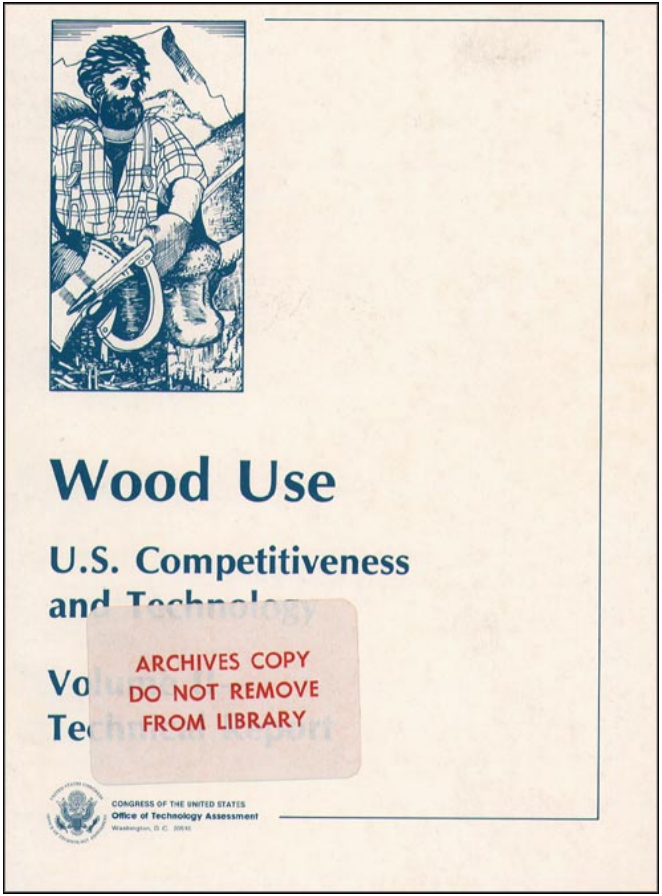
Wood Use: U.S. Competitiveness and Technology—Vol. II

November 1984

NTIS order #PB85-156081



Wood Use

U.S. Competitiveness and Technology

Volume II: Technical Report

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D.C. 20510

Recommended Citation:

Wood Use: U.S. Competitiveness and Technology—Volume II-Technical Report (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-M-224, November 1984).

Library of Congress Catalog Card Number *83-600567*

For sale by the Superintendent of Documents
U.S. Government Printing Office, Washington, DC 20402

Preface

The Office of Technology Assessment assessed the role of wood in the U.S. economy at the request of Senator Mark Hatfield, Chairman of the Senate Committee on Appropriations, and Senator Thad Cochran, Chairman of the Subcommittee on Agriculture, Rural Development, and Related Agencies, Representative James Weaver, Chairman of the Subcommittee on Forests, Family Farms, and Energy, joined in support of the assessment in the House of Representatives. The final report of this assessment was published as volume I of Wood Use: U.S. Competitiveness and Technology, Representative Weaver requested that this second volume, a technical report on wood technologies and wood use, be prepared.

Volume II reviews the status of wood manufacturing technologies and surveys the current and future uses of wood products. It explores the existing or developing technologies and manufacturing processes that can enable the United States to benefit from its vast timber resource. Technologies for increasing the growth and production from the forest and the efficiency of harvesting and transporting timber were treated in volume I.

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Acknowledgments

Volume II was prepared by the Office of Technology Assessment Industry, Technology, and Employment Program staff. OTA wishes to acknowledge the assistance and cooperation of D. A. Tillman, A, J. Rossi, and S. O. Simmons of Envirosphere Co., Bellevue, Wash., who contributed significantly to the assessment as contractors.

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Abstract

The role of technology in achieving self-sufficiency–and perhaps in expanding export capacity-in wood products has received little attention. Although the United States has immense timber resources, it has been a net importer of wood products for a number of years, and Government projections of future wood supplies and demands indicate rising timber prices and increased dependence on foreign supplies.

Several ways exist to avoid wood shortfalls. They include increasing timber production through intensified timber management, better utilization of wood residues, more efficient harvesting, and use of currently underutilized species. Technology can help expand the resource base by enabling effective utilization of a wider range of wood species and sizes and by increasing the yield of products manufactured from a given amount of wood raw material through improved design and conservation.

The Office of Technology Assessment has assessed U.S. wood use and production at the request of Congress. This volume reviews wood manufacturing technologies that might be used to extend the timber resource through improved utilization and explores the prospects for changes in the way wood products are manufactured and used.

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Findings and Conclusions

1. Technologies for wood use could affect future U.S. timber requirements in two ways: 1) by extending the wood resource through improved product recovery and 2) by substituting wood for nonrenewable materials.

The United States currently has abundant productive timber resources compared to those of most other industrialized countries. However, the U.S. Department of Agriculture's (USDA) Forest Service forecasts possible shortfalls in the year 2030 of domestic timber species and sizes currently used for structural materials, pulp, and paper. At the same time, the U.S. forest products industry sees a potential for increased export of wood products and a more active U.S. role in world wood trade, Technology will play a major role in both extending timber resources and developing new and improved ways to use wood,

Il. **Existing and emerging manufacturing technologies could increase wood product yield significantly and may result in increased utilization of forest residues for industrial energy production.**

Because nearly half of all industrial forest products are lumber and structural panels, increased yield of these products alone could have a major impact on domestic timber demand. However, increased yield of solid wood products also could reduce the amount of waste wood available for energy generation in lumber mills and pulpmills, a situation that could stimulate greater use of forest residues and other biomass in the forest products industry, Lumber products, generally used for structural support, are long, thin, rectangular pieces of solid wood. Panel products often are used for structural sheathing and generally are manufactured in 4-by 8-ft sheets usually less than *1* inch thick. Pulp products include paper and paperboard, films, and fabrics,

The amount of roundwood required for lumber production could be reduced 20 to 40 percent by using currently available technologies such as Best Opening Face (BOF), saw-dry-rip (SDR), or edge-glue and rip (EGAR), although it will take several years to achieve even a 20-percent reduction. Such savings would be significant, since lumber consumption of over 50 million tons in 1979 accounted for about half of all wood products consumed.

Composites—such as parallel-laminated veneer (PLV) and corn-ply-are probably the most material-efficient lumber products. They are manufactured by gluing veneers or particles together and sawing the resulting boards into a variety of products. Use of these processes can increase lumber recoveries 40 to 90 percent or more. However, this technology is not yet used on a large commercial scale (probably less than 1 percent of all lumber products are composites]; such technology would require new facilities entirely different from those in conventional lumber mills. Even though composite lumber products offer increased lumber recovery and use of lower quality wood, they are unlikely to replace conventional sawn lumber to any great extent during the next two decades because of the large capital investment requirements, high variable costs (e. g., glue costs), and possible problems resulting from formaldehyde emissions from adhesives.

Adoption of several new technologies could increase lumber recovery of existing mills up to 30 percent without major plant alterations. Among these are the BOF program and the EGAR process. BOF is a computer-assisted method for increasing lumber volume and grade by optimizing sawlines. Laboratory tests and some inservice tests indicate that BOF could increase lumber yields by more than 20 percent. EGAR is an innovative sawing-and-gluing technique that reduces loss of wood in the sawing process, can increase lumber recovery 10 to 13 percent, and permits the use of lower quality raw material.

Product yields in the manufacture of composite wood panels are 75 to 80 **percent by weight, compared with the average current plywood recovery of about** 50 **percent.** Composite wood-panel products (particleboard) are manufactured from woodchips, flakes, wafers, or strands that are glued and formed into plywood-like sheets. Composite panels with the strength of plywood are now being produced and eventually will substitute for plywood in many structural uses.

Substitution of composite wood panels for plywood already has begun, and substantial additions to waferboard and oriented strand board (OSB) production capacity has been completed, Composite panels will begin to replace significant amounts of plywood in structural use by the middle of the decade, Within 10 to 20 years, it is likely that these products will replace most construction plywood, Limits on production of composite panels probably will have more to do with access to investment capital in processing facilities than with institutional or technological constraints.

Increased use of improved mechanically produced pulps can increase fiber yields from about 50 percent to almost 95 percent, reducing wood requirements to 1.05 tons per ton of paper. Over 75 percent of current U.S. pulp and paper production is from the relatively low-yielding kraft chemical pulping process. Since about one-third of industrial roundwood in the United States is used for pulp and paper (53.5 million tons in **1979),** a significant improvement in overall fiber recovery would result if highly efficient mechanical pulping replaced chemical pulping. For example, thermomechanical pulping (TMP)—an improved mechanical pulping process that produces higher quality paper than other mechanical processes—could displace about 300 pounds of the kraft paper currently used in each ton of newsprint. Opportunities also may exist for reducing the amount of kraft pulp used in other printing papers. There probably are practical limits, however, on the extent to which mechanical pulps can substitute for chemical pulps, because high-strength and permanently bright papers cannot yet be manufactured from mechanically produced pulps.

Opportunities for improved mechanical pulps to make significant contributions to pulp consumption over the next two decades are reasonably good. Production of improved mechanical pulps already has begun and is expected to expand.

III. Technology could expand the use of currently abundant hardwood species, enabling use of wood material now underutilized.

Over one-third of the total volume of existing U.S. timber is hardwood. Hardwood inventories are increasing at a rate over six times that of softwoods, which have been more heavily utilized because of their superior properties for the manufacture of many conventional wood products. In the Eastern United States, hardwoods comprise over 62 percent of the standing timber, yet account for only 44 percent of the harvest. Thus, in the East, and particularly in the South, hardwoods are a significant and underutilized wood resource. Because of their wood qualities, softwoods currently are preferred for manufacture of lumber, plywood, and some types of paper, However, existing and emerging technologies may be capable of using hardwoods to make many products that are now produced mostly from softwoods.

Composite lumber and particleboard, which can be manufactured from hardwoods, could substitute for softwood lumber and plywood. In addition, SDR technology could enable the manufacture of high-quality sawn lumber from underutilized and abundant hardwood species, SDR is a modification of the normal sequence of lumber processing that may reduce defects and waste in hardwood lumber manufacture. The SDR process maybe adopted without major equipment changes or additions to existing mills.

Increased use of hardwoods for pulp and paper may be possible with the adoption of mechanical and chemimechanical pulping technologies. Hardwood species are used extensively for the production of newsprint and fine printing papers. However, papers manufactured from hardwoods are weaker than those made from softwoods, which have long fibers; thus, their end use is limited to applications where paper strength is not of prime importance. Chemimechanical pulping (CMP), which involves chemical treatment of wood prior to grinding, may be able to produce strong hardwood papers that could displace or supplement the use of some softwood papers,

Press-dry papermaking technology offers perhaps the greatest opportunity to expand future hardwood utilization. Press drying, which produces paper from hardwood pulp using high pressure and high temperatures during part of the papermaking process, could produce heavy-duty linerboard with strength properties generally superior to those of conventional kraft linerboard. Linerboard currently uses about one-fourth of the wood pulp produced in the United States (approximately 13 million tons/y r), and prospects are good for increasing linerboard exports. Response to the markets and a combination of press-dry technology and hardwood CMP in the production of linerboard, could expand significantly the use of several currently underutilized hardwood species. Softwood pulps also can be processed by press drying, but the principal advantage of the technology is that it enables manufacture of high-strength papers from hardwoods. The press-dry process was developed by the U.S. Forest Products Laboratory (FPL) and requires further modification and testing before it can be commercialized.

IV. Conservation of solid wood materials through increased recycling of waste paper and improved structural design could reduce demands for wood.

Approximately one-fourth of the total paper pulp produced in the United States annually comes from recycled paper. Recycling presents some opportunities for energy conservation. The use of 14 percent recycled fiber for the manufacture of newsprint, for example, could reduce electricity consumption in paper making by 7 to 10 percent. Two major barriers to increasing recycling remain, however, in the United States: 1) used paper usually is contaminated with glue, ink, and other materials that are expensive and difficult to remove; and 2) the economics of waste-paper collection and transportation make recycling generally unprofitable, except in metropolitan areas. Only a few paper mills operate with recycled paper alone; most often, they blend it with virgin pulp, which lends strength to the weaker, recycled fibers. The practical upper limit for using recycled fiber in furnished paper is about 40 percent.

Some construction techniques and designs can reduce structural wood products requirements in residential construction by nearly one-third. Since over 50 percent of the lumber and panel products consumed in the United States are used for residential and nonresidential construction or structural maintenance, significant savings in total wood consumption could be realized from a modest reduction in construction wood use. Designs that rely on the interaction of individual building components for structural strength–e.g., truss framing, wall and floor assemblies, and sandwich panels that replace framing and sheathing—also conserve wood. Penetration of these innovations into construction markets is likely to be slow, however, due to the conservatism of building codes, the construction industry, and home buyers. Also, some current trends, such as the use of wider framing lumber for increased energy efficiency, may result in increased structural requirements.

V. New pulping technologies could reduce energy requirements for pulp and paper making and even produce additional energy for outside sale.

An estimated one-half of the wood (both industrial roundwood and other wood) removed from U.S. forests, over 120 million ovendried tons, eventually is consumed for energy production. Almost two-thirds of the wood fuel burned in 1981 was consumed by the wood products industry. The pulp and paper sector alone accounted for about 3 percent of total U.S. energy consumption. As a result of this large energy usage, pulp and paper manufacturers have become industrial leaders in energy conservation and electric cogeneration.

Innovations could boost waste heat recovery in mechanical pulping for use in paper drying, space heating, and water treatment. In addition, use of pulping technologies such as pressurized groundwood (PGW] pulping, CMP, and chemithermomechanical pulping (CTMP), would result in lower energy requirements than those of TMP and chemical pulping technologies.

Process improvements in chemical pulping may allow mills to approach energy self-suf-

ficiency. Among the strategies available to reduce energy consumption are: 1) increasing the use of wood waste in cogeneration, 2) using spent pulping liquor more efficiently for fuel, and 3) recovering low-quality energy more efficiently through heat pumps and heat exchangers.

Improvements in drying technology offer the greatest opportunities for reducing energy consumption in lumber and panel manufacturing because about 70 percent of the average energy consumption is used in kiln operations and panel drying. Solar kilns, vacuum kilns, and microwave drying are current options for reducing energy consumption. Improved operation of conventional steam-heated kilns through use of sensors and computer controls also provide opportunities for reducing energy consumption.

Improvements in residential stove and furnace design and in technologies for producing industrial wood energy could probably raise the efficiency of direct wood-fuel combustion to 80 percent of the heat-producing potential of the wood. Conversion from open fireplaces to efficient wood stoves could change wood fuel-use efficiency from negative values (heat loss) to as high as 50 percent. Use of self-stoking furnaces, heat storage devices, and circulating systems could raise residential wood-use efficiencies to 80 percent of the fuel's heat potential. In larger commercial and industrial applications, fluidized-bed burners can achieve efficiencies of up to 80 percent, though current efficiency averages 70 percent. Gas turbine technologies coupled with fluidized-bed burners could efficiently cogenerate electricity if technologies were developed to cleanse the combustion gases.

It is feasible (but uneconomical using existing chemical technologies) to convert forest biomass to chemical feedstocks and intermediate products that are currently extracted from petroleum. These may be transformed into nearly all the major industrial organic chemicals. Optimistic projections indicate that liquefaction, gasification, pyrolysis, and hydrolysis of less than 60 million tons of wood and wood residues theoretically could supply a significant proportion of the synthetic polymers currently consumed in the United States. However, the complex processes required for their manufacture are uneconomic at this time. Production of ethanol and methanol from wood and the oxygen gasification of wood could result in production of liquid fuels and syngas for energy conversion.

VI. New **wood products may serve as substitutes or complements for materials derived from nonrenewable resources.**

For example, composite materials made of wood and fiberglass, plastics, or metal have demonstrated superior performance in some applications, although these composites currently account for only a small proportion of the total wood materials used. Experiments at FPL have demonstrated the technical feasibility of producing very stiff, high-strength paper, which, with further development, may some day be used for wall sheathing or modular structural panels. Tests of paper construction materials have yielded mixed results, and a significant amount of additional work is probably needed before paperboard could become a major structural material.

CHAPTER I

Introduction

CHAPTER 1

Introduction

Few materials are as widely used or as versatile as wood. For millenia, wood's extensive natural occurrence and its adaptability, renewability, and workability have combined to make it a material of choice in a wide range of applications. When abundant, wood has helped build and fuel many great civilizations. Scarcity of wood has sometimes contributed to a civilization's decline.

For many purposes, wood has required comparatively little alteration from its natural state,

More recently, technology has helped transform wood into an expanding variety of products bearing little resemblance to wood as it appears in trees or is used in conventional lumber (table 1). In addition to lumber and firewood, products that can be made from wood now include chemical feedstocks and plastics, reconstituted wood-building materials, liquid and gaseous fuels, food supplements, and 14,000 kinds of paper,

Table 1 .—Taxonomy of Major Forest Products

Product	Description	Status of lifecycle	Major end use
Lumber type products			
Boards[a] -	1" thick, 4" to 16', > 1" wide	M	General purpose
Dimension[a] lumber	2" to < 5" thick, > 2" wide, usually 4' to 16' long solid wood, sometimes edge glued	M	Structural framing
Timbers	5 + thick, > 4" wide, various lengths; solid or laminated wood	M	Structural framing beams, and large supports
Parallel laminated veneer (PLV)	Usually same dimensions as lumber and timbers, made from wood veneers laminated with parallel grains	G	Structural framing and supports, Can also be used in millwork and molding
Utility poles	9" to 14" diameter, 50' to 80'	M	Transmission lines
Panel type products			
Plywood	Flat panels, usually 4' x 8', less than 1.5" thick, made from wood veneers laminated with grains of adjacent veneers perpendicular, Usually 3 to 5 plies (veneers)	M	Structural sheathing, flooring, and a variety of semistructural uses
Hardwood	Flat panels made of individual wood fibers, usually glued together	M	Floor underpayment, facing for architectural concrete, wall linings, door inserts, stereo, radio and TV cabinetry, and furniture
Particleboard	Flat panels, less than 1.5" thick, cut to size of 4' x 8', composed of very small wood particles glued together	M	Underlay merit, furniture core
Medium-density fiberboard	Same as hardboard, with extremely flat, smooth surface and edges	M	Furniture, wall siding
Semirigid insulation board	Flat panels made of individual wood fibers, usually loosely matted, fibers bonded by interfelting	D	Insulation, cushioning
Rigid insulation board	Same as semirigid insulation board	D	Interior walls and ceilings, exterior sheathing
Waferboard	Flat plywood-like panels made with flat, nonalined wafers or large chips of wood glued and pressed together	G	Paneling, substitute for plywood in structural use, wallboard
Oriented strand board (OSB)	Flat plywood-like panels made with aligned strands or ribbon-shaped pieces of wood, Sometimes crossbanded (strands in different layers oriented perpendicular to adjacent layers), sometimes veneered	G	Same as plywood
Corn-Ply	Flat plywood-like panels or lumber-like pieces, with particleboard cores and wood veneer faces	B	Same as lumber and plywood

Table I.–Taxonomy of Major Forest Products (continued)

Product	Description	Status of lifecycle	Major end use
Paper products			
Unbleached kraft paper	Brown, somewhat coarse, stiff paper manufactured primarily by the kraft sulfate process from hardwoods and softwoods	M	Heavy packaging, bags, and sacks
Bleached kraft paper	White fine textured paper manufactured by either the kraft sulfite process or the kraft sulfate process from either softwoods or hardwoods. The better papers are provided from softwoods	M	Fine writing and printing papers and paperboard for packaging
Newsprint and groundwood printing papers	Coarse textured paper of low strength and limited durability, which tends to yellow with age. It is manufactured from mechanical and semimechanical (particularly chemically treated) pulp, which uses either hardwoods or softwoods	M	Printing of newspaper and for other printing uses not requiring durability
Corrugating medium	Coarse, low-strength paper produced primarily from sulfite pulping of hardwoods	M	Corrugated boxes as dividers and stiffeners between the paperboard liners
Linerboard	Stiff, durable, thick paper made primarily from unbleached kraft paper made by the sulfate process	M	Heavy duty shipping containers and corrugated boxes
Paperboard	Stiff paper of moderate thickness made primarily from bleached sulfate kraft pulp	M	Milk cartons, folding boxes, and individual packaging
Coated paper	Printing papers that have been coated with materials that improve printability and photo reproduction	M	Magazines, annual reports, and books
Specialty papers	Diverse group of products ranging from thin filter papers to stiff card stock	M	Cigarettes, filter papers, bonded papers (with cotton fibers) index cards, tags, file folders, and postcards
Tissue paper	Thin, soft, absorbent papers manufactured primarily from chemical groundwood pulps	M	Toweling, tissues, and hygenic products
Other products			
Rayon	Synthetic fiber produced by the viscose process using pure cellulose produced by the dissolving pulp process. Rayon has properties similar to cotton	M	Woven cloth as a cotton substitute
Acetate	Synthetic fibers produced from dissolving pulp-like rayon, but further chemical treatment make them water resistant with properties more like nylon or orlon	M	Woven cloth as a substitute for nylon and other petroleum-derived synthetic fibers
Cellulosic films	Film made from dissolving pulp by the rayon and acetate processes, but extruded as sheets of various thicknesses	D	Packaging (cellophane) protective coverings, photographic applications, transparent drafting and graphic materials

NOTE: B = beginning; G = growing; M = mature; D = declining.

[a] Nominal dimensions, i.e., 1" nominal = 3/4" actual

SOURCE Office of Technology Assessment

Characteristics of Wood

Wood is grouped into hardwoods and softwoods. Hardwoods generally are broad-leaved deciduous trees, while softwoods are conifers, with needles or scalelike leaves that generally are evergreen. Although there are broad differences in the characteristics of wood from hardwoods and softwoods, variations in microstructural, physical, chemical, and mechanical characteristics are significant between and within species and even between pieces of wood from different parts of a single tree.

Microstructure of Wood

Differences in microstructure between softwoods and hardwoods give the wood from these species different properties, Softwoods have fewer cell types, generally longer fibers, thinner cell walls, and more uniform cellular arrangements than do hardwoods. Because of their strength, softwoods often are preferred in structural applications. Hardwoods vary considerably in their machining and drying characteristics, which makes the commercial use of hardwoods more complex, However, grain patterns and color make them attractive for furniture and cabinetry.

There also can be microstructural differences within species of wood. Leaning trees contain compression wood (softwoods) or tension wood (hardwoods), apparently a result of the tree's microstructure changing to accommodate the uneven load distribution as it grows. Fertilization, pruning, and other silvicultural* practices also change the microstructure of wood. These changes, currently under investigation by wood technologists, may have some effect on the utilization of wood grown in controlled environments (the so-called plantation wood).

Chemical Characteristics of Wood

The major chemical constituents of wood include: 1) cellulose, 2) lignin, 3) hemicellulose, and 4) extractives. **Cellulose,** which comprises approximately 50 percent of wood by weight (ovendry), is the primary structural component. The exceptionally strong chemical bonds within cellulose molecules give wood great strength relative to its weight, Cellulose fibers are the major component of paper and can be altered chemically to produce a wide range of products such as chemicals, plastics, synthetic fibers, and films, **Lignin,** which cements the fiber together, is a complex organic chemical the structure and properties of which are not fully understood. Theoretically, lignin could be converted into a number of chemicals. Currently, however, it is burned to produce energy as a waste product from pulp and paper manufacturing, **Hemicellulose** is similar to cellulose in composition and function. It plays an important role in fiber-to-fiber bonding in papermaking. Finally, several **extractives** are contained in wood but do not contribute to its strength properties,

Physical Characteristics of Wood

Physical properties of wood vary considerably, both between and within species. Some of the more important physical properties of wood are: 1) density (or specific gravity); 2) mechanical properties (strength and stiffness are most important); 3) shrinking and swelling due to changes in moisture content; 4) thermal properties; 5) electrical properties; 6) machining or working qualities; 7) susceptibility to decay; 8) degree of resistance to chemicals; 9) combustibility; 10) weathering; and 11) appearance, such as grain, texture, and sheen, The range of values for some of these properties and their importance is shown in table 2.

Density (mass per unit volume] is generally a good indicator for other properties (including mechanical, thermal, and electrical). Specific gravity varies with different locations in the tree and is influenced by silvicultural practices; hence, it influences a tree's other properties, Manipulation of growth factors is one of the few controls available to "manufacture" the wood substance to desired properties. This contrasts with other materials, in which many variables can be manipulated to achieve desired properties,

Wood moisture content (the ratio of the amount of water in the wood to its dry weight) is another important variable. This moisture, bound in the cell walls, influences wood properties. Stiffness and strength decrease, and thermal and electrical conductivity increase, as moisture content increases, The moisture content of living trees usually is above 50 percent but varies considerably by species, time of year, and associated weather conditions. Once felled, however, the wood dries and tends toward an equilibrium moisture content (EMC) corresponding to prevailing relative humidity and temperature conditions. Air or kiln drying is used to reduce the moisture content of

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*Pertaining to the branch of forestry that deals with the development and care of forests.

Table 2.—Physical Properties of Wood

Property	Range or average	Importance
Density (specific gravity)	20-45 lb/ft^3 (0.3 to 0.7)	Density can affect the ability of wood to hold coatings such as paint, stain, and adhesives. It affects the machinability and other working qualities and the weight and ease of handling the products.
Shrinkage and swelling	Hardwood: 10-19 percent by volume Softwood: 7-14 percent by volume	Shrinkage upon drying can result in warping, crooking, and bowing in lumber. Some woods have a greater tendency toward internal stresses caused by shrinkage, which may make them less suitable for lumber or may require special treatment to avoid deformities. Shrinkage along the grain is only 10 percent of shrinkage across the grain.
Thermal properties	Resistance: R= 1.25 [ft^2 h“ F/Btu/in] Diffusivity: D=O.25 x 10^{-3} (in^2/s)	Wood is a good thermal and electrical insulator. Because its thermal conductivity is a fraction of that of most metals, wood tends to gain heat slowly from its surroundings.
Electrical properties	Dielectric constant: 2-5 Resistivity: 10^{10} to 10^{13} ohm-m (10^3 to 10^4 when saturated)	Wood is a poor electrical conductor, though its conductivity increases with increasing moisture content.
Decay and chemical resistance	—	Different species vary in resistance to decay and chemicals. Wood deteriorates more rapidly in warm humid environments than in other conditions. It is often used in chemical processing operations where exposure to mild acids and acidic salt solutions would corrode ordinary steel or cast iron.
Combustibility		Two important aspects of wood combustibility are flame spread and char development. Rate of charring into large wood members is very slow; hence, strength is retained for a long time in a fire situation.
Working qualities		Working qualities refers to the ease and quality of planing, shaping, turning, mortising, sanding, steam bending, and nail and screw splitting. They affect appearance, useful life, and range of use of wood products.
Weathering		Weathering causes boards to warp, pull out fasteners, check or split, and turn gray. Sometimes weathered appearance is desirable for decorative use.
Appearance		Color, grain, texture, sheen, and surface roughness affect the appearance of wood. Fine furniture woods require special characteristics, as do woods used for paneling and cabinetry. The appearance of structural material is less important.

SOURCE Adapted from U S Department of Agriculture, Forest Service, Forest Products Laboratory, *Wood* Handbook *Wood as an Engineering* Material (Washington, D C U S Government Printing Off Ice, 1974)

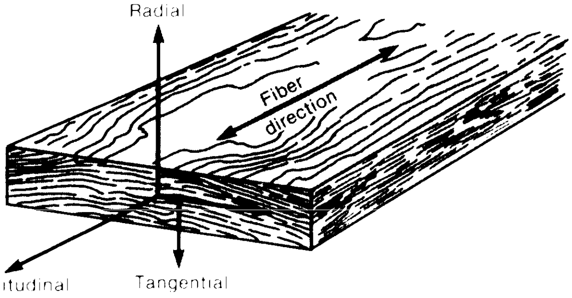
green lumber to approach the EMC to meet the end-use requirement.

In contrast to most other structural materials such as ceramics, concrete, and metals, which have the same properties in all directions, wood is naturally anisotropic, having different mechanical and physical properties along its three dimensions. The three mutually perpendicular, characteristic dimensions of wood are called: longitudinal (along the grain), radial (across the grain, out from the center), and tangential (across the grain, tangent to the annual rings) (fig. 1). Stiffness and strength, as well as other properties, vary considerably in the three directions.

Strength, particularly along the grain, is one of the most important mechanical properties of wood. Wood's strength is compared on a strength-to-weight basis with other materials in table 3.

During use, wood is subjected to a number of different loading modes including bending, compression, shear, and tension. Most impor-

Figure 1 .—Three Characteristic Directions of Wood That Are Influenced by Wood Properties



SOURCE: USDA Forest Products Laboratory, *Wood Handbook*, Agricultural Handbook No. 72 (Madison, Wis.: USDA Forest Service, 1974), p. 4-2.

tantly, wood is a very efficient material for bending applications, and designers can compensate for its relatively low shear strength parallel to the grain by making long, slender structural members that stand up well to bending. * In addition, because its compression strength is relatively high, wood is an excellent material for columns. Its inherent strength is less important in the design of columnar supports than its geometry and stiffness. Clear wood also has high tensile strength. As a result, higher grade (clear] material is used in tension members of trusses or in the outer layers of laminated beams.

Energy Consumption in Wood Products Manufacture

The amount of energy required to produce construction materials and paper from wood generally is less than that required for producing products from metals, plastics, or masonry on a weight basis (table 4). Production of paper, for example, uses less than half the energy per ton than does the production of plastics and less than 10 percent as much as the production of aluminum foil for packaging. Thus, wood, being a renewable resource, could substitute for other materials that require large amounts of energy for their manufacture.

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*A measurement of wood's ability to withstand bending prior to failure is described as its "modulus of elasticity."

Table 3.—Structural Properties of Some Wood, Metals, and Masonries

Material	Specific gravity	Tensile strength[a] (10^3 psi)	Elastic modulus (10^6 psi)	Specific[b] tensile strength (10^3 psi)	Specific[b] elastic modulus (10^3 psi)
Wood	0.50	20.00	1.5	40.00	3.0
Western plywood	0.504	0.11	1.25	0.20	2.48
OSB	0.66	0.12	1.25	0.18	1.89
Waferboard	0.67	0.07	0.5	0.10	0.75
Aluminum (2024-T3)	2.77	70.00	10.6	25.00	3.8
Steel (AISI 304)	8.03	87.00	28.0	11.00	3.5
Copper	8.9		17.0		1.9
Nickel	8.9		32.0		
Granite	2.67	1.85	7.3	0.69	2.7
Marble	2.72	1.40	8.0	0.51	2.9
Brick	2.00		2.0		1.0

[a] Specific tensile strength and specific elastic modulus are the tensile strength and elastic modulus divided by specific gravity.
[b] Measured by through-the-thickness internal bond strength for plywood, OSB, waferboard.

SOURCE: Adapted from Wangaard, F. F., (ed.), *Wood: Its Structure & Properties*, Educational Modules for Materials Science & Engineering Project, Materials Research Laboratory, The Pennsylvania State University, University Park, PA 16802, 1979, p. 407.

Table 4.—Energy Requirements for Primary Commodities (million **Btu (oil-equivalent)/ton))**

Commodity	Extraction	Processing	Transport	Available residue energy	Net[a] total
Softwood lumber	0.943	4.846	1.966	8.313	2.909
Softwood sheathing plywood	0.747	6.871	2.081	3.697	6.002
Structural flakeboard	0.956	7.511	1.314	8.616	2,270
Underpayment particleboard	4.6172[b]	8.101	1.198	1.529	12.387
Concrete	0.52	7.60	0.40	—	**8.52**
Concrete block	0.52	7.60	0.65	—	8.77
Clay brick	0.57	7.73	0.76	—	9,06
Steel studs	2.45	46.20	1.67	—	50.32
Steel joists	2.45	46.20	1.67	—	50.32
Aluminum siding	26.80	172.00	1.67	—	200.47

[a] Assumes residue energy can be offset only against gross manufacturing (processing) energy.

[b] Includes energy input in logging plus preparation of particleboard furnish in the form of planes shavings, plywood trim, and sawdust.

SOURCE: Adapted from F. F. Wangaard, *Wood: Its Structure and Properties,* Educational Modules for Materials Science and Engineering Project, Materials Research Laboratory, the Pennsylvania State University, University Park, Pa., 1979.

Present and Prospective Uses of Wood

Domestic production of wood has increased by about one-third since 1950. Much of the growth in demand for wood has been in high-value wood products such as lumber, plywood and veneer, and pulp, while the declines have been in lower value products, such as railroad ties and mine timbers. Wood is used for a variety of purposes, including shelter and other construction, communication, packaging, information storage, energy, textiles, and chemicals.

The chemical constituents of wood, primarily carbon and hydrogen, may be converted to forms that can be used to manufacture a wide range of products currently derived from petroleum—although few now are so used, Chemicals recovered from wood through pulping are used in turpentine, rosins, pine oils, furfural, and other commonly used chemical products. Lignin, although currently burned as a waste product to produce energy within pulpmills, shows promise as an adhesive, dispersing agent, binder, and source of vanillin and dimethyl sulfoxide (DMSO). Rayon, cellulose acetate, and cellulose esters, manufactured from woodpulp, maybe used for cloth, packaging films, and explosives. Sawdust and wood flour are used as cattle feed and as bulking agents in human food.

As an energy source, wood's historical importance is difficult to overstate. Until 1870, wood was the primary fuel for both industrial and residential heating in the United States.[1] Even in 1940, when coal had long supplanted wood as a residential heating fuel, more households were heated with wood than with gas, electricity, and oil combined. The recent resurgence of wood in home heating—brought about by the rising costs and potential shortages in other energy sources—has both stimulated and been stimulated by technological innovations in wood-burning stoves and other devices adapted to home heating.

The forest products industry itself has become an industrial leader in the use of wood as an alternative energy source. Roughly half of the energy needs of the industry are produced from wood residues and byproducts. In some cases, mills have become virtually energy self-sufficient. In addition, a few wood-fueled central electric-generating stations of modest size have been constructed by utility companies. Gasification technologies offer potential for converting wood into energy products that are easily transported and may be used in conventional gas combustion equipment. Wood may also be converted to liquid fuels, such as ethanol and methanol. In the event of

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[1] U. S. Department of Commerce, Bureau of the Census, *Historical Statistics of the United States: Colonial Times to* 1970 (Washington, D. C.: U.S. Government Printing Office, 1975), pp. 587-588.

an oil supply interruption or larger increases in the price of petroleum, wood could back up domestic supplies of coal and other fossil fuels.

Wood has been the paper industry's major source of raw material for well over a century. Paper may also be manufactured from a variety of natural cellulose materials, including cotton, bagasse, and other agricultural crops, and from recycled waste paper, By removing lignin and other extractives and separating the strong individual wood fibers through chemical or mechanical processes, paper may be formed into a variety of products, ranging from tissues and newsprint to construction board.

Some of the oldest and still major uses of wood are framing, sheathing, cabinetry, and a variety of semistructural and decorative purposes in construction. The most notable new developments in wood utilization involve reducing wood to smaller integral components, such as chips, strands, flakes, wafers, or fibers and reconstituting them into products with performance characteristics different and frequently superior to those made from solid natural wood. Recent developments include waferboard and oriented-strand board (OSB) made from a variety of species into composites that can substitute for conventional plywood.

Modern materials science also has made it possible to combine different materials in a way that can produce composite products with performance characteristics superior to those of either of the parent materials, Wood and metal have been laminated to provide not only a more durable finished furniture panel, but also one that resists cigarette burns by dispersing heat through metal foils. Composite panels faced with plastics are widely used for countertops, desktops, and tabletops. Plastic-impregnated papers are used for various types of packages that must resist or contain liquids.

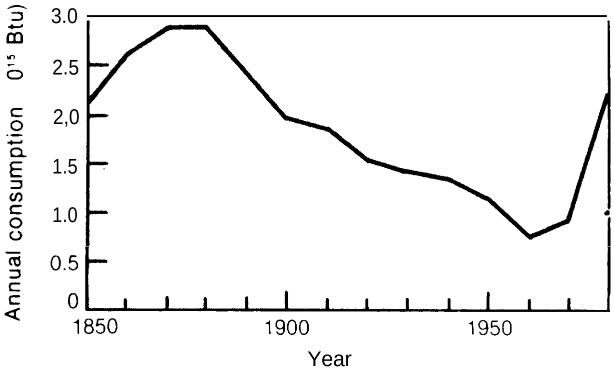
In the future, wood maybe combined in very different ways at the fiber level to produce entirely new materials. For example, wood materials could be extruded, molded, and formed into complex shapes by combining wood fibers with binders, adhesives, and resins. Wood also may be combined with other fibrous materials such as fiberglass or graphite to produce new high-strength, lightweight materials with special properties.

Wood as a Fuel

This section updates information on wood energy use and summarizes several important aspects of wood energy explored in detail in a 1980 OTA report, *Energy From Biological Processes.*[2]

The rapid growth in coal and petroleum as energy sources since 1870 resulted in a rapid decline of wood's contribution to total energy use. Since the 1973 oil embargo, wood energy use has grown rapidly, so that it again is the largest use for wood by volume (fig. 2).

Figure 2.– U.S. Wood Energy Consumption, 1850-1980



SOURCE Charles E Hewett, et al "Wood Energy in the United States, " *Annual Review of Energy,* Jack M Hollander (ed) (Palo Alto, Calif Annual Reviews, Inc), 1981

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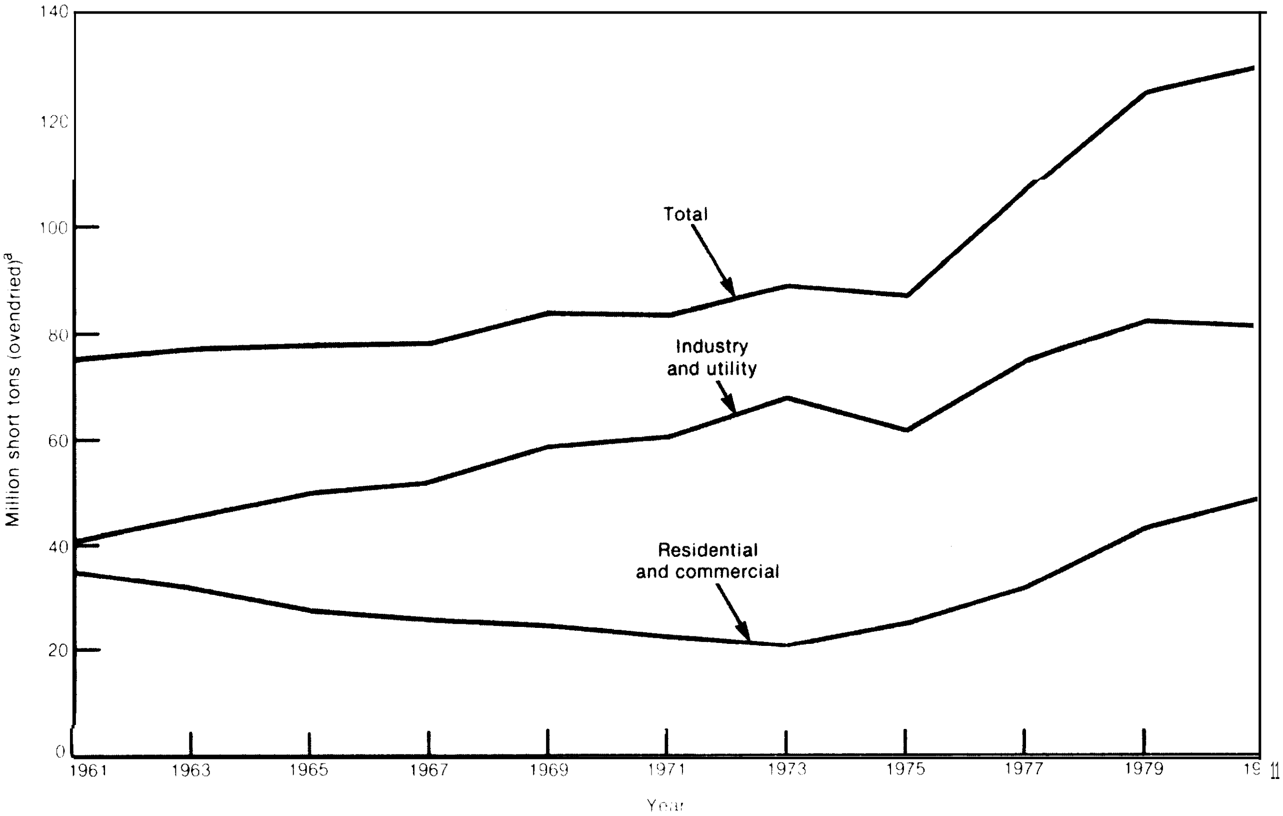
[2] U.S. Congress, Office of Technology Assessment, *Energy From Biological Processes,* vols. I-III (Washington, D.C.: U.S. (government Printing office, 1980).

Wood-fuel consumption totaled 2,2 quadrillion Btu (2.2 Quads) in 19803—about 3 percent of U.S. energy use (74 Quads).[4] The forest products industry accounted for 63 percent of 1980 wood energy use.[5] Nearly all the remaining wood energy consumption was for residential home heating (fig. 3).

OTA estimates that energy accounted for about 55 percent of the wood removed from U.S. lands in 1980, the first year for which comprehensive survey data is available (table 5). A partial explanation for the high proportion of fuelwood compared with other wood used in 1980 is that demand for other forest products was low due to recession. However, use of wood as a fuel has increased rapidly since the 1%0's, even during periods when demand for forest products was high.

The potential exists for significantly greater wood energy production. OTA's *Energy From Biological processes* assessment concluded that wood has the greatest potential to contribute to the Nation's energy supply among alternative biomass energy sources. The study found that 4 Quads/yr of wood energy could be produced from wood by the year 2000 without significant Government action. With incentives and improved forest management, as much as 10 Quads/yr could be produced. Much

Figure 3.—Estimated Wood-Fuel Consumption, 1961-81



a1 Ovendried ton = 17.2 million Btu (avg.).

SOURCE: U.S. Department of Energy, August 1982.

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[3] U.S. Department of Energy, *Estimates of U.S. Wood Energy Consumption From 1949 to 1981* (Washington, D.C.: U.S. Government Printing Office, 1982).

[4] U.S. Department of Energy, *Monthly Energy Review: November 1982*, p. 4.

[5] *Estimates of U.S. Wood Energy Consumption From 1949 to 1981*, op. cit.

Table 5.—OTA Calculations of Wood-Fuel Removals, 1980

1980 quantities of wood removed	Million tons of oven dried wood
Wood (bark excluded) for forest products industry (estimated at 11.6 billion cubic feet)	160
Bark portion of forest products industry removals	21
Residential fuelwood (quantity harvested for use in 1980-81 heating season: 42 million cords, at approximately 1 ton each)	42
Total 1980 quantity of wood removed	223

1980 wood-fuel consumption	Quads	Million tons of oven-dry wood needed to produce the equivalent amount of energy
Industrial (including mill residues, and spent pulping liquors)	1.4	81
Residential	0.8	42
Total 1980 wood-fuel consumption	2.2	123

NOTE: The ratio of the 1980 wood-fuel consumption to the 1980 quantity of wood removed as 123/223 or 55 percent. This figure is based on very crude estimates and calculations and provides only a rough approximation of the importance of wood fuels. It furthermore is subject to wide fluctuations corresponding to changes in annual removals of industrial roundwood. In 1981, for example, the ratio certainly increased, as removals declined and wood-fuel consumption continued to increase.

SOURCE: *Estimates of U.S. Wood Energy Consumption From 1949 to 1981* (Washington, D.C.: U.S. Department of Energy, 1982), p. 95; Kenneth E. Skog and Irene A. Watterson, *Residential Fuelwood Use in the United States: 1980-81* (draft report), U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, March 1983, p. 1, p. 17, and table 4; conversation with Robert B. Phelps, Research Forester, Demand Price and Trade Analysis, Forest Resource Economics Research Staff, U.S. Department of Agriculture, Forest Service, May 26, 1983; letter from John G. Haygreen, Professor and Head, Kaufert Laboratory, Department of Forest products, College of Forestry, University of Minnesota, to James W. Curlin, Project Director, Office of Technology Assessment, U.S. Congress, letter dated Nov. 1982; and conversations with Kenneth E. Skog, Research Forester, Engineering and Economics Research, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wis.

of this amount could be produced from byproducts of wood processing, logging residues, and woody biomass removed during thinning of timber stands, stand conversions, and other management activities.[6]

Industrial Wood-Fuel Use

The forest products industry consumed 81 million ovendry tons (81 million cords) of wood in 1981. Industrial wood energy consumption totaled 1.4 Quads of wood fuel, of which about 1.0 Quad was consumed by the energy-intensive pulp and paper industry and the remainder by the solid-wood-products sector. The pulp and paper industry now derives about half of its energy needs from wood fuels and lignin byproducts produced during pulping,[7] An estimated 73 percent of the solid-wood-products industry energy needs were supplied from wood in 1981, up from 69 percent in 1978.[8]

Most wood fuels used by the industry come from wood residues and processing wastes, rather than from trees specifically harvested for energy use, However, some firms now harvest wood for energy use, and some residues are traded among businesses within the industry as a marketable commodity.

Continued increases in wood-fuel use by the forest products industry are probable but will grow more slowly in the future. The industry now uses over 96 percent of the woody raw materials that enter mills for either products or energy (fig. 4). Opportunities to increase wood energy further may depend on: 1) increased recovery of woody materials at harvest, and 2) capital investment in more energy-efficient manufacturing processes.

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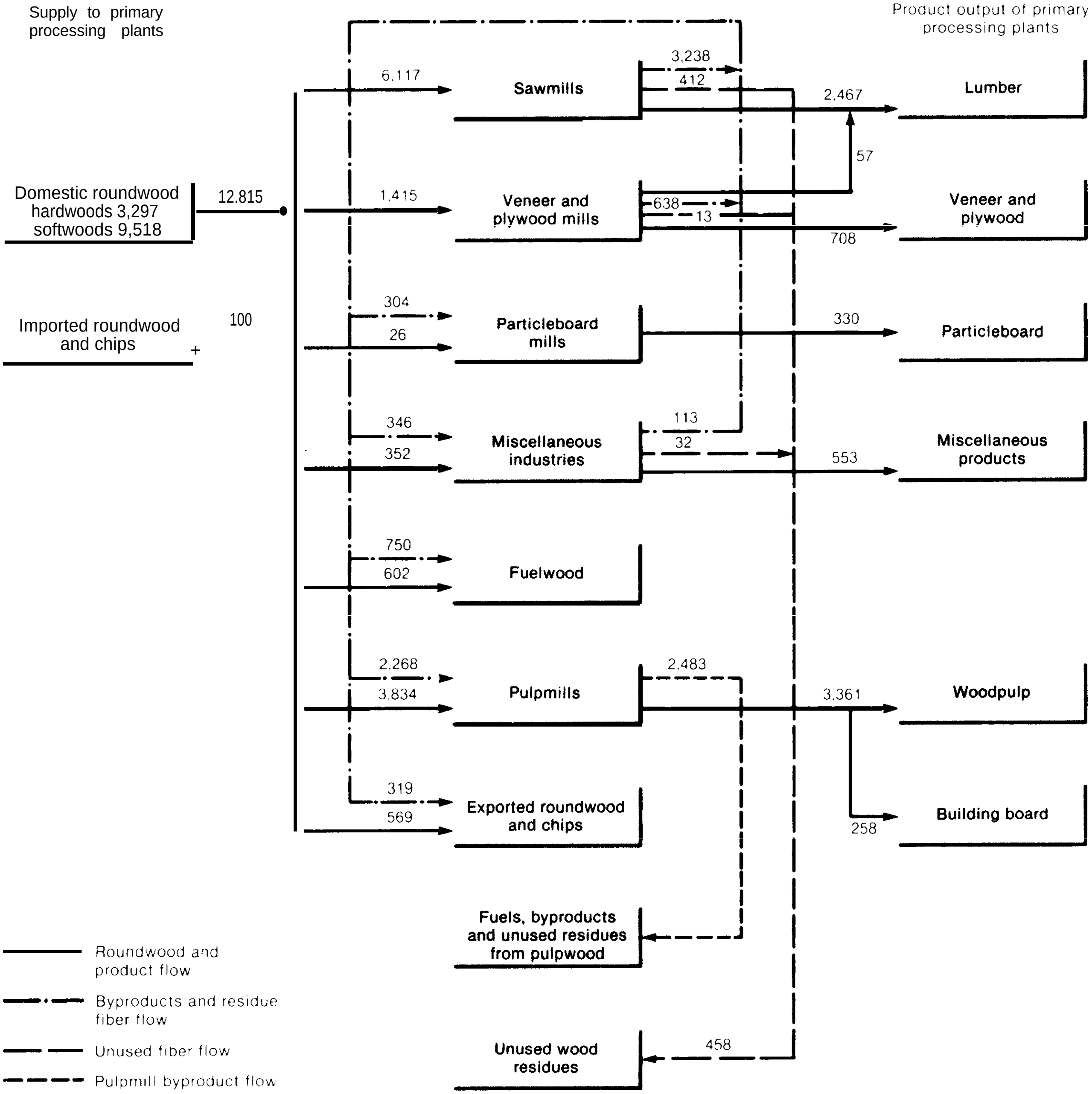
[6] *Energy From Biological Processes*, op. cit., vol. I, p. 24.

[7] American Paper Institute, *Statistics of Paper, Paperboard and Wood Pulp 1982: Data Through 1981* (New York: American Paper Institute, 1982), p. 49.

[8] National Forest Products Association, *Industrial Energy Conservation Program* (Washington, D.C.: National Forest Products Association, 1981).

Figure 4.—Timber Supply to and Product Output From Primary Processing Plants, 1976 (million cubic feet)



SOURCE: T. Ellis and C. D Risbrudt. Unpublished manuscript

Over the long term, as new facilities and technologies designed for energy conservation gradually are introduced, it is possible that some forest product firms will produce more energy than they consume, thus becoming net energy producers. The pulp and paper industry already is a leader in cogeneration—the simultaneous generation of useful heat and electricity. The industry has the largest number of cogeneration facilities among U.S. industries and currently accounts for 29 percent of the U.S. cogeneration capacity, ranking second to the primary-metals industry in cogenerated electrical power, g At one Maine pulp and paper mill, total self-sufficiency in electricity reportedly has been achieved through a newly constructed biomass powerplant and company-operated hydroelectric stations. Surplus power is sold to a local utility.[10]

Residential and Commercial Fuelwood Use

The U.S. Department of Energy (DOE) estimates that about 48,2 million ovendry tons (48.2 million cords) of wood was consumed in residential heating in 1981.[11] Residential fuelwood consumption has at least doubled since the 1973 oil embargo, according to the DOE survey. Other indications, such as a fourfold increase in the use of wood stoves (from 2.6 million in 1973 to nearly 11 million in 1981), also suggest rapid growth in residential fuelwood use[12] (table 6).

Home fuelwood use may continue to increase, although probably not as rapidly as in the 1970's. Factors that will affect home fuelwood use include: 1) price and availability of wood relative to alternative fuels, 2) proximity of fuelwood users to wood supplies, 3) homeowner willingness to cut and transport fuelwood and maintain wood-burning stoves and furnaces, and 4] introduction of technologically superior wood-burning stoves and furnaces that burn wood more efficiently or conveniently.

Table 6.—Estimated Wood Stove Shipments and Inventory (thousands)

Year	Wood stove shipments	Wood stove imports	Wood stove inventory
1970	224	NA	3,079
1971	220	NA	2,866
1972	225	20	2,751
1973	235	20	2,630
1974	474	80	2,744
1975	853	280	3,295
1976	835	200	3,850
1977	1,302	240	4,807
1978	1,681	380	6,088
1979	2,116	437	7,868
1980	2,116	437	9,531
1981	2,116	437	10,960

SOURCE U S Department of Energy *Estimates of U S Wood Energy Consumption From 1949 to 1981* (Washington, D C Department of Energy 1982)

Commercial sector (nonforest products businesses) wood-fuel use also is increasing, although currently it comprises less than 1 percent of total wood-fuel consumption. In many areas, market prices for wood fuel currently are competitive with fuel prices for oil, natural gas, and coal. Commercial wood-fuel use may continue to grow, especially in areas like the South, which have abundant wood supplies. Some States actively encourage commercial use of wood fuels. The Georgia Forestry Commission, for example, finances wood-fuel demonstration projects in hospitals, schools, and other public institutions.[13]

In a few instances, public utilities have established wood-fueled central electric-generating stations, as in Burlington, Vt., and Eugene, Oreg. Limitations on wood-fuel generating stations include large capital costs and difficulties in assuring wood supplies from timbersheds at economic transportation distances from plants.

Secondary Fuels and Chemicals From Wood

Almost all wood fuels are directly burned. A variety of long-established and emerging

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[9] U.S. Congress, Office of Technology Assessment, *Industrial and Commercial Cogeneration*, 1983, p. 11.

[10] "Biomass Power Plant," *Dravo Review: A Quarterly Publication of Dravo Corporation*, 1982, p. 17.

[11] *Estimates of U.S. Wood Energy Consumption From 1949 to 1981*, op. cit., p. 2.

[12] Ibid., p. 34, table 3.

[13] Information provided by J. Fred Allen, Georgia Forestry Commission.

technologies can process wood and wood-based residues into "secondary fuels" (gas, liquid, and solid). Similar technologies and processes can be used to produce chemical feedstocks for the manufacture of a high proportion of chemicals, plastics, and other products now produced from petroleum (fig. 5).

Bioconversion processes such as saccharification, fermentation, and gasification were used to produce fuels and/or chemicals commercially on a minor scale during both World War I and World War II, but they were not able to compete with petroleum fuels and petrochemicals in peacetime,[14] Recent developments have focused renewed attention on production of secondary fuels and chemicals from wood. The technologies for conversion of wood and other forms of biomass to energy and chemicals are discussed fully in OTA's *Energy From Biological Processes* report.[15]

The potential for wood to be used as an alcohol fuel is discussed in DOE's *Alcohol Fuels Policy Review.*[18] If used on a widespread basis, methanol and ethanol could offset somewhat U.S. gasoline consumption (about 101 billion gal in 1981).[17] However, there are economic difficulties in commercializing processes to convert woody biomass to alcohol.

Wood currently is used to produce silvichemicals valued at over $500 million per year. Silvichemicals include naval stores (oleoresins, tall oil, turpentine, rosins, and the like) and chemicals derived from pulping byproducts, such as lignin products, vanillin, DMSO, and a variety of other useful substances,

Use of wood as a substitute for petroleum feedstocks is technically possible but will depend on the price of petroleum and coal (which can also be used as a petrochemical substitute) and capital expenditures for new plant construction. Coal is widely viewed by the chemical industry as a more likely short-term substitute for petroleum feedstocks than wood. Nonetheless, evolutionary growth in wood chemical use is probable—especially when wood can be used in less highly processed forms or to produce chemicals not readily derived from coal or petroleum.

Lignin chemistry is one promising area of research.[18] Lignin has a complex structure that makes it difficult to process, but, left intact, it can be used in plastics, adhesives, and various other compounds, About 3 percent of the lignin byproducts produced during pulping are recovered for production of chemicals; the rest is burned for energy.

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[14] The history of wood chemical and secondary fuel use through World War II is discussed in Egon Glesinger, *The Corning Age of Wood (New* York: Simon & Schuster, 1949). Another book by Glesinger, *Nazis in the Woodpile: Hitler's Plot for Essential Raw Material* (Indianapolis; New York: Bobbs-Merril, 1942) discusses the military and strategic importance of wood as a fuel and chemical to the Third Reich,

[15] *Energy From Biological Processes,* vol. II: *Technical and Environmental Analyses* (Washington, D. C.: office of Technology Assessment, 1980),

[16] U.S. Department of Energy, *Report of the Alcohol Fuels Policy Review* (Washington, D. C.: U.S. Government Printing Office, 1979].

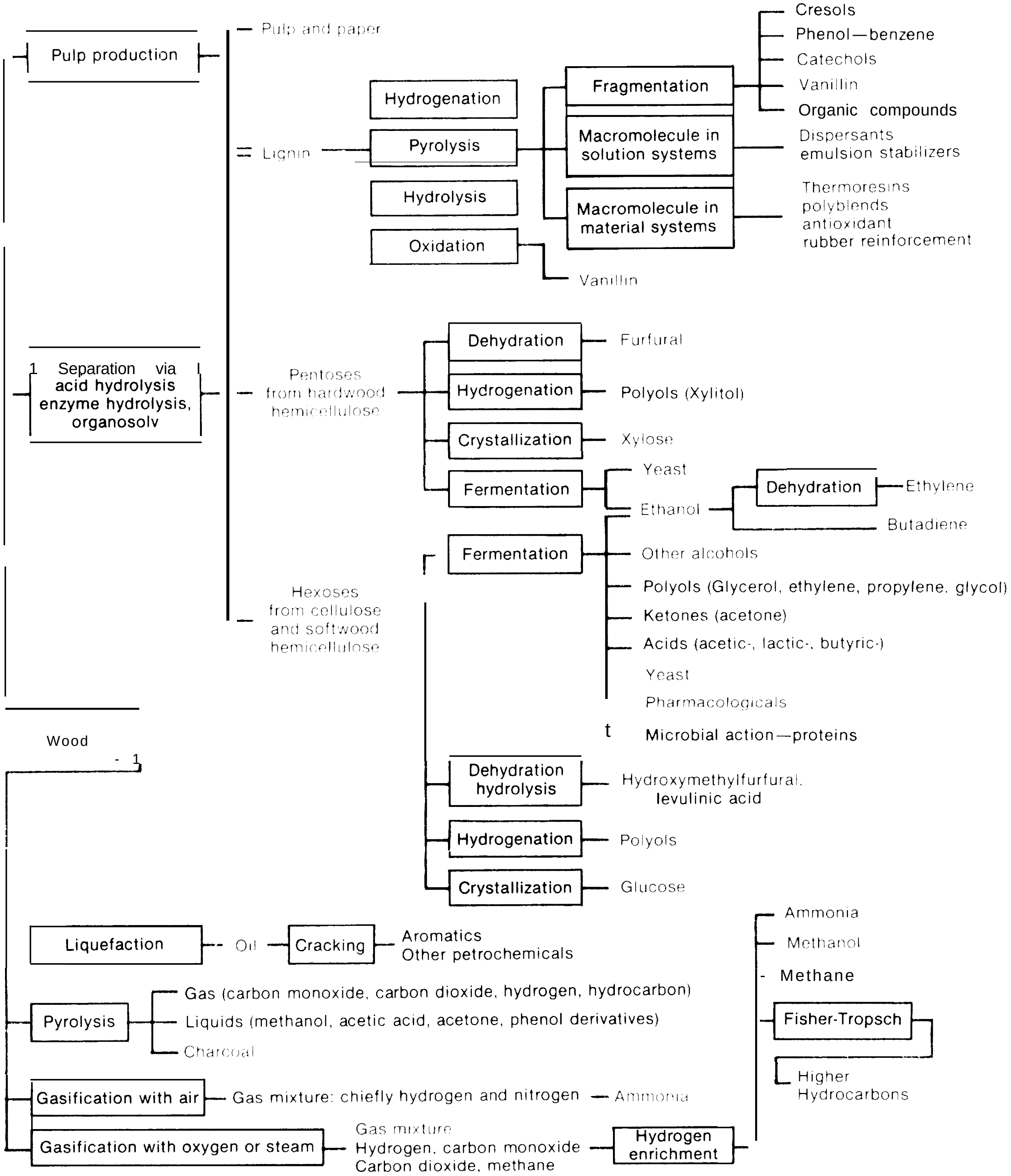
[17] Figure *derived* from *Monthly Energy Review: November* 1982, op. cit., p. 36.

[18] Henry J. Bungay, "Biomass Refining, " *Science,* vol. 218, Nov. 12, 1982, p. 643.

Wood Technology and the Resource Base

While an extraordinary range of wood products exists, they must compete with other materials for their share of an often highly specialized market. Just as wood can be substituted for many other materials, those materials can substitute for wood in some applications, with little change in product performance. In terms of the national materials mix, economics and market forces generally determine which material is predominantly used for any specific purpose, But other factors, including existing plant equipment and capital investment, energy consumption, raw material availability and security of supply, and institutional

Figure 5.—Chemicals From Wood



SOURCE: Office of Technology Assessment.

considerations—government policies, industry structure, and societal customs, practices, and preferences—also play a role.

Recently, the forest products industry has experienced changes in portions of its traditional market shares. In the highly competitive market for residential building materials, which constitutes the largest single market for forest products, wood has retained its dominance but lost portions of its markets in several areas such as flooring, siding, and furniture, At the same time, a variety of new building materials made from wood are available that could help retain current markets or expand into other areas in time,

Even within the family of wood products, substitution takes place: plywood has replaced lumber for many uses, and now particleboard challenges plywood in the market for structural panels. In some cases, composite materials have enhanced wood's competitiveness by permitting it to enter new markets and helping to retain portions of markets that otherwise might be lost. A salient example of the former is the plastic-coated boxboard that has virtually replaced half-gallon milk containers made of glass.

At one time, other biomass materials (primarily cotton) provided nearly all feedstocks for plastics manufacture. By 1960, fossil fuels accounted for 90 percent of plastic feedstocks, even though the volume of wood feedstocks remained about the same. Uncertainties about petroleum prices and supplies have led to some recent, though modest, increases in wood-derived feedstocks. In addition, petroleum-derived plastics have competed successfully for many specialized markets formerly dominated by paper.

Although wood is a renewable resource, in contrast to metals or fossil fuels for which a fixed amount is available, the possibility of a timber famine in the United States as a result of the scarcity of softwood sawtimber has been raised repeatedly for more than a century. Softwoods have been used more heavily than hardwoods because of their wood properties and the fact that they tend to have most of the usable wood in a well-formed trunk. As a result, softwoods are growing scarcer relative to many hardwoods, which remain largely underutilized. Moreover, over the past century, the real (deflated) price of softwood sawtimber has increased steadily.

The United States has a large inventory of both softwood and hardwood species, Growth, on a nationwide basis, still is greater than annual harvest for both types of wood, although the margin of annual growth over harvest is much narrower for softwoods. Capacity of the Nation's forests to provide increasing amounts of wood maybe limited, however, and technologies for improving the efficiency of wood utilization could help extend the timber resource by offsetting increases in demand. Technology could increase utilization by: 1) increasing the proportion of products recovered from roundwood, or wood raw material, in primary processing; 2) expanding the ability to utilize hardwood species and defective material; and 3) increasing the efficient use of manufactured wood products,

The United States has harvested approximately 12 billion cubic feet (ft^3) of roundwood annually for decades, In recent years, the proportion of this harvest that has been wasted has dropped dramatically, In 1976, less than 4 percent of the roundwood entering primary processing was wasted, although that portion still represented 10 million tons. Because many residues from one phase of the manufacturing process may be used as raw material for other uses (fig. 4), an increase in the product recovery at one point in the manufacturing process may reduce the amount of residue available to produce other products or energy. While there are significant opportunities for technology to change the products manufactured from a specific quantity of wood, there appears to be little chance to increase the efficiency of wood utilization in primary processing as a whole—with the exception of some pulping technologies that provide higher fiber recovery.

On the other hand, technology has already significantly affected the ability to use a wider variety of wood species and materials formerly considered worthless. The introduction of panel products and hardboard opened avenues for wood from limbs, branches, treetops, roots, hardwoods, and even dead or defective wood and bark. New technologies for paper manufacture offer enormous potential for using hardwoods to produce strong papers for packaging and communication, Even in lumber and plywood manufacture, which still depend on wood cut from the trunk of the tree, the ability to utilize smaller logs has expanded significantly. Possibilities also exist for increased use of hardwoods. Regardless of future levels of demand, wood-utilization technology has the potential to ease pressures on the timber resource base (table 7).

Significant opportunities also exist for more efficient end use, particularly in construction. It maybe possible to reduce the amount of lumber and panel products used (through improved integrated structural design) without adversely affecting the quality and strength of the structure. Present commercial techniques could reduce wood consumption in framing by nearly one-third, for example.

Recycling technologies also may extend the timber resource base. Recycled wastepaper can reduce not only the amount of virgin wood fiber needed for pulp and paper manufacturing, but also the amount of energy consumed in the pulping process. Little solid wood is reused currently, but with appropriate designs and new methods of fastening, it also might be recycled.

Research and Development on the Use of Wood

The future uses of wood and the degree of efficiency in wood utilization largely depend on research and development (R&D). Three major institutional groups in the United States are involved in R&D on the use of wood: 1) the Federal Government, which funds as well as performs R&D; 2) the forest industry, which is instrumental in developing products and improving manufacturing processes; and 3) academic institutions that conduct training and basic research. Each plays an important role in the activities that lead to the invention, development, and eventual commercialization of wood products and processes.

The relative proportions of industry and Government funding for **all** R&D in the United States have shifted in the past 30 years. In the 1950's and 1960's, the Federal Government was the major funding source for R&D, but the gap between industrial contributions and Government funding began to narrow in the early 1970's, Industry outspent the Government for the first time in 1980. The National Science Foundation (NSF) estimates that over $69 billion was expended for all R&D in the United States in 1981. Forty-nine percent of the expenditures were made by industry, while 47 percent came from Federal agencies. The remaining 4 percent originated from foundations and other private sources.

Current trends suggest that industry funding as a percentage of total funding will continue to advance, while the Federal sector's contribution will decline.[19] The funding structure for research alone (excluding the development function) is the reverse, however. In 1981, over 53 percent of the expenditures for basic and applied research were derived from the Federal Government, while industry contributed approximately 37 percent. z” The private sector actually performed more of the total R&D undertaken in the United States than it funded, because some private research was Government supported. In 1981, 71.2 percent of the R&D (measured by dollars expended) was performed by industry. The Federal Government

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[19] J. Duga, *Probable Levels of R&D Expenditures in* 1982: Forecast *and Analysis* (Columbus, Ohio: 13attelle Columbus Laboratories, 1981), p. 2.

[20] National Science Board, *Science indicators* 1980 (Washington, D. C.: National Science Foundation, 1981), p. 253,

Table 7.—Status of Selected Technological Developments in Wood Utilization

	Rationale for or advantage of technology	End-use product	Status of commercialization	Wood type
Pulp and paper industry:				
Pressurized groundwood pulping (PGW)	Reduced energy requirements and higher quality paper in comparison with traditional groundwood pulping processes; less kraft pulp needed for mixing	Newsprint, printing papers	Five mills worldwide as of 1980; 15 mills ordered (4 in U.S.); rapid growth expected	Softwoods
Chemithermomechanical pulping (CTMP)	Reduced energy requirements; higher quality paper than in traditional mechanical pulping technologies because long fibers are left relatively intact; less kraft pulp needed for mixing	News print , printing pages	Installed at some thermo-mechanical pulpmills	Softwoods
Hardwood chemimechanical pulping (CMP)	Permits utilization of low-value hardwoods such as red oak and poplar; reduced energy consumption in comparison with other mechanical techniques; less kraft pulp needed for mixing	Newsprint printing papers	Two small mills in U. S.; rapid expansion possible	Hardwoods
Press drying paper	Permits utilization of hardwoods in production of linerboard that is superior in quality to conventionally dried softwood kraft paper, except in tear strength; reduced energy requirements and chemical processing needs	Linerboard	Feasible, but commercial-scale facility has yet to be developed	Hardwoods
Pyrolytic recovery	Reduced energy requirements in recovering pulping chemicals	Process efficiency	Demonstrated	Any
Organosolv pulping	Reduced energy requirements; expanded hardwood utilization	Process efficiency	Yet to be demonstrated; possible in next two decades	Hardwoods or softwood
Oxygen pulping	Oxidation of pulping liquors reduces need for bleaching chemicals and facilities; may reduce need-for water pollution control expenditures due to less chlorine in bleaching	Process efficiency	Yet to be demonstrated; possible in next two decades	
Solid wood products:				
Best opening face	Higher lumber recovery factor; permits product yield improvements of 4 to 21 %	Lumber uses	Mill-tested but not widely used	Primarily softwoods
Saw-dry-rip	Higher lumber recovery reduces defects in product by 19 to 87°/0	Lumber uses	Used by some mills, but not widely accepted	Hardwoods and softwoods
Edge glue and rip	Higher recovery of product, higher lumber quality	Lumber uses	None	Hardwoods and softwoods
Parallel laminated veneer	Permits higher recovery of lumber from logs, improves lumber quality; faster processing at the mill	Lumber and timber uses	Some manufacturing currently in production	Hardwoods and softwoods

Table 7.—Status of Selected Technological Developments in Wood Utilization—continued

	Rationale for or advantage of technology	End-use product	Status of commercialization	Wood type
Com-ply	Can lengthen life of existing plywood mills where log supply is a problem	Lumber and panel uses	Unlikely to increase; may penetrate small number of panel markets	Hardwoods and softwoods
Machine stress rating	More efficient lumber use; less variation in grades in marketed products; less subjective than visual grading	Lumber rating	Not widely accepted, but ready for commercial application	Hardwoods and softwoods
Structural panels (waferboard, oriented strand board)	Higher recovery of wood in processing, uses hardwoods	Panel products	Expanding production taking place	Hardwoods and softwoods
Medium density fiberboard	Better quality product, near 100% recovery of wood in processing	Furniture	Increases in use expected	Hardwoods and softwoods
Fuel and chemical uses:				
Large capacity fluidized-bed burners	Can burn efficiently heterogeneous wood feedstocks with variable moisture and size efficiently. Efficiencies of 80% are possible, as opposed to 70% average in presently operating devices	Industrial heat	Yes, but presently economic in relatively small scale	Any
Advanced small capacity wood furnaces	High efficiencies achieved (up to 80%) with corresponding lower production or pollutants than with with most existing wood-burning stoves; can be used with heat storage and distribution technologies	Residential heat	Trends show increases in use of wood furnaces likely	Any
Large-scale aerobic, gasification with close-coupled combustion	Relatively high efficiencies (70-90%) achieved when gas is immediately burned; can be retrofitted to existing gas-burning devices and has potential for use in gas turbines however, problems with feedstock variability have been noted	Industrial heat and mechanical energy	Increased industrial use of high-efficiency furnaces expected	Any
Large-scale anaerobic gasification with close-coupled combustion	Very efficient (88-90%) when burned immediately; does not require oxygen plant needed by comparable aerobic technologies; can accommodate feedstocks with high moisture contents	Industrial heat and mechanical energy	No, small-scale prototype has been developed	Any
Sacchrification and related processes	Separates and reduces wood constituents into simple sugars which can be further processed into many derivative substances	Simple sugars, from which derivative products (e.g., ethanol and other chemical feedstocks) can be made	Basic processes used in WW I and II; new processes are being developed	Any
Wood gasification	Permits use of wood feedstocks as an alternative to fossil fuels in the production of fuels and chemicals. Has promise to make organosolv pulping energy self-sufficient	Synthesis gas (syngas), no methane, formaldehyde	No	Any

SOURCE: Office of Technology Assessment.

conducted 13 percent; universities and colleges, 12 percent; and the balance was performed by miscellaneous nonprofit organizations.

Within the forest products sector, the structure of R&D funding is obscured by the lack of reliable and sufficiently detailed information on Government and industry outlays for wood-utilization R&D. NSF reports an estimated aggregate expenditure in 1979 of $148 million for lumber and wood products R&D and $454 million for pulp and paper products R&D, but does not provide a breakdown of funding by contributor.[21] Funding levels for R&D within the forest products sector remained about the same for 1977 through 1979, when measured in constant dollars. Between 1970 and 1980, R&D expenditures for lumber and wood products grew approximately 62 percent, and pulp and paper R&D increased 70 percent, when measured in actual dollars. However, little real growth occurred in the R&D budget because of inflation during the past decade.

Federal Government R&D Activities

Wood-utilization research conducted by the Federal Government is concentrated in the Forest Service of the U.S. Department of Agriculture (USDA), In fiscal year 1981, the Forest Service funded over $16.8 million of in-house wood science and utilization research, about **72** percent of which was performed at the Forest Products Laboratory (FPL) in Madison, Wis. The balance was conducted at the regional Forest Experiment Stations and at various research centers throughout the United States, (University research funded by the Forest Service is discussed in a following section,) The Forest Service tends to concentrate its in-house wood science and utilization research on projects that generally are regarded as beneficial to the United States—i.e., that are long-term, high-risk, and therefore unlikely to be undertaken by the private sector,

FPL's fiscal year 1981 R&D program included 18 activities involving approximately 97 scientist-years of effort, funded for $12,1 million (table 8). Its fiscal year 1982 budget was targeted at $13.7 million to support an effort of 104 scientist-years. The laboratory's research efforts are centered on the protection of wood

Table 8.—Funding and Man-Year Commitments by Activities at the U.S. Forest Service, Forest Products Laboratory, Madison, Wis.: Fiscal Year 1981

Activity	Funds (thousand dollars)	Percent	Scientist-years
Protection of wood in adverse environments	$ 1,178.5	9.8	8
Engineered wood structures	1,149.1	9.5	6
Wood fiber products and processing development	942.9	7.8	5
Engineering properties of wood	888.3	7,3	7
Improved chemical utilization of wood	869.1	7,2	7
Structural composite products	840.5	6.9	7
National timber and wood products requirements and utilization economics	822.7	6.8	8
Improved adhesive systems	791.0	6.5	6
High-yield, nonpolluting pulping	758.0	6.2	6
Quality and yield improvement in wood processing	690.0	5.7	6
Criteria for fiber-product design	641.0	5.3	5
Microbial technology in wood utilization	525.0	4.3	4
Improvements in drying technology	503.7	4.2	5
Fire-design engineering	371.0	3.1	4
Engineering design criteria	370.0	3.0	4
Corrugated-package engineering	341.5	2.8	4
Center for anatomy research	293.0	2.4	4
Pioneering research unit in descriptive wood anatomy	141.0	1.2	1
Total	$12,116.3	100.0	97

SOURCE Cooperative Research Information Service (CRIS), U S Department of Agriculture

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211t)id., p. 279.

from decay and insects and on the engineering of structural wood products, wood fiber products, and manufacturing processes. Approximately 35 percent of FPL's budget is used for fundamental research—e.g., properties and anatomy of wood—and 65 percent is used for applied research. The level of research effort has been approximately the same since 1978, based on constant dollars expended. From 5 to 10 percent of the laboratory's annual budget is devoted to cooperative research with academic institutions.

In addition to research centered at FPL, the Forest Service supported an R&D program of $4.7 million and 40 scientist-years in fiscal year 1981 at the research centers of the regional forest range and experiment stations (table 9). Most of this research centered on the utilization of hardwood species and on the economics of improving the performance of the regional wood products industries,

R&D on wood energy and wood as a substitute for petroleum products is conducted by DOE at its national laboratories, although funding for these activities was reduced in the fiscal year 1982 and 1983 budgets. At its peak in fiscal year 1981, DOE spent $11 million on R&D related to wood combustion, gasification, and liquefaction. This work is funded in fiscal year 1983 at $2.2 million. Other research related to wood science and utilization, such as research on toxic preservatives and adhesives, may occur incidentally to the missions of other R&D agencies, but its size in relation to the total Government effort is small.

R&D in Academic Institutions

Academic research plays a unique role in complementing the research in wood science and utilization undertaken by industrial and Government laboratories. Funding for academic research in fiscal year 1981 was approximately $9.5 million (table 10). Less than one-third of the academic research budgets in 1981 came from the Federal Government; State and industrial contributions accounted for 71,6 per-

Table 9.— 1981 Funding and Scientist-Years by Activities at the U.S. Forest Service Experiment Stations

Activity	Location	Funds (thousand dollars)	Percent	Man-years
Improving wood-resource harvesting and utilization	Forest Sciences Laboratory Missoula, Mont.	$ 447,0	9.5	4.0
New and improved systems, methods, and techniques for processing hardwoods	Carbondale, Ill,	361.0	7.7	3.0
Regional economics of forest resources	Duluth, Minn.	512.0	10.9	4.1
Low-grade hardwood utilization	Princeton, W.Va.	418.5	8.9	2.1
Timber quality and product-yield potential of Western softwood resources	Pacific Northwest Range Exp. Sta. Portland, Oreg.	573.3	12.2	5.0
Developing more productive markets and uses for forest resources of the Central and Southern Rocky Mountains	Ft. Collins, Colo.	286.8	6.1	4,0
Utilization of Southern timber.	Southern Forest Exp. Sta. Athens, Ga.	594.2	12.7	6,0
Wood products research	Southern Forest Exp. Sta. Athens, Ga.	500.3	10.7	6.0
Processing Southern woods	Alexandria, La,	998.9	21.3	6.0
Total		$4.692.0	100.0	40.2

SOURCE Cooperative Research Information System (CR IS) U S Department of Agriculture

Table 10.— Funding of Wood Utilization R&D Performed by U.S. Academic Institutions in Fiscal Year 1980

	Source (thousand dollars)				
Activity	McIntyre-Stennis	Other Federal	Non-Federal	Total	Percent
Structural panels (including plywood and composites)	$ 278.1	$ 103.7	$1,505.1	$1,886.9	19.9
Economic analysis and data/information	76.2	165,5	1,076.8	1,318.5	13,9
Properties and performance of wood and wood products	376.0	80,7	610.4	1,067.1	11,2
Energy and chemical production from wood.	181.3	257,4	458.4	897.1	9.4
Protection, preservatives, and coatings	78.8	94.5	523.5	696.8	7,3
Pulp and paper technology.	125.6	68.0	394.8	588.4	6.2
General and miscellaneous wood utilization	42.6	47,2	399.2	489.0	5.2
Adhesives and bonding	109.0	38.8	338,1	485.9	5.1
Structural design and fasteners.	78,1	52.0	335,9	466.0	4.9
Drying and moisture characteristics ...	119,1	46.9	292,0	458,0	4.8
Composite and laminated beams/lumber.	54.8	5.9	233,6	294,3	3.1
Sawmill design and process technology	22.7	23.4	164.0	210.1	2.2
Wood anatomy and fiber quality	40.7	0	158.5	199.2	2.1
Sawing and machining	3.2	16.7	163.0	182.9	1,9
Whole-tree chipping and chip processing	14.8	61.2	106,1	182.1	1.9
Species utilization	22.0	18.6	38,4	79.0	0.9
Total ...	$1,623.0	$1,080.4	$6,797.8	$9,492.3	100,0
Percent	17.0	11.4	71.6	100.0	

SOURCE Cooperative Research Information System (CRIS), U S Department of Agriculture

cent of the total. Major emphasis was placed on R&D related to composite structural panels (19.9 percent), economic analysis and wood products data (13.9 percent), and properties and performance of wood and wood products (11.2 percent).

Within the federally funded portion of the academic research budget, 17 percent of the funds originate from McIntyre-Stennis Act programs (76 Stat. 806), which are administered by the USDA's Cooperative State Research Service. The Forest Service, NSF, DOE, and other agencies provided 11 percent of the total academic budget devoted to wood science and utilization research in 1981. The remaining 72 percent came from State and industry sources.

While the proportions of R&D funds contributed by industry and the States are not identified by USDA in its Cooperative Research Information System (CRIS) (table 10), a recent survey of forest-products research in the South suggests that industry contributed approximately 15 percent of the academic research funds in that region, with the States accounting for 47 percent of the funds expended,[22] The remaining 38 percent was funded by various Federal agencies. The Southern colleges and universities included in the survey received half (48.8 percent) of the total wood science and utilization R&D funds provided to all U.S. academic institutions in 1981. To the extent that the South reflects the national situation, the States appear to be the major funding source for wood-utilization R&D at colleges and universities.

Industrial R&D

Because of the proprietary nature of much of the forest products industry's R&D and the reluctance of the private sector to disclose R&D budgets, a detailed assessment of industrial R&D is not possible, although the information available suggests that major emphasis within the industry is aimed at process improvement rather than basic research.

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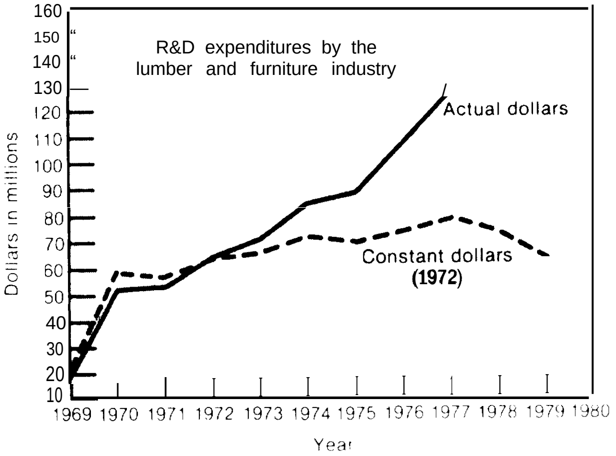
[22] K. Thompson, *Status of Forest products Research at Public Institutions in the South* (Mississippi State, Miss.; Mississippi Forest Products Laboratory, 1982), p. 12.

In terms of both dollars and scientist man-years allocated, the forest products industry is the largest supporter of wood science and utilization R&D in the United States. NSF estimates that in 1979 the industry spent a total of $148 million on lumber, wood products, and furniture R&D, and $454 million on paper and allied products R&D, Of the funds expended by the pulp and paper industry, 4 percent were for basic research, 25 percent for applied research, and 71 percent for product and process development. According to NSF, the solid-wood-products manufacturers spent 68 percent of their R&D budgets on development, 28 percent on applied research, and 4 percent on basic research. ’s

A recent McGraw-Hill survey estimated the pulp and paper industry’s 1980 R&D expenditures at $508 million and its 1981 expenditures at $584 million,[24] An estimated 40 percent of the R&D funds were spent for improving existing products, 27 percent for developing new products, and 31 percent for developing new manufacturing processes, Industry analysts expect greater emphasis on new processes in the future and a slight increase in emphasis on new products by the pulp and paper industry through 1985,

While actual-dollar R&D expenditures by the forest products industry increased at a significant rate between 1969 and 1979 (fig. 6), funding remained nearly level, measured in constant dollars. Between 1977 and 1981, R&D expenditures by the pulp and paper industry (fig. 6) increased approximately 10 percent annually in actual dollars, compared with an average annual increase of 15 percent in all industries.[25]

Figure 6.— Historical Research and Development Expenditures



SOURCE Economics Department, *27th Annual McGraw-Hill* Survey *of Business Plans for Research and Development* Expenditures (New York McGraw HIll Publication Co , 1982)

The manner in which the forest products industry reports R&D activities may mask the nature of industrial R&D programs, For example, many of the large pulp and paper producers and integrated forest products firms have extensive forest management research programs in addition to wood-utilization R&D. NSF, the Federal Trade Commission, and the Securities and Exchange Commission report aggregate R&D funding and do not report the proportion of corporate funds devoted to forest management versus that spent on wood-utilization R&D. For this reason, the R&D funding statistics quoted in this report include forest management research; therefore, the actual amount spent on wood utilization R&D probably is less than reported.

Other industrial sectors also perform R&D that is used by the forest products industry; likewise, some forest products industry R&D affects other industries. The major R&D effort related to wood utilization is funded directly by the forest products industry. A relatively small proportion of the total wood-utilization R&D effort appears to come from machinery suppliers, coating (paints) and resin manufacturers (chemicals), and users of wood products. It appears that most R&D performed by lumber firms is specifically used by the lumber indus-

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[23] Industry Studies Group, *Science Resources Studies Highlights: Real Growth in Industrial R&D Performance Continues in 1979* (Washington, D. C.: National Science Foundation, 1981), NSF 81-313, p. 2.

[24] Economics Department, *27th Annual McGraw-Hill Survey of Business Plans for Research and Development Expenditures* (New York: McGraw-Hill Publications Co., 1982], p. 8.

[25] ” A Research Spending Surge Defies Recession, ” *Business Week,* July 5, 1982, p. 68.

try, while less than 50 percent of the R&D performed by pulp and paper firms is used primarily by the industry itself.[26]

Compared to other manufacturing industries, the pulp and paper sector is well below the mean in its funding of R&D as a percentage of sales and capital expenditures. In 1981, R&D expenditures by the pulp and paper industry were less than 1 percent of its sales—significantly less than the 2.5-percent average for all manufacturing industries.[27] Electrical communications, aerospace, and the scientific instrument industries led all other manufacturing industries in 1981, Aerospace led all other manufacturing industries, devoting over 16.2 percent of its capital expenditures to R&D, which was 24 times more than that devoted by the pulp and paper industry.[28]

The relatively low premium put on R&D by the forest products industry may be due to a combination of factors: 1) the industry is mature in the sense that wood products are well developed and have been used in essentially the same form for a long time; 2) wood products are not high technology and, therefore, are not likely to be subject to revolutionary technological breakthroughs in their manufacture and use; 3) the industry is resource-oriented in that it focuses on the conversion of timber to useful products, rather than on the manufacture of a specific commodity that could be made from a range of materials; and 4) forest industry management generally is promoted from within; thus, the industry's R&D direction generally is less exploratory and is focused on product improvement or process efficiency rather than on new products.

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[26] F. Scherer, *Using Linked Patent and R&D Data to Measure Inter-Industry Technology Flows* (Cambridge, Mass.: National Bureau of Economic Research, 1981), p. 3.

[27] Economics Department, op. cit., p. 11.

[28] Economics Department, op.cit.,pp. 11-12.

Chapter II

Solid Wood and Panel Products

Chapter II

Solid Wood and Panel Products

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.

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*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 to 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,’

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

[2] USDA 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.

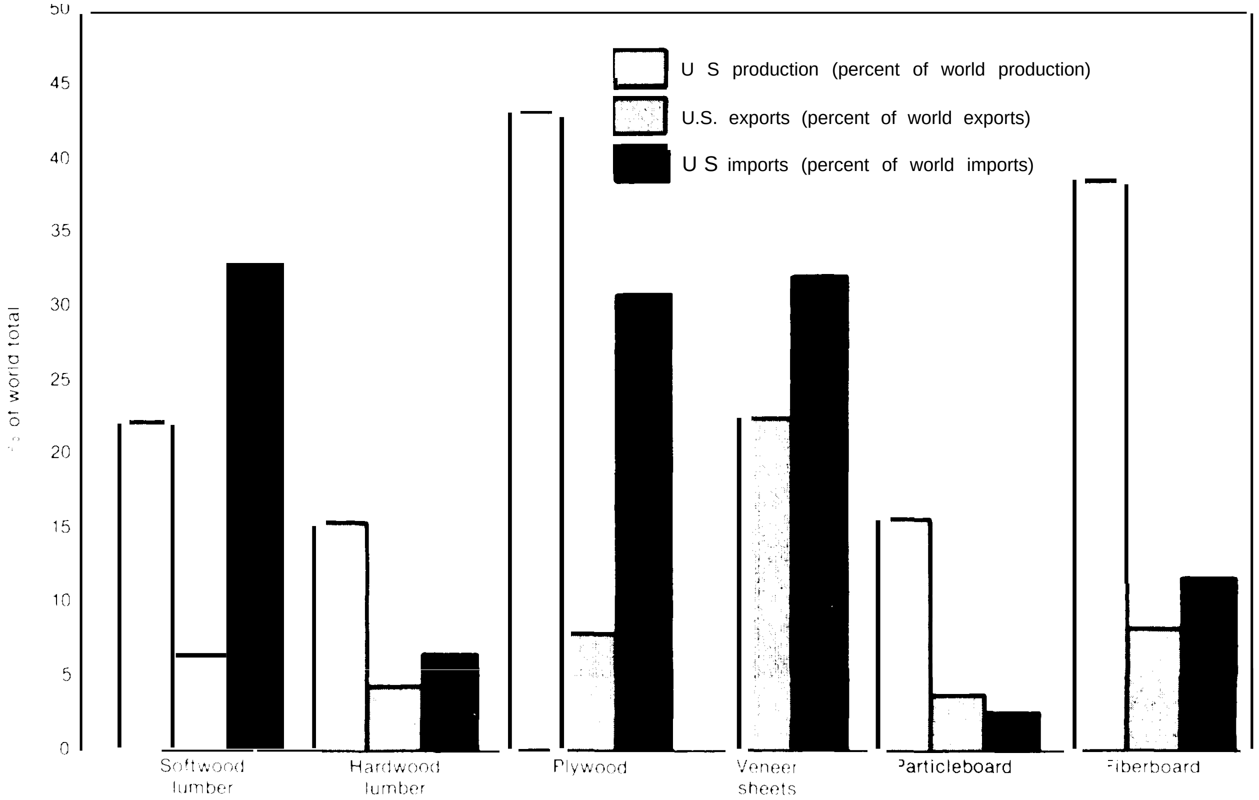
Raw Materials

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-

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

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

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,

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[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			Total tons (million)	Percent of total wood use
	Million board feet	Tons (million)	Percent of total lumber	Million ft² (3/8" basis)	Tons (million)	Percent of total plywood	Million ft² (3/8" basis)	Tons (million)	Percent of total panels		
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 [illegible]

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 Service 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 panel 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.

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

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.

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[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 industry, 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, large-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.

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

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

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.

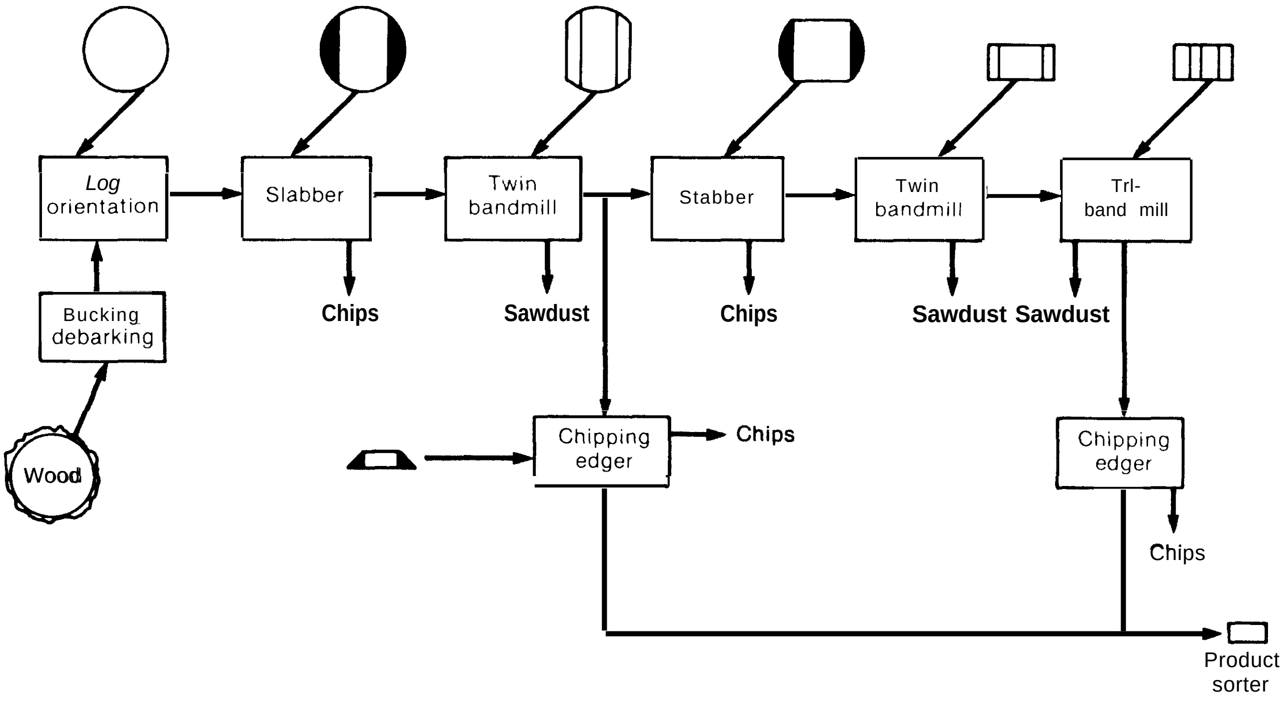
Potential Improvements in Milling Efficiencies and Lumber Manufacture

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.

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, whverticle 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).

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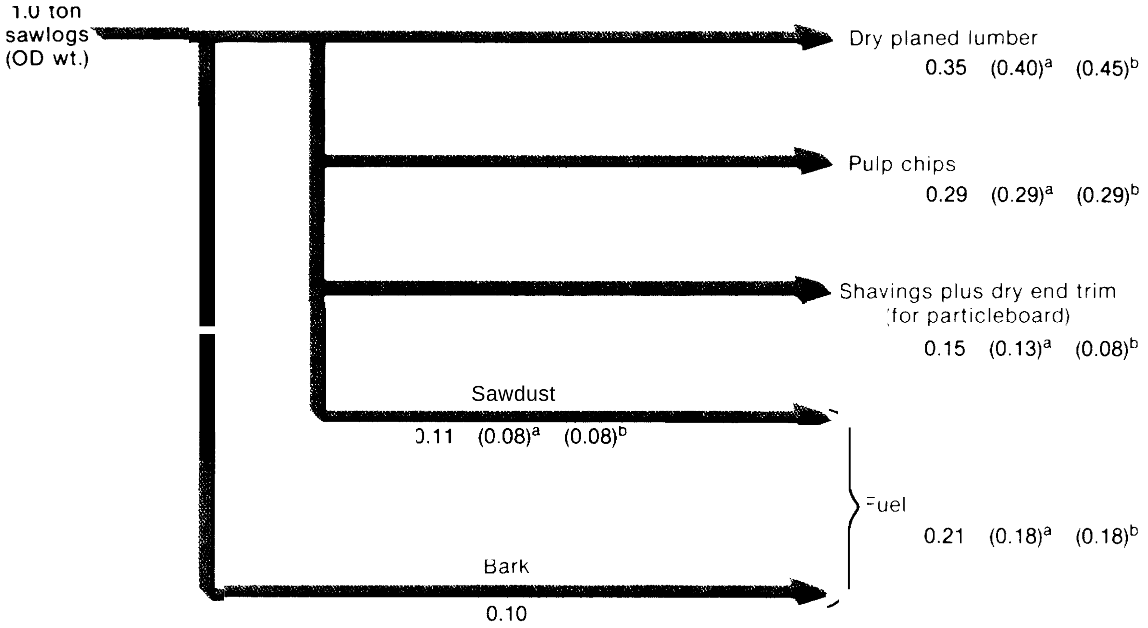
[13] USDA Forest Service, *U.S. Timber Production, Trade, Consumption, and Price Statistics, 1950-1980,* Miscellaneous Publication No. 1408, 1981.

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

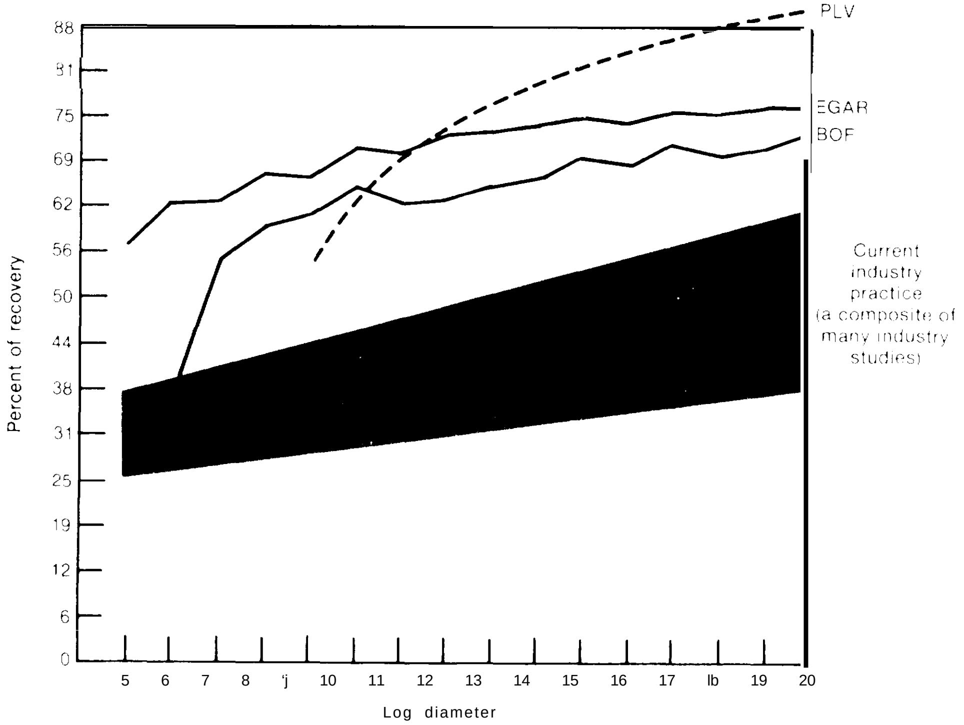
There is a practical limit to the amount of lumber that can be recovered from any log, However, some new processes can increase the lumber-recovery efficiency of dimension lumber without major sawmill modifications; e.g.: 1) the BOF program, which can produce higher grades and increase recovery of lumber;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

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* 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. 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-

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[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.

*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 1977 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

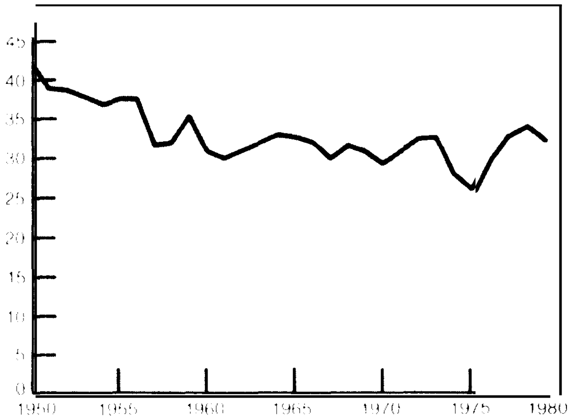
Lumber consumption in the United States has been relatively stable for several decades, increasing from just over 5 billion ft^3 in 19.50 to almost 6 billion ft^3 in 1979.[16] At the same time, per capita consumption of lumber has declined by over 20 percent over the past three decades (fig. 11).

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 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,

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.

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-

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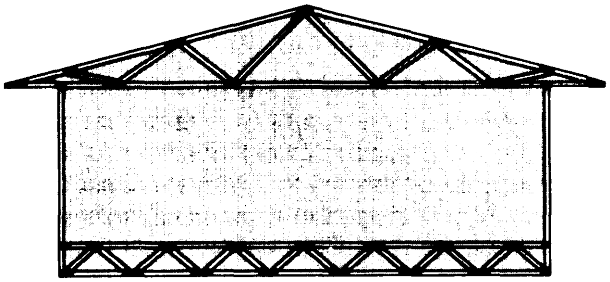
[16] See note 2.

Figure 12.—The Truss Frame System



This truss framed system combines floor, walls, and roof into a unitized framp 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.

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

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[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.

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.

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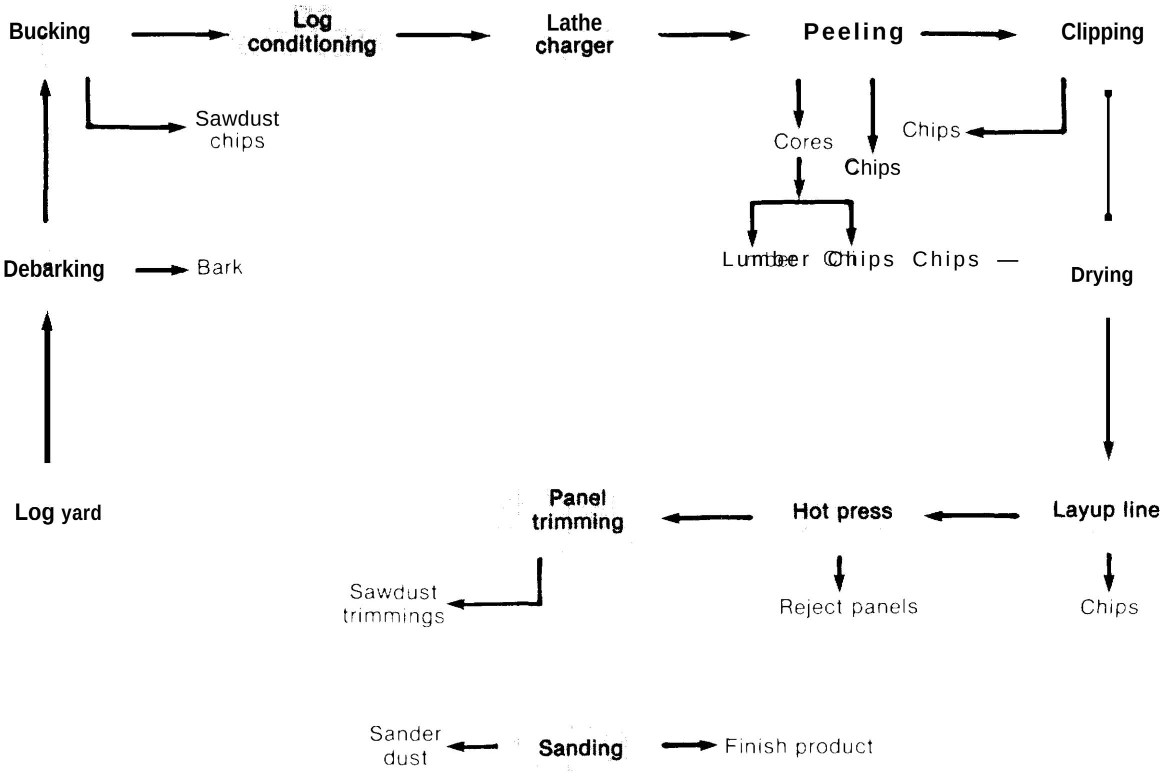
[20] See note 8.

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

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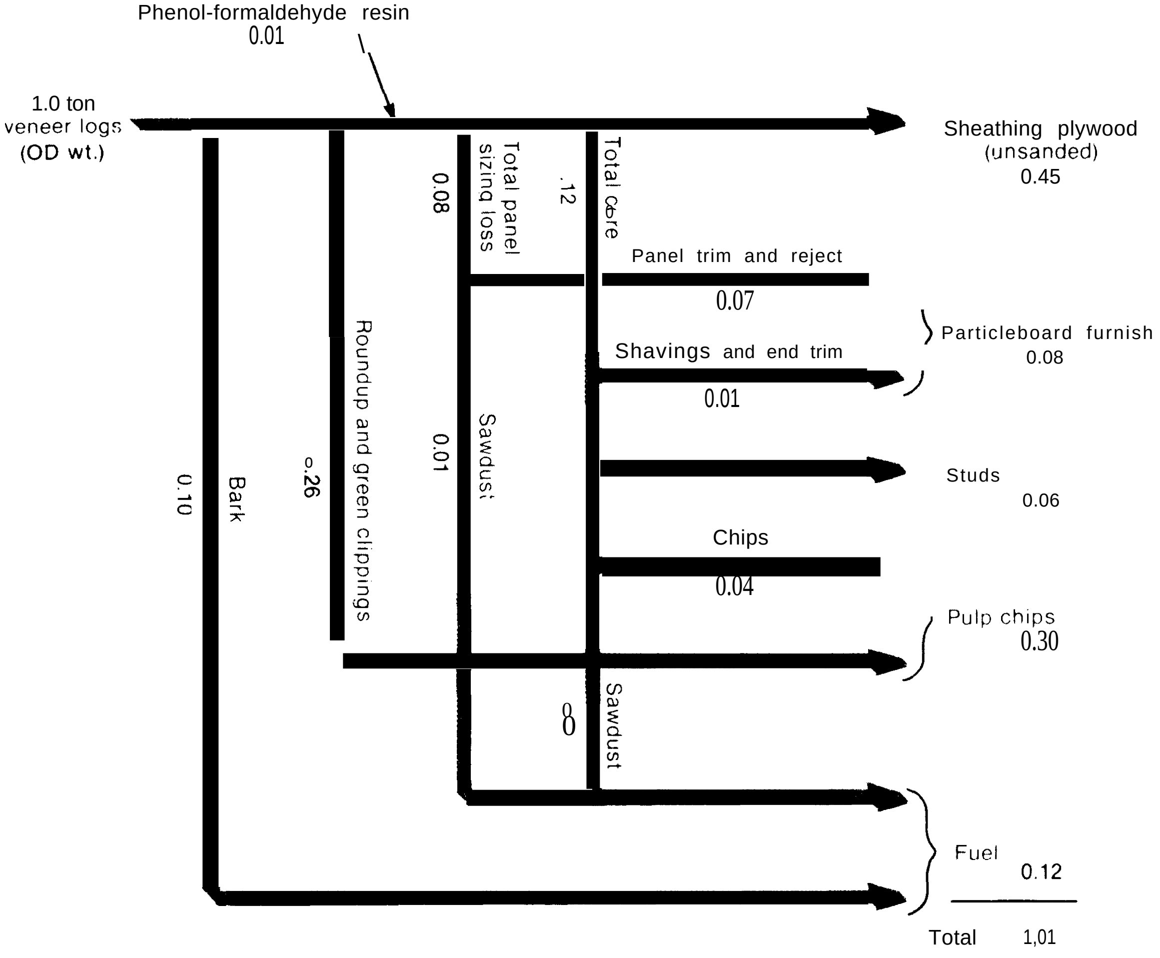
[21] Frank J Fronszak, "Preventing Veneer Bolt Spinout," *Modern Plywood Techniques*, proceedings of the Seventh Plywood Clinic, Portland, Ore., March 1979

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]

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*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.

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[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]

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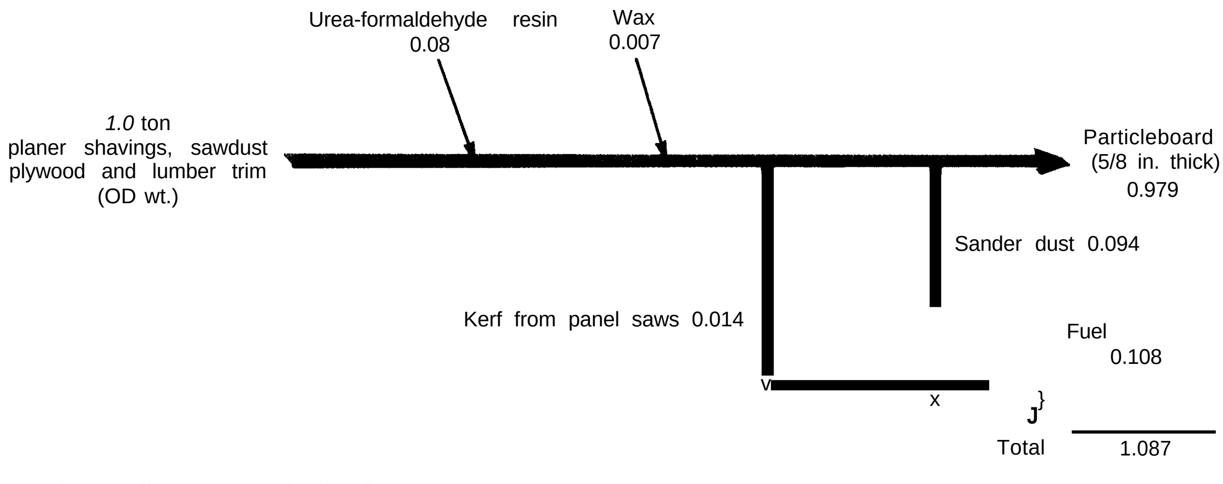
[27] Gene Wengert and Fred Lamb, "An Overview of Composite Boards," *Furniture Design and Manufacturing* 54(3), March 1982.

[28] See note 25.

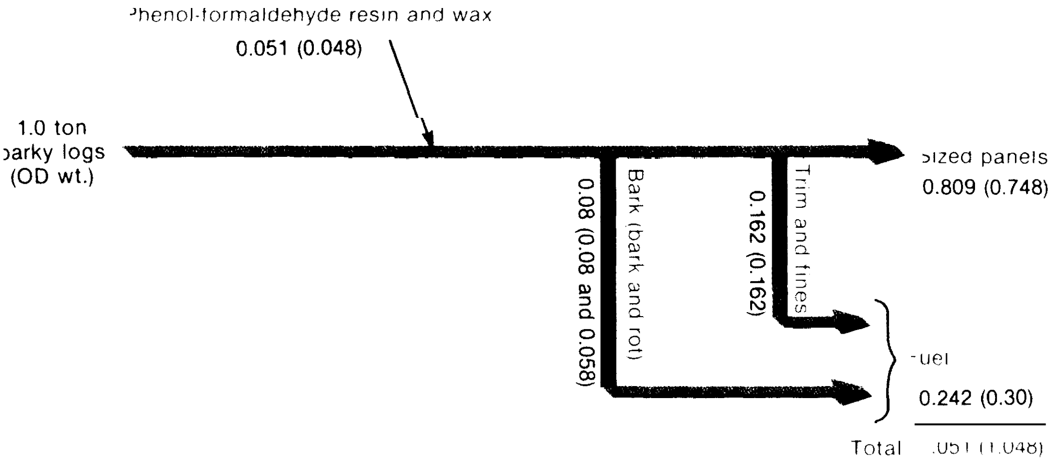
Figure 15.— Materials Balance for the Manufacture of Underpayment Particleboard Based on Ovendry Weight(OD wt.)



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 Fiber* 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

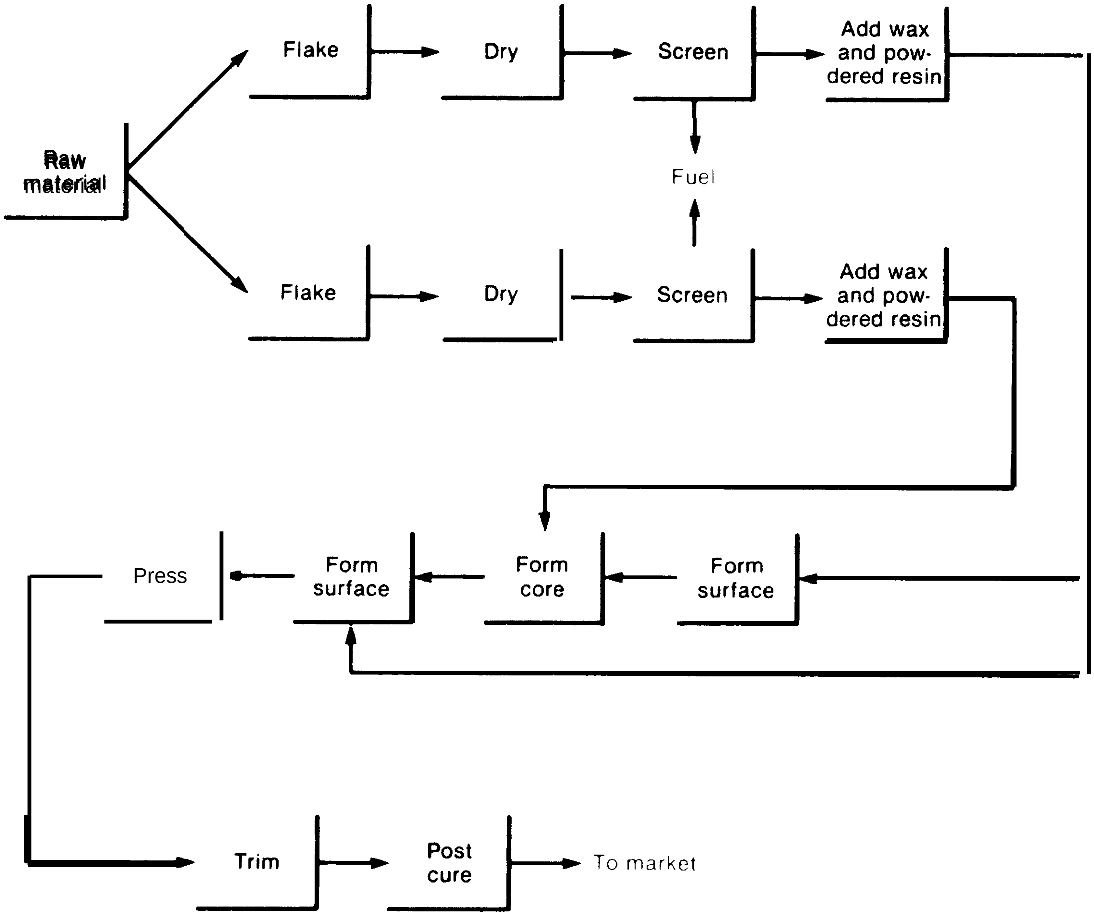
Structural composite panels were developed in an effort to get more out of the wood resource, a focus still primary in the industry. Nearly all the new panel products developed in the last two or three decades can use hardwoods and some defective wood material as well, although high-quality structural 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.

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-

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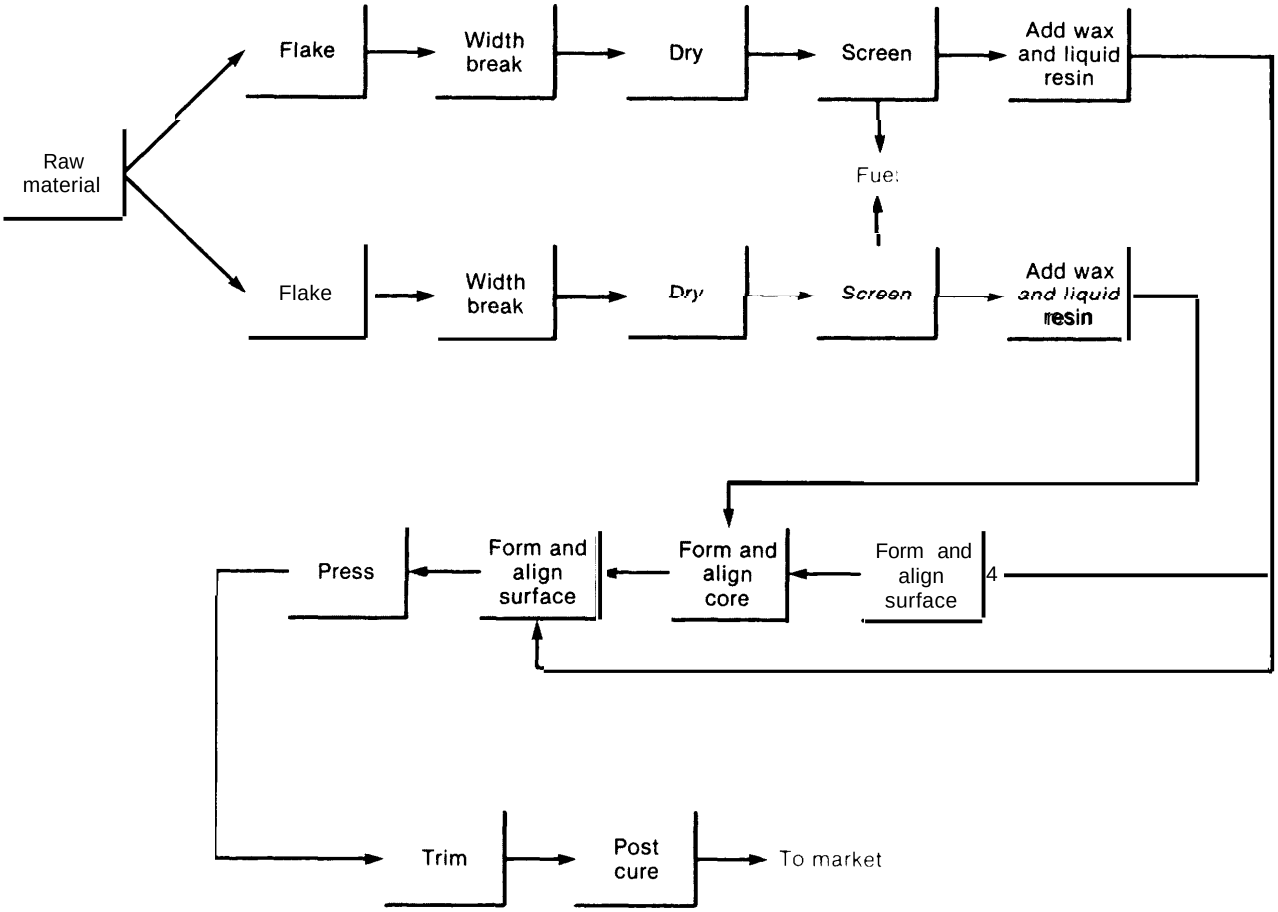
[29] Se~ note 8.

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-

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

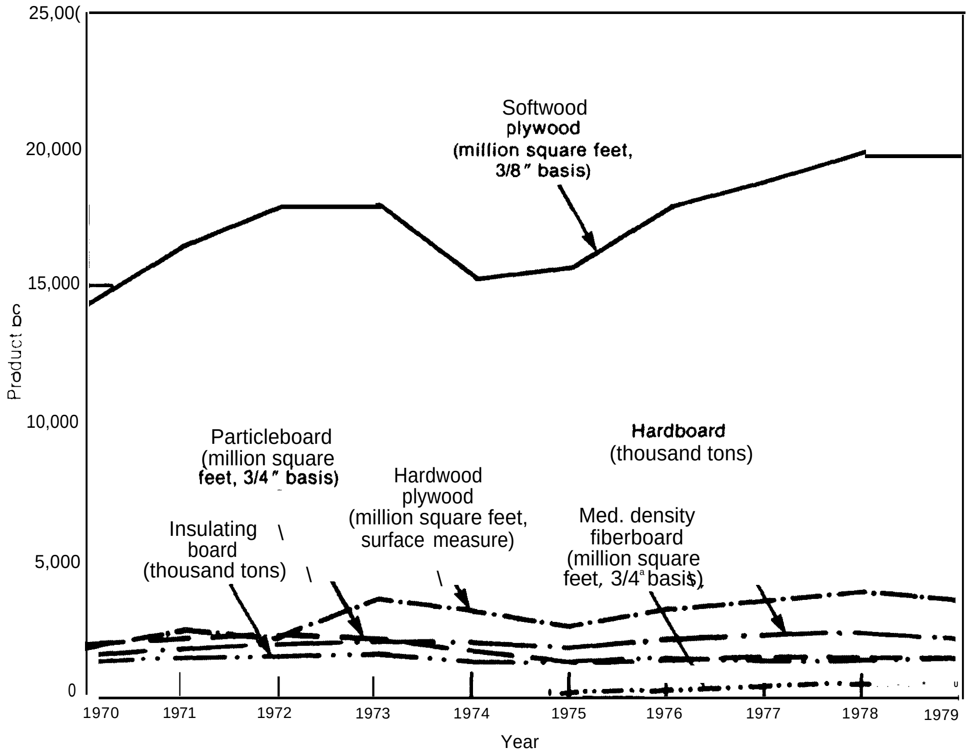
dried) to 11.8 million tons. During the same period, use of panel products (including fiberboard) rose from 1.3 million air-dry tons to 10.1 million. Statistics on per capita consumption of structural panel products, exclusive of hardboard and fiberboard, are not available.

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-

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



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[31] See note 8

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 ft^2) which has since been reduced to 17.9 billion ft^2

[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	0-5
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 Office 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 lumber 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).

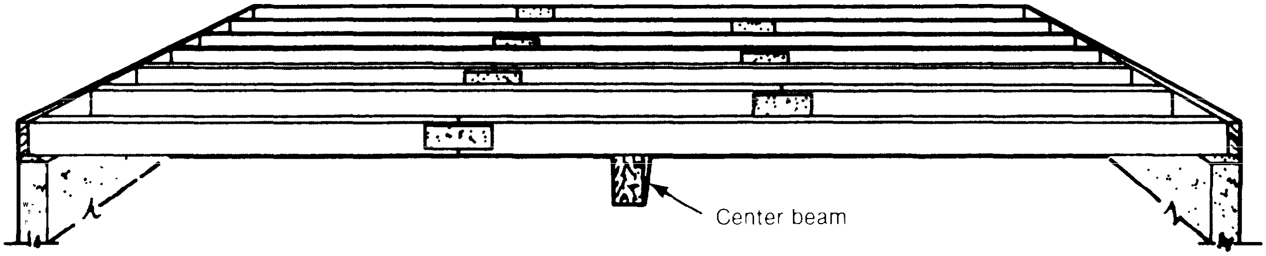
Framing and Attaching Assemblies

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



End joints properly located

SOURCE: HUD (F)

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

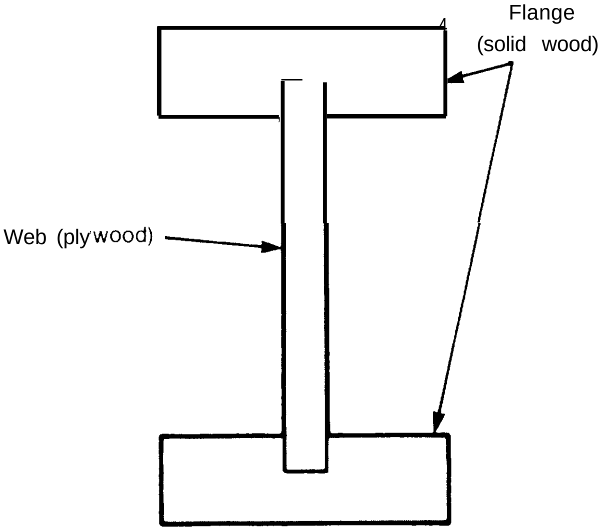
Even greater efficiencies may be possible using **sandwich panels** constructed to bear the loads required on walls, floors, and roofs, Sandwich panels can use plywood or other panel product facings, and their cores can be made of a variety of materials, such as foamed plastic, honeycomb paper, or bark.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

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

Table 21 .— Benefits of Truss Framing

Economic benefits
- Labor savings
- Material savings
- Quick 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 construct 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 construction (malted Joints)
- Meets or exceeds current structural, architectural, and safety provisions in model codes

SOURCE Adapted from USDA Forest Service, "Truss Framed Technology Transfer Plan 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 and 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 an 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.

CHAPTER III

Pulp, Paper, and Fiber Products

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Pulp, Paper, and Fiber Products

Summary and Conclusions

Pulp and paper manufacturing is moving toward the production of higher quality pulps that require less wood input per ton of pulp and paper produced. Increased energy costs, increasing raw material costs (for both roundwood and sawmill residues), a market that now emphasizes printability and other nonstrength factors, and the availability of immense amounts of less expensive hardwood timber have prompted the U.S. pulp and paper industry to consider more energy-efficient and materials-efficient manufacturing technologies.

The adoption of mechanical pulping technologies could reduce the amount of fiber required to produce a ton of paper from about 2.5 tons of wood, for the kraft chemical pulping process, to about 1.05 tons for thermomechanical pulping. With this reduction, it is estimated that each future increase of 2 percent in pulping capacity would necessitate an increase of only 1.7 percent in wood fiber feedstocks.[1] These potential increases in pulping efficiency and fiber yield can effectively extend the Nation's usable wood supply, reducing the likelihood of raw materials shortages and relaxing the pressures on the shrinking U.S. timberland base. Expanded use of hardwood species that are presently underutilized may further extend the domestic timber supply.

Pulping technologies like organosolv hold prospects for the industry to become a net energy producer. The organosolv process may also permit utilizing hardwood species and obtaining high fiber yields with little sacrifice in product strength. Such processes are still in the developmental stages but may be commercially available in 25 years. Meanwhile, the pulp and paper industry could reduce the amount of energy required by increasing the use of mechanical pulping and expanding the use of recycled paper. In addition, the efficiency of chemical pulping may be increased by adopting pyrolytic technologies for the recovery of spent pulping liquor, autocaustisizing to reduce the energy required in the lime-kiln process, and using anthraquinone as a catalyst for chemical kraft pulping to increase fiber yields.

Press-drying technology, while still in developmental stages, shows promise for both reducing the amount of energy required in the papermaking process and enabling the use of hardwood species not currently used in large quantities. In some respects, the quality of the paper produced by this method exceeds that of unbleached kraft paper produced by conventional processes. It may also afford an opportunity for the U.S. pulp and paper industry to capitalize on a growing export market in linerboard and other heavy-duty packaging materials.

Advanced research and development (R&D) on improving the strength and stiffness of paper could lead to development of structural fiber products able to compete with a number of metallic, ceramic, and plastic materials. In addition, paper may be combined with other materials such as plastics, coatings, and synthetic fibers to produce composite materials with superior qualities.

Although plastics have made significant inroads in certain types of packaging, and have significantly displaced paper sacks for light-duty uses, paper still commands a major proportion of this market and will probably continue to do so. Moreover, increases in energy costs could improve paper's competitive position relative to petroleum-based plastics, which require larger energy inputs in production. The paper industry could further strengthen its

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[1] G. Styan, "Impact of North American Timber Supply on Innovations in Paper Technology," *Paper Trade Journal,* vol. 164, May 30, 1980.

competitive position if it continued to adopt existing energy-efficient technologies.

Electronic telecommunications technology, on the other hand, could have significant impacts on demand for printing and writing paper in the future. While the magnitude of its effect on paper is yet uncertain, the introduction of advanced electronic devices such as electronic filing (the "paperless" office), video magazines, electronic newspapers, and video catalogs and directories may increasingly affect the use of paper now and during the next two decades. Recently, the use of word processors and office copying equipment has increased the demand for paper products, a trend that may decline as electronic communications gain increased acceptance in offices. In the final analysis, the long-term effects of telecommunications technologies on paper requirements are unknown,

Introduction

Profile of the Pulp and Paper Industry

The United States has the largest per capita paper and paperboard consumption in the world, averaging more than 600 pounds annually. It is also the world's largest producer of paper and paper products, accounting for approximately 35 percent of the world's total output. The U.S. pulp and paper industry is ninth in size of tons produced and 11th in gross assets among the domestic manufacturing industries. In 1981, U.S. production of pulp, paper, and paper products was estimated at $82.1 billion (current dollars).[2]

Raw Materials

In 1978 the pulp and paper industry used approximately 77 million tons of pulpwood (oven dried). Forty-four percent of this came from chips and sawmill residues, which are wood wastes from the manufacture of lumber and other solid wood products. About 26 percent of the pulpwood used in 1978 was hardwood. (Trends in wood use in the past 40 years have been toward increased use of hardwood species and increased reliance on chips and sawmill residues.) In addition, the U.S. pulp and paper industry used approximately 15 million tons of recycled wastepaper for pulp and paper production in 1978.[3]

The pulp and paper industry also uses about one-quarter ton of chemicals for each ton of paper or paperboard produced, ranking sixth among all industries in dollar value of chemical products purchased. It is also the largest user of water for processing among all manufacturing industries. Finally, the industry is one of the leading industrial consumers of energy, using roughly 7,2 percent of the Nation's industrial energy requirements and 2,8 percent of the total energy used in the United States. Approximately half of the energy used by the industry is produced internally from wood residues and other waste products. Because of the large energy requirements and the sensitivity of production costs to energy prices, the pulp and paper industry has become an industrial leader in energy conservation and cogeneration (internal generation of electricity from steam heat),

Product Demand

Demand for paper and paper products is closely tied to economic growth and disposable income levels. Although year-to-year fluctuations occur, correlating with economic trends, the industry is relatively free from the cyclical variations experienced by other primary industries such as mining, metals, and solid wood products.

Capital

The pulp and paper industry has exceptionally high capital requirements for plant and

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[2] U. S. Department of Commerce, *1982 Industrial Outlook* (Washington, D. C.: U.S. Government Printing Office, 1982), p. 39.

[3] Joan E. Huber, *The Kline Guide to the Paper Industry* (Fairfield, NJ.: Charles H. Kline & Co., 1980), pp. 66-67.

equipment, Capital investment currently ranges from $350,000 to $1 million per installed ton of daily capacity, depending on a mill’s design and whether the investment is an addition to the existing mill or a new facility.[4] The paper industry invested $6.8 billion in capital expenditures in 1980; however, $369 million, or 5 percent, was spent on pollution control equipment that did not increase production capacity.’

Industry Size and Production

With over 4,000 firms employing about 626,000 workers, the pulp and paper products industry is an important component of the U. S. economy. It produces over 14,000 different paper products, and its potential for developing new and even better paper and fiber products in the future is high. At the same time, more efficient manufacturing processes could reduce energy use and lead to increased use of presently underutilized, but prevalent, hardwood species.

It is estimated that paper products account for almost three-fourths of the wood-based sales of the top 40 firms in the forest products industry.[6] While the pulp and paper sector consists of a large number of competing firms, the 10 largest firms manufacture over half of the pulp, paper, and paperboard products produced in North America. In addition, a number of the major pulp and paper manufacturers produce a variety of secondary products, including solid wood items, containers, writing papers, and sanitary paper products (table 22). Fifteen companies that produce both paper and solid wood products are prominent among the wood-based industries, but together they accounted for only 24 percent of all wood-based sales in the United States in 1978.7

In 1976, the South produced 67 percent of the Nation’s wood pulp. Southern forests are particularly attractive to the industry because of the abundance of both softwoods and hardwoods, The pulp and paper industry *has ex*panded its capacity in the South in recent years; while the South’s share of total pulp production was only 48 percent in 1947, it is now over two-thirds, The West produced 17 percent of the Nation’s wood pulp in 1976. The remaining 14 percent was produced in the East and in the North Central States. [B]

While pulpmills are located near raw materials, the manufacturing sector of the industry, which makes containers, bags, sanitary products, and stationery, is concentrated near the markets. Thus, the New England Middle Atlantic, and North Central States produce 62 percent of all paper products. Much of the timber resource in these regions is hardwood, which has not been used extensively for paper production in the past. Wood pulp production in these regions currently constitutes only 16 percent of total U.S. wood pulp production.

Uses of Pulp, Paper, and Paperboard

Total U.S. pulp production has been projected to increase from 53.2 million short tons in 1981 to 54.8 million short tons in 1982. How ever, the actual volume may be *lower* as a result of the 1981-82 recession. [8] In addition to the domestic products used, approximately 4.3 million short tons of pulp were imported in 1981, primarily from Canada. Pulp exports totaled 3,7 million tons, most of which was shipped to Europe, Mexico, Japan, and Korea. The total 53.8 million short tons of pulp used were converted into over 66 million tons of paper and paperboard. Imports of primary paper and paperboard products were about 8 million tons in 1981, while exports slightly exceeded 4 million tons,

Wood pulp is converted into a variety of paper products (table 23). The major uses of paper, which accounts for 49 percent of the wood

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[4] Conversation between Benjamin Stayton, API, and James Curlin, OTA.

[5] George H. Boyd III and Chad E. Brown, *Paper—Forest Products Industries: Capital Expenditure Forecast* (New York: Peabody & Co., 1981), p. 6.

[6] Jay O’Laughlin and Paul V. Ellefson, “U.S. Wood-Based Industry Structure: Part I—Top 40 Companies,” *Forest Products Journal*, October 1981, vol. 31, p. 56.

[7] Jay O’Laughlin and Paul V. Ellefson, “U.S. Wood-Based Industry Structure: Part II, New Diversified Entrants,” *Forest Products Journal*, November 1981, vol. 3, p. 27.

[8] Huber, op. cit., pp. 39-40.

[9] U.S. Department of Commerce, op. cit., p. 42

Table 22.—Estimated North American Capacity by Grade of Top 20 Pulp, Paper, and Paperboard Producers (thousands of tons)

	Pulp		Paper										Paperboard					Other
Rank Company	Total market pulp, paper, and paperboard capacity	Market pulp	Newsprint	Uncoated groundwood papers	Coated papers	Uncoated book papers	Wood pulp writing papers	Specialities, cover, and thin papers bleached bristols	Unbleached and bleached packaging papers	Tissue papers	Total all papers	Unbleached kraft linerboard	Corrugating medium	Recycled paperboard	Bleached board	Total paperboard	Building and wet machine board
1 International Paper	7,534	1,000	1,440	—	305	830		320	580	59	3,534	2,000		—	1,000	3,000	—
2 Weyerhauser	3,987	1,100	210	—	—	—	550	—	115	—	875	1,235	375	—	275	1,885	127
3 St. Regis Paper	3,470	720	650	58	675	—	—	491	50	—	1,924	850	200	335	50	1,435	—
4 Boise Cascade	3,071	292	690	225	185	860		80	110	—	2,442	370	100	—	—	470	159
5 Crown Zellerbach	3,015	200	485	100	350	140		60	500	350	1,965	525		325	—	850	—
6 Abitibi Price Group	2,999	193	2,001	407	—	218		—	—	—	2,626	—	—	60	—	60	100
7 Georgia-Pacific	2,957	796	—	—	—	421		—	527	443	1,391	272	118	281	119	770	—
8 Champion Internatonal	2,793	280	—	—	330	775		—	225	—	1,330	535	300	118	250	1,203	—
9 Mead	2,612	358	80	—	432	374		54	—	—	940	690	280	206	140	1,316	—
10 Union Camp	2,453	—	—	—	—	525		—	425	—	950	1,300	—	80	125	1,505	—
11 Great Northern Nekoosa	2,407	100	350	375	110	630		12	50	—	1,527	585	215	—	—	780	—
12 MacMillan Bloedel	2,384	507	1,323	—	—	44		—	—	—	1,367	440	70	—	—	510	—
13 Westvaco	1,900	125	—	—	375	150		—	160	—	585	585	100	—	425	1,090	—
14 Container Corp.	1,895	—	—	—	—	—	—	—	—	—	—	745	410	570	170	1,895	—
15 Scott Paper	1,835	—	—	—	350	—	260		—	1,025	1,635	—	—	—	—	—	—
16 Continental Forest Inc	1,620	—	—	—	—	—	—	—	375	—	375	785		—	460	1,245	—
17 Time Inc.	1,580	115	—	—	—	—	—	—	100	—	1,200	630	390	—	325	1,345	—
18 Domtar	1,538	147	418	—	—	350		50	78	—	894	313	63	121	—	497	—
19 Kimberly-Clark	1,390	—	730	—	—	—	145		—	515	1,390	—	—	—	—	—	—
20 Owens-Illinois	1,193	—	—	—	—	—	—	—	—	—	—	650	543	—	—	1,193	—

Table 23.—U.S. Production of Paper and Paperboard in 1981 and Projected for 1984 (thousand tons)

	1981	1984[a]
Paperboard	14,558	15,360
Kraft fiberboard	1,067	1,140
Other kraft paperboard	4,717	5,070
Bleached paperboard	3,926	4,100
Recycled paperboard	7,070	7,150
Total paperboard	31,338	33,020
Paper:		
Uncoated free sheet	7,882	8,720
Coated free sheet and groundwood	4,951	5,340
Uncoated groundwood	1,440	1,540
Bristols and other	1,530	1,580
Total printing and writing	15,803	17,180
Newsprint	5,238	5,730
Unbleached kraft	3,891	3,760
Bleached regular and industrial	1,603	1,670
Tissue	4,485	4,730
Total paper	31,020	33,070
Total paperboard and paper	62,358	66,090

[a] Morgan Stanley estimates

SOURCE Thomas P Clephane and Jeanne Carroll Linerboard *Industry Outlook (New* York Morgan Stanley & Co 1982) p 25

pulp produced, are for printing and writing papers [50.9 percent), newsprint (16.9 percent), tissue (14.5 percent), and packaging (17.7 percent). Over 51 percent of U.S. wood pulp production is converted to paperboard (a stiff, heavy paper). Linerboard, which is kraft paperboard used for boxes, shipping containers, and packaging, accounted for 46.4 percent of the paperboard produced in 1981. Overall, packaging materials (both paper and paperboard) made up 59 percent of all paper and paperboard produced in the United States, and was one of the most rapidly expanding pulp uses.

Since the price elasticity of demand (the change in demand resulting from a change in price) for paper products is generally small, the recent decline of relative prices has probably had only a small positive impact on apparent paper consumption.[10] The U.S. Department of Commerce projects shipments of primary paper and paperboard products to rise at the rate of 3 percent annually for the next 5 years. Market projections through 1986 suggest a steady increase in domestic and worldwide demand for paper products in general. Demand for primary paper and board products is expected to be exceptionally strong. Economic factors affecting demands for communications, packaging and shipping papers, and boards, however, will ultimately determine actual demand levels.

The most promising markets during the ensuing 5 years are expected to be for linerboard and high-quality printing papers. An increase of 6 percent in the trend line of 1982 linerboard exports is forecast by some analysts,[11] and the demand for high-grade printing and publishing papers is projected to increase at an annual rate of about 7 percent.[12] Demand for both printing paper and linerboard is expected to expand at rates twice that for products of the paper industry overall. While domestic consumption will probably increase gradually in response to a stronger economy, the demand for exports is expected to increase even more, in response to expansion of the industrial economies of the People's Republic of China, Japan, Malaysia, Indonesia, the Philippines, Taiwan, and Korea.

Advanced Paper Materials

The development of stiff, durable paper, with strength characteristics currently achievable only at the experimental level, offers future prospects for new structural building products, Paperboard has been tested for use as sheathing and wall modules in buildings with mixed results.[13] The effects of moisture on the dimensional stability and stiffness of the paperboard is a major factor limiting the usefulness of paper as a structural material. New high-strength papers with protective coatings, coupled with innovative designs for paper-based structural materials, are a possibility, But considerable R&D remains to be done prior to commercialization.

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[10] Calculations by the Kidder, Peabody Economics Group indicate that the relative price elasticity of demand for paper is approximately 0.5 percent.

[11] Thomas P. Clephane and Jeanne Carroll, *Linerboard Industry Outlook (New* York: Morgan Stanley & Co., 1982), p. 1z.

[12] Corporate Strategies, "A Narrowed Boise Cascade Focuses on Paper, " *Business Week*, Apr. 26, 1982, p. 81.

[13] "Emergency Housing for $2,500, " *Technology Review*, May/June 1982, p. 86. "Paperboard Houses Now Approved for all Exposures by FHA, " *Paper Trade Journal* (Aug. 23, 1971], p. 53; "Paper Houses Buyers, " *Chemical Engineering*, Sept. 8, 1969, RP 76-71.

Wood pulp may be converted into paper products ranging in character from superabsorbent fluffy tissue to extremely hard, boardlike materials. Wood pulp's versatility results from the ability to vary paper's stiffness over a wide range. Wood fibers are extremely flexible, strong, and durable. When brought into close contact, they form a durable fiber web as a result of hydrogen bonds, strong bonds which provide the strength and stability of paper. Hemicellulose acts as an adhesive between the fibers and adds strength.

Stiffness is the major quality that makes papers so suitable for boxes, shipping containers, and, possibly, structural building materials. Although strength is also important, it is more frequently lack of stiffness that limits the choice of materials for these products. Because cellulose fibers attract water, moisture can affect paper's structural integrity by softening the fibers and reducing their stiffness, Tests in modifying paper to enhance stiffness and moisture resistance, performed at the U.S. Forest Service Forest Products Laboratory (FPL), have demonstrated that super-strength paper may, on a weight basis, be capable of matching the performance of other solid materials like solid wood, aluminum, and steel.[14]

The major factors affecting stiffness that are subject to control by the papermaker are fiber orientation, density and fiber bonding, and shrinkage control during the drying cycle.[15] The prospects for improving paper stiffness through the use of synthetic resin additives are not considered as promising as improved bonding and fiber orientation in the papermaking process.

Researchers at FPL hypothesize that an elastic modulus of approximately 1.5 million pounds per square inch (psi), with a specific gravity of 0.4, could be achieved in paper in which the fibers are parallel and shrinkage is carefully controlled during drying. This level of stiffness is approximately equivalent to that of wood parallel to the grain at the same specific gravity. Laboratory tests have produced paper sheets of specific gravity of 0.75, with a tensile strength of 38,000 psi and an elastic modulus of 3.8 million psi.[16] These values substantially exceed the specific strength and stiffness-to-weight ratios of all common structural materials, including solid wood. Only certain graphite and boron fiber composites surpass the strength of this "super paper" at the specific gravity tested. Laboratory researchers conclude that paper can be produced that is stiffer and stronger than the wood from which it is made, If high-strength papers can be developed that are capable of maintaining stiffness and dimensional stability in high humidity, they may be used for a range of structural applications now being served by wood, plastics, or metals—e.g., housing, furniture, and containers,

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[14] V. Setterholm, "Factors That Affect the Stiffness of Paper, *The Fundamental Properties of Paper Related to Its Uses,* vol. 1, F. Bolam (cd.) (London, England: The British Paper and Paperboard Industry Federation, 1976), pp. 253-266.

[15] Ibid., p. 266.

[16] Ibid., p. 260.

Role of Paper and Cellulosic Materials in the U.S. Material Mix

Competition with traditional paper commodities for U.S. markets comes primarily from two areas: plastics and electronic communications. Competition from plastics is often in the form of substitution of plastic products for paper products and, occasionally, composite products made from paper and plastics, Electronic communications, on the other hand, have the potential for displacing a share of the paper market by reducing the need for writing, copying, printing, and business forms. So far, however, electronic communications has probably resulted in greater consumption of paper, owing to increased use of word processors, high-speed computing systems, and inexpensive office copiers.

The impact of competition from plastics and the electronics media on paper materials will vary among paper products. Newsprint, writing and printing papers, business forms, paper bags, and wrapping papers constituted 47 percent of paper consumption in the United States in 1979 (table 24). Some anticipate that these products, in contrast to linerboard and paperboards used in shipping containers, will be seriously affected by competition from plastic products and the electronic media. The printing and writing paper sector, which constitutes one-third of U.S. paper consumption, will likely experience the greatest impact from the expan-

Table 24.—Uses, Grades, Production, and Consumption of Paper Products in the United States in 1979

Market	Grade	Production (thousand tons)	Percent	Apparent consumption (thousand tons)	Percent
Newspapers	Newsprint	4,062	6	11,215	16
Magazines, directories, catalogs	Uncoated groundwood	1,530	2	2,254	3
Magazines, annual reports, other periodicals	Coated papers	4,526	7	4,640	7
Books	Uncoated book				
Commercial printing, envelopes, business forms, lables, duplicator covers, and text	Writing and related	7,868	12	7,913	11
Cigarettes, carbonizing condensers	Thin paper	376	<1	391	<1
Bond, writing, other business, and technical	Cotton fiber	125	<1	126	<1
Tabulating index, tag and file folder, post card	Bleached bristols	1,114	2	1,116	2
Wrapping, bag, sack, shipping sack	Unbleached kraft packaging and individual converting	3,934	6	3,937	6
Bleached bags, wrapping glassine, greaseproof	Other packaging and industrial converting paper	1,791	3	1.729	2
Industrial converting	Special industrial paper				
Sanitary tissue papers, waxing, and wrapping tissues	Tissues	4,525	7	4,514	6
Total paper		29,851	46	37,835	54
Facing for corrugated or solid fiber boxes	Unbleached kraft linerboard	14,076	22	12,611	18
Tube, can, drum, file folder, shipping containers	Other unbleached kraft fiberboard	1,127	2	1,050	1
Recycled corrugating medium, chip and filler board boxes, partitions and dividers	Semichemical paperboard	4,721	7	4,737	7
Folding cartons, milk cartons, paper plates, cups, posters	Solid bleached paperboard	4,023	6	3,310	5
Folding cartons, setup boxes, gypsum wallboard facing	Recycled paperboard	4,883	12	7,533	11
Total paperboard		31,631	49	29,241	42
Construction products, insulating board, binder, and shoe board	Building and wet machine board	3,466	5	3,763	5
Other		—	—	(462)	—
Total paper		64,947	100	70.340	**100**

SOURCE Adapted from G Boyd Ill and H Dudley, *Paper Industry Outlook for 1980 Through 1982, Part // (New* York K!dder , Peabody & Co 1980) p 10 sion of electronic communication if telecommunications technology is accepted by the business community and home use expands significantly in the future. Plastic substitutes for paper bags, wrapping papers, and miscellaneous office supplies could displace 10 percent of the paper consumed in the United States annually,

Competition From Plastics

The use of low-density polyethylene film (LDPE) for packaging, wrapping, and sacking, and high-density polyethylene film (HDPE) for printing and wrapping paper, is a comparatively recent trend that began during the past decade and continues to expand at a steady rate. Plastics claimed only a l-percent share of the grocery sack market (small sacks used for individual items) in 1979, but within 2 years expanded to 5 percent of the market. The plastics industry projects that plastics could capture as much as 25 percent of the grocery sack market by 1985,'[17] but, according to some analysts, the penetration of plastics into the traditional kraft paper markets will probably be selective, For example, the grocery bag market (larger, multiwalled, heavy-duty bags) may be less vulnerable to inroads by plastics, at least during the intermediate term (10 to 15 years).[18]

Several factors will determine the future competitiveness of plastics in relation to paper products: 1) relative production costs, including raw material (resin for plastics and wood, and chemicals for paper), labor (in general, the paper industry is more labor-intensive), and energy consumption; 2) rate of technical innovation; and 3) consumer acceptance.

Sack/Bag Market

Plastics' share of the merchandise bag market was estimated to be 35 percent in 1981, an increase of 10 percent over the previous year, Investment analysts at Morgan Stanley & Co. estimate that plastic bags will control 60 percent of the merchandise bag market by 1985.[19] Production of 275,000 tons of finished bags annually account for only 5 percent of the total production of unbleached kraft paper. Morgan Stanley estimates that by 1985, merchandise bags will require no more than 3 percent of the total production of unbleached kraft paper production.

Large grocery bags consumed 12 percent (467,000 tons) of the unbleached kraft paper produced in 1981, Small grocery sacks accounted for 95 percent of the 1.3-million-ton total grocery sack market in 1981 and used approximately 34 percent of the unbleached kraft paper produced during that year. Until recently, plastics were not considered to be serious competitors of kraft paper for the grocery bag/sack market; however, some analysts now predict that plastics may be able to capture rapidly an increasing and significant share of the market, The paper industry confirms that plastics now compete at prices ranging from $0,029 to $0.031 per sack and sell for 10 to 15 percent less than unbleached kraft sacks. The major plastic sack producers include several oil companies and chemical companies: Mobil, Exxon, and Union Carbide,

One reason for plastics' current success in competing with kraft paper in the bag and sack market is the availability of low-cost resins. Another is technological developments in polyethylene that permit substantial reduction in plastic thickness and volumes without sacrificing strength. For example, development of the Unipol process for making linear, low-density, polyethylene resin in 1979 constituted a major breakthrough for the plastics industry because it required considerably lower capital investment and consumed less energy per unit of resin produced.

Paper currently possesses properties that are superior to plastics as a material for bags and sacks. The rigidity of paper sacks enable them to stand freely for filling in grocery and retail stores. To compensate for lack of sidewall rigidity, plastic sacks must be mounted in racks for ease of filling. Although such technology does not yet exist, it might eventually be possible to develop a rigid-wall plastic sack capable of competing economically with paper

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[17] Clephane, p. 18.
[18] Ibid., p. 17.
[19] Ibid., p. 16.

sacks. The conversion from LDPE to newer low-density polyethylene film could provide even greater price advantages for plastic sacking.

Multiwall Sacks

One major segment of the paper sack market that has not yet been seriously challenged by plastics is the multiwall, bulk shipping sack. Plastics have not made significant inroads in this sector because the strength properties required put plastics at a cost disadvantage relative to kraft paper. Plastics currently occupy 10 percent of the multiwall sack market, and some industry analysts assume that this market penetration will remain stable over the long term unless unforeseen technological developments occur. Product developments in the pulp and paper industry may reinforce paper's share of the multiwall sack market. For example, St. Regis Paper Co. recently introduced Stress Kraft, a superior-strength paper permitting a 20-percent reduction in the weight of the paper used for multiwall sack construction.[20] Multiwalled sacks consumed approximately 26 percent of the unbleached kraft paper produced in 1981.

Liquid Containers and Packaging

Plastic containers for liquid have made significant gains in competition with glass and coated-paper containers. Plastic l-gallon milk containers now dominate the market, although most smaller l-quart and l-pint containers continue to be coated paper. Technological innovation accounts for the current inroads of plastics in the packaging sector, yet plastics have still captured only a small proportion of the packaging and container market. Because plastics are petroleum derivatives that are not biodegradable, and in some cases may produce toxic fumes if incinerated, plastic packaging products have met opposition from environmentalists.[21]

The market for tissue wrapping papers and glassine and parchment papers has not been significantly penetrated by plastics, although plastic bakery bags and cereal box liners are in wide use, The major limitations to the use of plastics in these areas are primarily linked to the difficulty of adapting automatic packaging machines for the new materials. HDPFs have properties similar to the cellulose films and may some day challenge conventional paper materials in this area.

While plastic and aluminum foil trays have significantly challenged paperboard fiber trays for packaging meats, fish, and prepared and frozen vegetables, recent trends in microwave cooking (which cannot use aluminum foil containers and requires heat-resistant receptacles) have resulted in a new generation of oven-resistant packaging. Polyester coatings have been joined with molded paper trays to create a composite product suited for microwave cooking conditions. [22]

A number of composites, which combine paper with plastics and metals, provide a product superior to those made with one material. Among these are collapsible plastic bags inside paperboard cartons equipped with a spout for dispensing liquids, thermoplastic-coated paperboards for water-resistant food containers, paper meat trays coated with plastics, paperboards treated with clay-adhesive mixtures and bonded with metal foils, and paper cartons laminated with plastic foams.

Printing and Writing Papers

Plastic films have not significantly displaced printing and writing papers, except for specialized uses. The properties of paper (printability, flexibility, wearability, and price) are well suited for printing, recordkeeping, business forms, magazines, and books. The durability of plastics (e. g., in Mylar and waterproof papers) makes them useful for transparent reproducible graphics, children's books, and outdoor use, However, the cost of printable plastic films is approximately twice that of the highest

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[20] "St. Regis Introduces New Kraft Paper," *The Journal of Commerce*, Apr. 17, 1982.

[21] "Plastic Food Packaging Makes Deeper Inroad on Paper, Metal, Glass," *The Wall Street Journal*, May 8, 1978, p. 1.

[22] W. Lemaire, "Paperboard Packages for ot'ens,'" *Food Engineering*, January 1978, p. 62,

grades of paper.[23] Paper industry analysts believe the probability is low that plastics will be able to displace paper in general business and commercial use, except for the highly specialized applications named above.

Synthetic **Fibers**

The major petroleum-based synthetic fibers that compete with rayon and acetate are the polyesters, nylons, acrylics, and olefins. In 1968, the worldwide volume of cellulosic manmade fiber produced was about the same as that of noncellulosic manmade fibers (3.9 million tons).[24] Since that time, the noncellulosic fibers have dominated the artificial fiber market. This trend may continue, although the market shares for rayon and acetates appear to have stabilized. Some predict that a slight resurgence in the use of rayon may occur if petroleum prices increase significantly.

Improvements in the viscose rayon process or the development of new processes that could reduce the cost of rayon manufacture may also reinforce the market position of cellulosic products. Some claim that the rayon industry has suffered from a reduction in R&D in the 1950's and 1960's, the period when petroleum-derived synthetics displaced rayon as the predominant manmade fibers.

The rayon and acetate industries, however, consider their major competitor not to be the petroleum synthetics but natural cotton fibers, Cotton and rayon have similar properties with regard to moisture absorption and other wear characteristics, making possible development of improved, cottonlike rayon fibers that are directly substitutable for cotton. The rayon industry sees an opportunity to expand its market without meeting competition from petroleum synthetics, based on the forecast that worldwide demand for cotton will increase at a rate exceeding the capacity of the agricultural industry to meet the requirements. 's

Competition From Electronic Technologies

Recent developments in large-scale, integrated circuitry are revolutionizing the communications and information fields by reducing the size of computers and microprocessors, expanding their capacities and flexibilities, reducing costs, and increasing availability to a wider range of potential users.[26] Through the use of satellite communications, microwave, and interfacing devices on home television receivers, electronic communications may be linked with large centralized information systems that are capable of providing a wide range of user services. Further developments in optical digital-disk technology (a specially coated plastic disk on which information is encoded by a high-powered laser beam) may enable the permanent storage and relatively cheap retrieval of immense amounts of information.[27] Fundamental research on new concepts of data storage and retrieval may pave the way in the future for even greater expansion of information technology.

Achievements in telecommunications technology during the past two decades offer a number of opportunities for improving the speed and flexibility of communications, Electronic mail is being considered by the U.S. Postal Service and private firms as a way to speed textual communications and eliminate the need for handling and physically transporting mail.[28] Some foresee electronic filing leading to the paperless office.[29] Video magazines, which may be transmitted directly into the

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[23] "Where Plastic Papers Stand in Printing, Bags and Tissues, " *Modern Plastics,* March 1973, p. 55.

[24] Committee on Renewable Resources for Industrial Materials (CORRI M), *Fibers as Renewable* Resources *for Industrial Materials* [Washington, D. C.: National Academy of Sciences, 1976], p. 234.

[25] G. Daul, op. cit., p. 84.

[26] U.S. Congress, Office of Technology Assessment, *Computer-Based National Information Systems: Technology and Public Policy Issues,* OTA-CIT-146 (Washington, D. C.: U.S. Government Printing Office, September 1981), pp. 3-12.

[27] C. Goldstein, "Optical Disk Technology and Information, " *Science,* vol. 215, Feb. 12, 1982, p. 862.

[28] J. Free, "Electronic Mail: Good-bye to Paper?" *Popular Science,* September 1980, pp. 78-141.

'°'' Electronic Filing to Threaten Cut Size Paper Markets, " *Fiber Market News, No.* 72, Dec. 14, 1981, p. 1, home via satellite and conventional television receiver, are in the early stages of development.[30]

Television-adapted versions of the phone directory, retail catalogs, and other merchandising devices, which can be viewed on home televisions, are currently being evaluated for public use.[31] Also, a number of major newspaper publishers are interested in producing electronic newspapers; in the United Kingdom at least three such teletexts are already operating.[32] Futurists consider as long-range prospects the use of vast central information systems—"hypertex capableable of retrieving, displaying, and manipulating information from "grand libraries" through personal consoles.[33]

Such broad-scale application of electronic communications could affect dramatically the use and demand for paper in the future. Although telecommunications has experienced rapid growth during the past decade, its application for office and home use is still in its infancy, Thus, uncertainties regarding the rate of commercialization and public acceptance and forecasts of its impacts on paper must be considered speculative. While there is little disagreement among analysts that electronic communications may ultimately displace the need for some writing and printing papers, the timing and extent of the impacts are subjects of debate.

Euro-Data Analysts, a British-based market consulting group specializing in the paper, board, and packaging industry, forecasts a major shift from the use of paper toward increased reliance on electronic media.[34] Over the long term, Euro-Data considers it likely that the developed countries will achieve a nearly paperless society as the rate of commercialization of electronic communications accelerates. Euro-Data forecasts that during the current decade, paper will lose a share of the market to the electronic media through video telephone directories, office communications, telex, video books, video newspapers, consumer magazines, and electronic funds transfers.

The American Paper Institute (API) sees immediate competition with the electronic media in electronic fund transfers, office reproductions that require less paper, electronic mail, and electronic storage and microforms.[35] Beyond 1985, API anticipates competition developing in direct-mail advertising; voice message systems that would reduce the requirements for envelopes and business forms; expanded use of home video catalogs and directories; video publication of periodicals; interactive videotext, which might reduce book publishing; and video systems displaying time-critical news, which could displace some newsprint.

By 1995 and beyond, portable handheld video displays could displace printed magazines, books, and newspapers (table 25). API notes that the electronic media accounted for over 60 percent of the total communications expenditures during the 1970's. If the trend continues, its share could exceed 70 percent by the year 2000, while the paper-based media's share may drop to less than 30 percent.[36]

Other analysts agree that electronics technology will probably reduce the demand for printing and writing papers during the next decade, International Resource Development, Inc. (IRD), a technology consulting firm, sees home video as potentially flattening the growth in demand for paper directories and catalogs within 6 years.[37] IRD projects that by 1991, electronic filing could reduce demand for office paper by 300,000 tons per year (5 percent of current office consumption). Data Resources Inc. (DRI) estimates that home video systems could start affecting newsprint demand by 1985.[38] If elec-

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[30] "Tips on Tape: Cassette Magazines Arrive, " *Time*, June 14, 1982, p. 78.

[31] " Paper Chases the Electronic Age, " *Business Week, Apr.* 5, *1982,* pp. 112-115,

[32] K. Edwards, "The Electronic Newspaper, " *Communications Tomorrow* (Bethesda, Md.: World Future Society, 1981), pp. 54-59.

[33] H. Freedman, "Paper's Role in an Electronic World, " *Communications Tomorrow' (Bethesda,* Md,: World Future Society, 1981), pp. 60-65.

[34] Euro-Data Analysts, *The Impact of Communications Technologies on Demand for Printing and Writing Papers* (Ashtead, Surrey, U. K.: Euro-Data Analysts, 1980),

[35] American Paper Institute, *Information Technology and Paper Demand (New* York: API, 1981], p. 52.

[36] Ibid

[37] "Paper Chases in the Electronic Age, " op. cit., p. 112.

[38] Ibid.

Table 25.—New Information Technologies and Their Potential Impact on Paper Construction

Paper end-use categories/relevant information techniques

Commercial business and printing papers:

. ***Printing papers."***

- ***—Advertising: direct*** mail— Home video information (videotex and teletext) may open new avenues for advertising and could thereby adversely impact print-based advertising, including direct mail. Timeframe: beyond 1985.
- *—Printing: financial and* legal— Expanded use of word processors and intelligent printer/copiers will encourage more in-house production of forms. Electronic funds transfers will continue to grow, subtracting from the use of printed forms in financial transactions.

• Office *graphic reproduction —Growth* in the use of intelligent copier/printers will encourage more in-house offset printing. Timeframe: currently taking place; trend is expected to continue.

Duplexing and reduction capabilities, both of which operate to conserve paper, will become common features of office copiers, including those positioned at the low end of the price scale. Timeframe: currently taking place; trend is expected to continue.

Converting papers:

- Envelopes- Expanded use of electronic mail and voice-message systems may hold down the number of envelopes used by businesses and individuals. (Voice-message systems are not expected to come into widespread use before 1985.)
- *Business forms—An* increased proportion of business forms will be produced in-house using intelligent copier-printers. Electronic storage and microforms will continue to displace paper forms in selected applications.
- *Stationery and tablet—A* modest, negative impact from electronic mail, electronic pads, and voice-message systems appears possible. Timeframe: beyond 1985.

Paper end-use categories/relevant information techniques

Magazine publishing: Modest, negative impact possible from home video information. The future development of a full-page portable display for reading electronically stored information could also impact paper consumption by magazines. (The advent of portable displays is not anticipated until the 1985-95 timeframe, or beyond.)

Other periodical publishing: Home video information may hold down paper consumption for catalogs and directories. The future use of videodiscs as a storage medium for reference materials may have a negative influence on paper consumption for catalogs and directories. Timeframe: beyond 1985.

Book publishing: Possible use of home and office videodiscs to store large quantities of infrequently examined information could limit future demand for reference books such as encyclopedias. Interactive videotex may likewise have a negative influence on the demand for reference books. Timeframe: beyond 1985.

As noted above, next to magazines, the advent of a portable, full-page display possessing adequate image quality for prolonged periods of reading may lead to reductions in the demand for paper-based, printed materials, including books. Timeframe: 1985-95, or beyond.

Computerized printers reduce the need for special labels in certain applications.

Newspaper publishing: Home video information may draw classified advertising and financial listings away from newspapers. It may also compete with newspapers by becoming an efficient transmitter of time-critical news information. Timeframe: beyond 1985.

Advent of compact display could also have repercussions on newsprint consumption. Timeframe: 1985-95, or beyond.

SOURCE American Paper Institute, Information Technology and Paper Demand (New York, API, 1981), pp 10-11

tronic media affect newspaper advertising as television has, by 1995 they could displace 800,000 metric tons (tonnes) of newsprint annually (15 percent of current U.S. production),

In the short term, demand for writing and printing paper seems to have increased with the proliferation of word processors and office copiers, which enable fast and inexpensive copies of texts and graphics to be made, Although this phenomenon is considered by some industry analysts to be temporary, others forecast that paper will continue to dominate office communications, magazines, and newspapers.[39] However, both International Business Machines (IBM) and American Telephone and Telegraph (AT&T) have stepped up activities in the field of information storage and transmittal, and some analysts consider their entry into the market as the harbinger of rapid progress and expansion in electronic communications.[40]

With **30** percent of U.S. paper production being used for storage and transmission of information, the short-term trend in increased paper usage as a result of electronic office equipment is expected by some industry analysts to give way to sharp decreases in paper use during the next 20 years.[41]

The future impact of electronic media on paper demand may depend on its effects on the attitudes of a generation of children accus-

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[39] Freedman, op. cit., p. 60.

[40] C. Brown, "Tomorrow in the Pulp and Paper Industry: An Outsider's View," speech to 1982 Annual Employee Regulations Conference of the American Paper Institute and Fiber Box Association, St. Louis, Me., Jan. **27, 1982** (New York: Kidder Peabody and Co., Inc., 1982), p. 4.

[41] ibid.

tomed to the partial substitution of electronics for paper. While many older people, not so accustomed, find acceptance of nonprinted media difficult, the present school-age generation, who use nonprinted communications throughout their educational careers, will accept electronic communications for business and home use more readily. In addition, although current technology limits the use of electronic communication to desktop consoles and large computer and wordprocessing installations, the development of handheld portable devices with readable screens—and microelectronic processors capable of storing entire books and magazines—could have a significant impact on the substitution of electronic media for print.

Pulp, Paper, and Cellulose Fiber Manufacturing

Paper was supposedly invented in 105 A.D. by Ts'ai Lun, a member of the Chinese imperial court.[42] Ts'ai Lun's method for papermaking involved soaking tree bark, hemp, rags and other cellulosic materials in water to soften them and then beating the softened material until the fibers separated and swelled. He dispersed the fibers in a wet suspension and formed a thin sheet that was transferred to a felt cloth and pressed. The resulting web was dried in the sun.

Paper is still made by essentially the same process: 1) pulping, to separate and clean the fibers; 2) beating and refining the fibers; 3) diluting, to form a thin fiber slurry, suspended in solution; 4) forming a web of fibers on a thin screen; 5) pressing the web to increase the density of the material and remove excess liquid; 6) drying to remove remaining moisture; and 7) finishing, to provide a suitable surface for the end use. The three methods for pulping wood and other cellulose materials include chemical pulping, mechanical pulping, and semichemical or chemimechanical pulping—a combination of the first two methods.

In mechanical pulping, wood chips from debarked logs are ground, or are passed through a mill, and in some versions of the process are treated with high-pressure steam (thermomechanical) to separate the individual fibers, which can then be formed into sheets of paper. Mechanically separated fibers contain lignin, which makes them remain stiff, bond poorly, and yellow with age.

Chemical pulping is done by cooking wood chips in acid, alkaline, or neutral salt solutions under pressure and high temperatures, which breaks down the wood structure and dissolves some or most of the lignin and hemicellulose contents. Delignification by chemicals causes the individual fibers to become flexible and increases contact and binding among the fibers forming the paper mat, thus increasing the strength of the paper. Semichemical and chemimechanical pulping first breaks down the wood chemically, then by grinding.

The range of commercial pulping processes currently used by the pulp and paper industry is shown in table 26. Nearly three-fourths of the wood pulp is produced by the kraft process (fig. 22).

Mechanical Pulping

Commercial Mechanical Pulping Technologies

There are four basic mechanical pulping processes: 1) stone groundwood pulping, 2) refiner mechanical pulping, 3) thermomechanical pulping, and 4) the recycling of paper. Flow diagrams of the three mechanical pulping processes are shown in figure 23. Mechanical pulping is generally used with softwoods because of the added strength imparted by the long fiber length of softwood species. Mechanical pulps are used principally to manufacture newsprint, printing papers, and tissues that do not require high-strength paper. Secondary

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[42] F.F. Wangaard, *Wood: Its Structure and properties* ((University Park, Pa.: Pennsylvania State University, 1981), p. 335,

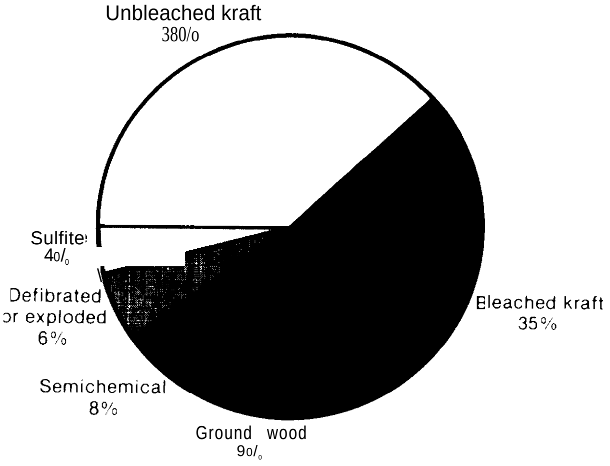
Table 26.—Major Commercial Wood-Pulping Methods, Grades of Pulp, and End-Products

Pulp grades	Wood type	Percent yield per dry weight of wood	End-products, utilizing grade
Chemical pulps:			
Sulfite pulp	Softwoods and hardwoods	53-56[b],[c] 45-50[a,d]	Fine and printing papers
Kraft sulfate pulp	Softwoods and hardwoods	40-50[a] 52-53[b]	Bleached—printing and writing papers, paperboard. Unbleached—heavy packaging papers, paperboard
Dissolving pulp	Softwood	33-35	Viscose rayon, cellophane, acetate fibers, and film
Semichemical pulps:			
Cold-caustic process	Hardwoods and softwoods	80-95	Newsprint and groundwood printing papers
Neutral sulfite process	Hardwoods	70-80	Newsprint and groundwood printing papers
Mechanical pulps:			
Stone groundwood[e].	Softwoods	95	Corrugating medium
Refiner mechanical (RMP)[e].	Softwoods	95	Newsprint and groundwood printing papers
Thermomechanical (TMP)[e].	Softwoods	95	Newsprint and groundwood printing papers

[a] Bleached pulps made from softwoods
bun bleached pulps made from softwoods.
[c] Unbleached pulps made from hardwoods
[d] Bleached pulps made from hardwoods
‘For paper and board

SOURCE George H Boyd Ill and Chad E Brown, *Paper Industry. Outlook for Market Pulp (New* York Kidder, Peabody & Co , 1981), p 5

Figure 22.— Proportions of Woodpulp Produced by Commercial Pulping Processes



SOURCE: Joan E. Huber, *The Kline Guide to the Paper Industry* (Fairfield, N.J.: Charles H. Kline & Co., 1980), p. 90.

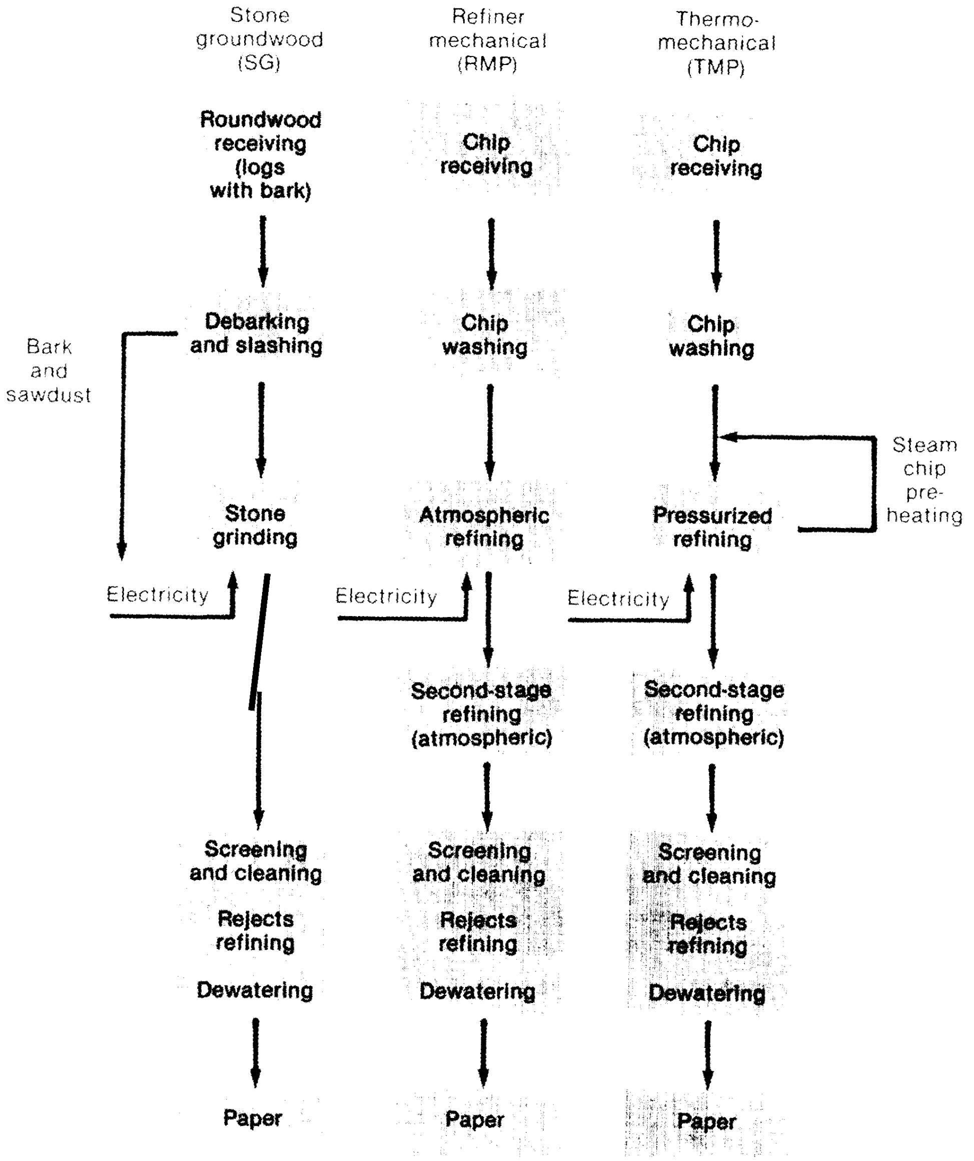
uses include wallpaper and paperboard. Recycled pulp is used mainly for the manufacture of folding boxboard (grayboard), tissue, corrugated board, and newsprint.

In the stone groundwood (SG) process, debarked short logs (roundwood) are fed whole into grinders. The abrasion of the grinding wheel against the wood physically separates the wood fibers. The grinding process usually is automatic and continuous, although sometimes it is semicontinuous, Refiner mechanical pulping (RMP) uses chips in lieu of roundwood and produces paper with higher strength than conventional groundwood because of less damage to the fibers in the pulping process, A wider range of species, including hardwoods, can be processed by the refiner pulping process.

The most advanced commercial mechanical pulping system is the thermomechanical process (TMP), which was developed as a modification of the RMP process. In TMP, wood chips are steamed for several minutes under pressures ranging from 4 to 45 psi and subsequently refined in one or two stages.

Recycled pulp is manufactured from wastepaper, which is processed into paper stock for further use in making paper. A small proportion of the paper stock (5 to 10 percent) is de-inked, usually with caustic, soda-based chemicals. Most recycled paper, however, is pulped without de-inking. Pulping is accomplished through violent agitation and shearing action

Figure 23.—Schematic Flow Diagram of Alternative Mechanical Pulping Processes



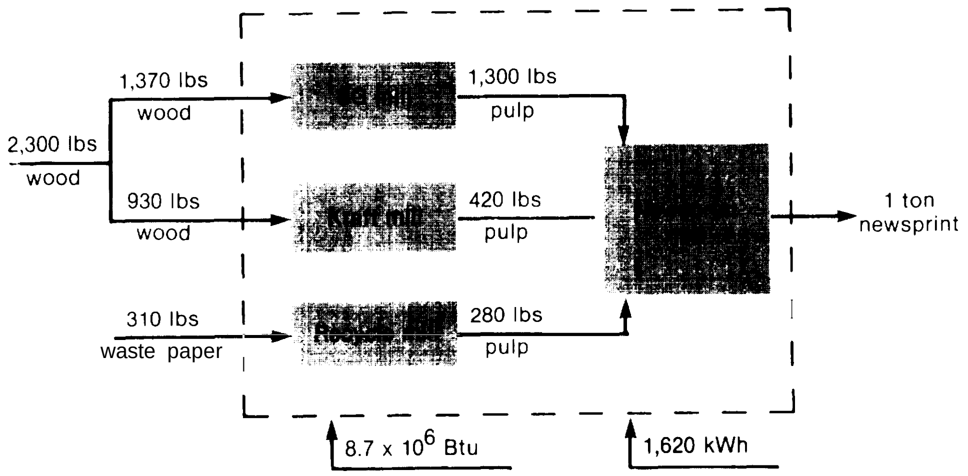
SOURCE: N. H. Hersh, *Energy and Materials Flows in the Production of Pulp and Paper* (Argonne National Laboratory, 1981).

performed at high temperatures. The paper produced from recycled pulp generally is weaker than papers from virgin materials, owing to the breakdown of the used fibers and the loss of bonding.

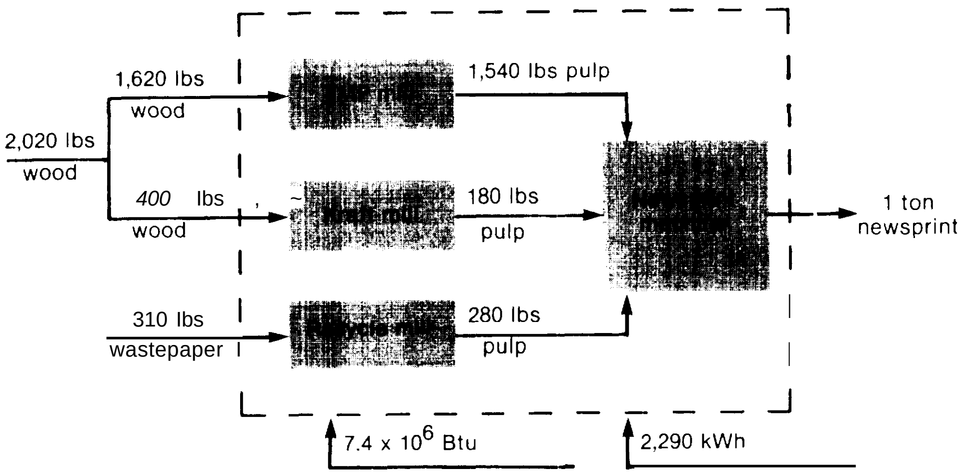
A comparison of materials and energy consumption for SG and TMP with a recycled pulping operation for the production of newsprint is shown in figure 24. As illustrated, mechanical pulp newsprint uses a small amount

Figure 24.—Wood and Energy Flows in Mechanical Pulping Mills in Conjunction With Recycling

(SG) Groundwood with recycle



(TMP) Thermomechanical pulp mill with recycle



of kraft pulp to improve its wet strength and processing on the paper machine. While paper using TMP consumes 11 to 13 percent less chemical pulp than ordinary newsprint, improved materials efficiency is gained at the expense of higher energy consumption. When the cost of energy is considered as well as the cost of wood, TMP is actually more costly than SG. Pulp yields from all the mechanical pulping processes typically are near 95 percent recovery, which is a higher yield per unit of wood than with the chemical pulping methods. The principal variables that influence the choice of mechanical pulping methods are: 1) furnish (raw material) requirements or wood species, 2) pulp strength, 3) expected gross energy consumption, and 4) expected net energy consumption.

The process variables that affect the quality of mechanically produced pulp are listed in table 27. Increases in paper strength are gained by increases in energy consumption, but brightness and opacity, qualities that affect the use of paper for printing, are largely independent of the pulping process. Recycling can effectively reduce the consumption of both wood raw material and energy when used in conjunction with other mechanical pulping processes. However, it does so at the sacrifice of some paper strength.

Improvements in Mechanical Pulping

Technical improvements in mechanical pulping have largely been directed at reducing energy consumption and improving the quality of mechanical pulps. Pulp yield is approaching the practical upper limit, since all of the lignin and most of the hemicelluloses remain in the fiber, and fiber recovery from mechanical pulping is frequently twice as high as that from competitive chemical pulping. By reducing energy costs, mechanical pulping has remained cost competitive, and improvements in paper quality have enabled mechanical pulps to displace some of the more costly, higher quality pulps produced by chemical processes. As noted in table 27, although improvements in quality result in some increases in the consumption of energy, the higher quality pulp produced more than offsets the higher costs of energy.

Three major developments in mechanical pulping technologies show promise for improving pulp quality and/or reducing energy consumption: 1) pressurized groundwood (PGW) pulping, 2) chemithermomechanical pulping (CTMP), and 3) hardwood chemimechanical pulping (CMP). Each of these new processes has reached some stage of commercialization. A fourth major development is waste-heat recovery.

PRESSURIZED GROUNDWOOD PULPING

In PGW pulping, debarked logs are fed to the grinding wheel through a heated, pressurized chamber. The heat and pressure help separate the fibers, breaking down fewer fibers in the grinding process and improving pulp quality. The longer fibers give the end product a higher tear index than paper made from SG, but it is slightly inferior to that of TMP. The tear resistance for PGW pulp is 5.6, compared with 3.9 for SG and 7.1 for TMP (table 27), The tensile index for PGW pulp (35) also lies between that for SG pulp (32) and TMP (37). In addition to improved strength, PGW promises some reduction in energy consumption. It is estimated that the energy requirement may be reduced by 40 percent from that required for the thermomechanical process, or from 1,833 to 2,417 kWh/ton of pulp to approximately 1,100 to 1,450 kWh/ton.[43]

Table 27.—Summary of Process Variables for Mechanical Pulping (based on the production of 1 ton of ovendry pulp)

Variable	Process			
	Ground wood pulping	Refiner mechanical pulping	Thermomechanical pulping	Recycle
Furnish type	Debarked logs	Residual chips, sawdust	Residual chips, sawdust	Waste paper
Furnish requirements	2,100 lb	2,100 lb	2,100 lb	2,200 lb
Energy requirements (kWh/ton)	1,340-1,790	1,800-2,400	1,800-2,000	360
Strength:				
Burst	1.4	1.8	2,0	
Tear	**3.9**	**5,7**	*7.1*	
Tensile,	32.0	35.0	37.0	
Other:				
Brightness	60.0	57.0	57.0	
Opacity	95.0	95.0	94.0	

SOURCE: Envirosphere Company, *Wood: Its Present & Potential Uses*, contract report to OTA, April 1982

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[43] C. W. Evans, "Pressured Process for Groundwood Production Making Healthy Progress," *Pulp and Paper*, vol 54, 1980, pp. 76-78.

By 1980, five mills worldwide had installed PGW systems. Fifteen more plants have been ordered, including four to be located in the United States. Some industry analysts consider PGW technology to have significant potential for reducing mechanical pulping energy requirements and for displacing some high-quality chemical pulps in the manufacture of newsprint and other printing papers.

CHEMITHERMOMECHANICAL PULPING

CTMP involves treating softwood chips with mild sulfite solutions prior to pulping. This "sulfonation" treatment results in paper with higher tear indices than do TMP, RMP, or SG pulping processes.[44] Energy consumption for CTMP may range from 1,360 kWh/ton to 2,000 kWh/ton, depending on the strength of the sulfite solution. Thus, energy consumption of CTMP lies within the range of SG pulping, is less than that required for RMP or TMP, and results in a higher quality paper. Pulp yields decrease slightly to between 85 and 95 percent with CTMP, but these yields are still large compared to chemical pulping and to mechanical chemical pulp blends. Some TMP pulpmills have begun to add sulfite chemicals in their operations to improve pulp quality and reduce energy consumption.

HARDWOOD CHEMIMECHANICAL PULPING

Mechanical methods for producing pulp from underutilized hardwood species involve pretreating hardwood chips with hydrogen peroxide or sodium hydroxide and processing them like RMP. Both poplar [softwood) and red oak (hardwood) have been pulped successfully by these techniques. However, fiber recoveries are lower for hardwood CMP than for softwood CMP. Pulp recoveries of 80 to 85 percent have been reported for poplar, 90 to 95 percent for red oak.

Energy consumption for CMP ranges from 500 to 1,500 kWh/ton using hydrogen peroxide for chemical pretreatment and 700 to 1,100 kWh/ton using sodium hydroxide.[45] Hardwood CMP consumes significantly less energy than do either SG or other chemimechanical hardwood pulping technologies.

Pulp and paper technologists expect hardwood CMP to expand significantly during the next 10 to 25 years because of the large volumes of inexpensive hardwood available, a phenomenon that could have a profound impact on the utilization of presently underutilized species such as poplars, red alder, and American sycamore that are abundant throughout the Eastern United States. Pulp produced by hardwood CMP can be used to produce newsprint and printing papers. Two small U.S. mills, which range in capacity from 200 to 250 tons of pulp per day, have already installed CMP systems to process hardwood species.

WASTE HEAT RECOVERY SYSTEMS

Mechanical pulping systems create a large amount of frictional heat during the grinding and refining processes. Heat recovery systems that enable use of waste heat (for drying paper, space heating, and water treating) are important to the reduction of energy costs in the pulping process. Such systems are particularly important in TMP, which requires large quantities of mechanical energy and produces high-quality heat (i.e., high heat under temperature and adequate pressure).[46] Because of the higher temperature of waste heat from TMP processes, a higher percentage of usable waste heat can be recovered from TMP than from conventional groundwood pulping,

Heat recovery technologies currently recapture 3 million to 5 million Btu/ton of pulp produced.[47] For mills consuming 1,800 to 2,400 kWh/ton, 95 percent efficiency in heat recovery would represent a total of 5.8 million to 7.8 mil-

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[44] D. Atack, et al., "Sulphite Chemimechanical Refiner Pulp-Another Option for Newsprint, " *Pulp and Paper,* vol. 54, 1980, pp. 70-72.

[45] J.D. Sinkey, "CMP and CTMP—A Review," paper presented at Forest Products Research Society Conference, St. Paul, Minn., 1981.

[46] P. J. Walker and E. J. Batsis, "Heat Recovery From TMP Operations Results in Energy Conservation," *Pulp and Paper,* vol. 52, 1978, pp. 146-148.

[47] *The Fossil Energy Conservation Potential Associated With Producing Wood Products From Managed Stands* (Bellevue, Wash.: Envirosphere Co., 1981).

lion Btu.[48] With current technology, the industry captures 50 to 65 percent of the theoretically recoverable waste heat, Widespread adoption of these efficient systems has not yet occurred because of the problems of retrofitting and high capital costs.

Future Prospects for Mechanical Pulping

The three major new mechanical pulping technologies—PGW pulping, CTMP, and CMP—have improved pulp quality and reduced energy consumption compared with conventional groundwood processes. The resulting higher quality mechanical pulps will displace the kraft pulps that are currently mixed with mechanical pulps to improve paper strength. For example, the shift from SG pulping to TMP displaced 300 pounds of kraft pulp per ton of newsprint. Use of the new technologies will further reduce the amount of kraft pulp required in newsprint and printing papers, reducing the demand for softwood timber because the pulp yield from these processes is nearly twice that of kraft processes.

The configuration of mechanical pulpmills for newsprint manufacturing will likely change significantly during the next 10 to 20 years. By employing CMP and CTMP technologies, using a higher percentage of hardwood as raw material, and installing highly efficient heat recovery systems (85 percent recovery), the mechanical pulpmill of the future could reduce its heat requirements by 1.0 million Btu [300 kWh/ton of heat) and reduce electrical energy consumption by 97o kWh/ton of newsprint from that currently required by TMP mills. Savings of this magnitude of purchased electric power is equivalent to a savings of 11 million Btu of heat input at the powerplant. In addition, 3.5 million Btu of usable heat could be recovered, offsetting over 50 percent of that currently required in the pulp and papermaking process.

Further improvements in energy efficiency and wood utilization could result if a recycle pulpmill were integrated with either SG or TMP pulpmills (fig. 25). The practical upper limit of recycled fiber in the pulp mix is estimated to be about 40 percent. A small proportion of kraft pulp is required in the mix to strengthen the newsprint if larger proportions of recycled pulp are used.[49] The major gains in energy efficiency between a wholly roundwood C M P or CT M P mill and one integrated with a recycle pulpmill are in reduced electrical-energy consumption. Reductions in energy consumption of between 179 and 358 kWh/ton of pulp may be achieved by recycling, so Process heat requirements remain approximately the same when recycling is used, but the amount of recoverable waste heat is decreased from 3.5 million to 2,2 million Btu.

Substantial technical improvements are possible in mechanical pulping processes within the next **20** years, providing that economic incentives exist and capital formation is possible.

Chemical Pulping

Commercial Chemical Pulping Technologies

Chemical pulping processes involve treating wood chips with chemicals to remove the lignin and hemicellulose, thus separating and delignifying the fibers, Delignification gives the fibers greater flexibility, resulting in a substantially stronger sheet of paper—because of greater contact between the fibers in the finished sheet—than can be manufactured from fibers with lignin produced by mechanical pulping.

Two major chemical pulping technologies are currently in use: 1) kraft (sulfate) pulping and 2) sulfite pulping. The kraft process dominates the pulp and paper industry, accounting for over 75 percent of all pulp produced for paper and paperboard in 1979.[51] Other chemical pulping processes, such as acid sulfite pulping, bisulfite pulping, and neutral sulfite semichemical pulping account for approximately 3 percent (the remainder was produced by mechanical pulping), Paper made from pulp

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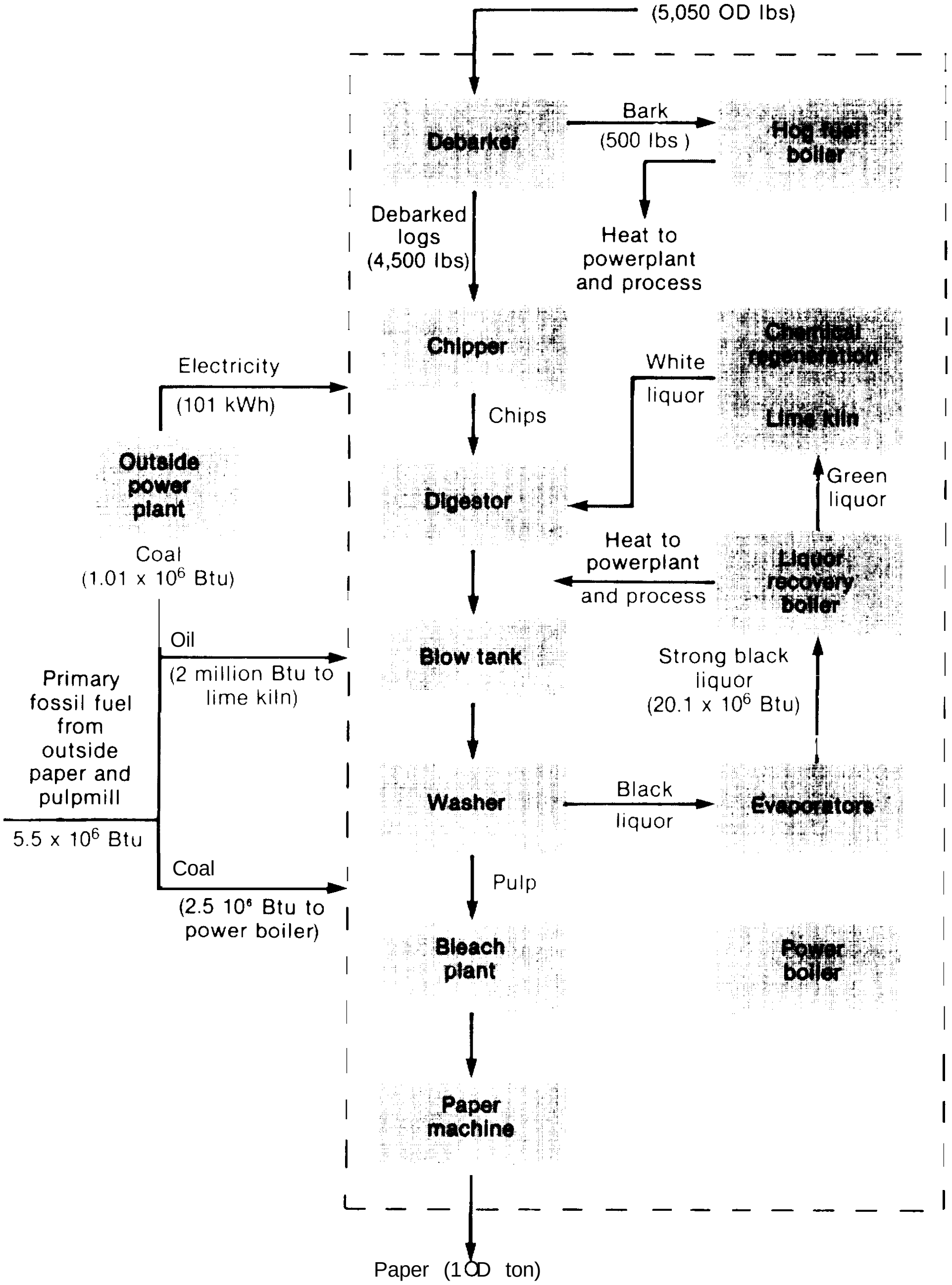
[48] Walker and Batsis, op. cit.

[49] W. E. Franklin, *Paper Recycling: The Impacts of Contaminants 1973-1985. Summary and Overview* (Kansas City, Mo.: Midwest Research Institute, 1975).

[50] P. Sizifert, R. Secor, and P. Cruea, "Waste-Paper Pulping With Minimum Energy," *TAPPI*, vol. 59, 1981, pp. 111-113.

[51] American Paper Institute, *Statistics of Paper and Paperboard: 1980* (New York: API, 1980), p. 54.

Figure 25.—Material and Energy Flow into a Kraft Pulpmill



SOURCE: P. J. Hurley, *Comparison of Mills Energy Balance: Effects of Conventional Hydropyrolysis and Dry Pyrolysis Recovery Systems* (Appleton, Wis.: Institute of Paper Chemistry, 1978).

produced by the kraft process accounts for most of the bleached boxboard and linerboard used by the packaging industry (which consumes 58 percent of the paper in the United States).

In addition, bleached softwood kraft pulps often are mixed with mechanical pulps to add strength to newsprint and printing papers. Bleached hardwood kraft pulps are added to bleached softwood pulp to improve printability for specialty paper products like magazine stock and coated papers.

KRAFT (SULFATE) PULPING

The kraft process involves treating wood chips and sawdust with a sodium sulfide and sodium hydroxide solution. The highly alkaline chemical mixture is cooked in a digester for 1 to 3 hours at temperatures ranging from 320° to 350°F (fig. 25). The complete pulp and paper making process is shown in figure 26.

Fiber recovery from the kraft pulping process is largely a function of the wood species used, the amount of chemicals used, the time and temperature of cooking, the degree of bleaching, and the paper strength required. Generally, kraft pulp recoveries from softwoods are approximately 47 percent for unbleached pulp and 44 percent for bleached.[52] Hardwood recoveries range from 50 to 52 percent for unbleached kraft pulp and 45 to 50 percent for bleached.

Energy is used in a mill in different forms (as chemical heat of reaction, as thermal energy, and as electrical energy), and these typically are expressed in different units (Btu for thermal and for heat of reaction in fuel combustion, and kWh for electricity). While the **units** may be converted simply (i.e., 1 kwh = 3,412 Btu), the actual forms of energy may *not* be converted without loss of energy available for doing useful work. Thus, in a typical powerplant, it takes 10,000 Btu of heat input to produce 1 kWh of electricity (in contrast to the unit conversion above), and two-thirds of the input is lost as exhaust. There are, then, two ways to compare a mill's energy uses: 1) simple unit conversions, representing all uses in a common unit; or 2) representing all uses in terms of the heat values of their original forms, while recognizing energy conversion losses.

The different conclusions reached by these approaches is illustrated by the following: the first method gives rise to the conclusion that self-generation in today's typical kraft paper mill provides about 50 percent of the mill's energy needs, while the second method (table 28) shows that 82 percent of the primary fuel supplying the total energy needs of a typical kraft mill is self-generated. The first method relates better to concerns for fossil-fuel avoidance, while the second helps relate the fuel value of wood-process residuals to other potential uses. Of the two approaches, the latter is the more useful for assessing process efficiency.

Energy consumption is a major cost in the manufacture of kraft pulp and paper. The combined process requires approximately 30 million Btu of primary fuel per ton of bleached kraft paper (table 29). This energy value includes fossil fuel burned at an outside powerplant to provide purchased electricity as well as the thermal energy derived from the wood resource. Approximately 78 percent of the energy demand is for thermal energy used in the plant, the major portion of which is used for paper making and self-generation of electricity rather than in the pulping process. While the combined kraft pulp and paper making process requires approximately 1,050 kWh/ton of electricity, mostly for drive motors, all but 101 kWh generally is produced internally through cogeneration (table 29). Burning waste liquors and bark provides 82 percent of a mill's primary energy needs.

The kraft process is suitable for pulping both softwoods and hardwoods. Wood chips, sawdust, and wood residues from sawmills and veneer mills can be used as furnish, Over 35 percent of the total wood supplied for kraft paper are wood residues. In the Pacific Northwest, nearly 90 percent of the wood originates from sawmill or veneer mill residues. Whole tree chips, including bark and branches, currently

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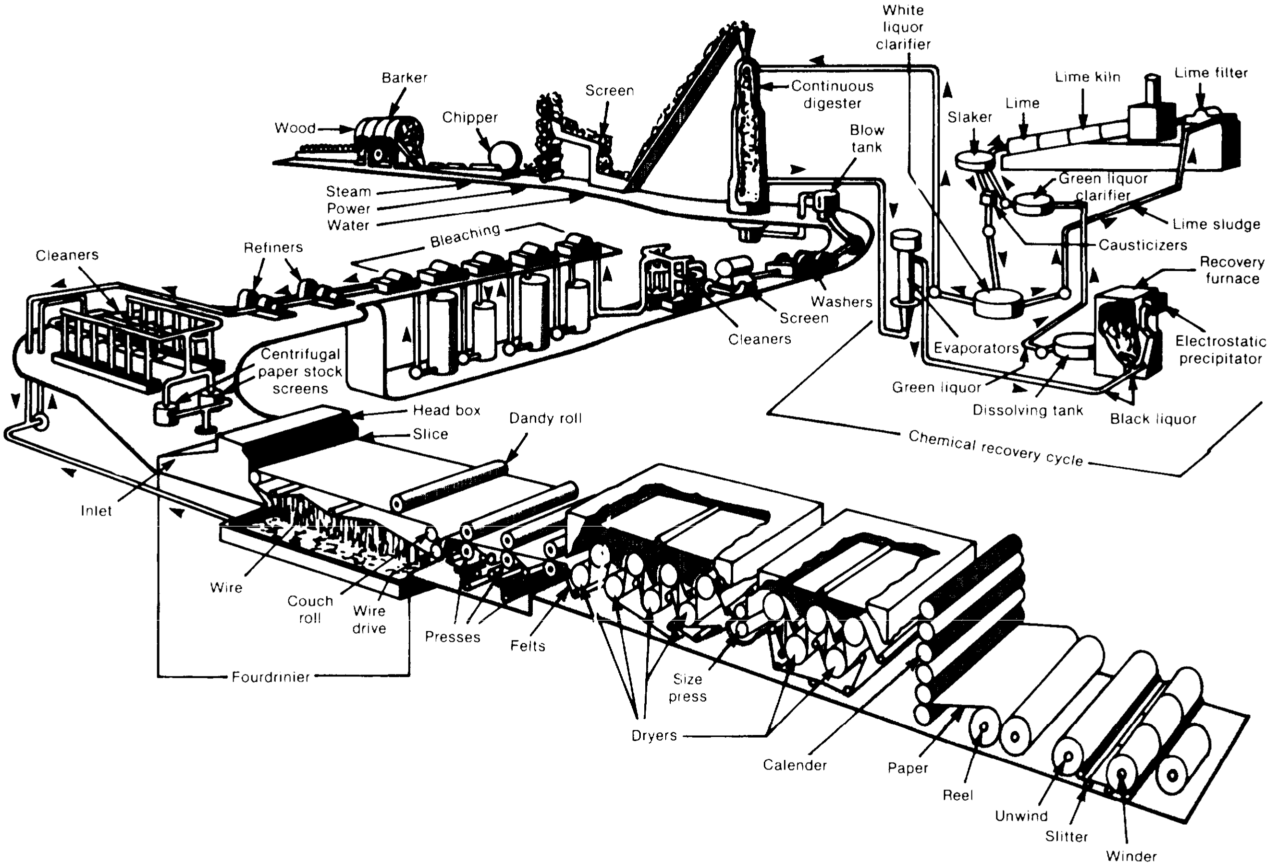
[52] P. J. Hurley, *Comparison of Mills Energy Balance: Effects of Conventional Hydropyrolysis and Dry Pyrolysis Recovery Systems* (Appleton, Wis.: Institute of Paper Chemistry, 1978).

Figure 26.—Overall View of Papermaking From Chemical Pulp by the Kraft Pulping Process



SOURCE: F. F. Wangaard, *Wood: Its Structure and Properties* (University Park, Pa.: Pennsylvania State University, 1981), pp. 342-343.

are used in limited quantities, although their proportion of the total furnish is increasing. Because of the density, extractive content, and chemical nature of these materials, increases in their use may cause the pulping liquors (chemicals) to react more slowly, resulting in a need for longer digestion periods and increased energy expenditures.

SULFITE PULPING

The four fundamental sulfite pulping processes currently in commercial use are: 1) acid sulfite, 2) bisulfite, 3) neutral sulfite, and 4) alkaline sulfite. The major differences between the sulfite processes are the levels of acidity and alkalinity of the sulfite chemical solutions used to break down the wood and remove the lignins. The cooking liquor consists of a salt base—generally calcium, magnesium, sodium or ammonium—and sulfuric acid. Sulfite processes are suitable only for species with low extractive contents, i.e., those low in tannins, polyphenols, pigments, resins, fats, and the like, because of the interference of these substances with the sulfur pulping process. Although calcium is the cheapest base available, it forms insoluble compounds that cannot be reclaimed economically or disposed of easily. Thus, calcium-based pulping is seldom used. Because magnesium- and sodium-based chemicals are recoverable, and ammonium-based chemicals can be burned without harmful environmental effects, they are the most frequently used.

Sodium-based sulfite pulping can consist of multistage cooking, successive stages of which differ in acidity. Because one stage optimizes chemical liquor penetration and the other the

Table 28.—Energy Demand Per Ton of Kraft Paper

	Energy demands	
	Million Btu	kWh
Thermal:		
Process:		
Digester	3.8	
Bleach plant	2.4	
Paper machine	6.8	
Evaporation	3.0	
Liquid heating	2.9	
Other	2,5	
Subtotal	21,4	
Lime kiln	2,0	
Total	23.4	
Electric:		
Self -generated:		949[a]
Fuel-value material recovered in plant and burned for electricity	5.7[b]	
Purchased from outside:		101[a]
Fuel used by outside powerplant to produce electricity	1.0[c]	
Totals:		
Total electricity		1,050
Total fossil fuel consumed	30.1	

[a] Hurley, P J
[b] Incremental heat rate to generate electricity in plant 6,000 Btu/kWh
[c] Assumes outside electric plant is fess! I-fueled at 10,000 Btu/kWh

SOURCES J J Watkins and W S Adams, "The St Regis Hydrolysis Process as an Approach to Energy Conservation in the Pulp & Paper Industry, " *Proceedings of TAPPI '78 Engineering Conference Book ///*
P J Hurley, *Comparison of Mills Energy Balance Effects of Conventional Hydropyrolysis and Dry Pyrolysis Recovery Systems* (Appleton, Wis Institute of Paper Chemistry, 1978)

removal of lignin, more lignin may be removed with less fiber degradation, so that fiber yields are higher, fibers are stronger, and a wider range of wood species may be used. Neutral sulfite pulping, using sodium and ammonium bases, recovers the largest proportion of fiber (75 to 90 percent) of all the sulfite pulping methods.

Improvements in Chemical Pulping

Two kinds of improvements have been made in chemical pulping technologies: 1) better efficiency of current processes and 2) development of new pulping technologies that depart from the conventional commercial processes. The greatest potential for dramatically improving pulp and paper manufacturing lies in new technologies. Such innovations could enable the use of large quantities of currently underutilized hardwood species and may even have prospects for developing superior new papers for future specialized uses. At the same time, new concepts in energy use and cogeneration could achieve new levels of energy efficiencies. Among the most promising new pulping and papermaking processes are: 1) press-dried paper, **2)** green liquor pulping, 3] autocausticizing, and 4) pyrolytic recovery of chemicals in spent pulping liquor. These developing technologies are not yet commercially available.

PROCESS IMPROVEMENTS

Major efforts in process improvements, or means in which the efficiency of existing commercial processes is improved, have centered on increasing fiber recovery and energy efficiency. Most such efforts have focused on the kraft process, which produces 90 percent of all chemical pulps manufactured. Greatest emphasis has been placed on reducing energy consumption because it is the largest cost factor.

Anthraquinone (AQ) recently has been tested as a catalyst in kraft pulping. When added in small quantities to the cooking liquor, AQ speeds up the pulping process and can improve fiber recovery by as much as 2 to 4 percent. Although the percentage increase in yield may seem small, the increases in absolute yield are considered substantial because of the very large volumes involved. AQ pulping was developed by Canadian Industries, Inc., and is

Table 29.—Energy Consequences of Pyrolytic Recovery (basis: 1 ton pulp)

		Recovery method	
Energy required	Conventional	hydropyrolysis	Dry pyrolysis
Process yield (percent ovendried)	47.5	48.75	47.5
Electricity (kWh):			
Internally generated	949	850	812
Purchased	101	256	258
Inplant fossil fuel (thousand Btu)	10,411	5,458	6,296
Inplant fossil-fuel savings (percent)		48 0/0	40 "/0

SOURCE: P. J. Hurley, *Comparison of Mills Energy Balance: Effects of Conventional Hydropyrolysis and Dry Pyrolysis Recovery Systems* (Appleton, Wis.: Institute of Paper Chemistry 1978) used commercially in both Japan and the United States. Its potential broad-scale application in the United States, however, maybe limited by its cost and the lack of technology to recover the used AQ.[53] The U.S. Food and Drug Administration (FDA) recently has approved AQ for use in paper packing for food, opening new market potentials for AQ pulp.

The industry's goal is for the kraft pulping process to become as energy self-sufficient as possible. Substantial gains in energy efficiency are expected within the next 20 years, but it is not known whether total self-sufficiency is attainable. Kraft mills may approach self-sufficiency if some modifications are made; for example: 1) the temperatures in boilers that burn wood residues and black (lignin) liquor can be reduced (primarily by adding more efficient heat exchangers for heat recovery, and 2) lime kilns maybe fueled with dried sawdust without seriously contaminating the calcined lime used for making the pulping liquor. The latter has been demonstrated successfully in Sweden.[54] These system modifications are expensive and may increase the operating costs of a plant. Their adoption will depend on the future costs of energy and the availability of capital.

GREEN LIQUOR PULPING AND AUTOCAUSTICIZATION

Economy in chemical pulping depends on effective recovery of chemicals from the used cooking liquor. Upon interaction with wood in the cooking process, the "white liquor, " that is, the original sodium sulfide and sodium hydroxide solution, becomes "black liquor," rich in lignin salts and other organics removed from the wood in the pulping process. The black liquor is pumped to evaporators that remove the water and concentrate the remaining salts and organic solids. The resulting viscous solution is burned in a recovery furnace to remove the organic residues (fig. 26).

The remaining salts—mostly sulfides and carbonates of soda—form a molten stream referred to as "smelt" and are recombined with water to form "green liquor. " The sodium carbonates in the green liquor normally are converted into hydroxides for reuse by the addition of calcium hydroxide in a process referred to as "causticizing."

Pulping of hardwoods and softwoods using green liquor, which eliminates the causticizing process, is now an accepted commercial technology for producing semichemical pulps. In this process, disodium borate is used instead of sodium hydroxide in the original white liquor, and the liquor produced by dissolving the smelt can be reused directly in the digester. In this way, the entire regeneration loop, including the lime kiln, is removed. As much as 18 percent of the fossil energy required for pulping can be eliminated by autocausticization. Elimination of the lime kiln not only reduces energy consumption, but reduces capital costs by $35/annual ton of capacity and operating costs by $3/ton.[55] Industry experts give autocausticizing a high probability of commercial acceptance.

PYROLYTIC RECOVERY

Technology for pyrolytic recovery of black liquor has been developed in two processes: 1) a hydropyrolysis method developed by the **St.** Regis Paper Co., and 2) a dry pyrolysis method developed by Weyerhauser Corp. Pyrolytic recovery consists of applying heat in the absence of oxygen (anaerobic combustion) to decompose the organic compounds in the black liquor. These new spent-liquor recovery techniques, designed to extract energy from the spent liquor while retaining the chemicals for reuse, are more energy efficient than are current processes. They are important because regeneration of the pulping chemicals requires a large share of the energy used in the pulping process.

Hydropyrolysis technology currently is being evaluated on a pilot basis in St, Regis' Pensacola, Fla., mill. The process shows potential

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[53] Huber, op. cit., p. 85.

[54] K. Lappe, "Advanced Drying Process is Key to Burning Peat, Wood Byproducts, " *Energy* Systems *Guidebook (New* York: McGraw-Hill, 1980).

[55] J. Jansen, "Pulping Processes Based on Autocausticizable Borate, " *The Delignification Methods of the Future* (Helsinki, Finland: Europa Symposium, 1980).

for reducing the energy requirements for evaporating weak black liquor, i.e., that recovered in the initial washing stage, and for aiding in the energy recovery process. It is estimated that fossil-fuel energy required for generation of process heat may be reduced by 50 percent with the application of hydropyrolysis technology.[56]

St. Regis' experience with its pilot plant indicates that application of hydropyrolysis technology results in a tradeoff between purchased fossil fuel and purchased electricity. Lowered heat requirements for liquor recovery result in less process steam; thus, the potential for cogenerating electricity along with the steam needed is limited. The results of these tradeoffs are shown in table 29, where the data suggest that an in-mill fossil fuel savings of up to 48 percent can be achieved with hydropyrolysis and approximately 40 percent with dry pyrolysis. However, considering the fossil fuel used to generate the purchased electricity, the net fossil fuel savings are 28 percent and 20 percent, respectively.

OTHER CHEMICAL PULPING TECHNOLOGIES

Attempts to develop alternative pulping technologies that increase yields, energy efficiency, and pulp quality of the kraft process have led to two new chemical pulping concepts that show some promise: 1) organosolv (alcoholysis) pulping and 2) oxygen pulping. Since both still are under development, and neither has reached the demonstration stage, they must be considered long-range (25 + years) prospects for commercial application,

Organosolv Pulping.-Organosolv pulping is a two-stage process involving hydrolysis (decomposition of the wood by dilute acids or enzymes) and the removal of lignin with an organic solvent, usually a mixture of alcohol and water. The still-experimental process is suitable for both hardwoods and softwoods. Pulp recovery from organosolv pulping ranges between 50 and 60 percent for hardwoods, and 40 and 45 percent for softwoods. Typical hardwood-fiber recoveries compare favorably with those from kraft pulping: approximately 50 percent for red alder, sweetgum, and American sycamore, and 60 percent for cottonwood and trembling aspen.

Fibers produced by the organosolv process are weaker than those recovered by the kraft process, Thus, the papers produced from organosolv pulp are suitable for uses where strength is not the most important property, such as for printing papers, fluff pulps, and dissolving pulp,

Reaction temperatures are low—between 320° and 370° F for hardwoods and 360° to 390°F for softwoods if acid catalysts are used. Little waste is produced by the process, and low alcohols are recovered easily by distillation, thus requiring relatively low capital investment.[57]

Oxygen Pulping.—An extension of existing oxygen bleaching technologies, oxygen pulping may reduce or eliminate the need for bleaching plants in the paper mill. Oxygen pulping involves the introduction of gaseous oxygen into the pulping liquor to stimulate oxidative fracture of the cellulose-lignin bonds. This process could save capital and operating costs because equipment costs are lowered, less bleaching chemicals are used, and pollution control expense is cut by eliminating chlorine from the bleaching process.

The cost of oxygen pulping is largely a function of the cost of oxygen. Oxygen production requires approximately 400 lbs of oxygen and 54 kWh/ton of pulp produced (based on 1.2 kWh/hundred cubic feet(H3),or0.135 kWh/lb. Several manufacturers currently are developing plant equipment capable of applying oxygen pulping commercially.

PRESS DRYING PAPER

Press drying technology developed at FPL shows promise for both reducing the amount of energy required in the paper-making process and enabling the use of underutilized hard-

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[56] Hurley, op. cit.

[57] N. Sanyer, *Status of New Pulping Processes; Problems and Perspectives* (Madison, Wis.: U.S. Forest Product Laboratory, 1982], p. 10,

wood species. Press drying uses high-yield hardwood or softwood kraft pulp to produce linerboard with strength superior to that of conventional softwood kraft paper in every respect except tear strength (table 30). At the same time, press drying can reduce the amount of energy used in the drying process by applying pressure to the fiber (pulp) mat as it is dried. With conventional drying technology, pressure and heat are applied separately.

The superior strength of press-dried paper comes from the combined effects of heat and pressure, which force the fibers into closer contact and cause stronger bonds to be formed between them. The heat and pressure also cause natural polymer flow and cross-linkages among the fibers as a result of the hemicellulose contained in the pulp. Paper produced from press-drying kraft red oak pulp has been shown to have burst strength and tensile strength approximately 13 percent higher, and compression strength 50 percent better, than that of conventionally dried pine kraft paper. The lower tear strength of press-dried hardwood paper may limit its use for wrapping or sack paper; however, its higher burst strength and tensile strength make it suitable for linerboard.

Estimates of the potential net energy savings from using press-drying technology are about 19 percent for the papermaking process,[58] Although a commercial-scale, press-dried papermaking machine has not been built yet, press drying may actually reduce equipment requirements and capital investment in both the drying section and the pulping process because it can use unrefined pulp.[59] The major limitation to press drying paper, which must be overcome before the technology can be applied commercially, is the low speed of the papermaking machine and the resulting slow production rate of the pilot-scale equipment used at the FPL.

Dissolving Pulp Technologies

Dissolving pulp technologies are not pulping technologies as such, but secondary processes that produce nearly pure cellulose (alpha-cellulose) for conversion to rayon, plastics, and other chemicals. Pulps made by either the kraft or sulfite process are purified further chemically to remove all hemicellulose and leave only pure cellulose, which then can be transformed into products like viscose rayon, cellophane, and acetate fibers and film. The largest single use for dissolving pulp is in the viscose rayon process, which accounts for over 99 percent of the world's rayon production.

A variety of hardwood and softwood species is suitable for the production of dissolving pulp, including pine, hemlock, spruce, oak, birch, and gum. Highly resinous wood, such as Southern yellow pine, normally is not used for dissolving pulp because of the difficulty of removing extractives in the purification process. The highest grades of dissolving pulp are called cord, acetate, and nitrate pulps, which approach 98 percent pure cellulose; normal grades of viscose rayon pulp contain some hemicellulose and maybe only 93 percent pure. Because of the need for nearly pure cellulose,

Table 30.—Strength Properties of Press-Dried Hardwood Paper and Conventional Softwood Paper

	Anticipated strength with oak	Present strength with oak	Conventional strength with pine
Burst strength (lb/in w)[a]	155	145	97
Tensile strength (lb/in w)	100	68	54
Compression (lb/in w)	45	30	20

[a] Pounds per inch of width

SOURCE U S. Forest Products Laboratory, 1981

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[58] V. Setterholm and Peter Ince, "The Press Drying Concept for Papermaking," *Southern Lumberman,* Dec. 15, 1980.

[59] P. J. Ince, "FPL Press Drying Process: Wood Savings in Linerboard Manufacture," *TAPPI,* vol. 64, 1981, p. 109,

pulping yields for the kraft and sulfite processes are reduced to approximately 28 to 38 percent, depending on the pulp purity desired. The low yield of high-quality, alpha-cellulose pulps makes them expensive to produce—energy and pulpwood costs account for 50 to 60 percent of the manufacturing costs.[60]

Total U.S. production of dissolving wood pulp was approximately 1.5 million short tons in 1979 (23 percent of world production). Approximately 61 percent of the dissolving pulp produced was used for textile fibers; the remainder was used for the manufacture (in descending order) of chemicals and plastics, cellophane, cellulose nitrate (for propellants), and specialty papers for use in industrial and automotive filters.

In addition to the viscose rayon process for the production of fibers and cellophane (which is made by the same viscose process but is extruded through a slot to form film rather than through holes to form threads), cellulose may be converted into acetate forms (acetyl esters) that can be manufactured into cellulose acetate, cellulose diacetate, and cellulose triacetate for conversion into fibers. Cellulose nitrate continues to be produced in significant quantities as an explosive and a propellant. Other products manufactured from dissolving pulp include ice cream thickeners, detergents, carbon fibers of high strength and stiffness, and gels used in hand lotions and food products.

Rayon Manufacture

Rayon, first made in 1881, is the oldest manmade synthetic fiber. The success of rayon in the market is due to several factors:

- Cellulose continues to be the cheapest polymer for fabrics.
- Rayon's moisture absorption, capacity for absorbing dyes, and ability to swell makes it suitable for clothing. Rayon also can be blended with other synthetic fibers, like nylon, to improve their moisture-absorbing qualities.
- properties of the dissolving pulp can be varied to produce pulps suited for specific end uses. For example, ITT Rayonier, a leading U.S. producer of dissolving pulps, offers 16 grades of pulp matched to the properties of the rayon to be produced.

Rayon is made by dissolving cellulose xanthate in alkali and spinning the fiber through small pinhole jets into a sulfuric acid bath, which coagulates the fiber into final form. If the same xanthate-viscose solution is forced through a narrow slit, a cellophane film is formed.

Major developments in rayon technology have been aimed at:

- improving the efficiency of rayon production;
- reducing energy requirements;
- controlling or eliminating environmental pollutants generated by the viscose rayon process;
- developing more cottonlike rayons to supplement cotton production; and
- developing a completely new system for converting chemical cellulose to fiber by a nonviscose, environmentally sound, more efficient process using recoverable cellulose solvents.[61]

Major emphasis has been placed on developing a rayon with a high wet-strength to remedy the shortcomings of conventional rayon and to compete with cotton more effectively. A number of new fibers outperform conventional rayon; they include Courtauld's "Corval, " a cross-linked fiber; American Viscose's "Avril"; and Enka's "Fiber 700. "

Process developments within the rayon industry seem to be moving toward automation and computer control. Experts foresee new, versatile rayons made by solvent-extrusion processes similar to those used for making nylon and polyester. These may lead to a future one-step process from pulp to viscose solution; however, many of the current developments in this area are treated as proprietary and are not open to inspection.

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[60] C.B. Metz, "Dissolving Pulps-The Future Economic Situation, " *Proceedings of the 5th International Dissolving Pulps Conference* (Vienna, Austria: Oct. 8-10, 1980).

[61] G. Daul, "Rayon Revisited, " *Chemtech*, February 1981, p. 84.

The viscose process is one of the most versatile for manufacturing textile fibers. Modification of the viscose manufacturing process easily can accommodate stretching and orienting the fiber and building certain desired properties into it. For example, it is known that the addition of metallic salts, such as zinc and other modifiers, will delay the reformation to rayon to allow time for spinning and manipulating the fiber. Formaldehyde also has been found to be an effective modifier for the production of super-strong fibers; however, environmental problems associated with it must still be overcome.[62]

Research to improve the strength and performance of rayon materials continues. These efforts include the search for new solvents for use in the spinning (forming) process. One such process that shows promise uses a special solvent (methyl-morpholine-N-oxide, MMNO) to orient the molecules in solution to form rayon with high-strength cellulose fibers. Success of the MMNO process may depend on development of a solvent recovery system needed to make the manufacturing process economically competitive.[63] Some experts see the testing of other new solvents leading to a major new system for manufacturing rayon.[64]

Other Cellulosic Products

A number of other products can be made from dissolving pulp. For example, cellulose acetate is produced by steeping dissolving pulp or cotton liners in acetic acid to prepare fibers for conversion to acetate, This same process may be used to produce cellulose butyrate and cellulose propionate for the production of plastics.

An acetate of slightly different chemical form, cellulose triacetate, also can be made from dissolving pulp. Unlike rayon, it is water-repellent like nylon, orlon, and terylene. Its water repellency is attributable to the degree of acetylation of the fibers. It has good thermal properties and wear characteristics, and frequently is used in fabric blends with nylon, wool, and rayon in women's clothing.

Cellulose esters—acetate ester, acetate butyrate, and acetate propionate—are a family of plastic materials derived from dissolving pulp that can be formed, molded, and extruded by a variety of thermoplastic processes. Higher forms of these materials also maybe prepared; however, their high production costs restrict them to highly specialized applications such as cellulose acetate phthalate, which is used as a coating on pharmaceuticals. Cellulose ester powders are used in fluidized-bed and electrostatic coating processes, as well as in rotational molding processes. Modified cellulosic polymers are used in preparation of films, coatings, fibers, lacquers, and adhesives,

Finally, dissolving pulps also may be used to produce a variety of chemical products, including methyl- and carboxymethyl-cellulose, that are used as thickeners in latex paints and ice cream; ethylcellulose, used as a thermoplastic molding compound; and nitrocellulose, used as a propellant/explosive.

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[62] Ibid., p. 84.

[63] R.N. Armstrong, C. C. McCorsky, and J. K. Varoa, ''Spinnable Solutions of Cellulose Dissolved in Amine Oxides, " *Proceedings of the 5th International Dissolving Pulps Conference* [Vienna, Austria: Oct. 8-10, 1980).

[64] H.L.Hergert, R. B. Hammer, and A. F. Turbak, ''New Methods for Preparing Rayon, ' *Proceedings of the 4th International Dissolving Pulps Conference* (Chicago, 111.: Sept. 28-30, 1977),