CHAPTER I

Introduction

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 ifecycle	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,

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

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

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)

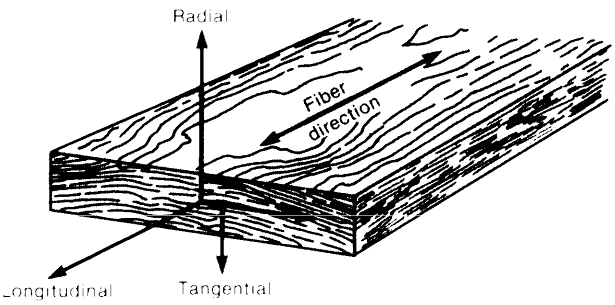
green lumber to approach the EMC to meet the end-use requirement.

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.

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

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.

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

[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.

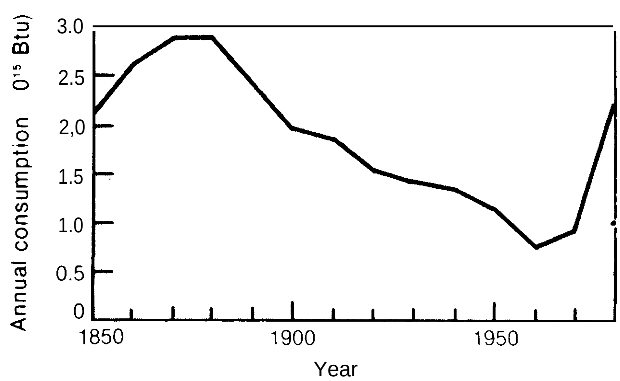
Wood as a Fuel

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).

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

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, Cal if Annual Reviews, Inc), 1981

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.

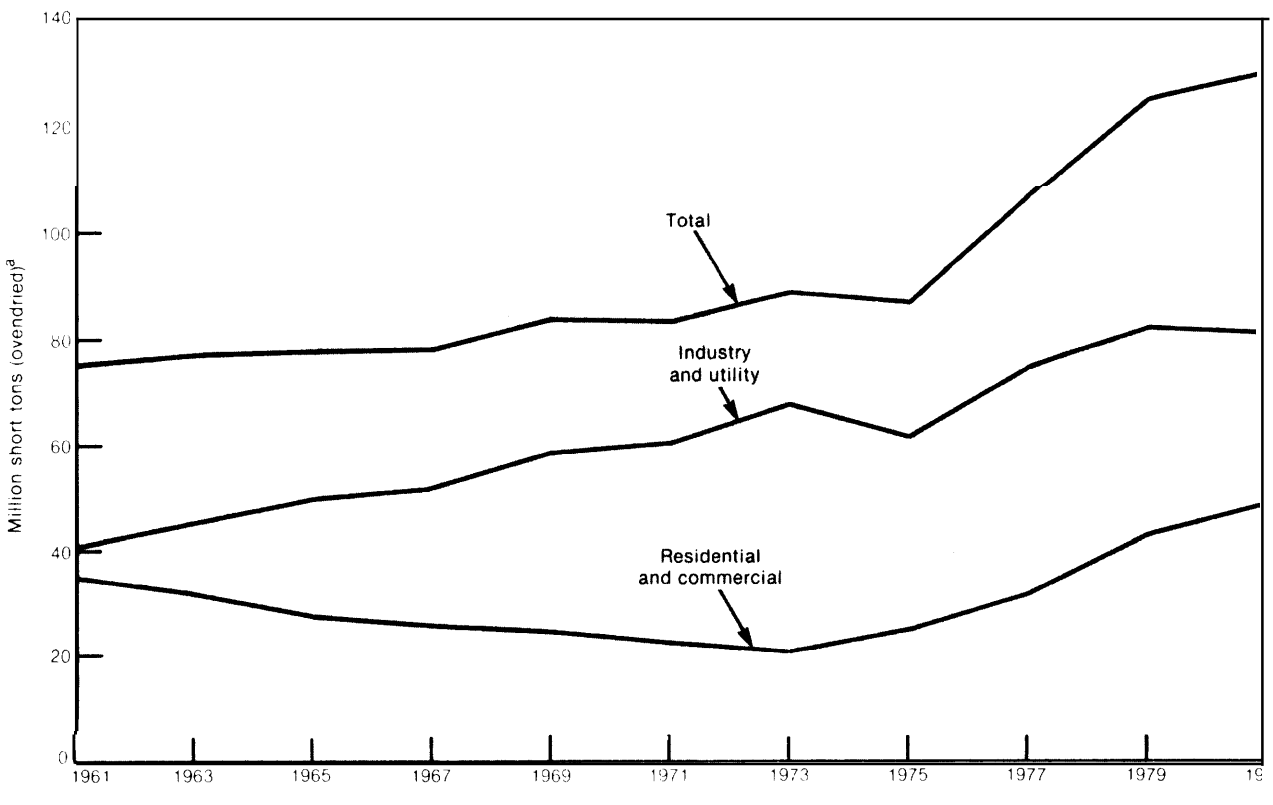
The potential exists for significantly greater wood energy production. OTA's *Energy From Biological processes* assessment concluded that wood has the greatest potential to contribute to the Nation's energy supply among alternative biomass energy sources. The study found that 4 Quads/yr of wood energy 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

[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.

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



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

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

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 managerncnt activities.[6]

Industrial Wood-Fuel Use

The forest products industry consumed 81 mill ion 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.

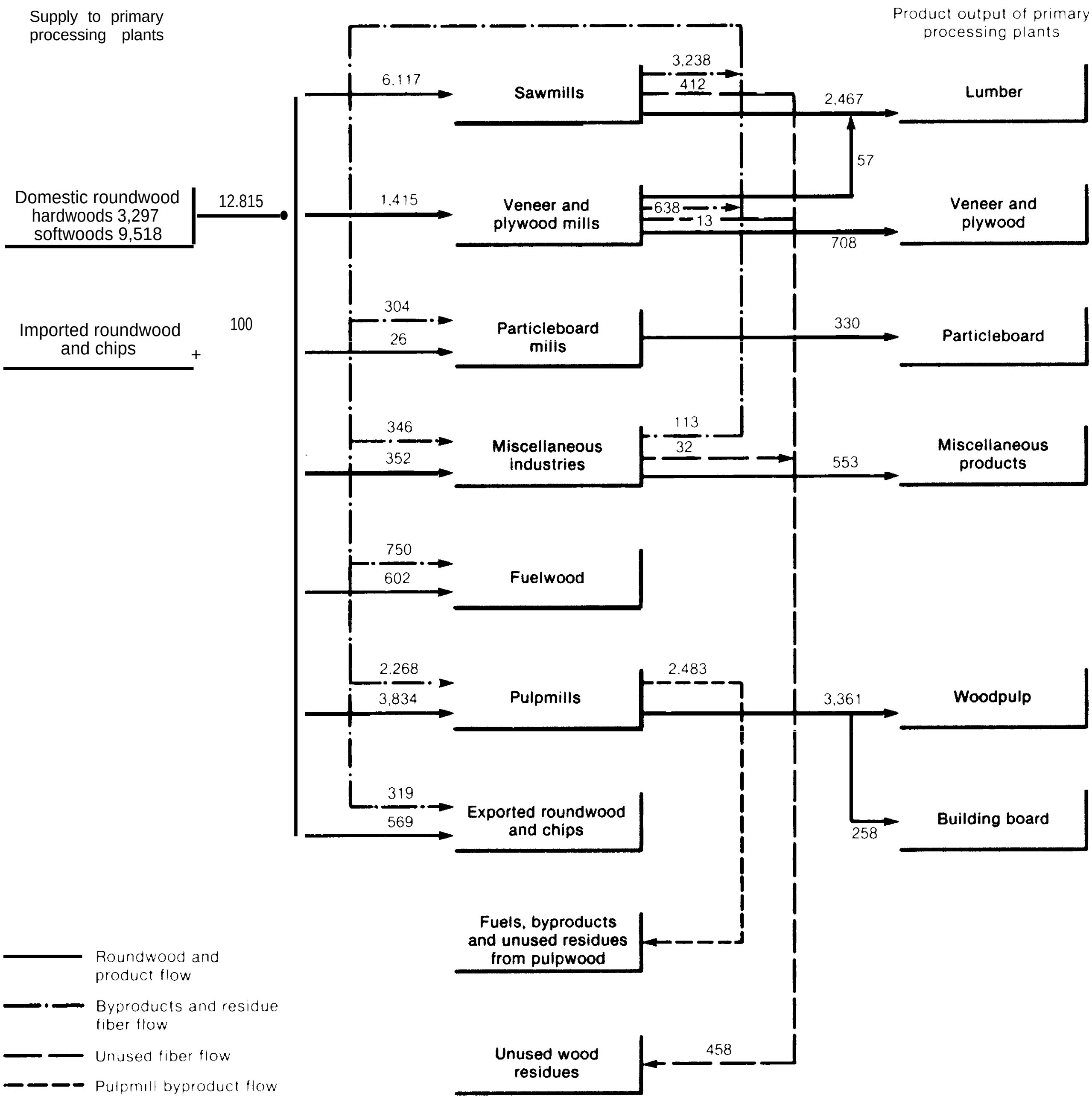
Continued increases in wood-fuel use by the forest products industry are probable but will grow more slowly in the future. The industry now uses over 96 percent of the woody raw materials that enter mills for either products or energy (fig. 4). Opportunities to increase wood energy further may depend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

[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

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)

that burn wood more efficiently or conveniently.

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

[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.

[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].

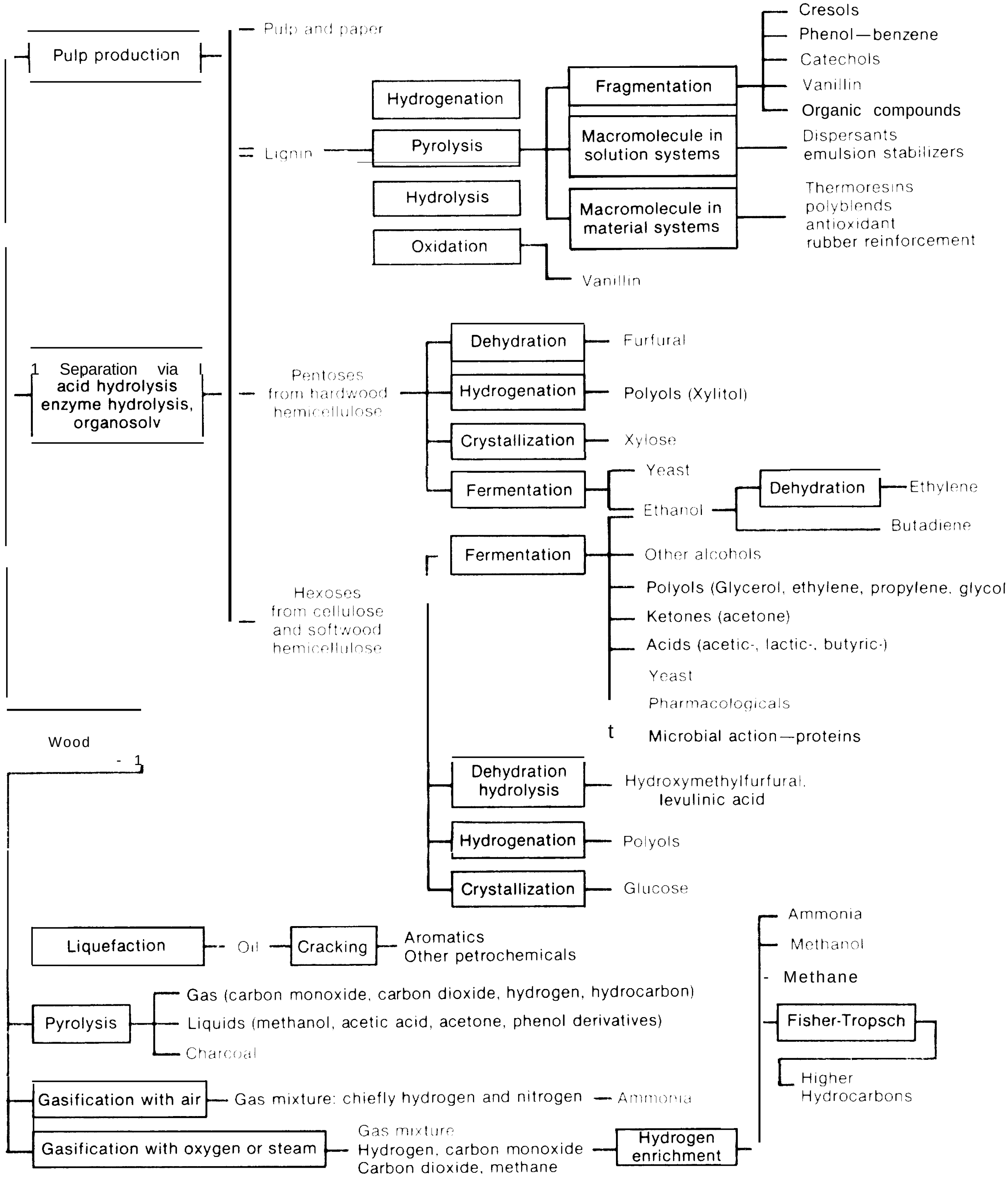
[17] Figure *derived* from *Monthly Energy Review: November* 1982, op. cit., p. 36.

[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

[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,

~~• 1-

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 o Selected Technological Developments n Wood Utilization—continued

	Rationale for or advantage of technology	End-use produc	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	Lumbe ating	Not widely accepted, but ready for commercial application	Hardwoods and softwoods
Structural panels (waferboard, oriented strand board)	Higher recovery of wood n 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 smal 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	Residentia 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 (syn-gas), 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.

211t)id., p. 279.

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 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

Actlvity	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 Cooperatlve Research Information System (CR IS) U S Department of Agrlculture

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.

[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,

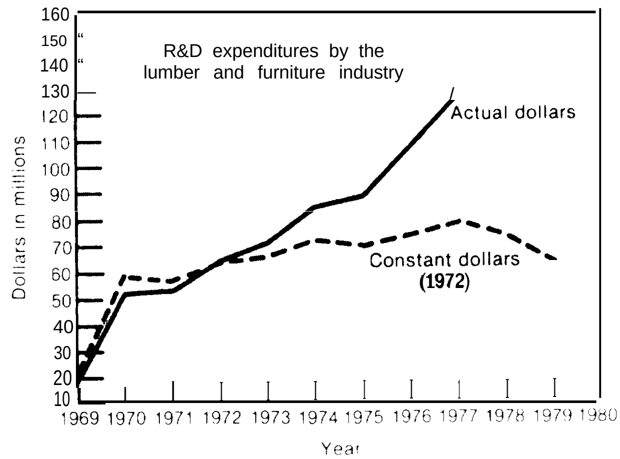
While actual-dollar R&D expenditures by the forest products industry increased at a significant rate between 1969 and 1979 (fig. 6), funding remained nearly level, measured in constant dollars. Between 1977 and 1981, R&D expenditures by the pulp and paper industry (fig. 6) increased approximately 10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

[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.

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 industry, 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.

[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.