Highlights From

Wood for Structural and Architectural Purposes

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Abstract

In 1970 the softwood and hardwood forests of the United States yielded 193 million tons (OD basis) of sawlogs, veneer logs, pulpwood, miscellaneous industrial wood, and fuel wood. By 1985, demand for such wood will likely be in the range from 248 to 260 million tons, while supply should be about 260 million tons. By the year 2000, demand will probably be in the range from 296 to 307 million tons, while supply will be about 307 million tons.

On an OD basis, structural wood commodities require from 1 to 3-1/2 tons of woody furnish per ton of commodity manufactured; reconstituted boards have highest product yield, and lumber the lowest; veneer products are intermediate. Production of lumber, including logging and transport to construction site, calls for net expenditure of about 3 million Btu of oil equivalent per ton of product if mill residuals are credited against energy demand of the milling process. Production of a ton of softwood plywood requires about 6 million Btu after allowance for energy generated by mill residues. Reconstituted boards, i.e., fiberboards and particleboards, require most net energy per ton produced (range 8-1/2 to 21 million Btu).

Production of commodities based on nonrenewable resources requires appreciably more energy than does production of wood-based counterparts. When data are translated into energy required to build 100-square-foot sections of housing, including extraction or logging, manufacture, transport to house site, and erection, wood-based designs are least energy intensive. In roofs, a design incorporating steel rafters required approximately twice the energy of constructions in which wood trusses or rafters were used. Exterior walls sided with brick or constructed of concrete block required 7 to 8 times the energy of all-wood constructions, and walls framed with metal required approximately twice the energy of counterpart wood-framed constructions. In floors, constructions with concrete slab or with steel supporting members required approximately 10 times more energy than wood floor systems. With a few exceptions, manpower and capital costs were not shown to be appreciably different for wood-based and nonwood-based systems.

An immediate substantial increase in research effort related to wood structural products could, by 1985, substantially reduce man-hours needed, and significantly reduce energy required, for their production. It is recommended that research be intensified to improve processes for manufacturing structural materials from flakes, strands, veneer, fibers, and pieces of small size, alone or in combination with other materials. Substantial effort should be devoted to inventing a competitive nonpetroleum-based exterior adhesive for wood. Economical green-wood and bark burners should be developed for direct-fired kilns and to heat boilers. Dryers, heating systems, and hot presses should be designed with improved thermal efficiency; additionally, logging and transport systems should be developed that minimize energy expenditure. Finally, research should be devoted to design concepts which are structurally more efficient.

THE OIL EMBARGO OF 1973 and the material shortages experienced in the early 1970s have focused attention on basic resources essential to the well-being of the United States. In consequence, the outlook for fossil fuels and other nonrenewable resources has been studied intensively. Renewable resources, including timber, have received little attention, however, in spite of their current importance as industrial raw materials and their potential for the future. Recognizing this, the National Research Council in 1974 appointed a Committee on Renewable Resources for Industrial Materials (CORRIM).

The Committee was instructed to assess the interchangeability of renewable and nonrenewable resources, to define the limits on supply and utilization of renewable resources, and to forecast the possible consequences of increased demand for renewable resources on energy consumption, society, and the environment.

To accomplish its mission, CORRIM established six panels, each of which conducted a study providing background data for the CORRIM final report (National Research Council 1976). Panel II was charged with studying wood for structural and architectural purposes as of 1970, and with projecting scenarios for the years 1985 and 2000. This paper is a condensed version of Panel II's 72-page background report (Boyd, et al. 1976).

In its report, Panel II focused on comparisons of wood versus steel, aluminum, concrete, brick, and petrochemical derivatives.

Statistics on the timber resource, its growth, its mortality losses, and its current use are fundamental to a study of this kind. The panel based its resource analysis on

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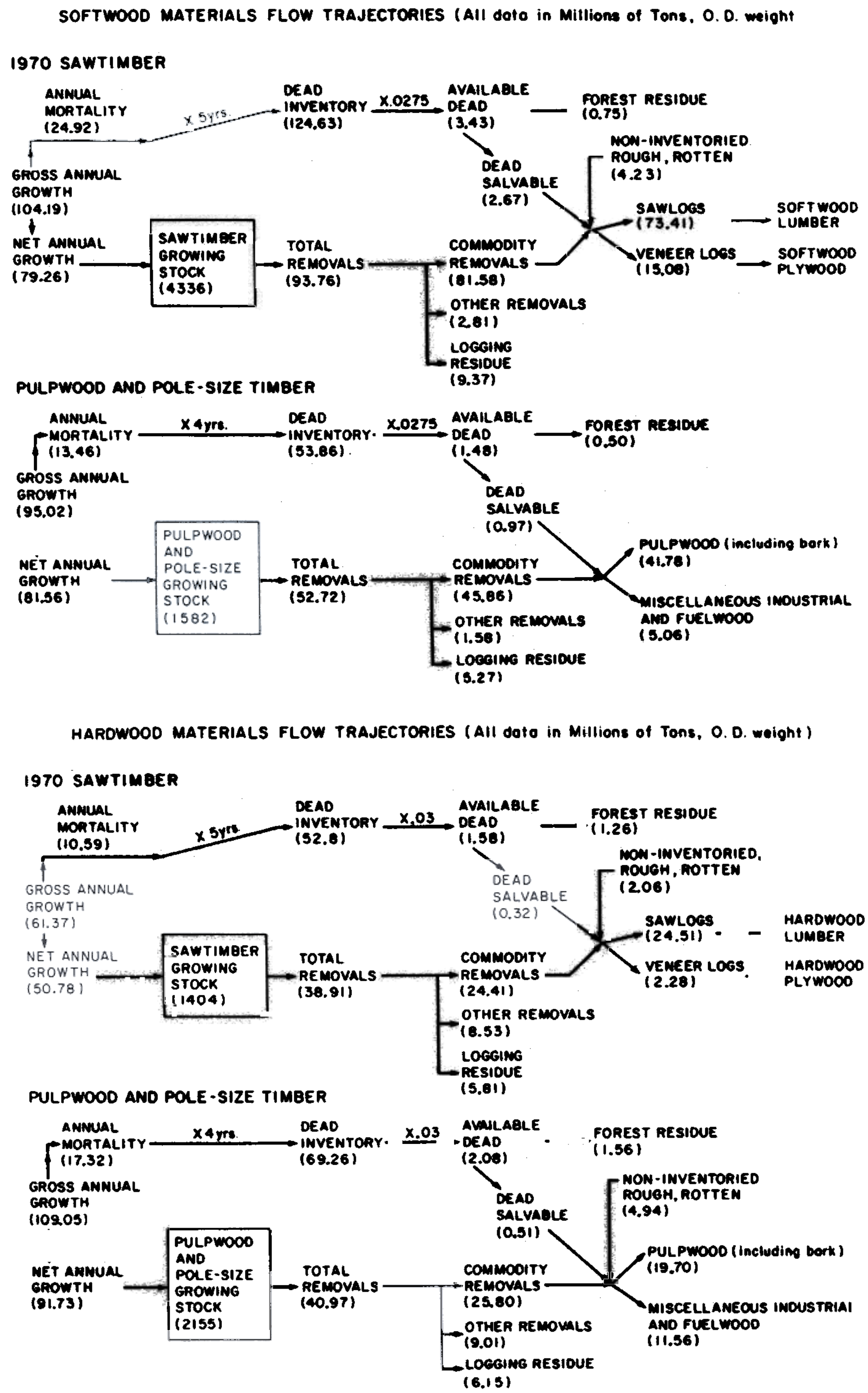


Figure 1. — Softwood (top) and hardwood (bottom) materials-flow trajectories for 1970. Data are principally from the "Outlook for Timber in the United States" (USDA Forest Service 1974); conversion of cubic feet to OD tons has been through multiplication by factors of 0.0137 for softwoods and 0.0164 for hardwoods. Data on growth and removal reflect current inventory standards. Tonnages shown in the "boxes" for growing stock should be increased by 10 percent to allow for (include) bark.

the 1970 statistical data contained in "The Outlook for Timber in the United States" (USDA Forest Service 1974). In presenting the analysis, it was useful to construct material flow trajectories; that is, graphical representations of material flow that account for (balance) all of the tonnage inputs and outputs. These charts, termed *materials flow trajectories* (synonymous with *materials balances*), are based on ovendry (OD) tons of material; unless otherwise specified, bark weight is included. Cubic foot conversion to dry weight was made consistent with the Reference Materials System concept (Bethel and Schreuder 1976) used throughout the CORRIM reports.

Timber Supply and Use in 1970

The Outlook Study (USDA Forest Service 1974) provides most of the data necessary to chart a national materials flow trajectory (Fig. 1) illustrating the flow from growing stock of standing timber to commodity removals in the form of sawlogs, veneer logs, pulpwood, miscellaneous industrial wood, and fuel wood. Also, it is possible to chart noncommodity removals—principally logging residues—and natural mortality leading to dead trees in the inventory, some of which are salvable. These data on growth and removals reflect current inventory standards; tonnages do not, therefore, add up to total biomass. Complete-tree utilization would permit about 35 percent greater commodity recovery, principally as pulp chips and fuel (Keays 1971).

In 1970, total annual removals of softwoods (146 million tons) were less than net annual growth (160 million tons). The 146 million tons removed plus 8 million tons of dead salvable timber and noninventoried rough or rotten timber yielded 135 million tons of sawlogs, veneer logs, pulpwood, miscellaneous industrial wood, and fuel wood (Fig. 1, top).

Hardwood growth also substantially exceeded removals. In 1970, net annual hardwood growth totaled 143 million tons, while removals totaled only 80 million tons. The 80 million tons removed plus 8 million tons of dead salvable timber and noninventoried rough or rotten timber yielded 58 million tons of sawlogs, veneer logs, pulpwood, miscellaneous industrial wood, and fuelwood (Fig. 1, bottom).

In 1970, therefore, the total harvest of softwood and hardwood sawlogs, veneer logs, pulpwood, miscellaneous industrial wood, and fuel was 193 million tons (OD basis). Diversion of these tonnages of roundwood into products was as follows in 1970:

Commodity	Roundwood consumed (million tons, OD)
	73.41
	15.08
	24.51
	2.28
	0.18
	61.30
	16.62

During conversion of these 193 million tons of roundwood, substantial tonnages of byproducts—e.g., chips, shavings, and trim-ends—were produced and incorporated into commodities as follows:

Commodity incorporating the byproduct	Byproduct weights (million tons, OD)
Structural	
Softwood lumber	2.6
Particleboard	2.4
Medium-density fiberboard	0.2
Insulation board	1.2
Wet-formed hardboard	1.1
Paper and paperboard	24.5

Primary Wood-Based Materials Used in House Construction

To assess the probable situation in 1985 and 2000, the Panel found it useful to first analyze material, energy, labor, and capital requirements to manufacture 10 primary wood-based structural materials used in house construction, and to compare these needs with those of competitive materials made from nonrenewable resources.

Materials Flow Analysis

Illustrative of materials balances constructed for the 10 wood-based structural materials is that for softwood lumber (Fig. 2). As a national average in 1970, each ton (OD basis) of softwood sawlogs with bark in place yielded about 0.35 ton of planed lumber, 0.29 ton of chips for pulp, 0.15 ton of shavings and dry board trimmings suitable for particleboard, and 0.21 ton of sawdust and bark available for fuel. Application of this conversion factor for lumber (0.35) indicates that the 73.4 million tons of softwood logs harvested in 1970 yielded about 25.7

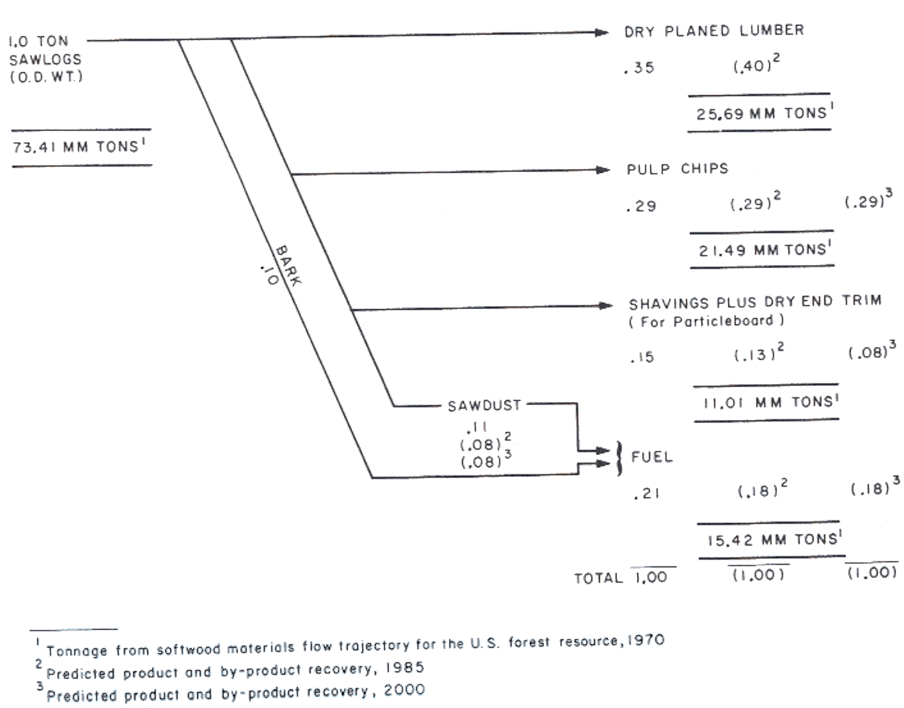


Figure 2. — Materials balance for softwood lumber manufacture in 1970, 1985, and 2000 (on basis of OD weight). Sawlog weight includes bark.

Table 1. — WOODY FURNISH NEEDED FOR THE MANUFACTURE OF 1 TON (OD BASIS) OF EACH OF SEVERAL PRODUCTS.

Commodity	Form of woody furnish	Input of woody furnish (tons, OD)
Insulation board	50-50 mix of bark-free and barky chips of mixed species	0.96
Underlayment particleboard	Planer shavings, sawdust, and plywood trim	1.02
Wet-formed hardboard	50-50 mix of bark-free and barky chips of mixed species	1.15
Medium-density fiberboard	50-50 mix of bark-free chips and barky roundwood of mixed species	1.16
Structural flakeboard and pallet lumber	Mixed-species barky logs	1.24
Lumber laminated from veneer	Barky logs	2.13
Softwood sheathing plywood	Barky logs	2.22
Softwood lumber	Barky logs	2.86
Hardwood plywood paneling	Barky logs	3.33
Oak flooring	Barky logs	3.57

million tons of planed softwood lumber (OD basis). It is anticipated that the conversion factor will increase to 0.40 by 1985 and to 0.45 by the year 2000 (Fig. 2).

Charts showing materials balances for the other nine wood-based commodities were similarly constructed. From them, the input of woody furnish to yield a ton (OD basis) of the 10 products is about as shown in Table 1.

The input for structural flakeboard listed in Table 1 is based on use of a shaping-lathe headrig to manufacture cants and flakes from presently unmerchantable roundwood. In this process pallet lumber, as well as flakeboard, is a primary product (Fig. 3).

Analysis of Manpower, Energy, And Capital Required

In the production of wood-based commodities, considerable quantities of manpower, energy, and capital are expended in forest activities such as logging and road construction; the major expenditures are made, however, in the manufacturing, or mill, phase of the conversion process. Derivation of data for forest activities, while explained in the source documents (Boyd et al. 1976; Koch 1976), will not be illustrated in this condensation; it seems useful, however, to explain how expenditures for manufacturing were apportioned. Allocation of manpower (man-hours), mechanical energy (horsepower-hours), heat energy (pounds of steam), and depreciation of capital (dollars) is illustrated for softwood lumber in Table 2. In most instances, but not all, allocation was made by weight proportions of materials; e.g., lumber, pulp chips, particleboard furnish, and fuel. Input data to make these allocations were collected from a wide variety of industrial sources.

Additionally, requirements for additives such as wax and resins were computed and appropriately allocated to composite commodities such as plywood, particleboard, or flakeboard. Finally, data on manpower, energy, and capital required to transport the commodities to retail yard, and beyond that to the building site, were collected from manufacturing and transportation associations and from retail distributors of building products. These data are all summarized in Tables 3, 4, and 5.

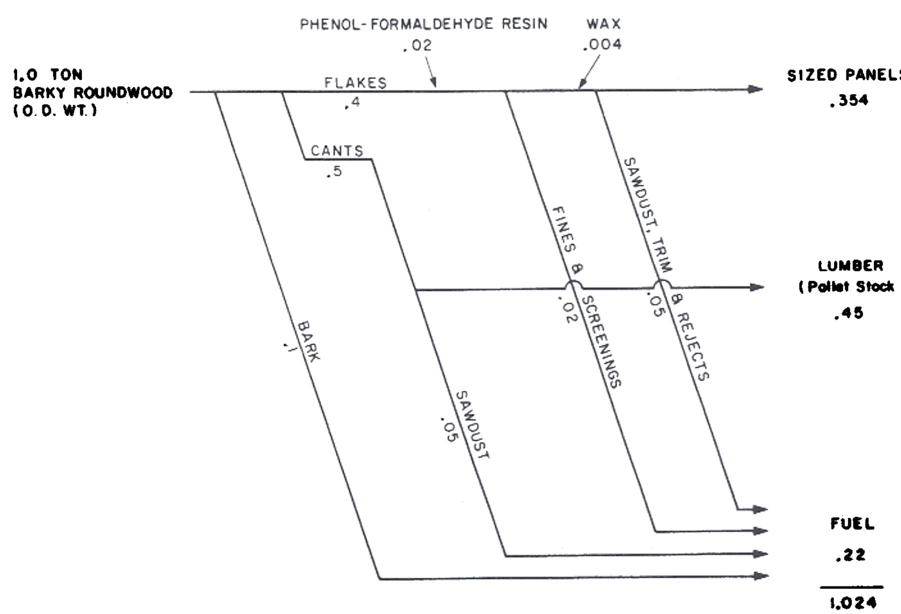


Figure 3. — A materials balance for structural exterior flakeboard based on use of a shaping-lathe headrig to make flakes as a residue from pallet cant manufacture. All weights are on an OD basis.

[1] Not in production in 1970. Information from U.S.D.A. Forest Service, Southern Forest Experiment Station.

Table 2. — MANPOWER, ENERGY, AND CAPITAL DEPRECIATION NEEDED TO MANUFACTURE SOFTWOOD LUMBER FROM 1.0 OD TON OF BARKY SAWLOGS.

Product	Product weight (OD tons)	Man-power (man-hr.)	Mechanical energy (HP-hr.)	Steam energy (lb.)	Depreciation of capital facilities ($)
Dry planed lumber	0.35	0.67	21.98	977	0.86
Pulp chips	0.29	0.56	18.21	0	0.70
Particleboard furnish	0.15	0.29	9.42	419	0.36
Fuel	0.21	0.40	13.19	0	0.51
	[illegible]	[illegible]	62.80	1396	

Table 3. — MAN-HOURS NEEDED TO EXTRACT, MANUFACTURE, AND TRANSPORT TO BUILDING SITE— SELECTED PRIMARY COMMODITIES.

	Logging or extraction	Manufacture	Transport (mill to bldg. site)	Total
		Man-hr./OD Ton		
Wood-based commodities				
Medium-density fiberboard	3.43	2.86	2.08	8.37
Underlayment particleboard	5.04	2.64	1.99	9.67
Softwood lumber	3.92	3.06	3.06	10.04
Structural flakeboard	3.97	3.99	2.14	10.10
Lumber laminated from veneer	3.08	4.53	3.06	10.67
Insulation board	2.28	6.54	2.13	10.95
Softwood sheathing plywood	3.10	4.55	3.31	10.96
Hardwood plywood	4.33	8.03	2.67	15.03
Oak flooring	4.46	8.07	2.67	15.20
Wet-formed hardboard	2.72	14.72	2.08	19.52
Total	36.33	58.99	25.19	120.51
Percent of total	30	49	21	
Mean	3.6	5.9	2.5	12.05
		Man-hr./Ton		
Nonwood-based commodities				
Gravel	0.08	.00	1.03	1.11
Concrete slab	.09	.79	1.03	1.91
Concrete block	.09	1.75	1.24	3.08
Gypsum board	.34	1.74	1.24	3.32
Clay brick	.08	2.93	1.36	4.37
Liquid asphalt	.10	4.30	1.33	5.73
Asphalt shingles	.18	4.40	1.33	5.91
Tar paper	.64	4.00	1.33	5.97
Vermiculite	.08	10.70	1.71	12.49
Steel nails	.89	10.10	2.18	13.17
Steel studs	.89	10.10	2.25	13.24
Steel joists	.89	10.10	2.25	13.24
Glass fiber	1.12	17.50	1.71	20.33
Aluminum siding	.62	50.10	2.25	52.97
Carpet and pad	1.61	93.70	2.98	98.29
Plastic vapor barrier	.82	96.70	1.48	99.00
Total	8.52	318.91	26.70	354.13
Percent of total	2	90	8	
Mean	0.5	19.9	1.7	22.1

[a]Man-hour requirements for erection of structure are not included.

Table 4. — CAPITAL DEPRECIATION ASSOCIATED WITH EXTRACTING, MANUFACTURING, AND TRANSPORTING TO BUILDING SITE OF SELECTED PRIMARY COMMODITIES.

	Extraction	Manufacturing	Transport	Total
		$/OD Ton		
Wood-based commodities				
Softwood lumber	3.09	3.91	3.25	10.25
Structural flakeboard	3.13	11.37	2.36	16.86
Lumber laminated from veneer	2.42	11.98	3.25	17.65
Softwood sheathing plywood	2.44	12.09	3.43	17.96
Underlayment particleboard	6.72	13.74	2.20	22.66
Hardwood plywood	3.41	18.37	3.14	24.92
Insulation board	3.84	24.06	2.29	30.19
Oak flooring	3.51	26.07	3.14	32.72
Medium-density fiberboard	3.21	27.89	2.18	33.28
Wet-formed hardboard	4.59	48.08	2.18	54.85
Total	36.36	197.56	27.42	261.34
Percent of total	14	76	10	
Mean	3.64	19.76	2.74	26.13
		$/Ton		
Nonwood-based commodities				
Gravel	.19	.00	1.17	1.36
Concrete slab	.19	.80	1.17	2.16
Concrete block	.19	.80	1.47	2.46
Clay brick	.19	.80	1.61	2.60
Liquid asphalt	.77	4.90	1.57	7.24
Gypsum board	.37	6.23	1.47	8.07
Tar paper	1.16	5.80	1.57	8.53
Asphalt shingles	.82	7.40	1.57	9.79
Steel nails	4.78	16.60	2.68	24.06
Steel studs	4.78	16.60	2.73	24.11
Steel joists	4.78	16.60	2.73	24.11
Glass fiber	.96	33.00	1.86	35.82
Vermiculite	.08	34.50	1.86	36.44
Aluminum siding	2.14	48.60	2.73	53.47
Carpet and pad	8.11	103.80	2.97	114.88
Plastic vapor barrier	6.29	117.40	1.64	125.33
Total	35.80		30.80	480.43
Percent of total	8		6	
Mean	2.24		1.93	30.03

Nonwood-Based Commodities Used In House Construction

Comparable data on manpower, energy, and capital requirements to make selected nonwood-based materials were obtained from Census reports and from the Brookhaven National Laboratory data bank. These data are also summarized in Tables 3 (man-hours), 4 (capital depreciation), and 5 (energy).

It is notable that production of commodities based on nonrenewable resources requires appreciably more energy per ton than does production of wood-based counterparts (Table 5). This is partly because processing of most wood commodities generates a substantial amount of fuel in the form of residues.

Comparisons of Wood- and Nonwood-Based Materials In House Construction

Early on, Panel II made the decision to focus on house construction in its comparison of wood- and nonwood-based structural materials. To make the comparison, a number of alternative designs for floors, walls, and roofs were examined for weights of commodities per 100 square feet of construction. With knowledge of the weight of

Table 5. — ENERGY NEEDED TO EXTRACT, MANUFACTURE, AND TRANSPORT TO BUILDING SITE — SELECTED PRIMARY COMMODITIES.

	Logging	Gross manufacture: Electricity	Gross manufacture: Heat	Transport	Gross total	Available residue energy	Net total[a]
	- - - - - - - -	- - - - - - - -	Million BTU (oil equivalent) per OD ton	- - - - - - - -			
Wood-based commodities							
Softwood lumber	0.943	0.786	4.060	1.966	7.755	8.313	2.909
Oak flooring	1.073	.844	4.847	1.977	8.741	11.388	3.050
Lumber laminated from veneer	.740	.144	6.443	1.966	9.293	3.540	5.753
Softwood sheathing plywood	.747	.145	6.726	2.081	9.699	3.697	6.002
Structural flakeboard	.956	.578	6.933	1.314	9.781	8.616	2.270
Medium-density fiberboard	.783[b]	3.748	5.555	1.146	11.232	2.741	8.491
Insulation board	.622[c]	4.920	5.619	1.243	12.404	.667	11.737
Hardwood plywood	1.041	.244	9.998	1.977	13.260	10.629	3.018
Underlayment particleboard	4.617[d]	2.503	5.598	1.198	13.916	1.529	12.387
Wet-formed hardboard	.743[c]	9.919	9.743	1.146	21.551	.797	20.754
Total	12.265	23.831	65.522	16.014	117.632	51.917	76.371
Percent of total (gross)	10.4	20.3	55.7	13.6			
Mean	1.23	2.38	6.55	1.60	11.76	5.19	7.64

Nonwood-based commodities	Extraction	Processing	Transport	Total
	- - - - - - - -	- Million BTU (oil equivalent) per ton		
Gravel	0.05	.00	0.40	0.45
Gypsum board	.14	2.73	.65	3.52
Liquid asphalt	.00	3.20	.73	3.93
Tar paper	.20	5.00	.73	5.93
Asphalt shingles	.03	5.70	.73	6.46
Concrete slab	.52	7.60	.40	8.52
Concrete block	.52	7.60	.65	8.77
Clay brick	.57	7.73	.76	9.06
Vermiculite	.04	14.20	.92	15.16
Glass fiber	.62	26.70	.92	28.24
Plastic vapor barrier	4.49	25.10	.75	30.34
Carpet and pad	6.60	28.69	1.90	37.19
Steel nails	2.45	46.20	1.48	50.13
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
Total	47.93	444.85	16.03	508.81
Percent of total	9.4	87.4	3.2	
Mean	2.99	27.80	1.00	31.80

[a]Assumes residue energy can be offset *only* against gross manufacturing energy (but not against logging or transport energy).
[b]Includes logging plus preparation of bark-free chips input.
[c]Includes logging plus preparation of chips.
[d]Includes energy input in logging plus preparation of particleboard furnish in form of planer shavings, plywood trim, and sawdust.

each commodity in each 100-square-foot section, it was possible to compute (primarily through use of the data in Tables 3, 4, and 5) the manpower, energy, and capital depreciation requirements of each design erected in place on the house site. Data on man-hours to erect the constructions at the house site, while not indicated in Table 3, were obtained from the homebuilding industry and incorporated in the manpower column of Table 6 (for details, see Boyd et al. 1976).

Thus, Table 6 compares manpower, energy, and capital depreciation required to build 100-square-foot sections of houses incorporating wood- and nonwood-based materials, including extraction or logging, manufacture, transport to house site, and erection. Table 6 does not include data on maintenance, nor does it include data on heating. All constructions were provided with acceptable (and comparable) levels of insulation, however.

Substantial differences in energy requirements between alternative constructions are evident. In roofs, a design incorporating steel rafters required approximately twice the energy of constructions in which wood trusses or rafters were used. Exterior walls sided with brick or constructed of concrete block required seven to eight times the energy of all-wood constructions, and walls framed with metal required approximately twice the energy of counterpart wood-framed constructions. In floors, constructions with concrete slab or with steel supporting members required approximately 10 times more energy than wood floor systems. With a few exceptions, manpower and capital costs were not appreciably different for wood-based and nonwood-based systems.

Direct comparison of energy requirements for wood- and nonwood-based components performing the same function is even more striking (Fig. 4). Steel floor joists require approximately 50 times more energy than their wood counterparts; aluminum framing for exterior walls requires nearly 20, and steel about 13 times as much energy as wood. Steel rafters require 7 times the energy needed for wood rafters. Aluminum siding requires 4 times the energy of wood siding, and brick siding calls for 25 times the energy needed for wood siding. Where

Table 6. — MANPOWER, ENERGY, AND CAPITAL COSTS OF HOME BUILDING, INCLUDING LOGGING (OR EXTRACTION), MANUFACTURE, TRANSPORT TO HOUSE SITE, AND ERECTION (PER 100-SQUARE-FOOT SECTION).

	Manpower (man-hr.)	Net Energy[a] (million BTU)	Capital Depreciation ($)
Roofs			
1. W-type wood truss with wood shingles	8.96	2.44	6.14
2. Same but with asphalt shingles	9.04	3.22	6.72
3. Steel rafters (flat roof)	9.17	5.11	6.38
4. Flat roof with LVL[b] rafters and flakeboard[c]	9.36	2.45	6.59
Exterior walls			
1. Plywood siding (no sheathing), 2x4 frame	7.99	1.99	4.15
2. Medium-density fiberboard siding, plywood sheathing, 2x4 frame	9.86	2.54	6.41
3. Medium-density fiberboard siding, 1/2-inch insulation board, and plywood corner bracing	9.26	2.69	6.71
4. Concrete building block, no insulation	18.45	16.53	5.56
5. Aluminum siding over sheathing	9.83	4.95	4.61
6. MDF siding, sheathing, steel studs	9.89	4.79	7.20
7. MDF siding, sheathing, aluminum framing	11.26	5.53	6.91
8. Brick veneer	22.00	17.89	8.37
Interior walls			
1. Wood framing	3.87	0.95	2.17
2. Aluminum framing	3.99	2.25	2.13
3. Steel framing	3.53	1.88	2.25
Floors (all with carpet and pad, except No. 2)			
1. Wood joist, plywood subfloor, and particleboard underlayment	9.15	2.85	7.58
2. Wood joist, plywood subfloor, oak finish floor	8.51	1.19	6.40
3. Wood joist, "single-layer floor"	7.77	2.09	6.32
4. Concrete slab	11.62	22.06	11.81
5. Steel joist, 2-4-1 plywood	11.97	23.26	16.34
6. LVL joist and flakeboard	7.76	2.05	7.23

[a]Energy from wood residues credited *only* against gross energy requirements of *manufacturing* phase, not against logging or transport of wood components.
[b]Laminated veneer lumber.
[c]Erection costs unavailable. Approximations based on similar construction were used.

conservation of energy is of prime importance, the advantages of wood for residential and light frame construction are apparent. Comparisons based on manpower and capital depreciation are less striking, but in general wood-based components compare favorably with nonwood-based components (Fig. 4).

On the basis of these comparisons, and assuming that energy conservation will continue to be critical over the next 3 decades, CORRIM Panel II predicted an increasing demand for wood in structural uses provided that an adequate supply of timber at a relatively reasonable cost can be assured.

DESIGN INCORPORATING COMPONENT	FUNCTION AND MATERIAL	LABOR MAN-HOURS	CAPITAL DEPRECIATION DOLLARS	NET ENERGY MILLION BTU
	FLOOR JOISTS			
FLOOR 1, 3	SOFTWOOD LUMBER	1.395	1.42	0.404
FLOOR 6	LAMINATED-VENEER LUMBER	1.195	1.97	.645
FLOOR 5	STEEL	5.562	10.13	21.134
	SUBFLOOR (Single-Layer)			
FLOOR 3	SOFTWOOD PLYWOOD	.997	1.63	.546
FLOOR 6	HARDWOOD FLAKEBOARD	1.192	1.99	.268
FLOOR 4	CONCRETE	4.469	5.01	19.849
	EXTERIOR WALL FRAMING			
EXTERIOR WALL 1,2,3,5	WOOD	0.593	0.60	0.172
EXTERIOR WALL 7	ALUMINUM	.795	.80	3.007
EXTERIOR WALL 6	STEEL	.596	1.09	2.264
	ROOF TRUSSES OR RAFTERS			
ROOF 1	LUMBER (Pitched) & PLATES	1.111	1.17	.457
ROOF 3	STEEL (Flat)	.751	1.37	2.868
ROOF 4	LVL (Flat)	.789	1.31	.426
	SIDING			
EXTERIOR WALL 2,3,6,7	1/2 INCH MED. DENSITY FIBERBOARD	0.728	2.90	0.739
EXTERIOR WALL 5	ALUMINUM	.795	.80	3.007
EXTERIOR WALL 1	5/8 INCH PLYWOOD	.997	1.63	.546
EXTERIOR WALL 8	BRICKS, 3 1/4 INCH	7.688	4.56	15.932

Figure 4. — Manpower, energy, and capital depreciation expended for floor joists, subfloor, exterior wall framing, roof trusses or rafters, and siding in alternative designs of 100-square-foot sections of floors, roofs, and walls. Expenditures include those for raw material extraction (or logging), material manufacture, and transport to house site. LVL is an abbreviation for laminated-veneer lumber.

Effect of Increased Research

Important forces affecting future manpower, energy, and capital requirements for wood-based structural materials can be categorized according to forest harvest conditions (tree size, natural stands vs. plantations, species mix, location of forest relative to mill, and specifications of forest utilization standard), fuel constraints (availability and cost of fossil fuel), societal changes (type of product demanded, environmental awareness, and house size), and legislative constraints (forest practices, manufacturing and processing—e.g., OSHA—and building codes). It is the judgment of CORRIM Panel II that an increased level of research and development related to wood structural products will influence the impact of these forces on requirements for manpower, energy, and capital, and that most of the changes will occur by 1985. The effects can be summarized as follows:

Requirement	Level of research and development: Current level	Substantial increase
	---------- Effect ----------	
Man-hours	Little change	Substantial decrease
Energy	Small decrease	Possible substantial decrease
Capital	Substantial increase	Small increase

Timber Supply and Use In 1985 and 2000

In assessing trends, CORRIM Panel II recognized that trees available for harvest will, on the average, be smaller in the future and that there are both economic and esthetic pressures for more complete utilization of all stems. Improved precision sawing is anticipated, which when combined with improved planing techniques will likely raise recovery of softwood lumber to about 45 percent of log volume in spite of smaller log diameters (Fig.2). Also, it was Panel II's judgment that wood in a variety of composite and reconstituted forms will be increasingly used for structural products, thereby substantially improving the degree of utilization.

Based on these considerations, and on future demand projections given in "The Outlook for Timber in the United States" (USDA Forest Service 1974)—which was only slightly revised in the 1975 Assessment (USDA Forest Service 1976)—several scenarios were deleveloped to span a range of demands for products derived from domestic timber resources. Two of these are presented herein.

Scenario I (Fig. 5) is based largely on the medium-level projection of growth in population and economic activity given in "The Outlook for Timber in the United States" (USDA Forest Service 1974), and on constant relative prices for wood-based commodities. Panel II departed from the assumptions of the 1974 study, however, in assuming that average dwelling units would remain at 1970 size (1,475 square feet) rather than increasing as they have in the past. On this basis, Panel II estimates that about 307 million tons of roundwood will be needed to meet anticipated demands in the year 2000 (Fig. 5). The 65 million tons of byproducts produced in the processing of this roundwood can contribute materially to manufacture of a variety of products (Fig. 5).

Scenario II (Fig. 6) is based on all the low-level projections of the Outlook Study (USDA Forest Service 1974), including a slower rate of population growth in the United States—266 million people by 2000 instead of the 281 million anticipated in the medium-level projection. Many demographers now consider the lower estimate to be the better one. Scenario II, like Scenario I, is based on the assumption that relative prices will remain unchanged through the projection period. According to this scenario, roundwood demand in 2000 will be 296 million tons, and 73 million tons of byproducts from this roundwood will be converted to useful products.

The projections embodied in these scenarios anticipate that demands on domestic timber supplies in the year 2000 will be between 53 (Scenario II) and 59 (Scenario

COMMODITY	1985 MM O.D. TONS: FROM ROUNDWOOD	1985 MM O.D. TONS: FROM BY-PRODUCT	2000 MM O.D. TONS: FROM ROUNDWOOD	2000 MM O.D. TONS: FROM BY-PRODUCT
STRUCTURAL				
1. SOFTWOOD LUMBER	80.4	3.5	64.6	4.0
2. SOFTWOOD PLYWOOD	17.7		14.6	
3. HARDWOOD LUMBER	34.5	1.4	42.2	1.4
4. HARDWOOD PLYWOOD	3.1		3.1	
5. PARTICLEBOARD		5.3		8.5
6. MEDIUM DENSITY FIBERBOARD	0.4	0.4	0.6	0.6
7. INSULATION BOARD		1.9		2.2
8. WET-FORMED HARDBOARD		1.9		2.9
9. STRUCTURAL FLAKEBOARD # 1	3.0[1]		5.1[1]	
10. STRUCTURAL FLAKEBOARD # 2 (RCW)	3.0		5.1	
11. LAMINATED-VENEER LUMBER	2.3[2]		4.4[3]	
FIBROUS				
12. PAPER AND PAPERBOARD	104.2	38.2	154.9	45.1
MISCELLANEOUS				
13. MISCELLANEOUS INDUSTRIAL AND FUELWOOD	11.3		12.2	
TOTAL	259.9	52.6	306.8	64.7

Figure 5. — Scenario I—anticipated roundwood use from domestic sources of hardwood and softwood in 1985 and 2000. Byproduct tonnages from conversion of the roundwood are shown allocated to appropriate products.

[1]More than one type of structural flakeboard is anticipated, but in total flakeboard will be equivalent to veneer from 5.9 million tons of veneer logs in 1985, and 9.7 million tons in 2000. These equivalents have been subtracted from projected roundwood demand for softwood plywood.

[2]1.5 million tons converted to softwood lumber and 0.8 million tons converted to hardwood lumber.

[3]2.8 million tons converted to softwood lumber and 1.6 million tons converted to hardwood lumber.

COMMODITY	1985 MM O.D. TONS FROM ROUNDWOOD	1985 MM O.D. TONS FROM BY-PRODUCT	2000 MM O.D. TONS FROM ROUNDWOOD	2000 MM O.D. TONS FROM BY-PRODUCT
STRUCTURAL				
1. SOFTWOOD LUMBER	81.3	3.3	75.1	4.0
2. SOFTWOOD PLYWOOD	18.2		18.6	
3. HARDWOOD LUMBER	29.8	1.4	31.7	1.4
4. HARDWOOD PLYWOOD	3.6		4.3	
5. PARTICLEBOARD		4.5		6.3
6. MEDIUM DENSITY FIBERBOARD	0.3	0.3	0.5	0.5
7. INSULATION BOARD		1.9		2.7
8. WET-FORMED HARDBOARD		2.0		2.7
9. STRUCTURAL FLAKEBOARD # 1	3.0[1]		5.1[1]	
10. STRUCTURAL FLAKEBOARD # 2 (RCW)	3.0		5.1	
11. LAMINATED-VENEER LUMBER	2.2[2]		4.6[3]	
FIBROUS				
12. PAPER AND PAPERBOARD	95.3	38.0	139.6	55.6
MISCELLANEOUS				
13. MISCELLANEOUS INDUSTRIAL AND FUELWOOD	11.1		11.6	
TOTAL	247.8	51.4	296.2	73.2

Figure 6. — Scenario II—anticipated roundwood use from domestic sources of hardwood and softwood in 1985 and 2000. Byproduct tonnages from conversion of roundwood are shown allocated to appropriate products.

[1]Structural flakeboard will be the equivalent to veneer from 5.9 million tons of veneer logs in 1985 and 10 million tons in 2000. These equivalents have been subtracted from projected roundwood demand for softwood plywood.
[2]1.5 million tons converted to softwood lumber and 0.7 million tons converted to hardwood lumber.
[3]3.4 million tons converted to softwood lumber and 1.2 million tons converted to hardwood lumber.

I) percent greater than the demands in 1970. These projections are similar to others that have recently been reviewed, and which range mostly between 50 and 70 percent (Zivnuska and Vaux 1975). The medium projection in the most recent assessment by the USDA Forest Service (1976) predicts an increase by 2000 in total U.S. demand for timber products of 73 percent over 1970.

Other CORRIM scenarios project decreasing *relative* prices for wood in the future as a consequence of the higher energy intensiveness and the depletion of competing nonrenewable resources, and would call for substantial increases (above Scenarios I and II) in the timber harvest. Scenarios I and II, however, appeared to Panel II as the most realistic.

Are forests of the United States capable of supplying 300 million tons of roundwood by the year 2000? To find out, we went back to the 1974 Outlook Study projections of supply for 1985 and 2000. In developing our materials flow trajectories (materials balances), timber in all commercial sizes was pooled because distinctions between sawtimber and pulpwood and poletimber no longer have much practical significance.

Figure 7 presents roundwood materials flow trajectories for both softwoods and hardwoods for the year 2000. The projection shows total removals slightly exceeding net growth in that year, but the growing-stock inventory of 6,673 million tons of softwoods will have increased from 6,510 million tons (4,770 plus 1,740) in 1970. In the year 2000, 174 million tons of softwood will be harvested as sawlogs, veneer logs, roundwood for pulp and structural flakeboard, and miscellaneous industrial wood and fuelwood. Harvest of hardwood sawlogs, veneer logs, roundwood for pulp and flakeboard, and miscellaneous industrial wood and fuel wood will total 133 million tons, again from an enlarged base of growing stock. Harvest of softwoods and hardwoods in the roundwood forms enumerated will, therefore, total 307 million tons.

A summary (Table 7) of harvestable tonnages of the roundwood forms just enumerated shows an increase from 193.3 million tons in 1970 to 306.8 million tons in 2000. In addition to these tonnages, by the year 2000, 28.2 million tons of logging residues and 7.8 tons of available (but not salvaged) dead timber will be potentially available for manufacture into commodities. It therefore seems likely that roundwood requirements under either Scenario I or II can be met in both 1985 and 2000, as follows:

Year	Demand: Scenario I	Demand: Scenario II	Supply
	Million tons		
1985	259.9	247.8	259.8
2000	306.8	296.2	306.8

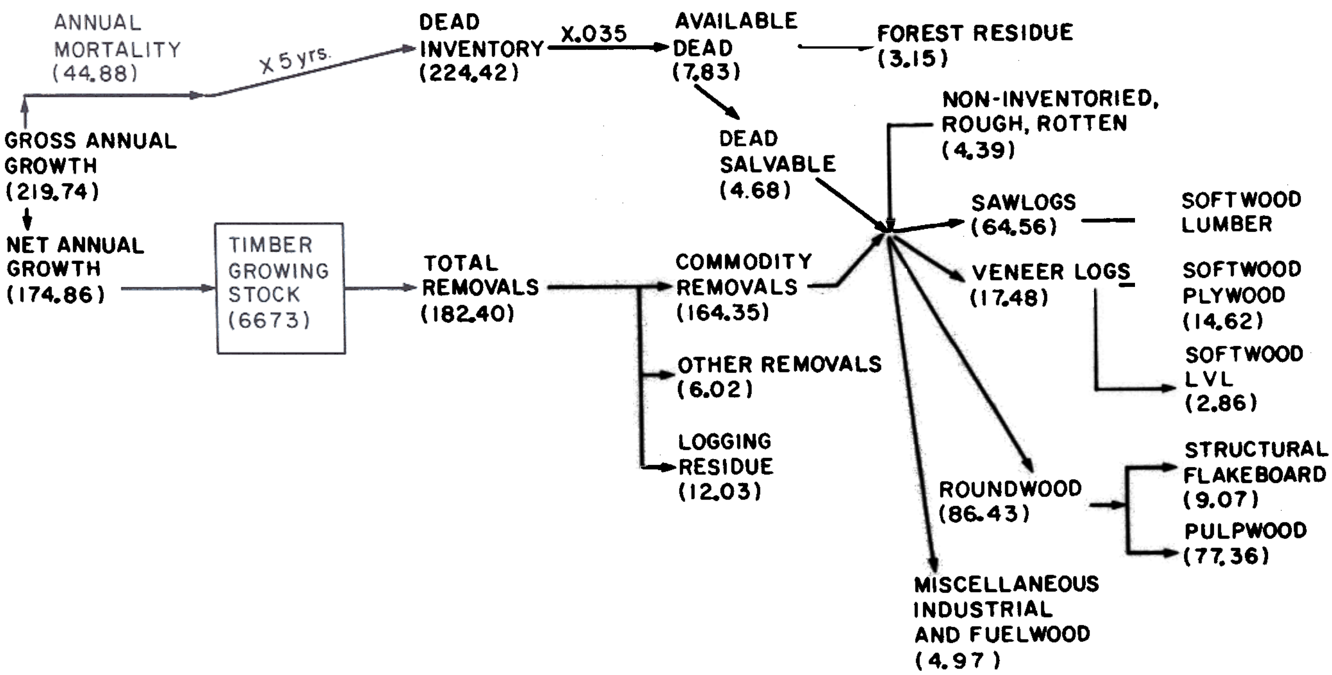
While the potential of forests in the United States to meet likely demands through the next quarter century is evident, the realization of this potential presents a challenge to makers of forest policy, to resource managers, and to the forest-based industry. Basic to our analysis is an assumption that imports of wood will remain constant at about 12 percent. We have also assumed that relative timber prices will remain at 1970 levels. We hope that both of these assumptions will be borne out, but they will not be unless the industry maintains the near-term timber production projected here.

If the cost of energy continues to climb, as it is expected to do, maintaining the supply of forest products to the building industry will become even more important. This is so because the cost of energy-intensive petrochemical-based plastics, metals, or even common concrete or brick will rise rapidly. Keeping timber supplied in adequate tonnages can likely be accomplished through increased research aimed at the more complete use of logging and milling residues.

Equally important is expanded research on improving the efficiency with which structural wood products are used. Examples of such research include recent work on the capability of subfloors to accommodate load sharing among joists (Goodman, Vanderbilt, Criswell, and Bodig 1974) and field application of elastomeric adhesives to

SOFTWOOD MATERIALS FLOW TRAJECTORIES (All data in Millions of Tons, O. D. weight)

2000 TIMBER - ALL COMMERCIAL SIZES



HARDWOOD MATERIALS FLOW TRAJECTORIES (All data in Millions of Tons, O. D. weight

2000 TIMBER-ALL COMMERCIAL SIZES

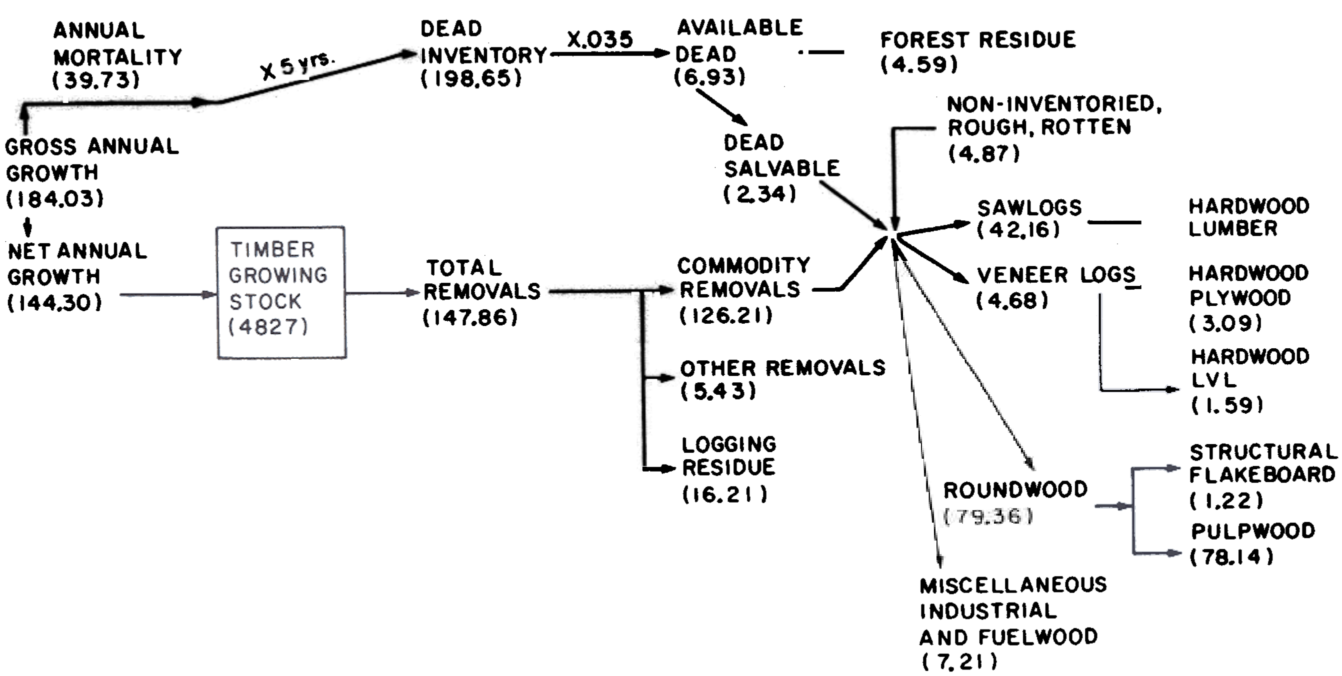


Figure 7. — Softwood (top) and hardwood (bottom) materials-flow trajectories for the year 2000. Data are principally from the "Outlook for Timber in the United States" (USDA Forest Service 1974); conversion of cubic feet to OD tons has been through multiplication by factors of 0.0137 for softwoods and 0.0164 for hardwoods. Data on growth and removal reflect current inventory standards.

Table 7. — SUMMARY OF MATERIALS FLOW FROM GROSS ANNUAL GROWTH (MILLION OD TONS).

	Available for all commodities			Potentially available for commodity use			
	Roundwood			Logging residues		Residues from mortality	
	Softwoods	Hardwoods	Total	Softwoods	Hardwoods	Softwoods	Hardwoods
1970	135.3	58.0	193.3	14.6	12.0	1.2	2.8
1985	156.1	103.7	259.8	12.7	15.3	2.6	3.6
2000	173.4	133.4	306.8	12.0	16.2	3.2	4.6

increase transfer of stress from joist to subfloor (Hoyle 1976). Widespread adoption of structural designs involving the more efficient use of wood can effectively stretch our wood supply.

Recommendations

CORRIM Panel II concluded its report with the following recommendations, which also appear in the report of the parent committee (National Research Council 1976):

- In view of the anticipated reduced sizes of raw material available for the manufacture of dimension lumber, studies should be initiated to develop improved processes for manufacturing structural materials from hardwood and softwood flakes, strands, veneer, fibers, and pieces of small size, alone or in combination with other materials. To be effective commercially, these studies must be followed by pilot plant evaluation.
- The changing raw material base for veneer demands that additional research efforts be focused on the further development of structural reconstituted products for both exterior and interior applications from a wide spectrum of softwood and hardwood species.
- A substantial research effort should be devoted to inventing a nonpetroleum-based exterior adhesive competitive in function and current price with the durable phenol-formaldehyde adhesives which are so central to the manufacture of exterior, structural reconstituted wood products. Lignin from wood could be a potential source for the development of such an adhesive.
- Inasmuch as a major portion of the energy required for the manufacture of wood structural materials can be provided from residue, research should be directed to the development of economical green-wood and bark burners for direct-fired dryers and to heat boilers.
- Additionally, research and development must be directed toward developing dryers, heating systems, and hot presses of high thermal efficiency and toward the reduction of power consumption in all phases of logging, manufacture, and transport.
- Inasmuch as manpower, energy, capital depreciation, and material required for structures are all positively correlated with weight, research should be devoted to design concepts which are structurally more efficient. Research should also be devoted to decreasing weight through increasing the strength and stiffness of components from which wood structures are built.

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