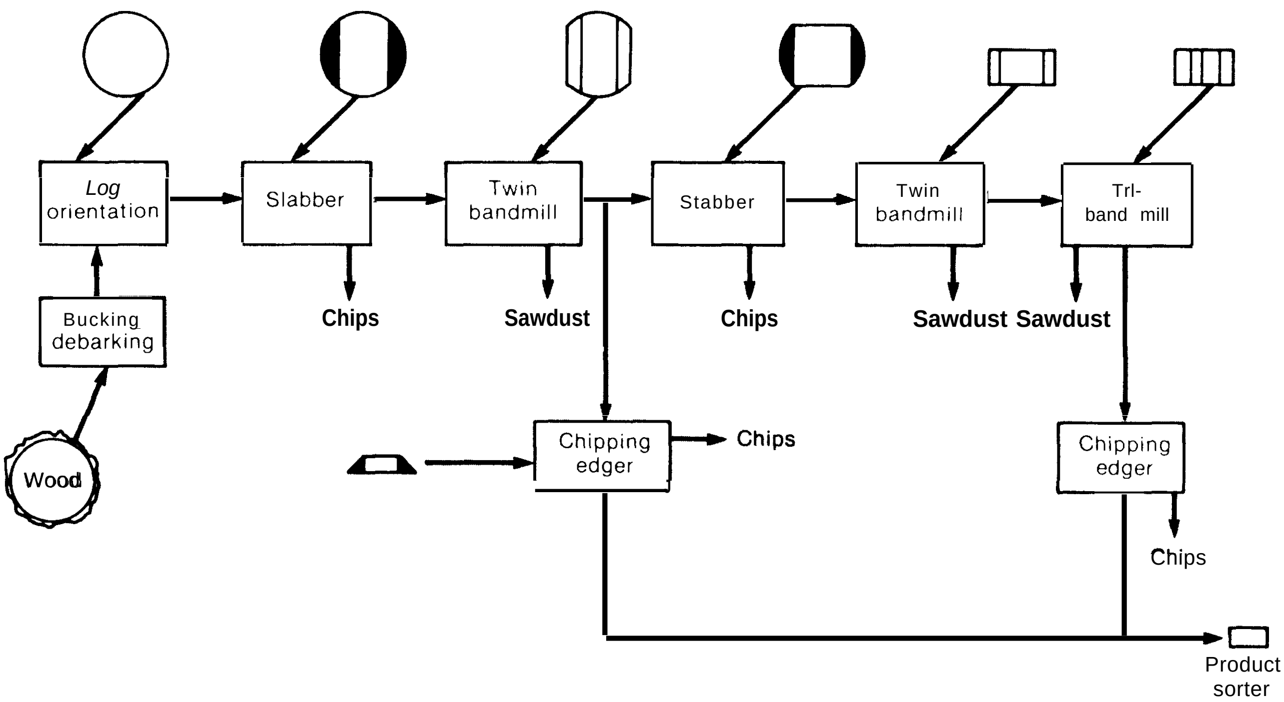
In 1979, lumber constituted almost 70 percent of the weight of all lumber and panel products produced in the United States and 53 percent of all wood products, except pulp and paper, consumed in that year.[13] Thus, even small improvements in milling efficiency can result in significant savings of the Nation's timber resources, particularly softwood. Several such improvements can be made in lumber manufacture by: 1) improving lumber recovery or wood-use efficiency in sawmilling, 2) decreasing energy requirements, and 3) improving grading procedures.

[13]USDA Forest Service, *U.S. Timber Production, Trade, Consumption, and Price Statistics, 1950-1980,* Miscellaneous Publication No. 1408, 1981.

Improving Lumber Recovery and Wood Use

The following existing technologies probably have the potential to more than double the efficiency of converting roundwood into lumber products (table 17). By installing or adopting technologies such as BOF, PLV, and SDR, the efficiencies of sawmills probably could be increased substantially, The potential increase in lumber recovery efficiency for PLV, EGAR, and BOF is shown in figure 10. In addition, several new technologies, such as SDR, corn-ply, and composite lumber, probably can reduce

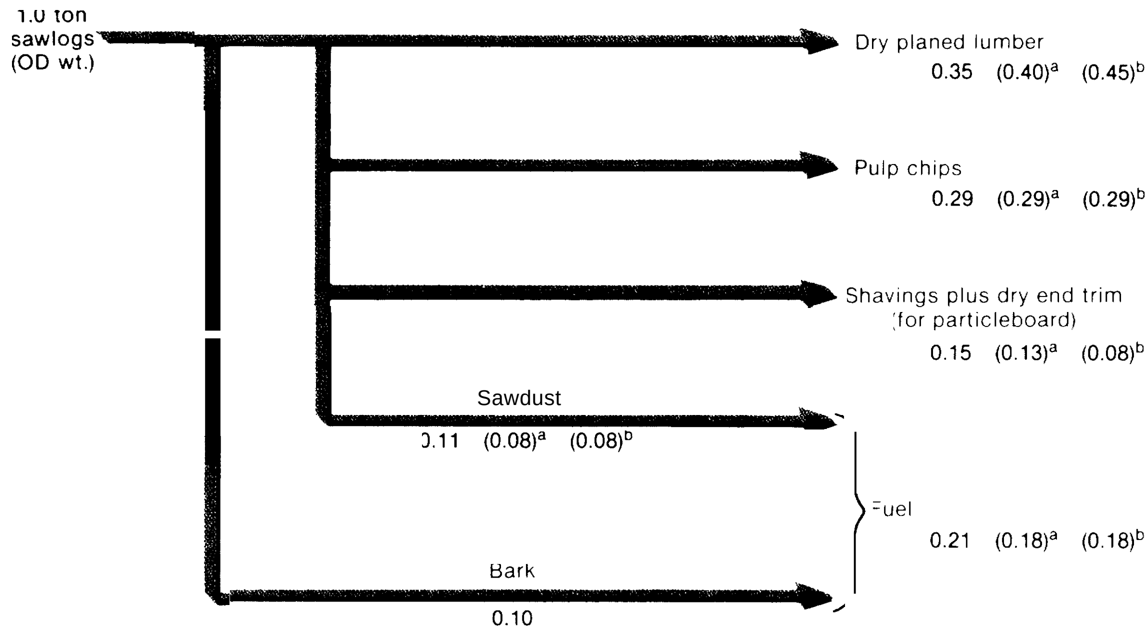
Figure 8.— Flow Diagram of a Typical State-of-the-Art Small-Log Sawmill, Indicating Process Waste Streams



NOTE" A log profile is shown at each machine (top) The shaded areas Indicate material which is chipped away, whvertical lines in other cross-sections indicate saw lines

SOURCE" E M Williston, *Lumber Manufacturing: The Design and Operation of Sawmills and Paper Mills* (San Francisco. Miller Freeman Publications, 1976).

Figure 9.— Present and Predicted Materials Balance for Softwood Lumber Based on Ovendry Weight (OD wt.) (sawlog weight includes bark)



[a]Predicted product and byproduct recovery by 1985.
[b]Predicted product and byproduct recovery by 2000.

SOURCE: C. W. Boyd, et al., "Wood for Structural and Architectural Purposes," *Wood and Fiber* 8(1):1-72, 1976.

the lumber industry's dependence on high-value softwood timber, whose scarcity (deflated price] has increased at the rate of about 2 percent per year (compounded) over the last century. The SDR process and the manufacture of composite lumber and timbers allow manufacturers to utilize hardwoods, defective timber, and wood residues formerly considered unmerchantable,

Expanding the resource base by using larger proportions of the wood produced in the forest is one of two major opportunities that exist to improve total utilization efficiency of wood in the United States. The other is increasing the efficiency in the way lumber is used (conservation). However, increasing the efficiency of mills may not significantly reduce the demand on the forest resource, unless increasing amounts of forest residues can be harvested economically and transported to mills. For example, the efficiency of lumber recovery may reduce the amount of residue available to produce energy, and pulp, paper, particleboard, and other fiber-based panels. Nationwide, the unused wood from primary processing consists of 52 percent softwoods and 48 percent hardwoods and represents 7.1 million tons of material, A significant portion of this material probably comes from lumber manufacturing, although the exact quantity is unknown.

Improving Yields in Traditional Sawmills

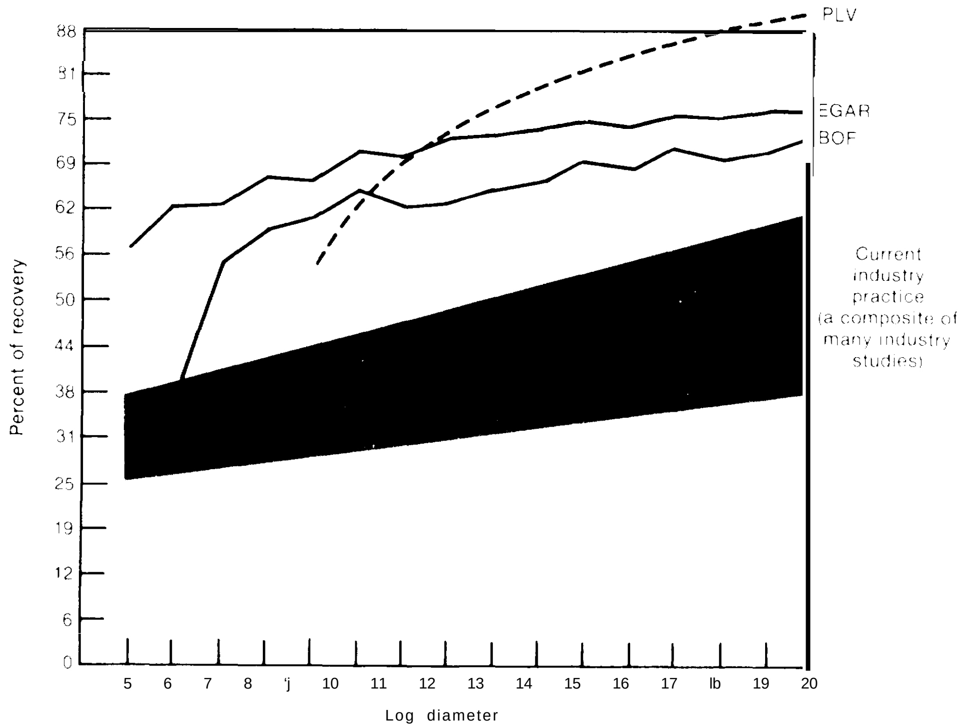
There is a practical limit to the amount of lumber that can be recovered from any log, However, some new processes can increase the lumber-recovery efficiency of dimension lumber without major sawmill modifications; e.g.: 1) the BOF program, which can produce higher grades and increase recovery of lumber; 2) the SDR process, which enables the use of hard-

Table 17.—Summary of Major Technologies for Improved Lumber Manufacture

Technology	Stage of development	Effect on resource base	Effect on recovery	Barriers to implementation	Estimated time scale to significant contribution
BOF	Commercially available	None	Theoretical increase of 20°/0 over conventional sawmilling.	Field results have shown average 40/0 Increase over conventional sawmilling.	0
EGAR	Process IS developed; no significant commercial use.	Possible increased small log utilization,	Increases recovery 10-130/0	More costly to manufacture; more labor-intensive.	15-20
SDR	Process is developed; no significant commercial use.	Increased hardwood utilization.	Reduces defects in hardwood lumber; increases lumber value.	Higher drying costs; requires high-temperature kilns.	10-20
MSR	Commercially available.	None	Reduces variability within lumber grades, allowing more efficient use of lumber in construction.	Modification of codes to allow most efficient use of MSR lumber.	0-5
PLV Lumber	Commercial availability limited to a few specialty products.	—	Theoretical yield of 70-90°/0	Development of continuous laminating presses; lack of accepted method for assigning product strength values; requires new milling facilities.	15-20
Corn-Ply Lumber	Not commercially available	Allows use of hardwoods, wood residue, defective wood.	Theoretical 95% recovery,	Requires new milling facilities or combination of veneer and particleboard facilities,	15-20
Improved Drying (solar kilns, high temperature drying, vapor recompression, dehumidification)	No significant commercial development.	—	Lower energy requirements; reduction in defects.	Usually higher capital investment and/or longer drying time.	15-25

SOURCE: Office of Technology Assessment

Figure 10.—The Maximum Yield of Lumber From Conventional and Innovative Processes



SOURCE: Jerome Saeman, "Solving Resource and Environment Problems by the More Efficient Utilization of Timber," *Report of the President's Advisory Panel on Timber and the Environment*, April 1973

woods, previously limited by their tendency to warp; and 3) the EGAR process, which reduces waste and can produce higher quality lumber,

Best Opening Face.—The initial sawline, or the opening face cut, sets the position of all other sawlines and therefore has a significant effect on lumber recovery efficiencies and grades. Deciding how to make the initial cut often is left to the judgment of the head saw operator. While a skillful operator can achieve high efficiencies, a computer can simulate various sawing patterns and more quickly choose the optimal opening face. The BOF, a computer program for selecting the best first cut, was developed by FPL nearly 10 years ago. In 1973, the Forest Service initiated a sawmill improvement program to demonstrate the BOF concept. Under laboratory conditions, BOF yields 6 to 90 percent more lumber from 5- to 20-inch logs and averages 21 percent more lumber recovery than does conventional sawing.

Saw-Dry -Rip .—The SDR process can increase the amount of sound, defect-free lumber recovered from hardwood timber by modifying slightly the conventional milling practices of sawing, ripping into lumber, and then drying, With SDR, crooks, bows, and twists in hardwood lumber may be reduced by first sawing, then high-temperature drying, and finally ripping" into lumber. Drying larger pieces at high temperatures by SDR minimizes the effect of the stresses that develop within wood as it grows, SDR may result in a lower LRF of green (undried) lumber than conventional milling, but this is generally more than compensated for by the reduction in warp.

Edge-Glue and Rip.—With EGAR, logs are sawn into flitches* * and lightly edged prior to drying.

* Ripping is sawing lengthwise, or parallel to grain, along the longitudinal axis of the lumber,

* * A flitch is a crosswise slice from a log, with two sawn faces and two rounded, or unsawn edges.

They are then glued edgewise into panels, and the panels are ripped into lumber. This reduces the amount of wood lost in edging, which usually sacrifices some sound wood from lumber edges in order to produce solid lumber of standard widths. Ripping can be done to yield the highest grade and strongest lumber by avoiding knots near the edges of the lumber. The EGAR process theoretically can increase lumber recovery from 35 to 77 percent from logs of 5 to 20 inches in diameter.[14] It is estimated that EGAR can increase the output of finished dimension lumber by 10 to 13 percent by eliminating edging loss.[15] Moreover, EGAR lumber has greater strength and less warp than standard lumber. However, the process itself is more labor-intensive than conventional lumber manufacture and requires additional drying, which may increase manufacturing costs.

Several new lumber-drying processes that could reduce energy consumption may come into wide use in the future, Because the lumber industry is a small energy consumer, savings in energy use by the lumber manufacturing industry probably will not contribute significantly to national energy conservation; they could, however, become more important to lumber manufacturers as energy prices increase. (The lumber industry, however, is a minor energy purchaser and is capable of producing much of its own energy through the use of mill wastes.)

Producing Composite Lumber and Timber Products

BOF, SDR, and EGAR are marginal modifications to conventional sawmilling. Lumber, or lumberlike products, also can be made from wood particles or veneer, as well as from solid wood or edge-glued pieces, Manufacturing such composite lumber can dramatically increase lumber recovery efficiency and extend the timber resource base through use of wood waste material and hardwoods, It is unlikely, however, that composite lumber products will replace conventional 2 by 4 framing lumber.

[14]Saeman, op. cit.

[15]George B. Harpole, Ed Williston, and Hiram H. Hallock, "EGAR Process Makes Wide-Dimension Lumber From Small Logs, " *Southern Lumberman*, Dec. 15, 1977.

Most opportunities for using composite lumber are in larger applications—for girders and beams-or for specialty applications. Two major processes have been developed to manufacture composite lumber and timber products: PLV and corn-ply.

Parallel Laminated Veneer.—Also known as press-lam and laminated veneer lumber (LVL), the PLV process consists of laminating (gluing) veneers with all plies parallel (as contrasted to plywood, where the veneers are laminated with grains perpendicular) to make dimension lumber or timbers. Like plywood veneers, the veneer sheets are press-dried, coated with adhesives, laminated in overlapping fashion, pressed, and ripped to desired dimensions. PLV has a number of advantages:

- it produces high-quality products from low-quality raw material or hardwoods;
- lumber or timber dimensions are not limited by log size; and
- it can convert logs into ready-to-use products in 1 hour.

In general, PLV produces higher grade lumber than does conventional lumber manufacturing. Moreover, PLV specialty products and large structural timbers from PLV might be attractive commercially; at least one firm now markets a joist, called Micro-Lam, * made from PLV. PLV also can be used to manufacture nonstructural wood products like millwork and cabinetry. Lumber recovery efficiency from PLV can be increased from an efficiency of 53 to 91 percent for 9- to 20-inch logs, an efficiency significantly greater than that theoretically attainable from any other lumbermaking process.

Despite its advantages, PLV may not make significant penetration into conventional dimension lumber markets in the near future. PLV manufacture requires equipment that cannot readily be adapted to conventional sawmills; thus, shifting to PLV probably will require entirely new mills with high capital costs. As existing sawmills are depreciated, PLV facilities may be built as replacements, particu-

*Trademark of the Trus-Joist Corp.

larly if real stumpage values increase and if building codes are modified to recognize fully the superior properties of PLV lumber. However, it may be possible to modify plywood or panel mills to produce composite lumber and products such as composite timbers (beams, joists, arches, girders, and the like), The substitution of composites for dimension lumber may occur slowly unless the price of high-quality softwood logs significantly increases. PLV can be used for large structural elements, such as beams or timbers, that vary in cross section across their length to meet strength requirements.

Com-ply.—Com-ply consists of a structural composite core, like particleboard, with veneer faces. It can be made into studs, larger dimension lumber, or panels. Corn-ply studs are strong enough to substitute for standard studs on a one-for-one basis in exterior house framing. The particleboard core constitutes 70 to 80 percent of the product and can be made from hardwoods. Because a corn-ply mill can use nearly all of its residues to produce the core material, it can operate with only 5 percent waste, a lumber-recovery efficiency of 95 percent. Economic analysis of corn-ply lumber production shows, however, that it is unlikely that corn-ply lumber will be very competitive with either conventional or PLV lumber,

Decreasing Energy Requirements

Up to 90 percent of the heat energy required in lumber processing is consumed in drying lumber to a moisture content of 13 to 16 percent. Lumber normally is dried in a steam kiln (although air drying is used sometimes) in which heated air is circulated. Kilns may be heated by natural gas or propane directly or, more commonly, by steam coils. Softwood lumber requires from 2 million to 4 million Btu/ thousand board feet while hardwoods require up to 6.5 million Btu. Several new drying technologies have been developed, including: 1) high-temperature kiln drying, 2) continuous-feed drying, 3) dehumidification, 4) predrying, 5) pressure drying, 6) solar drying, 7) solar dehumidification, 8) vacuum, 9) vacuum-radio frequency, and 10) vapor recompression drying, Of these, continuous-feed, dehumidification, pressure, solar dehumidification, vacuum, and vapor recompression drying may gain some commercial acceptance by 2000, although none seems likely to replace conventional steam kilns.

Improving Grading and Quality

Dimension lumber is graded according to strength and stiffness, Grades determine what end uses may be made of construction lumber, Improved grading systems are being developed to better determine the end-use properties and characteristics of lumber and thereby avoid overbuilding with lumber products or using high-quality material where lower grades are suitable. Because different defects such as twist, bow, crook, rot, or knots affect mechanical properties differently, current practices of visual grading often result in a wide variability in lumber properties within each grade. Builders often use lumber of better quality than is needed for construction to account for this variability in meeting building codes and avoiding liability.

Improved ability to determine the strength and stiffness of lumber, together with building code acceptance of better design practices based on more precise grading, could result in significant resource savings. Since lumber strength is related to the presence of knots, a system that can determine precisely the effect of each knot on each board would be quite valuable. As yet, it is unavailable, Another development that could aid in making more efficient use of framing lumber is a more precise understanding of the strength required in end-use applications, so that lumber strength can be matched to design specifications. Two major efforts are under way to improve grading in the United States: 1) MSR, an alternative grading technology; and 2) ingrade testing, a research program,

Machine Stress Rating is a mechanical grading system that measures lumber stiffness in a nondestructive, stress-rating machine. It does not eliminate the use of visual grading but instead gauges the stiffness before visual graders determine the grade based on defects.

MSR lumber, with a narrower range of variability than visually graded lumber, reduces the amount of high-quality lumber needed to meet particular design specifications. The primary market for MS R-graded lumber is in truss fabrication, where lumber is used for roof, floor, and wall framing. The amount of lumber that could be saved using MSR varies and depends on the design of the truss.

The **In-Grade Testing** Program was initiated in l977 by FPL to develop more precise data on mechanical properties of various grades and species of lumber and to assess the importance of these properties on the design and engineering of structures. Tests of walls, floors, and full scale indicate that houses generally are overdesigned. Information from the In-Grade Testing Program may be used in conjunction with engineering structural analysis to improve the efficiency of lumber use in light frame construction.

Consumption and Use of Lumber Products in the United States

Lumber consumption in the United States has been relatively stable for several decades, increasing from just over 5 billion ft^3 in 19.50 to almost 6 billion ft^3 in 1979.[16] At the same time, per capita consumption of lumber has declined by over 20 percent over the past three decades (fig. 11).

Construction (including new residential construction, upkeep, improvement, and nonresidential construction) uses about 60 percent of all lumber consumed in the United States. The remaining 40 percent is used in shipping, manufacturing, and other uses, with shipping accounting for 43 percent of lumber used for nonconstruction purposes. New residential construction alone accounts for 40 percent of all lumber consumption.

New Residential Construction

Historically, the housing industry has experienced wide swings in residential construction activity, and there are indications that that

[16]See note 2.

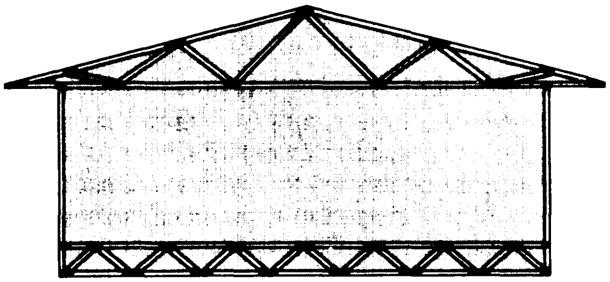
Figure 11.—Per Capita Consumption of Lumber 1950-79

SOURCE: USDA Forest Service, *U.S. Timber Production Trade, Consumption, and Price Statistics*, Miscellaneous Publication No. 1408, 1981.

activity may continue to be erratic and uncertain. An upturn in homebuilding could drive softwood log prices up, increasing the incentives for lumber manufacturers to streamline operations and to increase product yields to remain competitive. Low rates of residential construction could force many small lumber mills out of business, concentrating the industry in the larger mills, which tend to be more efficient. Other developments in the homebuilding industry also affect the lumber industry, such as trends toward smaller houses and multifamily dwellings,

The amount of lumber used per unit depends largely on the type of dwelling constructed and, to a lesser extent, on building techniques and design. Single-family detached dwellings use approximately twice the amount of lumber used in multifamily dwellings and 4.5 times the amount used in mobile homes. Most single-family dwellings and small clustered units (e.g., duplexes) are built onsite. Preassembled lumber products, such as trusses, have successfully penetrated the market for roofs in light frame construction and now account for the majority of roof framing. Floor trusses have been less successful, although they are gaining in acceptance in some areas. Trusses used to frame whole houses (fig. 12) recently have been de-

Figure 12.— The Truss Frame System



This truss framed system combines floor, walls, and roof into a unitized frame for structural continuity from the foundation up to the ridge

SOURCE: USDA Forest Service Forest Products Laboratory

veloped by the FPL and are in limited use today.

Residential Upkeep and Improvement

Home upkeep and improvement accounted for 14 percent of the lumber consumed in the United States in 1976[17] and almost 8 billion board feet of softwood lumber in 1980[18] compared with 4.7 billion in 197o. Indications are that such use may increase. The use of lumber per thousand dollars of expenditures on upkeep and improvement may have declined slightly, however, primarily because of substitution of panel products for lumber.

New Nonresidential Construction

New nonresidential construction accounted for just under 10 percent of the lumber consumed in the United States in 1976 for a range of public, private, and commercial projects. Building construction, including commercial and other buildings, accounted for about two-thirds of the lumber used in new nonresidential construction in the early 1970's.* Total lumber use for new nonresidential construction, which normally responds to general economic activity, is expected to double in the next 50 years, primarily because of economic growth.[19]

Manufacturing

Manufacturing, primarily of furniture, accounted for 11 percent of the lumber consumed in 1976. Much of the lumber once used for corestock has been displaced—first by particleboard, then, more recently, by medium-density fiberboard.

Shipping

Shipping accounted for 17 percent of the lumber consumed in 1976. Two-thirds of the lumber in shipping was used for pallets, with the remainder used for dunnage, blocking, bracing, and wooden boxes. These latter uses have been declining for two decades and are expected to continue declining.

Most pallets are made of low-grade hardwood lumber, usually rough (unsurfaced) lumber. Pallet markets, which consume the majority of the hardwood lumber produced in the United States, expanded rapidly during the 1970's for materials handling, and some further expansion is expected. The rate of increase in industrial pallet use, however, is expected to decline as the market becomes saturated.

[17] USDA Forest Service, *An Analysis of the Timber Situation in the United States 1952-2030*, review draft, 1980.

[18] Chiricotti, Lumber and Plywood Forecasting, Inc., "The Forest Products Industry and the 80's. Think Tank #1," Acapulco, Mexico; Apr. 3-4, 1982.

* Utilities, water and sewer systems, highways, and other nonbuilding construction accounted for the remaining one-third.

[19] See note 5.

Plywood and Panel Products

Panel products are used for many things, mainly in construction, Single-family housing construction uses 43 percent of the plywood and 25 percent of the particleboard and other structural panels produced in the United States (table 18), Panel products also are popular in residential upkeep and repair, accounting for 23 percent of the plywood and approximately

Table 18.—Plywood and Panel Products Consumed in New Residential Construction in the United States, 1962-80

	Type of home (ft², 3/8" basis)		
Year	Single family	Multifamily	Mobile
1962	3,010	1,800	1,840
1970	5,385	1,910	1,300
1976	5,815	3,255	1,610
1978	5,600[a]	2,650	550
1980	5,640	3,105	555

[a]Figures for 1962-76 include only plywood

SOURCES: USDA Forest Service, *An Analysis of the Timber Situation in the United States*, 1952-2030, Review draft, 1980 (Includes figures from 1962, 1970, and 1976)
Thomas P Clephane, *Outlook for Timber Supply/Demand Through 1990*, Morgan Stanely Investment Research, 1982 (Includes figures from 1978 and 1980)

40 percent of the structural panel market in 1976. The remainder is used in manufacturing, shipping, and other uses.

There are three types of plywood and panel products:

- Plywood—a flat panel made of laminated, crossbanded wood veneers, where each layer is arranged with the grain at right angles to its adjoining layers.
- *Structural composite panel—a* panel made of wood particles—e. g., chips, flakes, wafers, and strands—pressed into a flat panel and simultaneously bonded with a thermosetting adhesive.
- *Particleboard—a* nonstructural panel made from small wood particles bonded into a flat panel with adhesives under heat pressure.
- *Fiberboard—a* flat panel made of individual woodpulp fiber (like paper) bonded together. Insulation board and hardboards are special kinds of fiberboards.

Plywood

Current Plywood-Manufacturing Processes

Plywood manufacture consists of two processes: veneer production, and layup and gluing of the veneers into plywood (figs, 13 and 14). The five methods for manufacturing veneers for plywood include: 1) rotary cut, 2) staylog cutting, 3) cone cutting, 4) sliced veneers, and 5) sawn veneers. Over 90 percent of the veneer produced is rotary cut, i.e., peeled on a lathe. Other methods produce specialty hardwood veneers used in furniture and cabinetry.

To produce plywood, the veneer logs first are steamed and then are sent to a lathe that peels off a thin, continuous ribbon of veneer. The remaining core of about 4 to 5 inches subsequently is used for dimension lumber or is chipped to produce pulp and paper, particleboard, or fuel. The veneer sheet itself is cut into sheets by a clipper, which also removes knots and defects. After drying, the veneer is placed on an assembly line, where adhesives (usually phenol formaldehyde) are applied, and the veneers are stacked to form plywood. A typical five-ply plywood layup line can produce 6 to 8 five-ply panels or 12 to 16 three-ply panels per minute. Following layup, a panel is cold-pressed to consolidate it before loading the press, It is then hot-pressed under pressures of about 15o pounds per square inch (psi) at temperatures ranging from 2400 to 3000 F. After the panels cool, they are trimmed and squared, sometimes sanded, and then graded and prepared for shipment,

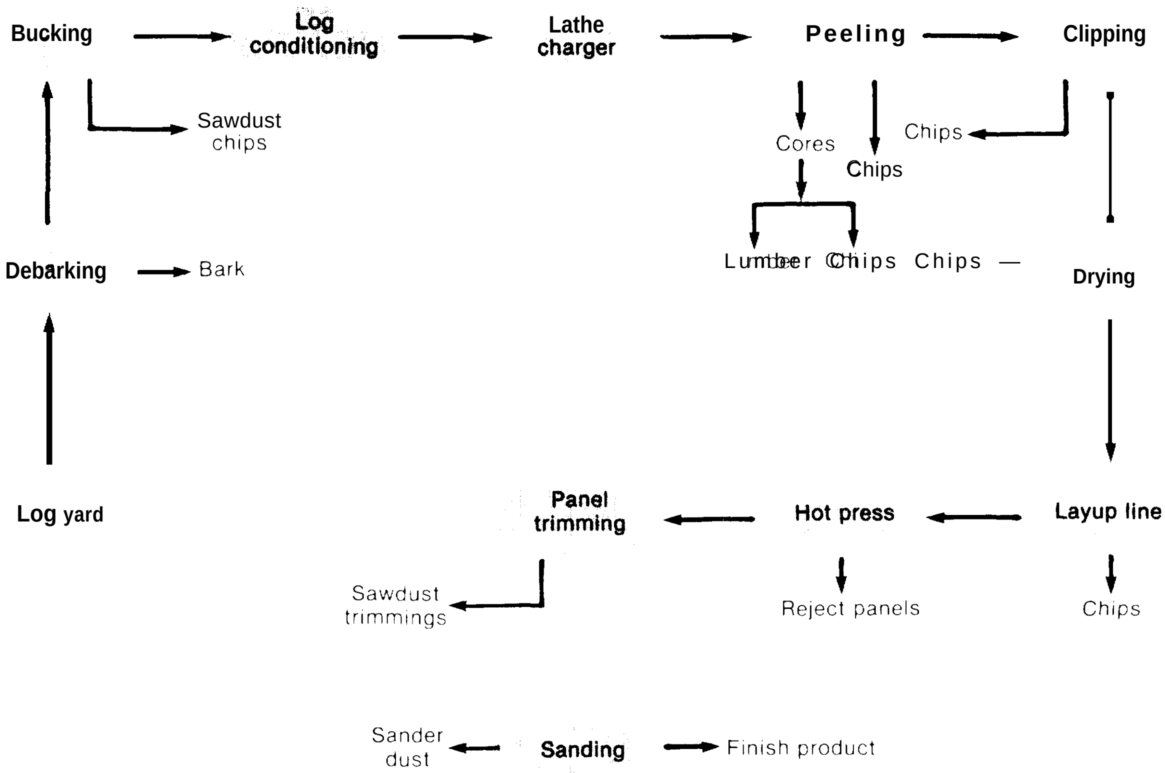
Potential Improvements in Plywood Manufacture

Current plywood recovery rates run between 47 and 53 percent and probably average 50 percent.[20] Less than 1 percent of all roundwood used in plywood manufacture ends up as waste. Residues from plywood mills are used to produce lumber, particleboard, pulp and paper, fiberboard, or energy.

Because plywood mills now are capable of using smaller logs than in the past, increased efforts are being made to use hardwood for structural plywood, Technical developments in plywood manufacture are aimed primarily at: 1] expanding the number of species and quality of the timber that can be used for plywood; 2) increasing automation; 3) reducing energy requirements; and 4) increasing the degree of computer-assisted process control, particularly in peeling and clipping.

[20] See note 8.

Figure 13.— Flow Diagram of a Small-Log Plywood Mill



SOURCE: Envirosphere Co., "Wood: Its Present and Potential Uses," contractor report to OTA, 1982.

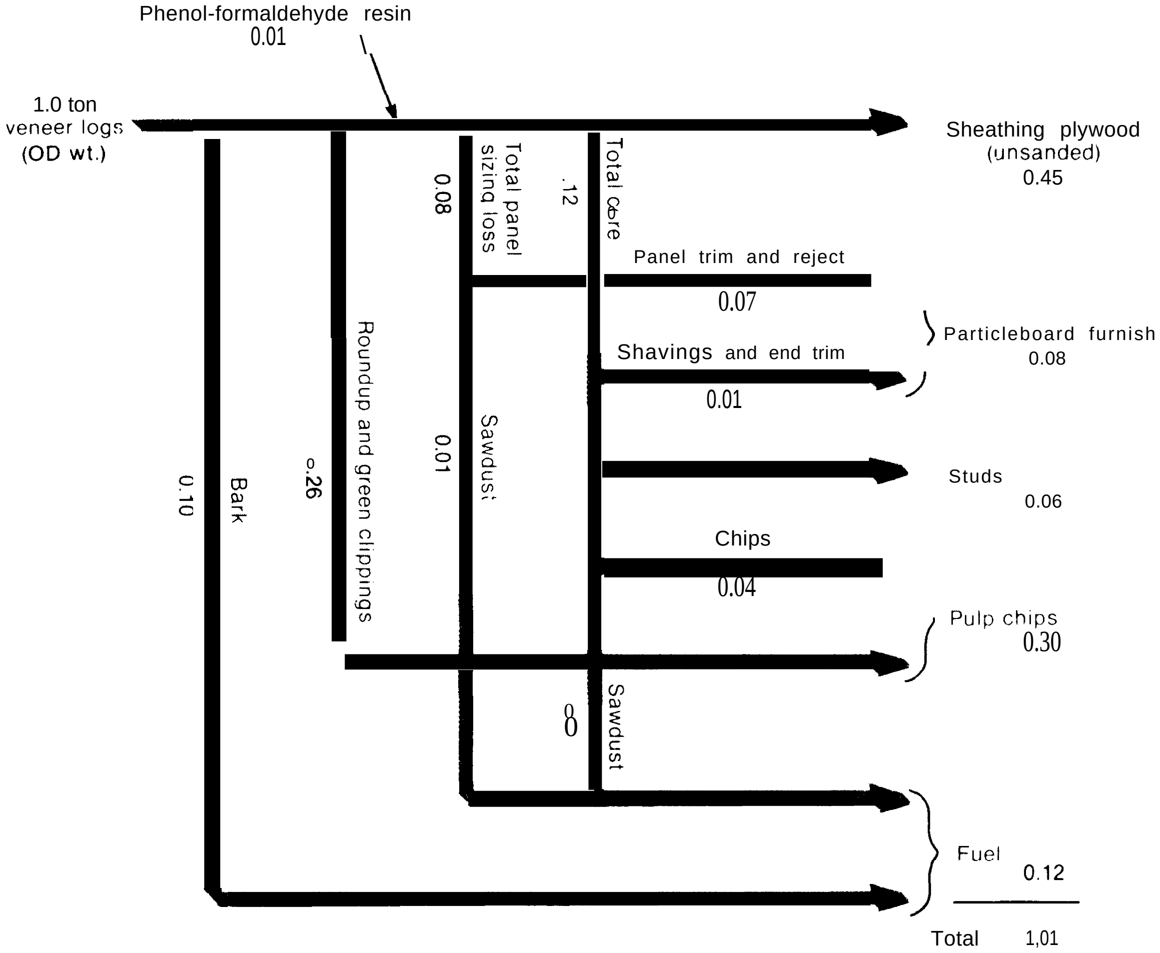
Expanding the Range of Usable Material.–The plywood industry historically has depended on a plentiful supply of large-diameter, straight, rot-free softwood timber. However, over the years, large softwood logs have become very costly, and future supplies are uncertain. As a result, in the early 1960's, the plywood industry began to move to the South, attracted by inventories of largely unutilized Southern pine. By 1980, the South was producing nearly as much plywood as the West, generally using smaller logs. Technology still is being sought to handle and process small logs and expand the range of logs that can be peeled.

Currently, 25 percent of the veneer logs are considered unpeelable.[21] Some mills lose 40 percent of their logs from splintering, cracking, and breakage on the lathe caused by too-small logs or internal defects. Because of the high value of veneer logs, increasing the amount of peelable material can greatly improve the productivity and profitability of the mill. Some techniques used to prevent wood losses include: 1) better chuck design to hold and rotate the logs against the knife; 2) new pressure-bar designs to position the knife on the log; 3) heating the log, which some believe can reduce the torque needed to peel the log; and 4) using backup torque rollers to increase deliverable torque at the lathe.

New types of pressure bars mounted on the lathe to control veneer thickness and peeling performance show some promise, Roller bars produce lower forces needed for peeling than do conventional, fixed bars, but initially cost more and have higher maintenance costs. The recently developed steam-heated, contoured

[21] Frank J Fronszak, "Preventing Veneer Bolt Spinout," *Modern Wood Techniques*, proceedings of the Seventh Plywood Clinic, Portland, Ore., March 1979

Figure 14.—Material Balance for Softwood Plywood Based on Ovendry Weight (OD wt.) (veneer log weight includes bark)



NOTE: The total adds to more than 1.0 because of the resin

SOURCE: C. W. Boyd, et al., "Wood for Structural and Architectural Purposes," *Wood and Fiber* 8(1): 1-72, 1976

fixed bar, however, may be as effective as the roller bars without the high cost.

Increasing the chuck* diameter could increase the amount of peelable roundwood, but larger chucks increase minimum core size as well. Further chuck modification is unlikely to produce significant increases in veneer recovery, and the backup roller was developed as a means of providing this auxiliary torque. Research on the optimum design and location of the backup roller is under way.

Finally, some efforts are being made to explore the potential of hardwoods in structural plywood production. Results of several studies indicate that construction-grade hardwood plywood made from a mixture of high- and low-density species could be competitive economically with softwood construction plywood.[22]

*The chuck is a device which holds the log by its end and turns it against the knife for peeling.

[22]R. W. Jokerst and J. F. Lutz, "Oak-Cottonwood Plywood: No Delamination After Five Years," *Plywood and Panel Magazine* 22(1), June 1981.

Improved methods of drying and seasoning hardwoods could provide additional impetus for hardwood utilization in plywood.[23]

Increasing Automation.—Automating plywood manufacture could increase productivity and reduce labor costs. Automated log handling could reduce handling time and optimize the speed of log processing and panel assembly. Automated continuous clipping, layup, and drying may improve process flow by programing the sequential machine centers to reduce delays, backups, and bottlenecks. Many lathes, for example, are capable of peeling up to 900 ft of veneer per minute, but scanners and clippers may be capable of handling only half that amount.[24]

Increased automation depends heavily on electronics. A number of large mills already are equipped with computers to control routine operations, detect and diagnose problems, and determine causes of downtime.

Another advance in automated log handling, developed by the U.S. Forest Service's Southern Forest Experiment Station, is a unique piece of roundup (bolt preparation) equipment called a shaping lathe headrig. This equipment not only produces flakes for particleboard or pulp manufacture but also produces cylindrical veneer logs in one revolution of the log.[25]

Reducing Energy Requirements.—Higher fuel costs have increased interest in improving veneer drying, recycling waste heat, and conserving heat. Veneer drying is a major cost factor in plywood manufacture, and improved drying processes not only reduce energy use but increase operating speeds.

Continuous veneer drying, with the veneer feeding directly into the dryer and clippers, can reduce labor requirements by 40 percent and achieve about a 4 percent savings in raw materials. **Platen drying,** in which veneer is fed into a merry-go-round of multiopening hot presses, increases recovery by 5 to 15 percent, shortens drying time, reduces the need for additional drying, and reduces the need for process steam by up to 50 percent. Since veneer drying accounts for up to 70 percent of the process steam used in plywood manufacture, platen drying represents a significant advance.

Press-drying can reduce energy requirements as well as speed up processing and produce a flatter and more stable veneer. One manufacturer uses a continuous-platen, press-drying technique in a softwood plywood plant.[26] R&D still is under way to optimize press-drying procedures and schedules.

Fuel costs also can be saved by using mill residue, wood dust, and bark for power generation, a common practice in many plywood mills. One manufacturer reports replacing propane with wood residue (plywood trimmings and scrap) in two dryers, saving over 70 percent in fuel costs. Another manufacturer is converting almost all of its wood sanding dust to energy, thus producing 40 million Btu/h as an auxiliary power source.

Improvements in Plywood Products.—Other advances in panel finishing and veneering may be used to improve the surface qualities of plywood panels, increase the grades and expand the range of materials suitable for plywood manufacture. Polyurethane compounds used as patches to mend knots and other defects permit the use of lower quality wood while allowing for both immediate stacking and production of panels with fewer flaws. Recently, modifications in films and overlays used to finish plywood have made it possible to surface plywood in many colors and textures and to improve surface durability. Another new development is that of a fiber mat, tradenamed Fibron, to replace the face and back veneers of plywood. Fibron surfaces can be printed or textured to produce panels for high-quality furniture manufacture.

[23]Walton R. Smith, "New Horizons in Hardwood Utilization," manuscript for presentation at Forest Products Utilization Research Conference, Forest Products Laboratory, Madison, Wis., Oct. 19-21, 1982.

[24]Robert Stone and George A. McSwain, "Wood-Based Panel Products: A Changing Industry in the United States," *Unasylva* 32(127), 1980.

[25]George A. McSwain, "Technical Developments in the Wood-Based Panel Products Industry," Food and Agriculture Organization of the United Nations, November 1978.

[26]See note 25.

Particleboard

Current Particleboard Manufacturing Processes

Other than plywood, most structural panels currently manufactured in the United States are particleboard made from a variety of wood particle types. The basic steps involved in standard particleboard manufacture (called dry-forming), are shown in figures 15 and 16, During the process, wood first is reduced to the desired particle geometry by flaking, disking, hogging, or hammermilling. The particles are dried using rotary-drum dryers or horizontal fixed dryers and classified according to size, They are blended then with adhesives and waxes and formed into a mat, sometimes with coarse particles at the core and finer particles at the surface. [27] The mat then usually is hot-pressed to the desired thickness and density, allowing the adhesive to cure. Panels then are cooled, trimmed, sanded, and graded.

A small proportion of the particleboard produced is wet formed, or extruded, wherein adhesive-coated particles are forced through a hot die. The extrusion process produces a particleboard that is weak in bending and stiffness and low in dimensional stability and generally is used for specialty purposes. To overcome strength problems, extruded particleboard often are honeycomb-shaped or fluted,

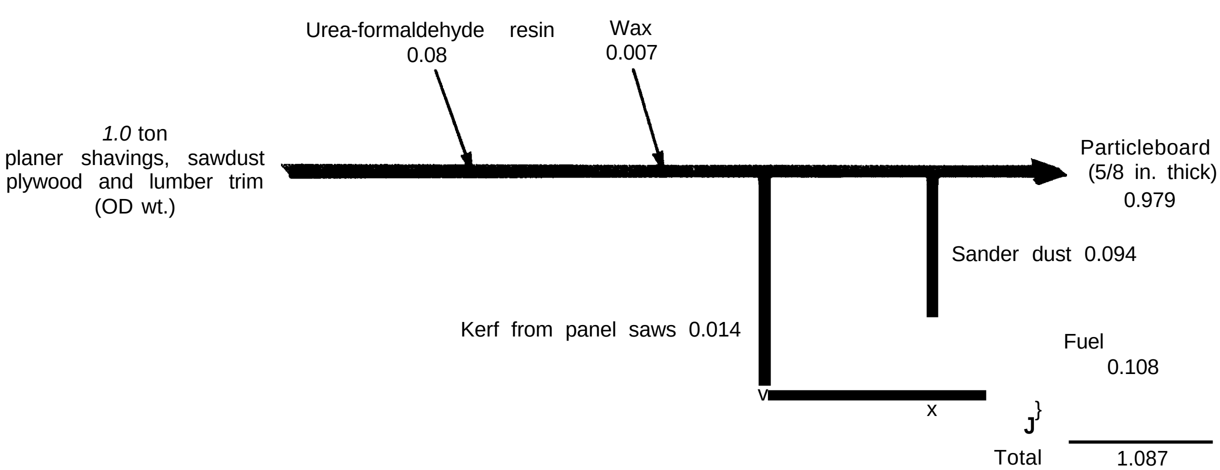
Potential Improvements in Particleboard Manufacture

Many particleboard markets have been declining due to competition from new structural panel products in construction and from medium-density fiberboard in furniture corestock. Some particleboard probably will continue to be employed in nonloadbearing structural use and in a variety of home and miscellaneous uses, but only if it is cost-competitive with other products. Particleboard manufacturers have been facing increased competition for raw materials—largely planer shavings and other sawmill residues—from pulpmills, As a result, the particleboard industry may focus on improving the utilization of forest residues and on developing economical harvesting and transportation methods.28

[27] Gene Wengert and Fred Lamb, "An Overview of Composite Boards," *Furniture Design and Manufacturing* 54(3), March 1982.

[28] See note 25.

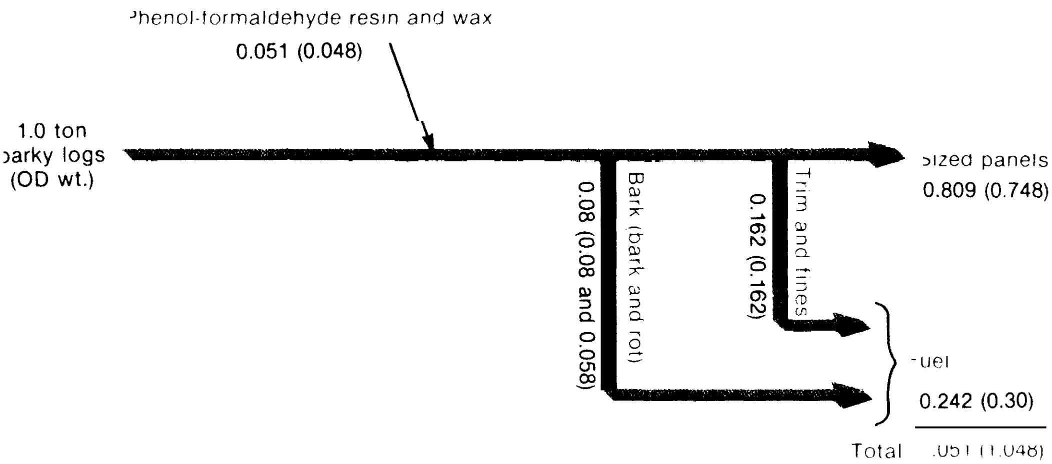
Figure 15.— Materials Balance for the Manufacture of Underpayment Particleboard Based on Ovendry Weight(OD wt.)



NOTE Total is more than 10 because of resin and waxes percentages may vary

SOURCE C W Boyd, et al , "Wood for Structural and Architectural Purposes, " Wood *and F/ber* 6(1)' 1-72, 1976

Figure 16.—Materials Balance for the Manufacture of Structural Particleboard Based on Ovendry Weight (OD wt.) of Chipping and Flaking of Sound Wood



NOTE Values in parentheses are those associated with chipping and flaking cull logs or other forms of residue with some rot Total is more than 10 because of the addition of resin and waxes Percentages may vary

SOURCE C W Boyd, et al "Wood for Structural and Architectural Purposes, " *Wood and Fiber 6(1)* 1-72 1976

Structural Composite Panels

Structural Composite-Panel Manufacturing Processes

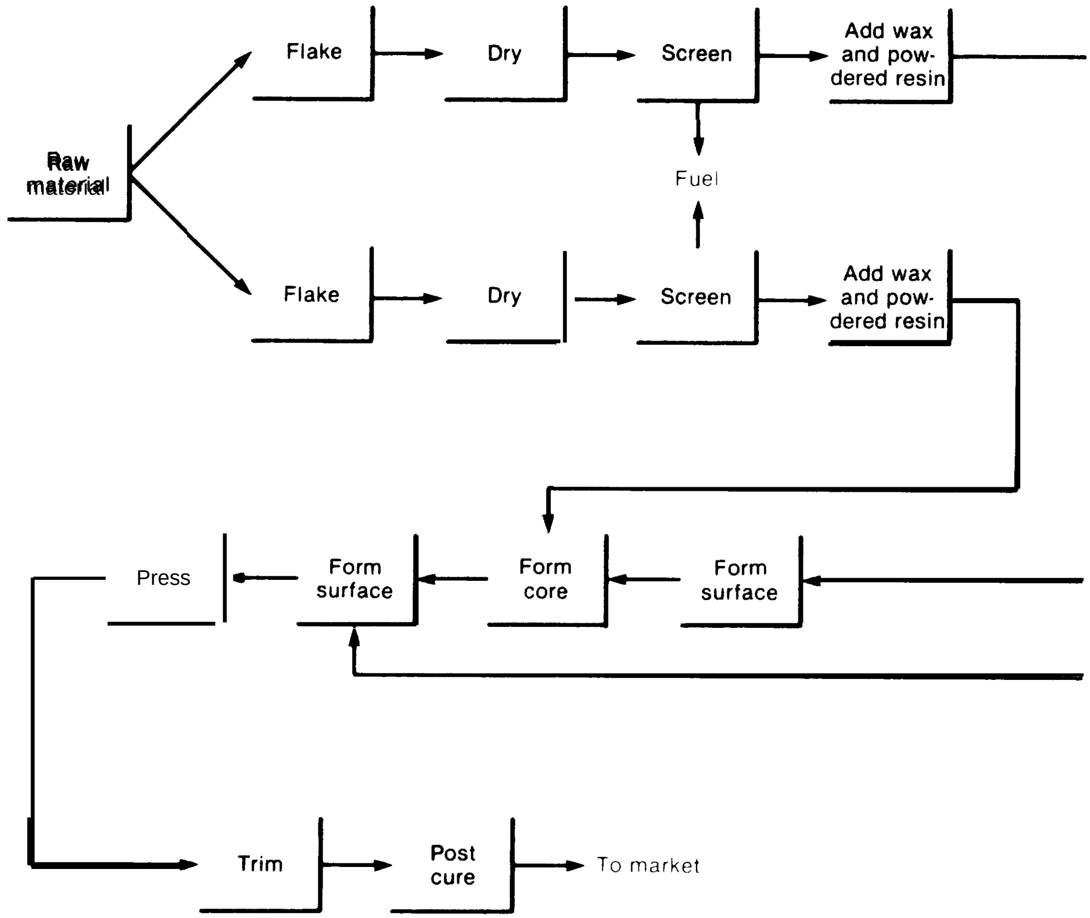
Structural composite panels were developed in an effort to get more out of the wood resource, a focus still primary in the industry. Nearly all the new panel products developed in the last two or three decades can use hardwoods and some defective wood material as well, although high-quality structural panels usually require roundwood for raw material. In the 1980's, R&D efforts likely will be aimed at improving the efficiency and engineering of particleboard-panel products made from flakes, chips, particles, and strands to meet design requirements.

There are three general types of new panel products, the first two of which are expected to provide competition to plywood in structural use: 1) waferboard; 2) OSB; and 3) veneer-faced, composite-core panels.

Waferboard, or flakeboard, originally introduced in Canada, is a panel made of wood wafers or large, flat flakes. High-quality flakeboard can be made using as much as **8** percent bark (although too much bark can cause problems) and 12 percent decayed wood. It also can be made from all hardwood and thus offers opportunities to extend the resource base and produce sheathing-quality panels at lower cost than possible with softwood plywood. The alignment of particles has proved difficult in waferboard, however, and the nonaligned particles produce a product with much lower strength and stiffness than plywood. However, waferboard is strong enough to substitute for plywood in many sheathing applications. Waferboard has been accepted widely in Canada, and there are several waferboard plants operating in the United States. A basic manufacturing flow diagram is shown in figure 17.

Oriented strand board is made from strands or ribbon-like pieces that can be laid down in layers to produce a three- or five-layer board with crossbanded construction much like plywood (fig. 18). The structure of OSB may overcome the strength problems of waferboard,

Figure 17.— Idealized Typical Waferboard Process



SOURCE: Henry M. Montrey III, *Current Status and Future of Structural Panels in the Wood Products Industry*, M.S. thesis, Massachusetts Institute of Technology, June 1982

OSB, unlike waferboard, uses liquid resins, which could reduce adhesive costs. These resins also may provide flexibility in the type of resins used, which may be useful if the industry moves to isocyanate (similar to Crazy Glue) binders in the future.[29]

Veneer-faced composite-core panels (comply) use particleboard cores with veneer faces, like plywood. These products have engineering properties similar to those of plywood, but sometimes are stronger and stiffer. However, their dimensional stability is somewhat less than that of plywood, and they are more dense, Corn-ply may be manufactured to a limited extent in existing plywood or veneer facilities; however, it probably will not compete with waferboard and OSB.

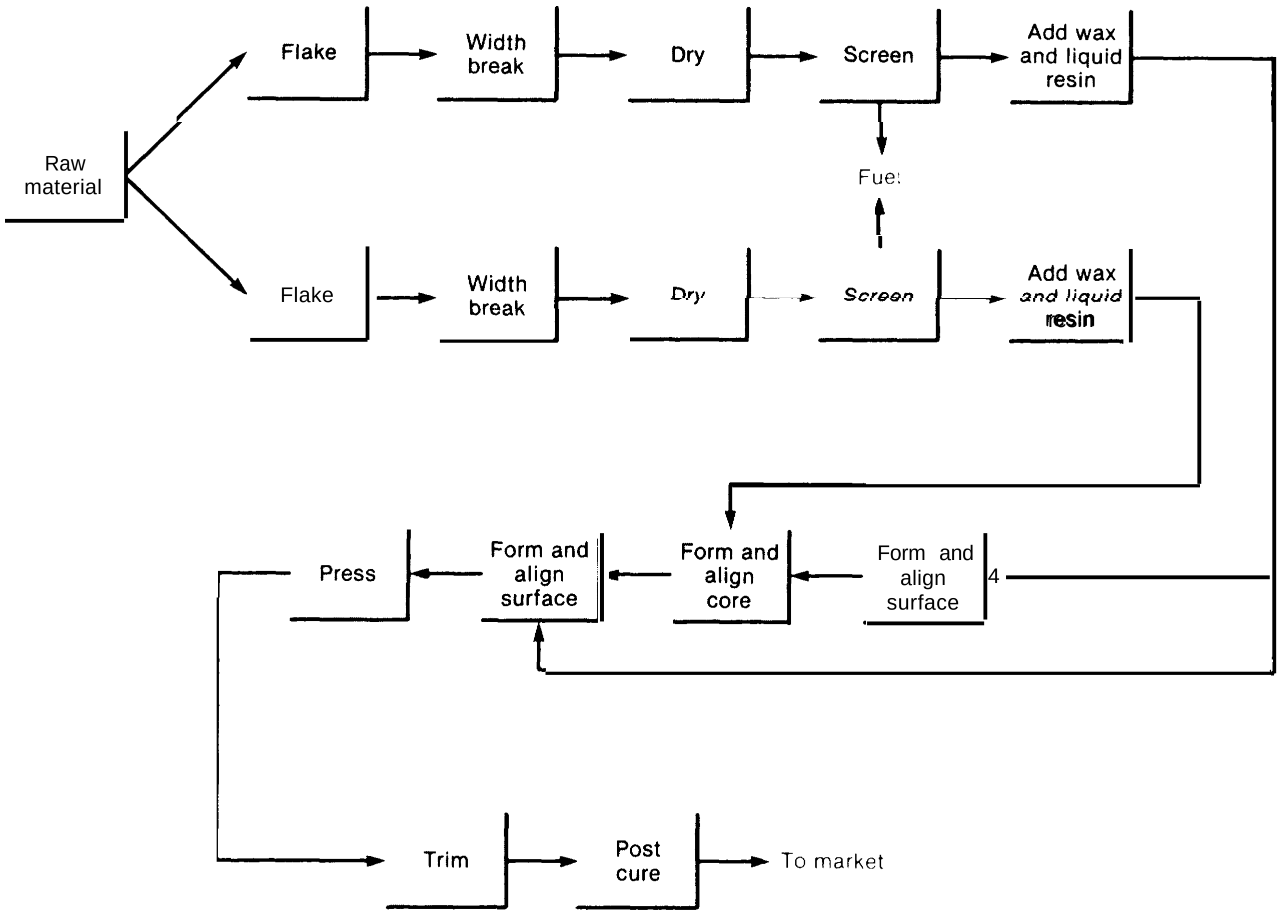
[29]Se~ note 8.

Potential Improvements in Structural Composite Panel Manufacture

In addition to extending the resource base, primary emphasis in R&D on structural panel products is in improving product performance, improving processing, and conserving energy.

Improving Product Performance.—Plywood retains much of the natural strength and physical characteristics of the original wood. Particleboard cannot match the performance of plywood in many high-stress, structural appli-

Figure 18.—Idealized Typical Oriented Strand Board Process



SOURCE Henry M Montrey III, *Current Status and Future of Structural Panels in the Wood Products Industry*, M.S thesis, Massachusetts Institute of Technology, June 1982

cations and therefore has been used mainly for floor underpayment and furniture corestock rather than sheathing, Research in producing structural panels that can substitute for plywood in sheathing and other structural applications has been a major R&D focus. Efforts have centered on controlling particle geometry and alignment during mat formation.

Improving Processes .—Developments in processes for aligning particles and pressing panels show future promise. Particle alignment [orienting wood particles with parallel grain) within a composite structural panel helps retain more of the desirable mechanical properties of solid wood, but allows the use of a variety of wood raw materials. This is a major factor in producing composite panel products suitable for high-stress, structural applications.

Both mechanical and electrostatic processes are used to align the particles, Mechanical alignment is used to produce OSB. Electrostatic alignment polarizes wood fibers or particles that become aligned with the electrical lines of force. These technologies are not developed fully; however, work on fiber alignment is continuing. Wafers historically have proven difficult to align. Equipment that could produce aligned waferboard may provide additional stimulus to this growing industry,

Developments in pressing panels have not been dramatic, but there is an ongoing interest in continuous presses to speed processing and reduce bottlenecks associated with conventional presses. Although continuous presses are available for producing thin boards and medium-density boards, those that can be used to produce a wider variety of structural panel products have yet to be developed, Another trend in board-pressing is toward the use of closed-liquid heating systems rather than the conventional, steam-heating systems. Liquid heating systems provide higher temperatures, have less temperature variability, are less likely to have "cold spots, " and save at least 20 percent of the energy required to operate a comparable steam-heated system.

Conserving Energy .—Particle drying is a major energy consumer in the manufacture of panel products. Innovations in drying have been modest.

Fiberboard

Current Fiberboard Manufacturing Processes

Fiberboard, insulation board, and hardboard are manufactured from individual fibers or fiber bundles, rather than from wood particles. The wet process, which can be used to manufacture any of these products, was first developed in 1924 by W. H. Mason and is known as the Masonite process. The prepared wood is heated by steam in a pressure vessel called a "gun." The pressure in the gun is raised from 600 to 1,000 psi and then suddenly is reduced, causing the chips to explode into a coarse mass of fiber which is reduced further by milling. The fibers are formed into a mat, much like paper, and finally pressed in a hot press.

Hardboard also can be manufactured using a dry process in which the chips are presteamed and ground in a mill. Most fiberboard currently is produced using mechanical disk refiners and thermomechanical pulping. Usually, resin and wax are applied to the fibers prior to milling, and the fibers are formed into a mat and hot-pressed like particleboard. The dry process uses resin to bond the fibers together, while the wet process relies on the combination of natural bonding action of the lignin in the fibers and the contact of the fibers to produce a cohesive panel and a synthetic resin bond.

Fiberboards are not used generally in load-bearing applications because of their tendency to creep under load. Also, they tend to be less stiff than other wood panels of similar density.

Potential Improvements in Fiberboard Manufacture

There have not been many recent developments in the fiberboard field in the United States, with the exception of MDF, Some efforts have focused on using lower grade raw materials and hardwoods, but since fiberboard is not a major consumer of wood raw materials, gains in this area would affect only modestly overall demands on the resource base. In addition, many fiberboard products have been replaced partially by vinyl, plastics, aluminum, and other types of insulation.

MDF was developed in the United States around 1970, and growth of its manufacturing capacity and markets has been significant, By 1981, the United States was capable of producing 668 million ft^2 of corestock MDF.[30] MDF can be produced using either wet or dry processes, and high-quality MDF corestock for furniture can be made from hardwoods. MDF probably will be used more for interior paneling and nonstructural uses, such as trim, door jambs, furniture, and casegoods. However, when produced with an exterior resin it can be used for exterior siding on houses,

Present and Future Use and Consumption of Panel Products

During the last 30 years, the decline in per capita consumption of wood products (including pulp) was offset partially by the increasing per capita consumption of plywood and veneer. Per capita use of plywood and veneer rose from 2.3 ft^3 in 1950 to 7.0 ft^3 in 1979, Overall consumption rose from 2,2 million tons (air-

[30]National Particleboard Association, "Industry Board Capacity by State and Product, " *Furniture Design and Manufacturing* 54(3), Mar. 11, 1982.

dried) to 11.8 million tons. During the same period, use of panel products (including fiberboard) rose from 1.3 million air-dry tons to 10.1 million. Statistics on per capita consumption of structural panel products, exclusive of hardboard and fiberboard, are not available.

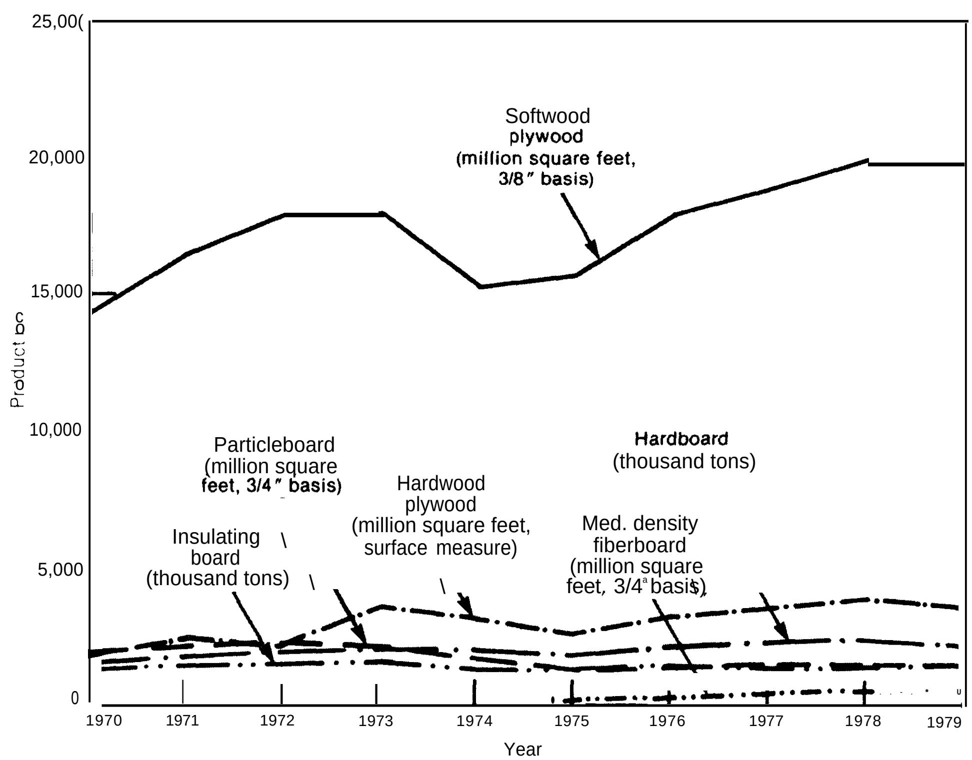
Although conventional plywood probably will continue for another 10 to 20 years to be the major structural panel product used in the United States, the greatest growth in panel products markets in the past few years has been in particleboard and MDF (fig. 19).[31] In 1979, unveneered structural panel products (waferboard, OSB) accounted for only 1.5 percent of the demand for structural panels. The American Plywood Association estimates that this demand will grow to 6.1 percent by 1984, and other sources forecast even higher demands, perhaps up to 20 percent. Because of the slow housing market since 1978, the apparent consumption of panel products (and most other wood products used primarily in light frame construction) dropped. Any resurgence in the housing market is expected to provide ample opportunities for growth of structural panel markets. Moreover, structural panels are expected to compete strongly with softwood plywood for most end uses (table 19).

The striking feature of panel products markets has been the displacement of lumber and plywood by composite panels. Structural panels probably will continue to increase market shares relative to plywood and may begin to compete with nonwood materials such as steel, aluminum, and plastics for some structural products.

A summary of major technical improvements is shown in table 20. Improvements in processing efficiency have reduced labor require-

[31] See note 8.

Figure 19.— Historical Production of Major Panel Products, 1970-79



ments, increased productivity, improved quality control, and helped reduce energy requirements. Larger panel products mills already are using almost all the wood wastes for electricity and heating requirements, a trend expected to continue.

Table 19.— Plywood End Uses and Their Susceptibility to Penetration by "New" Panels

	1976		End-market plywood susceptibility to penetration by "new" panels		
	Millions of square feet	Percent of total	High	Medium	Low
New ***residential construction:***					
Roofs	3,091	16.8%	X		
Floors	2,660	14.5	x		
Siding and trim	960	5.2		X	
Wall sheathing	505	2.7			X
Total new residential construction	7,712	41.9 "/0	X		
Repair and remodeling:					
Structural additions, alterations, and repairs	2,333	12.7		X	
Shelving and furniture	768	4,2			X
Small building and construction	322	1.7	X		
Total repair and remodeling	3,780	20.50/o		X	
Industrial markets:					
Products made for sale	1,688	9.2		X	
Materials handling	440	2.4			X
Plant repair and maintenance	421	2.3	X		
Repair and wholesale trade	381	2.1		X	
Total industrial markets	2,970	16.20/,		X	
Nonresidential construction:					
Nonresidential building	1,338	7.3	X		
Auxiliary uses	280	1.5	X		
Concrete forming	807	4.4		x	
Farm building	360	1.9	x		
Total nonresidential construction	2,785	15.1 %			
Other uses	1,153	6.30/o		x	
Total	18,400	100.0%	48.20/o	42.00/,	9.80/o

NOTE: Data based on an earlier estimate of production (18.4 billion ft²) which has since been reduced to 17.9 billion ft²
[a]Figures do not add to totals due to the exclusion of minor product uses

SOURCE: American Plywood Association; Kidder, Peabody & Co., Inc., estimates

Table 20.—Summary of Major Technologies for Plywood and Panel Product Manufacture

Technology	Stage of development	Effect on resource base	Barriers to implementation	Estimated time scale to significant contribution (years)
New pressure nosebar design	Commercially available	Increases ability to peel small logs; reduces number of unpeelable logs	High capital costs	0-10
Backup torque roller	In development	Same as above	None	o-5
Waferboard	Commercially available	Allows hardwood and residue use	None	0-5
Veneer-faced composite core panels	Commercially available on small scale	Allows hardwood and residue use	Requires integration of veneer and particle-board facility	10-20-
Oriented strand board	Commercially available	Allows use of residue	None	0-10

SOURCE Off Ice of Technology Assessment

Wood Use in Light Frame Construction

Wood Conservation

In general, houses probably are overdesigned, even considering the severe and unusual stresses to which they may be subjected. Failures are unusual in the wood members, but do occur at joints and edges. More sparing use of materials that are designed to provide strength and stiffness, based on new engineering designs, could improve the efficiency of wood use. Three areas where conservation of wood materials is possible are in conventional construction, framing and attaching assemblies, and substitutions for individual framing members,

Conventional Construction

Conventional construction techniques commonly waste 3 to 7 percent of the lumber and plywood used in a home. This waste could be reduced through new design, and the value of the waste material could be reduced through selection of lowest quality and smallest size material required. Door and window framing in nonloadbearing walls possibly could be eliminated. Proper positioning of framing members, such as joists, studs, and windows and door framing, could further reduce the 1umber required. Off-center, in-line joist splicing (replacing overlapping joists over the center beam or support) could minimize the size and grade of joist required (fig. 20).

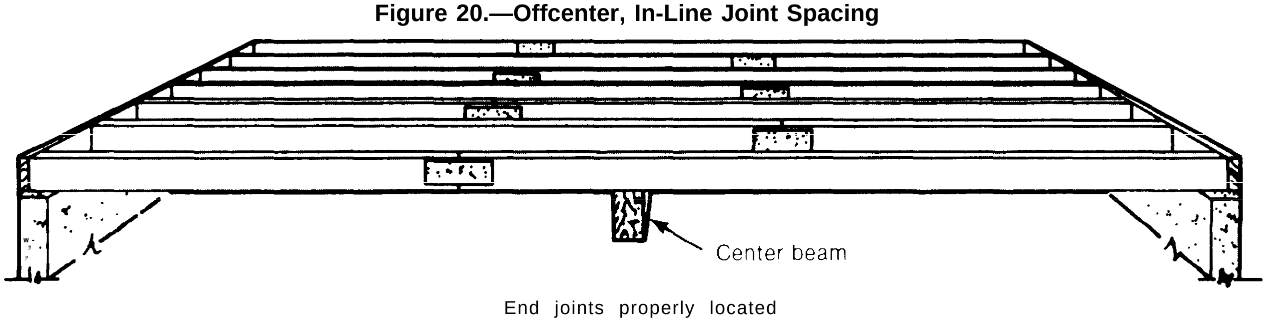
Framing and Attaching Assemblies

Panel assemblies consist of framing and sheathing nailed or glued together, often in combination with insulation, siding, and finishing materials. The strength and stiffness of a panel assembly is greater than the framing or sheathing alone; assemblies can be engineered so that each component enhances the strength of the others. Additional development is probably needed to develop this concept fully.

Factor construction of engineered panel assemblies has two advantages: 1) it allows the use of rigid adhesives, which increase the ability of individual pieces to share loads to a greater extent than occurs with mechanical fasteners or adhesives applied onsite; and 2) it reduces the scrap and shortens construction time. Factory-made assemblies are of two types: stressed-skin panels and sandwich panels.

Stressed-skin panels are made of framing fastened (usually with rigid adhesive) to a skin, or sheath. In Germany, stressed-skin panels using particleboard for skins are used in constructing one- and two-family homes. Stressed-skin panels can be made with stringers of 2-inch dimension lumber with plywood or other panels bonded to either or both sides to act as a series of I-beams, Factory-fabricated stressed-skin floor panels have been in use since 1965

Figure 20.—Offcenter, In-Line Joint Spacing



SOURCE: HUD (F)

and have performed satisfactorily. They have yielded savings in floor material of 20 to 30 percent compared with conventional methods.

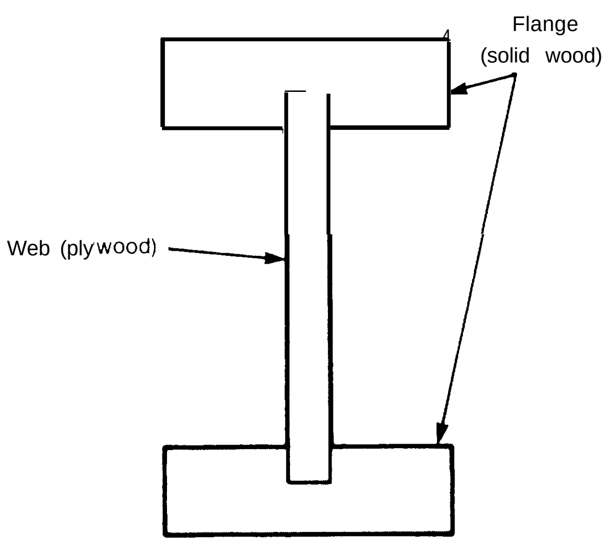
Even greater efficiencies may be possible using **sandwich panels** constructed to bear the loads required on walls, floors, and roofs, Sandwich panels can use plywood or other panel product facings, and their cores can be made of a variety of materials, such as foamed plastic, honeycomb paper, or bark. These panels use about 40 percent less wood than conventional construction,

Substitutions for Individual Framing Members

Some wood products can substitute for individual framing members. Two types of products that use less wood and provide needed structural strength are engineered wood beams and trusses.

At least one firm manufactures a **wooden I-beam,** which is made with solid softwood flanges and a plywood web and can be used as a grider, joist, or center beam (fig. 21). Similar products composed of particleboard or hardboard webs have been used in Europe for many years for structural framing of walls, roofs, ceilings, and floors. These do not use as much wood as a solid wooden beam does and can be used in place of steel I-beams in light frame construction,

Figure 21.—Wooden I-Beam Construction, Cross-Section



SOURCE Off Ice of Technology Assessment

Trusses, or pieces of lumber joined together to form framing members, were developed in Germany as early as 1830. The widespread use of trusses for roof framing is at least three decades old, Floor trusses, although slower than roof trusses to gain wide acceptance, now account for a minor portion of floor construction, Use of trusses to frame whole houses—consisting of floor, wall, roof, and ceiling members, all joined by truss plates—is a recent development.

Truss framing designs could further reduce the amount of wood required for construction and may provide other benefits as well (table 21), Trusses—which are joined with conventional truss plates, plywood gusset plates, or metal fasteners to distribute forces among members-increase the structure's rigidity and reduce the risk of failure. Truss frames eliminate the need for immediate supports and require 30 percent less structural framing lumber than conventional construction. A truss frame system, for example, could consist of an open web floor system, trussed rafters, and wall studs tied together into a unitized frame.

Although the use of trusses and panel assemblies or sandwich panels offers many opportunities to increase the efficiency of wood use in housing, the housing industry is interested in cost savings, not in materials savings per se. The truss frame system and panel assemblies often are simpler and faster to erect on site and may save labor,[32] which can account for over 30 percent of construction costs. Wood materials, on the other hand, account for a much smaller proportion of construction cost, and wood products designed to make light frame construction less costly therefore are more likely to be accepted if they also are labor-saving. The housing industry historically has been fairly conservative in adopting new building technologies. Part of this reluctance can be attributed to the need for building-code recog-

[12]USDA Forest Service, Forest Products Laboratory, "Truss-Framed System," no date,

Table 21 .— Benefits of Truss Framing

Economic benefits
- Labor savlngs
- Material savings
- Qutck assembly
- Faster buyer occupancy
- Weather protection of equipment and materials. good working environment, and security
- Adaptable to high-volume processes and inventories of standard size lumber
- Many energy-savings features

Fabrication and erection flexibility:
- Uses existing truss-manufacturing technology
- Can use a variety of truss-fabrication methods and equipment
- Time flexibility in completing finished buildings
- Flexibility in subcontractor scheduling
- Potential for relocatable structures

Design flexibility.
- Engineering design services readily available
- Flexible space utilization from clearspan con- struct ion
- Variety and flexibility in housing design

Safety and quality:
- Increased quality without added cost
- Strength through controlled assembly
- Strong connections between floors, walls, and roof
- Reduced opportunity for human error in construction
- Overcomes major weakness of conventional con- struction (malted Joints)
- Meets or exceeds current structural, architectural, and safety provisions ı n model codes

SOURCE Adapted from USDA Forest Service, "Truss Framed Technology Transfer Pl an mimeo, 1981

nition of new construction products and techniques, but buyer acceptance and resistance of building labor trades to adoption of new systems probably are also significant factors.

New Uses for Solid Wood Material

Two new wood products could replace concrete, stone, or cinderblock in new home construction: 1) the all-weather wood foundation a n d 2] the underfloor plenum system.

The all-weather wood foundation is a plywood-sheathed, stud wall made of preservative-t mated plywood and lumber that is at least partially below grade. Watertightness is provided by a sump in the gravel pad beneath the wood footing, polyethylene film covering the exterior of the foundation, and caulking between plywood panel joints. The National Association of Homebuilders Research Foundation, which helped develop the all-weather wood foundation, estimates that the system uses 33 percent more wood than does a typical two-story dwelling built on a cinderblock foundations. .

The underfloor plenum system, designed to replace the concrete slab now used extensively in the south, provides a n underfloor area through which warm or cool air can be distributed throughout the house for heating or air conditioning, eliminating ductwork, Properly constructed, the plenum has shown no tendency to rot from excessive moisture or to present insect problems. Because it can be buried, it does not detract from the appearance of the home. It is cost competitive with concrete structures.

The all-weather wood foundation has been accepted by building-code authorities, and there is no specific code prohibition against the underfloor wood plenum. Though both are cost competitive with conventional foundation building practices, they have not significant} penetrated the market. Again, the reason for this probably has to do with the conservatism of the building construction industry and buyer acceptance.

Composites of Wood and Other Materials

In general, the wood industry has not invested much time or resources in developing products that combine wood with other materials. Since the 1960's, however, composites of metal or plastic skins laminated to a wood core have met a number of industrial uses because they are strong, durable, and corrosion-resistant, The metal-skinned wood panel has been used in the past in aircraft, housings, partitions, truck and trailer doors, train interiors, cabinets and cases, pallets, and escalator balustrades. Wood composites also may be combined with foal insulation for cold-storage facilities. Although composite dimension lumber made from wood particles that incorporate continuous strands of high tensile-strength glass fibers have been developed, they have not performed satisfactorily to date because of technical problems that arise when materials with a great deal of difference in stiffness are "married. " Some composite panels are composed of wood and mineral-based products, such as cement boards made from excelsior and cement.