WOOD FOR STRUCTURAL AND ARCHITECTURAL PURPOSES

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ABSTRACT

This paper reports the findings and conclusions of Panel II on Structural Purposes, Committee on Renewable Resources for Industrial Materials (CORRIM), National Academy of Sciences/National Research Council. The Panel examined the use of wood for structural purposes and its conversion from standing trees to primary structural commodities as of 1970, and from this base year developed projections of use to the years 1985 and 2000. Concerns of the Panel included the availability of the renewable resource, the demand for wood products, and particularly the costs in terms of manpower, energy, and capital depreciation involved in production and transportation to the point of use. Comparable data from source to end commodity were compiled for other structural materials including steel, aluminum, concrete, brick, and petrochemical derivatives.

Wood products were found, with few exceptions, to be more homogeneous than nonwood-based commodities in man-hour and capital requirements. However, the most notable differences between wood-based and nonwood-based commodities are in their energy requirements. Commodities based on nonrenewable resources are appreciably more energy intensive per ton of product than are their wood-based counterparts. In part, this is the result of energy self-sufficiency in the manufacturing process attained through the use of wood residues as fuel.

[1] The authors, under the chairmanship of S. B. Preston, constituted Panel II of the Committee on Renewable Resources for Industrial Materials (CORRIM), National Academy of Sciences/National Research Council. The authors' gratitude to the many individuals in industry, education, and government who contributed to the compiling of the information presented in this report cannot be adequately expressed here. Suffice it to say that without their cooperation this report could not have been completed successfully. Financial support for the publication of this report was provided by the Southern Forest Experiment Station, USDA Forest Service. Reproduced, in slightly revised form, with permission of the National Academy of Sciences from Renewable Resources for Industrial Materials (National Research Council 1976), with the addition of extensive background data not contained in the National Research Council Report.

Because of the dominance of residential and similar light-frame structures in the total structural use of wood, housing was selected for closer examination of the relative efficiencies of wood and wood-based products in comparison with nonrenewable resource materials through the phase of installation in the structure. From an analysis of representative roof, exterior wall, interior wall, and floor systems, substantial differences between alternative constructions in energy requirements were revealed. In roofs, a design incorporating steel rafters required appoximately twice the energy of constructions in which wood trusses or rafters were used. Exterior walls sided with brick or constructed with concrete block required seven to eight times the energy of all-wood constructions, and exterior and interior walls framed with metal required approximately twice the energy of counterpart wood-framed constructions. Floors constructed from wood materials required only about ten percent as much energy as concrete slab construction or one with steel supporting members. With few exceptions, manpower and capital costs were not appreciably different for wood-based and nonwood-based systems.

Direct comparisons between wood and mineral-based components performing the same function in these designs were even more striking in terms of energy consumption. For example, steel floor joists required 50 times as much energy as wood counterparts. Aluminum framing for exterior walls was nearly 20 times as energy intensive as wood framing, and steel framing required approximately 13 times as much energy as wood. Steel rafters exceeded wood trusses nearly sevenfold in energy requirements and aluminum siding required approximately five times the energy of plywood and fiberboard. The energy requirement for brick veneer siding was approximately 25 times that of wood-based siding materials. No clear pattern emerged from the analysis in terms of labor or capital depreciation.

Where conservation of energy is of prime importance, the advantages of wood for residential and light commercial construction are apparent.

Materials-flow trajectories were developed for 1985 and 2000 based upon U.S. Forest Service projections of available timber supply. Finally, two scenarios were developed by the Panel spanning a range of anticipated demand for timber from domestic sources in the years 1985 and 2000. Requirements under these scenarios can be achieved under the projected materials-flow supply schedule. The potential of the United States forest resource to meet realistic demands through the next 25 years is evident, but realization of this potential presents a challenge to the makers of forest policy, to resource managers, and to the forest-based industries.

Much more research in the closer utilization of residues at the mill and in the forest will be needed to achieve the potentials suggested by the scenarios and trajectories presented in this report.

Keywords: aluminum, building board, building components, capital, costs, energy, flakeboard, floors, forest harvesting, future trends, hardboard, housing, insulation board, light-frame construction, lumber, manpower, metals, particleboard, petrochemicals, plywood, renewable resources, research and development, research management, residential construction, roofs, steel, structural particleboard, structures, timber demand, timber supply, walls, wood.

INTRODUCTION

Wood, with very minor exceptions, is the only renewable resource economically suitable for structural and architectural purposes. It was attractive to primitive societies as a structural material because it was easily available; it could be used in very nearly the form in which it grew; and, if it required modification for use, it could be worked with very simple tools.

In the United States today the use of wood for these purposes, among all wood uses, accounts for the greatest proportion of the timber harvest. Of some 250 million tons of raw wood—approximately equal to the combined production of all metals, cements, and plastics—that are processed each year by the nation's forest product industries (Cliff 1973), 63% is converted to lumber and rigid panels which are, in turn, used in structures and in innumerable manufactured commodities. Projections of the U.S. Forest Service (USDA Forest Service 1974) indicate an approximate doubling of the demand for raw wood between the years 1970 and 2000, with lumber and rigid panels accounting for over 50% of the total demand. During this 30-year period of increasing wood demand, major changes will be occurring in the size, quality, and mix of the raw-material base from the forests and in the environment affecting the manufacture of forest-based commodities.

Wood used in lumber and panel form takes maximum advantage of the basic biological structure of the parent tree and consequently achieves maximum benefit from the photosynthetic process as a material synthesizer. It is when wood is used in these forms that it exhibits its greatest advantage over most competitive materials in terms of energy. Use of the Reference Materials System concept (Bethel and Schreuder 1976) provides an opportunity to study the flow of forest-based materials into primary structural and architectural commodities and to examine energy, manpower, and capital requirements in the manufacture of these primary products, and their conversion into example building systems, as compared with selected alternatives manufactured from nonrenewable raw materials.

Inventory data classify trees, largely on the basis of stem diameter, as sawtimber or pole-size timber. Trees included in the first category yield logs generally considered of suitable size and quality to be converted to lumber or veneer, whereas trees in the second category have been generally considered too small for conversion into these two products. Technological advances in utilization, however, together with the economic practicalities of product manufacture from a given raw material supply, have largely eliminated the distinction between these categories from a utilization standpoint. These categories will be used here only because the National Forest Inventory still distinguishes them. Trees of all diameters must now be considered part of the raw-material base for structural and architectural commodities in the form of lumber or of structural timbers and panels derived from smaller pieces of lumber or from veneer, flakes, particles, or fibers. Fiber for paper and other pulp-based products is similarly drawn from a reservoir of raw material from both categories.

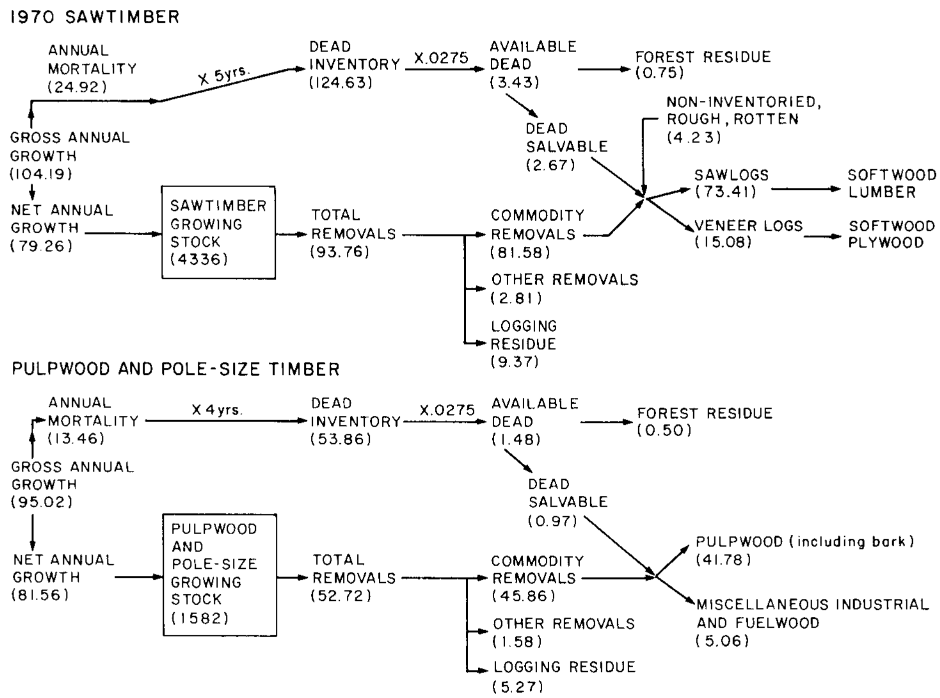
Materials-flow trajectories shown in Fig. 1 were derived from 1970 data reported in the Outlook for Timber in the United States (USDA Forest Service 1974). They indicate the domestic raw material base from which the forest products industry in 1970 harvested 193 million oven-dry (OD) tons of roundwood with bark intact[2]. Of this, 115 million oven-dry tons were from sawtimber yielding 98 million tons of sawlogs and 17 million tons of veneer logs. The remaining 78 million tons were cut from pulpwood and pole-size timber. Softwoods accounted for 135 million tons of material, approximately 70% of the total, of which 88 million tons were categorized as sawlogs and veneer logs. The remaining 58 million tons were hardwoods, of which 27 million tons were sawlogs and veneer logs. Essentially the same data are contained in the U.S. Forest Service's 1975 Assessment Report (USDA Forest Service 1976).

Manufactured from this raw-material mix flowing into industry were 42.8 million oven-dry tons of lumber and rigid panels suitable for building materials. Additionally yielded from this mix were 6.8 million tons of cooperage, piling, poles, posts, mine timbers, and other miscellaneous products, which are dependent in part for their utility on mechanical strength. In all, 26% of the total forest tonnage harvested in 1970 reached the market in the form of primary structural products (USDA Forest Service 1974; Phelps and Hair 1974).

For the purpose of this study, structural and architectural materials are considered to be those contributing to the form and structural integrity of the product. Thus, emphasis is given to renewable resources which, in primary processed form, have reliably known physical and mechanical properties, and are dimensionally suitable for structural use. Decorative and aesthetic characteristics, *per se*, are not considered. This study therefore concentrates on the processing of raw materials from the forest into prisms and rigid panels, and the con-

[2] This value equates with the 250 million tons cited by Cliff (1973) at a moisture content of 29% —approximately at fiber saturation.

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



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

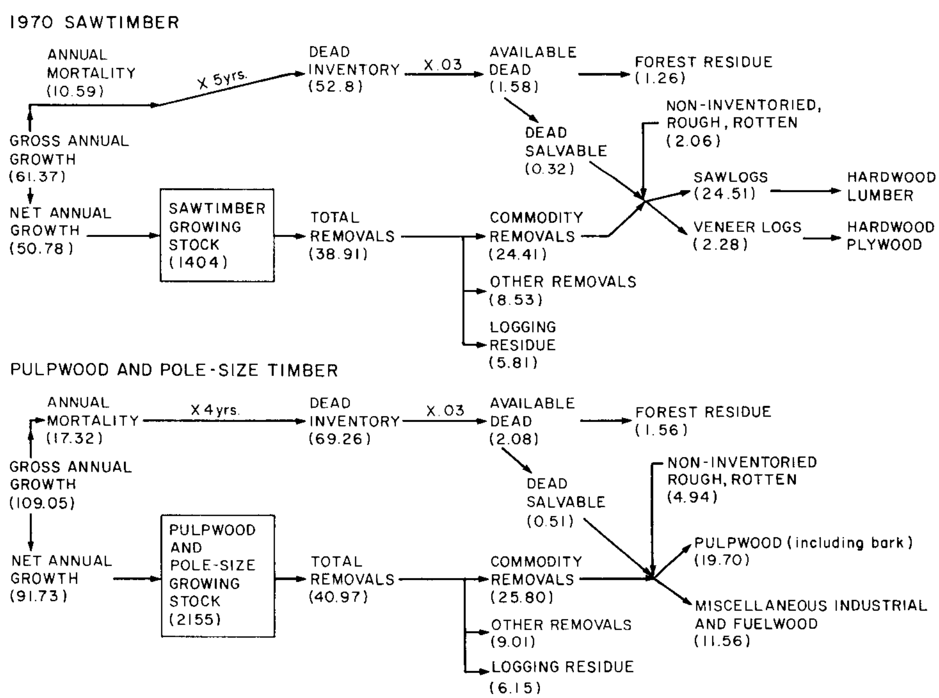


TABLE 1. *Uses of primary wood commodities, 1970*[a]

	Lumber		Plywood		Building Board[b]	
	Million Tons[c]	*Percent*	*Million Tons*[c]	*Percent*	*Million Tons*[c]	*Percent*
Construction						
Residential	13.2	43	3.3	49	2.3	43
Non-Residential	2.8	9	0.7	10	0.6	11
Total Construction	16.0	52	4.0	59	2.9	54
Manufacture						
Furniture	2.2	7	0.34	5		
Other	1.5	5	0.26	4	—	—
Total Manufacture	3.7	12	0.60	9	1.9	35
Shipping						
Pallets	2.5	8				
Other	2.1	7				
Total Shipping	4.6	15				
Miscellaneous Uses	6.45	21	2.1	32	0.6	11
Total	30.75	100	6.7	100	5.4	100

[a]Based on data from Timber Outlook (USDA Forest Service, 1974) and Phelps and Hair (1974). Except for building board totals, tonnages are approximations from data reported in other units.

[b]Includes particleboard, hardboard, and insulation board.

[c]Oven-dry tons.

version of these materials into engineered building components.

Basic primary structural materials manufactured from wood are lumber, which is sawn or shaped from the log, and rigid panels, fabricated by reducing wood to veneer, particles, flakes, strands, or fibers which are, in turn, reconstituted into thin sheets by pressing between heated platens, usually in combination with an adhesive. Sheets thus formed are broadly classified as plywood—fabricated from veneer—and building board that consists of an array of sheet products under generic classifications including particleboard, flakeboard, hardboard, and insulation board.

Lumber and panels suitable for building materials are used in a wide spectrum of secondary products other than structures which are not specifically included in this analysis. In 1970, 12% of all lumber, 9% of all plywood, and 35% of all building board was used in the manufacture of secondary products such as furniture, boats, truck bodies, and innumerable other items (Table 1). Of the secondary products using substantial quantities of primary structural materials, furniture manufactured in 1970 ac-

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FIG. 1. Softwood (upper) and hardwood (lower) materials flow trajectories for 1970.

Based essentially on data provided in the Outlook Study (USDA Forest Service 1974). Conversion of cu ft to tons (OD) has been through multiplication by 0.0137 for softwoods and by 0.0164 for hardwoods. Except for those shown in the four "boxes" for growing stock, all values include bark. Tonnages shown in these "boxes" for growing stock in 1970 should be increased by 10% to allow for (include) bark. Data on growth and removal reflect current inventory standards. Complete tree utilization, according to Keays (1971), would permit a commodity removal increase of 35% from the same growing stock, a net increase of 35.29 million tons after deduction of current logging residues from growing stock.

TABLE 2. *Demand for domestic roundwood and by-products for manufacture of wood-based commodities in 1970*

WOOD REQUIREMENT

COMMODITY	1970 MM O.D. TONS FROM ROUNDWOOD	1970 MM O.D. TONS FROM BY-PRODUCT
STRUCTURAL		
1. SOFTWOOD LUMBER	73.41	2.6
2. SOFTWOOD PLYWOOD	15.08	
3. HARDWOOD LUMBER	24.51	
4. HARDWOOD PLYWOOD	2.28	
5. PARTICLEBOARD		2.4
6. MEDIUM DENSITY FIBERBOARD	.18	.2
7. INSULATION BOARD		1.2
8. WET-FORMED HARDBOARD		1.1
9. STRUCTURAL FLAKEBOARD # 1		
10. STRUCTURAL FLAKEBOARD# 2 (RCW)		
11. LAMINATED-VENEER LUMBER		
FIBROUS		
12. PAPER AND PAPERBOARD	61.30	24.5
MISCELLANEOUS		
13. MISCELLANEOUS INDUSTRIAL AND FUELWOOD	16.62	
TOTAL	193.38	31.9

counted for 7% of all lumber, 5% of all plywood, 34% of all particleboard, and 17% of all hardwood. Since 1970 the proportion of particleboard consumed in furniture and allied products has increased. Currently, approximately 60% of the rapidly expanding production of particleboard is used in furniture and allied products with the remaining 40% being used in construction. Importantly, a very high percentage of the lumber used in furniture manufacture is hardwood, which currently has limited utility for structural and architectural applications.

Of particular significance, from the standpoint of hardwood utilization, is the demand for wood to be used in shipping in the form of wood containers, dunnage, blocking and bracing and, most importantly, pallets. Since the early 1960s the increase in wood used in shipping, approximately 15% of all lumber manufactured, has been largely attributable to the increased demand for pallets. Substantial increases in pallet consumption are projected in relation to growth in industrial production (Cliff 1973).

Sawn mainline railroad ties, which are in

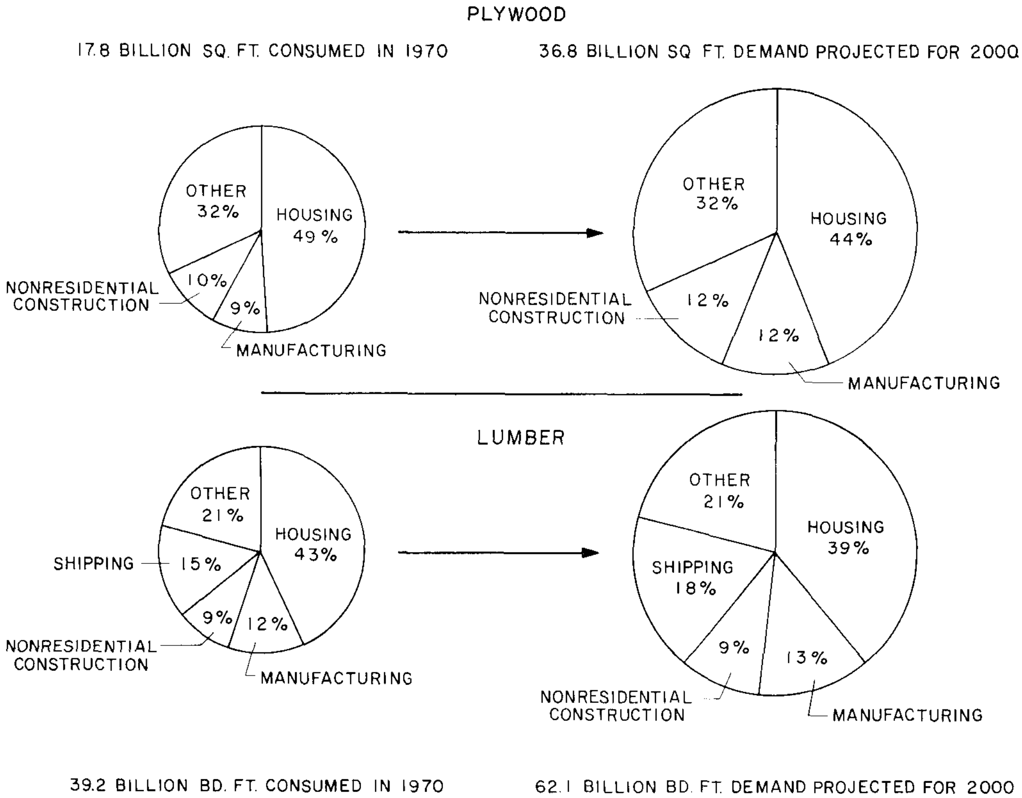


FIG. 2. Major uses of plywood and lumber: 1970–2000. From Cliff (1973).

short supply, provide another important use for hardwoods of limited value for other purposes. Of more than one billion crossties supporting some 350,000 miles of railroad track in the United States today, many have been in place longer than their expected life; additionally, increased axle loads are accelerating mechanical deterioration of ties in place. The rate of crosstie replacement until the end of the century will be predictably high. Low-grade hardwoods in solid or laminated form are well suited to this need (Howe and Koch 1976).

Piling, poles, posts, and mine timbers, which are largely roundwood, constitute a significant tonnage of structural products. Important among these are piling, for which 28.8 million linear feet of roundwood was required in 1970, and poles, of which 5.4 million were used during the same year.

Table 2 summarizes product use of the 1970 timber harvest by categories; i.e., specific structural commodities, paper and paperboard, and miscellaneous industrial and fuelwood. In total, 193 million tons of roundwood were converted to these commodities and equate to the commodity harvest from U.S. forests in 1970. In the processing of this roundwood, substantial tonnages of residue were generated, of which 32 million tons of chips, shavings, sawdust, and bark were additionally converted to commodities (Table 2).

Of the wide spectrum of uses of lumber and rigid panels, residential and nonresidential light construction stand out as being, to a very substantial degree, the most important. As previously indicated in Table 1, 52% of all lumber, 59% of all plywood, and 54% of all building board were consumed in construction in 1970. For each of these commodities, approximately 10%

of the total volume of the product used was for nonresidential construction. The demand for housing is projected to remain high through the year 2000 (Cliff 1973). Importantly, the wood-based primary structural products required for housing are also projected to remain high (Fig. 2). A continuing high percentage of lumber and plywood, which accounted for approximately three-quarters of the tonnage of primary structural products produced from wood in 1970, is projected to be used in housing until the year 2000 (Cliff 1973).

ANALYSIS OF MATERIALS USED IN RESIDENTIAL AND LIGHT-FRAME CONSTRUCTION

Panel II of CORRIM was concerned with the use of renewable resources for structural purposes and for obvious reasons focused its attention on wood versus steel, aluminum, concrete, brick, and petrochemical derivatives. Our charge was to examine the situation as of 1970 and to project Scenarios for 1985 and 2000 based on a variety of assumptions.

Because of the importance of residential and light industrial construction to the total demand for wood products, and because this also constitutes a substantial and attractive potential market for commodities manufactured from nonrenewable resources, this use was selected for the purpose of this study as an example from which to evaluate wood as a structural and architectural material. Representative designs of floor, wall, and roof constructions that were in use in 1970 or that are feasible in the foreseeable future were chosen for study. Wood-based and alternative structural materials incorporated in these designs were analyzed from the standpoints of energy, manpower, and capital requirements from the point of extraction of the raw material to erection on the building site. Changing manufacturing technologies resulting from changes in the forest resource, together with accompanying research and development needs, were considered.

Primary materials and their use in building components

Twelve primary materials fabricated from the forest resource were selected for study. Of these, eight which encompass a high percentage of all primary structural and architectural materials manufactured from wood are:

1. Softwood lumber
2. Hardwood lumber
3. Softwood plywood
4. Hardwood plywood
5. Underlayment particleboard
6. Medium-density fiberboard
7. Wet-formed insulation board
8. Wet-formed hardboard.

The remaining four, (1) structural flakeboard, (2) reconstituted structural board, (3) structural particleboard, and (4) lumber-laminated-from-veneer are technologically feasible and can be expected to be in production in the foreseeable future. For each of these primary products—with three options in the case of structural particleboard—a materials-flow trajectory was developed on the basis of one oven-dry ton of entering raw material. A trajectory was also developed for the conversion of pulpwood to chips. These materials-flow trajectories, conforming to the RMS concept used throughout the study, appear as Figures 3–17. All materials-flow trajectories were developed for manufacturing operations designed to maximize the output of the primary product under consideration. They are based on averages attained in efficient manufacturing plants with data supplied by knowledgeable industrial sources. Product and by-product yields are summarized in Table 3.

On the basis of information from the materials-flow trajectories, man-hours, energy in the form of mechanical horsepower and pounds of steam, and capital depreciation for the operation of the manufacturing facility were prorated among the output products (except for the reconstituted structural board described in Fig. 12, which was not further analyzed). For the most part—but

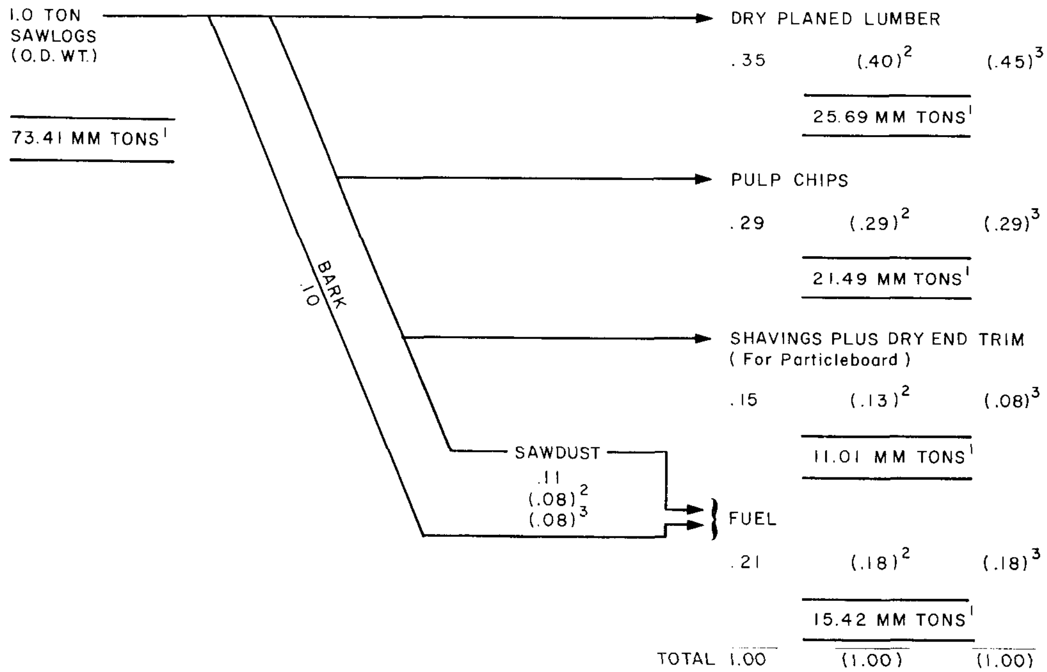
TABLE 3. *Materials balance summaries for wood-based commodities (Based on one oven-dry ton input of forest-based raw material, 1970)*

		Recovery (Oven-Dry Ton)					
Principal Product	Input Raw Material	Principal Product	Lumber	Pulp Chips	Fuel	Solubles and Volatiles	Other
Wet-Formed Insulation Board[a]	1/2 bark-free chips 1/2 forest residual chips	1.04			0.05	0.10	
Underlayment Particleboard[b]	Dry mill residue	.98			.11		
Wet-Formed Primary Hardboard[c]	1/2 bark-free chips 1/2 forest residual chips	.87			.05	.10	
Medium-Density Fiberboard[d]	1/2 roundwood 1/2 bark-free chips	.86			.17	.06	
Reconstituted Structural Board[e]	Barky logs	.64			.40		
Lumber Laminated from Veneer[f]	Barky logs	.47	Studs .06	.29	.12		Particleboard furnish .07
Softwood Plywood (unsanded)[g]	Barky logs	.45	Studs .06	.30	.12		Particleboard furnish .08
Structural Flakeboard[h]	Barky logs	.35	.45		.22		
Softwood Lumber	Barky logs	.35		.29	.21		Particleboard furnish .15
Hardwood Plywood (sanded)[i]	Barky logs	.30		.48	.23		
Hardwood Lumber	Barky logs	.28		.29	.23		Particleboard and medium-density fiberboard furnish .20

a .19 ton starch, wax, and asphalt added raw materials. Mechanical pulping assumed.
b .087 ton adhesive and wax added.
c .02 ton adhesive and wax added. Mechanical pulping assumed.
d .09 ton adhesive and wax added. Mechanical pulping assumed.
e .03 ton adhesive and wax added.
f .01 ton adhesive added.
g .01 ton adhesive added.
h .024 ton resin and wax added to flakeboard component - assumes use of shaping lathe headrig.
i .01 ton adhesive added.

not in all cases—proration was based on the weight of each product. Input requirements are considered reasonable averages for efficient manufacturing plants and were derived from manufacturers and knowledgeable industrial sources. Table 4 illustrates the assignment of man-hours, energy, and capital depreciation to the principal and residual products of a softwood lumber mill. Comparable data for each of the commodities studied are tabulated in Appendix I together with explanatory footnotes. Table I-13 summarizes these data.

Requirements for man-hours, energy, and depreciated capital were developed for harvesting and transport from stump to mill for the raw material supplied to the manufacturing plant on the basis of one oven-dry



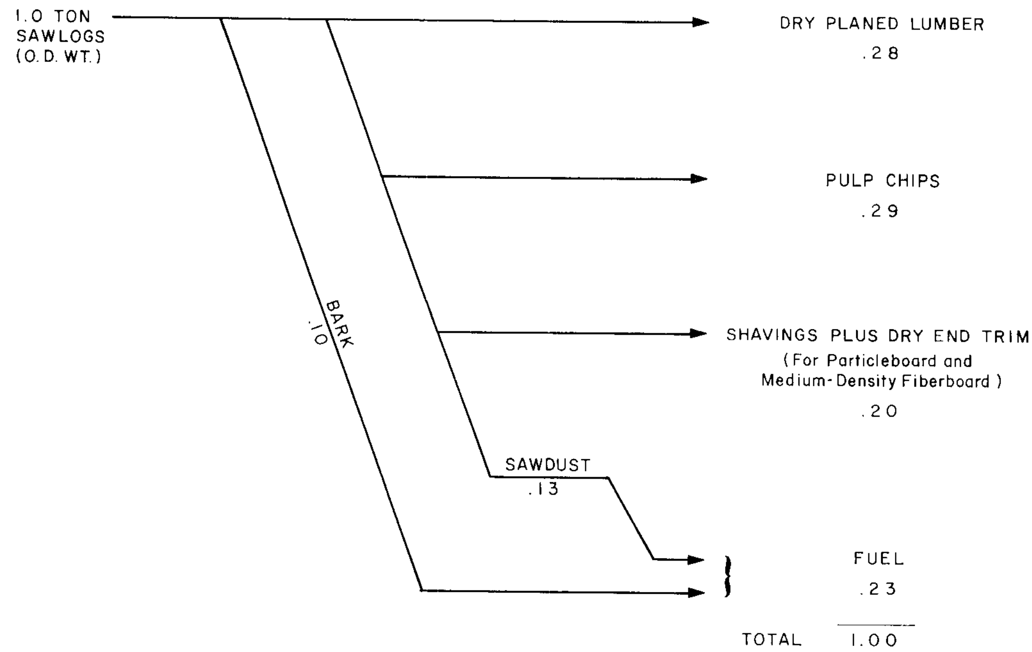
[1] Tonnage from softwood materials flow trajectory for the U.S. forest resource, 1970
[2] Predicted product and by-product recovery, 1985
[3] Predicted product and by-product recovery, 2000

FIG. 3. Materials balance for softwood lumber based on oven-dry (OD) weight. Sawlog weight includes bark.

ton of mill input raw material. These data include requirements for harvest planning and layout, road construction and maintenance, equipment and its maintenance, supervision and support functions, harvesting, and stump-to-mill transport. For those primary products using input raw materials other than roundwood—e.g., chips, flakes, or particles—the manpower, energy, and capital assigned to preparation of the feed stock were included. Harvesting data were derived primarily on the basis of southern and west coast operations, but are considered representative of the nation at large because of the heavy concentrations of forests and industries in these two areas. The detailed data are tabulated in Appendix II and summarized in Table II-5.

Transportation modes and distances for wood-based commodities from the manufacturing plant to the retail lumber yard, together with manpower, energy, and capital requirements, were developed on the basis of statistics assembled by manufacturing and transportation associations and from information derived from manufacturing industries. Information on transport from the retail yard to building site was based on data supplied by a geographically widely dispersed sample of retail distributors of building products. Erection data were provided by the National Association of Home Builders. Supporting data are tabulated in Appendix III (Tables III-4, III-5, and III-7, III-8, III-11, III-14, and III-15).

Data comparable to those assembled for wood-based structural and architectural products were developed for alternative building materials manufactured from nonrenewable resources (Table III-6). This in-



[1] Based on analysis of manufacture of oak flooring.

FIG. 4. Materials balance for hardwood lumber based on oven-dry (OD) weight. Sawlog weight includes bark.[1]

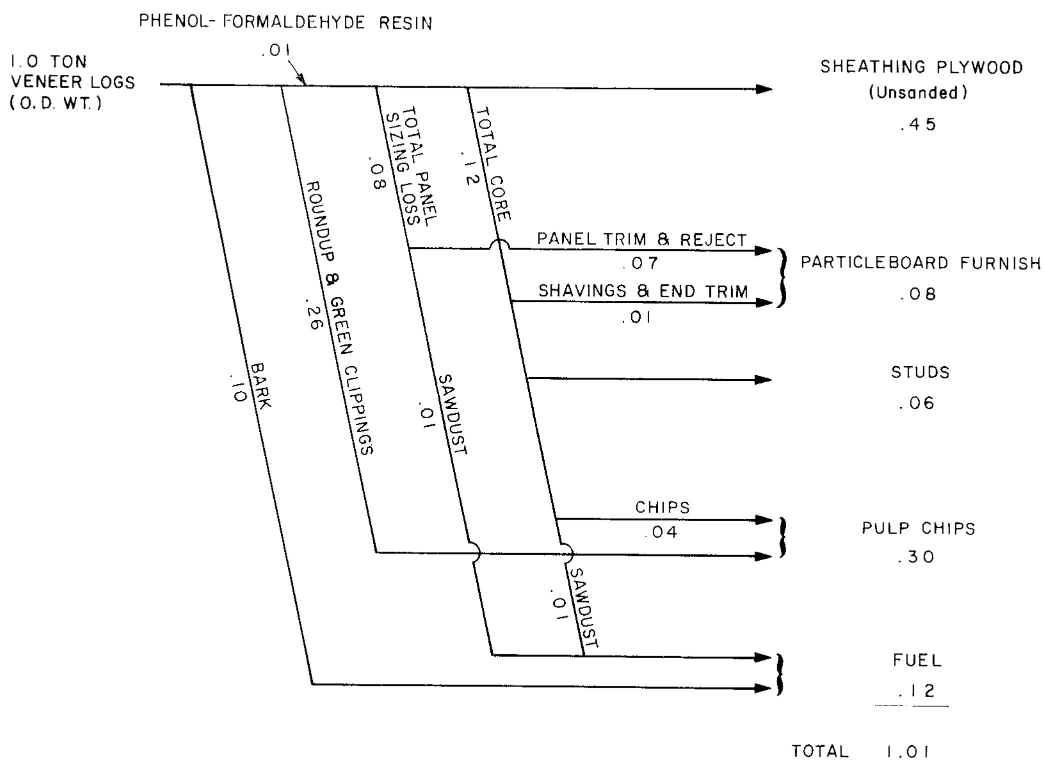


FIG. 5. Materials balance for softwood plywood (unsanded) based on oven-dry (OD) weight. Veneer log weight includes bark.

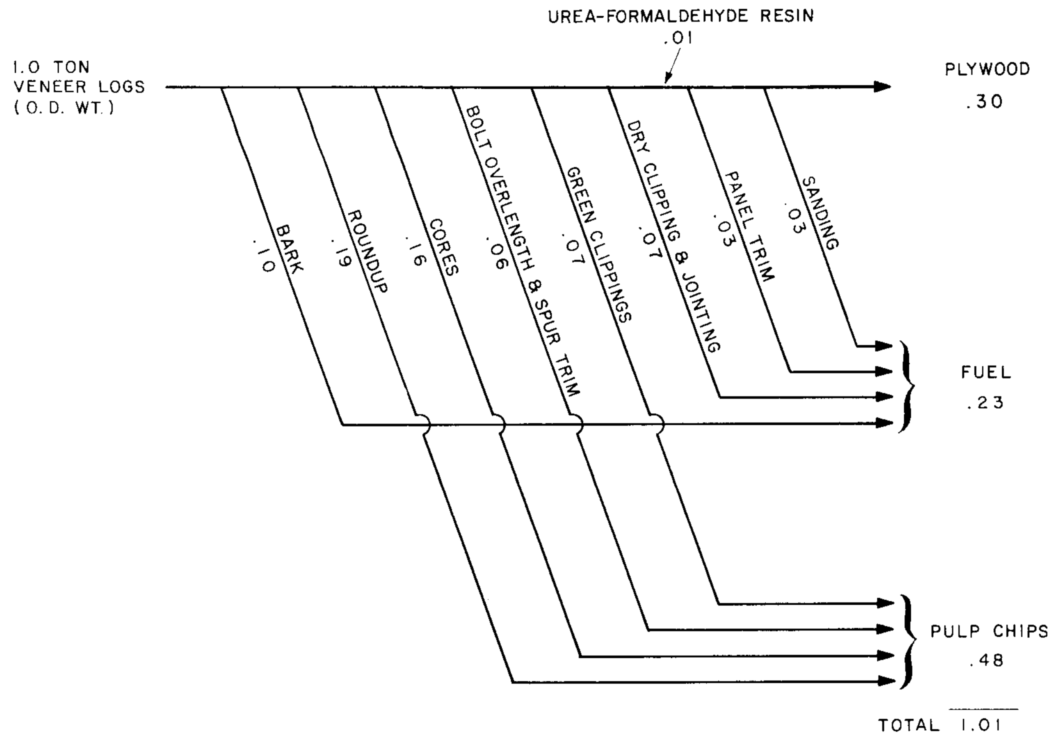


FIG. 6. Materials balance for hardwood plywood (interior paneling) based on oven-dry (OD) weight. Veneer log weight includes bark.

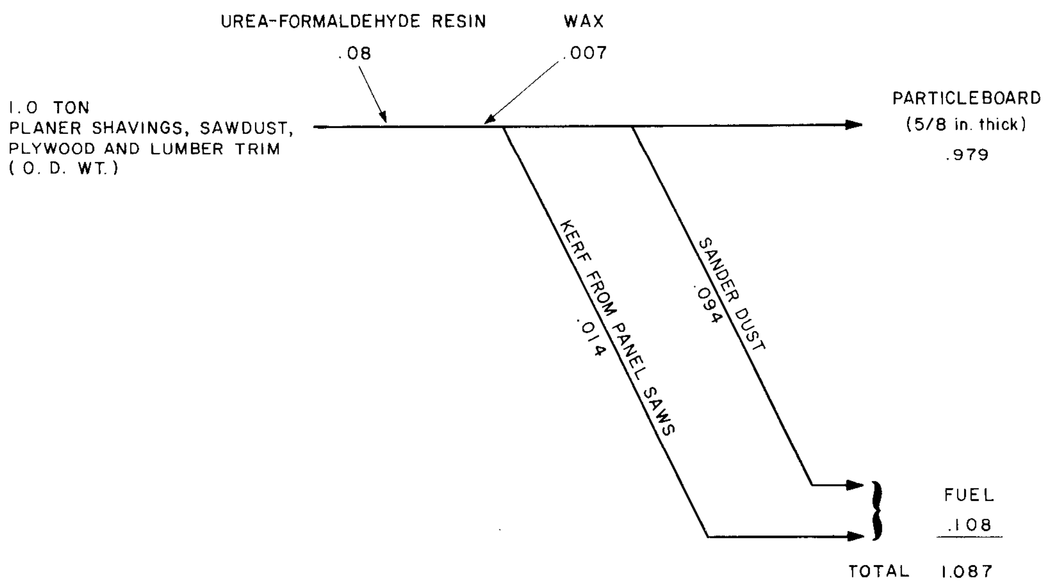
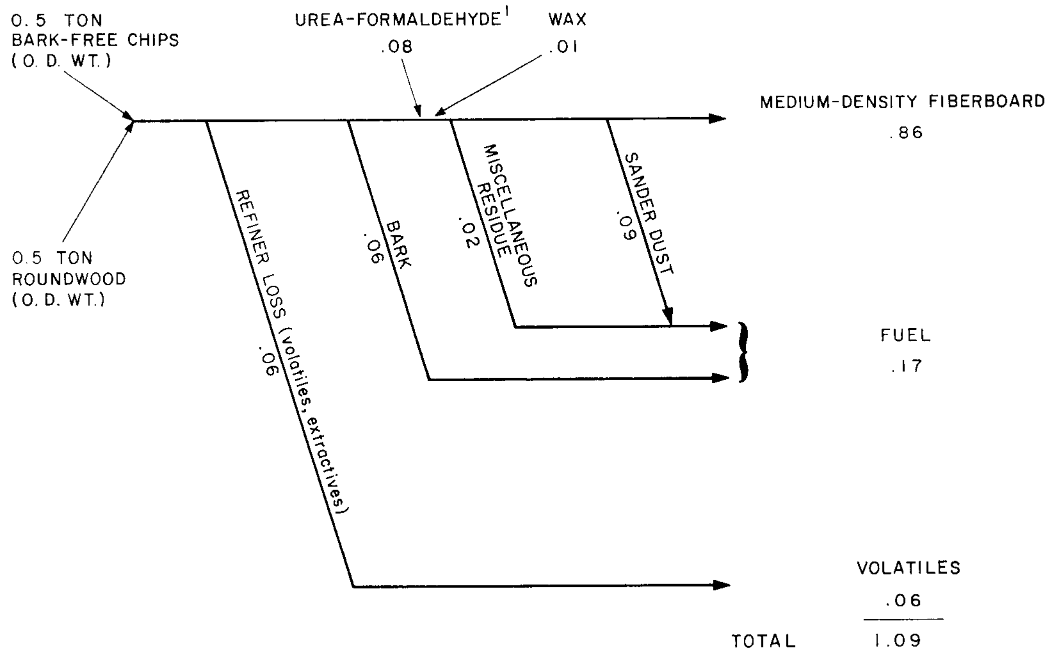
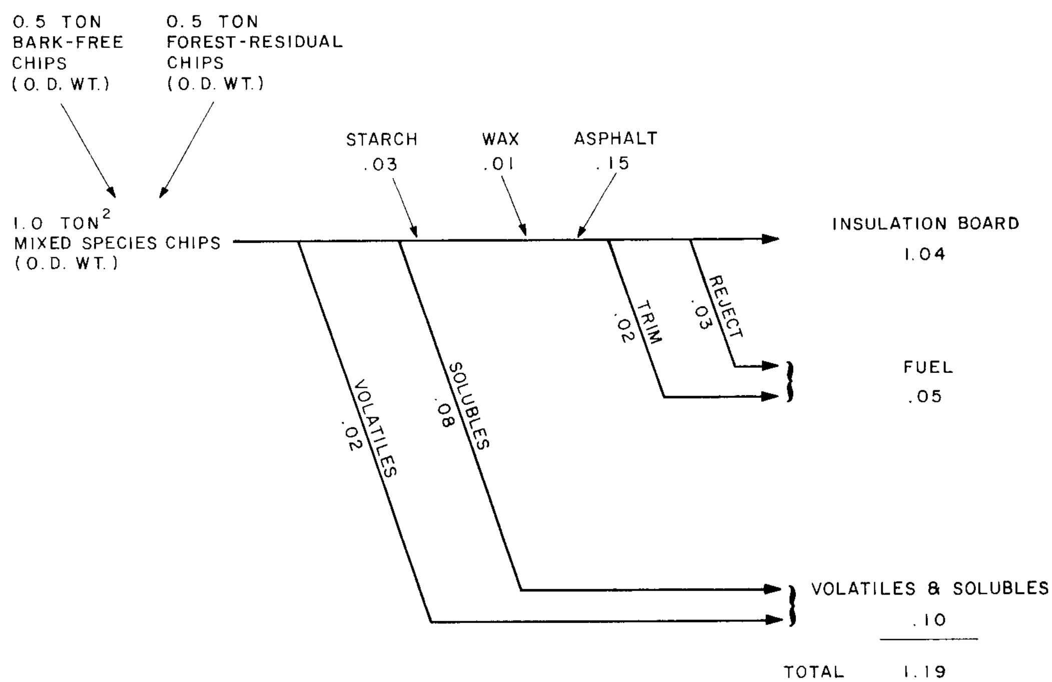


FIG. 7. Materials balance for underlayment particleboard based on oven-dry (OD) weight.



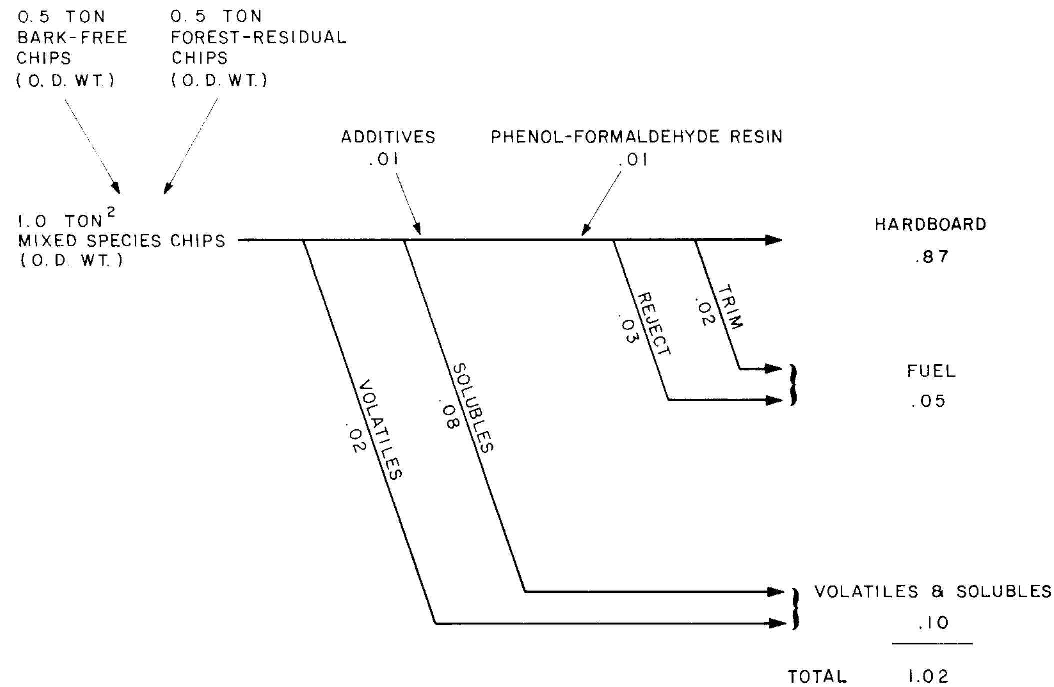
[1] For siding and other exterior uses, phenol-formaldehyde is used in place of urea-formaldehyde.

FIG. 8. Materials balance for medium-density fiberboard based on oven-dry (OD) weight. Assumes a mechanical pulping process with steam pretreatment.



[1] Assumes a mechanical pulping process with steam pretreatment (Bauer, Asplund Defibrator).
[2] No more than 5 percent bark.

FIG. 9. Materials balance for wet-formed insulation board based on oven-dry (OD) weight. Forest residual chips assumed to contain 10 percent bark.[1]



[1] Assumes a mechanical pulping process with steam pretreatment (Bauer, Asplund Defibrator).
[2] No more than 5 percent bark.

FIG. 10. Materials balance for wet-formed hardboard based on oven-dry (OD) weight. Forest residual chips assumed to contain 10 percent bark.[1]

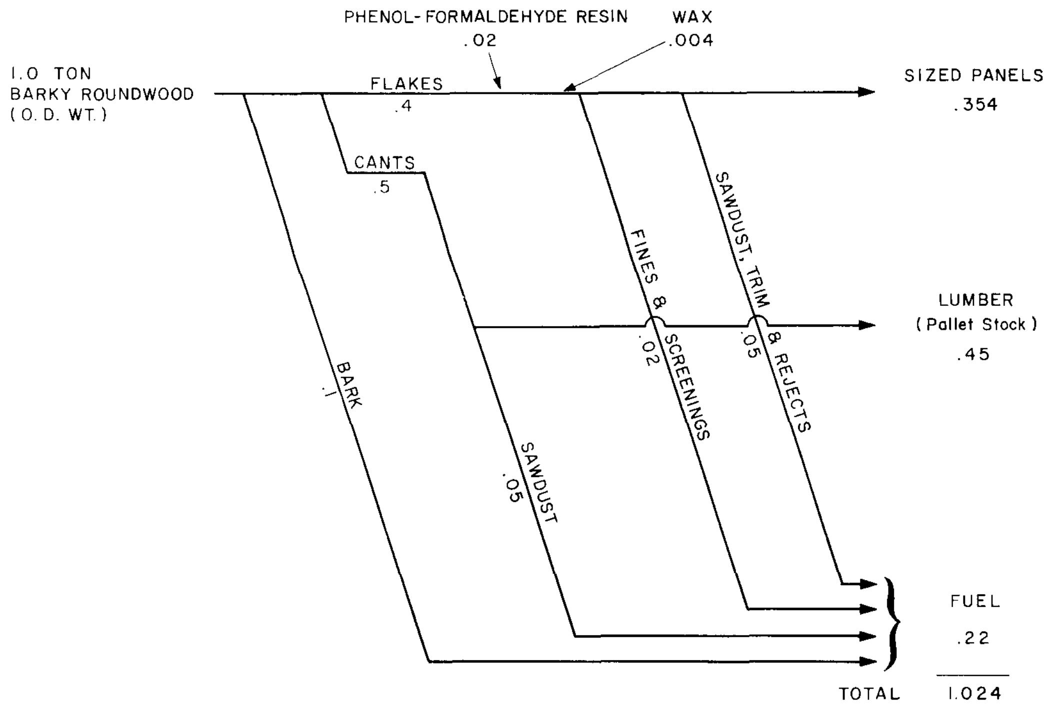
formation was computed from census data or extracted from the Brookhaven National Laboratory Data Bank. Distribution of nonwood building materials from the retailer to the building site was assumed to be similar to that of wood-based materials.

Summarizing the results of these surveys, analyses, and computations of costs of extraction, manufacture, and transportation to building site for a wide array of wood-based and nonwood-based commodities—in terms of manpower, capital depreciation, and energy—are Tables 5 (man-hours), 6 (capital depreciation), and 7 (energy). All values are based on one ton of commodity.

The data presented in Table 7 require some explanation. For wood-based commodities, energy expended in logging consists of diesel fuel and gasoline for all forest activities. Manufacturing energy consists of two parts, mechanical (electric) and process heat; energy consumed in the manufacture of additives such as resin and wax has been included in these totals. Transport energy encompasses diesel fuel and gasoline expended in shipping commodities from mill to building site.

To achieve a uniform mode of expressing energy consumed and available from residues, we have used the unit *million BTU thermal (oil)*. For example, a gallon of diesel fuel contains 138,336 BTU or 0.138 million BTU thermal (oil). A mechanical horsepower-hour was assumed equivalent to $7{,}825/10^6$ million BTU thermal (oil); this equivalency is based on the assumption that oil can be converted to mechanical power with about 32.5% efficiency. A pound of process steam was assumed to contain 1,200 BTU which, if generated with an oil-fired boiler at 82.5% efficiency, would require about $1{,}455/10^6$ million BTU thermal (oil).

In computing energy credits for manu-



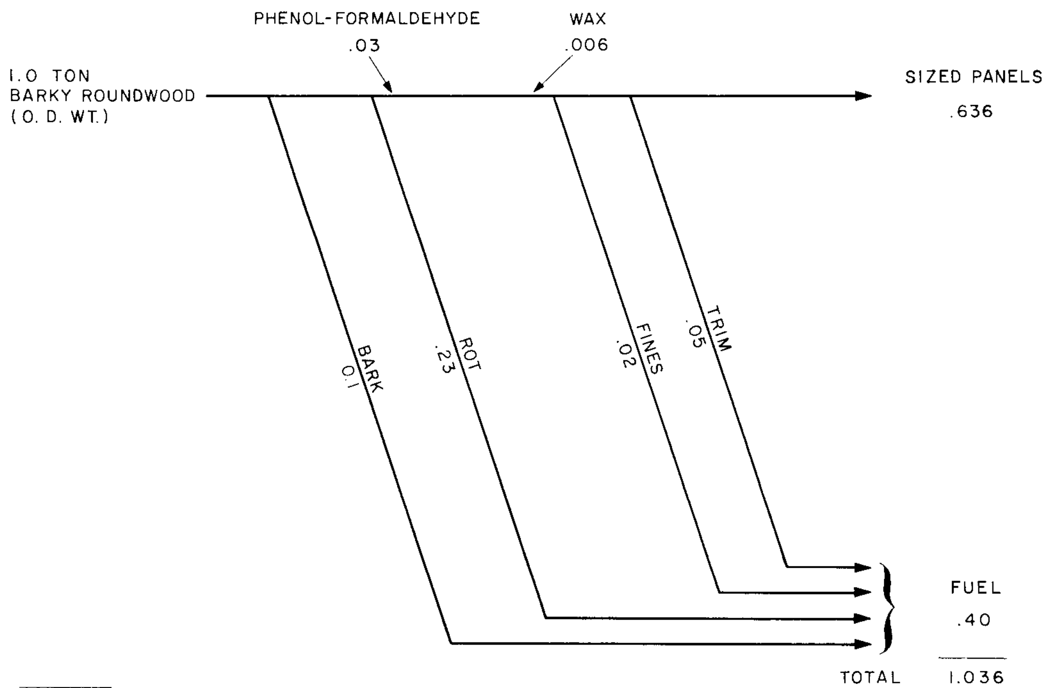
[1] Not in production in 1970. Information from U.S.D.A. Forest Service, Southern Forest Experiment Station.

FIG. 11. Materials balance for structural flakeboard[1] based on oven-dry (OD) weight. (Assumes use of shaping-lathe headrig.)

facturing residuals (e.g., green bark and sawdust), we have assumed that exhaust steam from turbines or steam engines will be used for process steam. Thus, a non-condensing turbine connected to an AC generator should consume about 16.3 pounds of high-pressure steam to deliver one brake horsepower-hour of mechanical work. The 16.3 pounds of spent steam at low pressure are then available for process heat. It has additionally been assumed that 1 pound of green bark (half water by weight) will generate about 2.6 pounds of high-pressure steam.

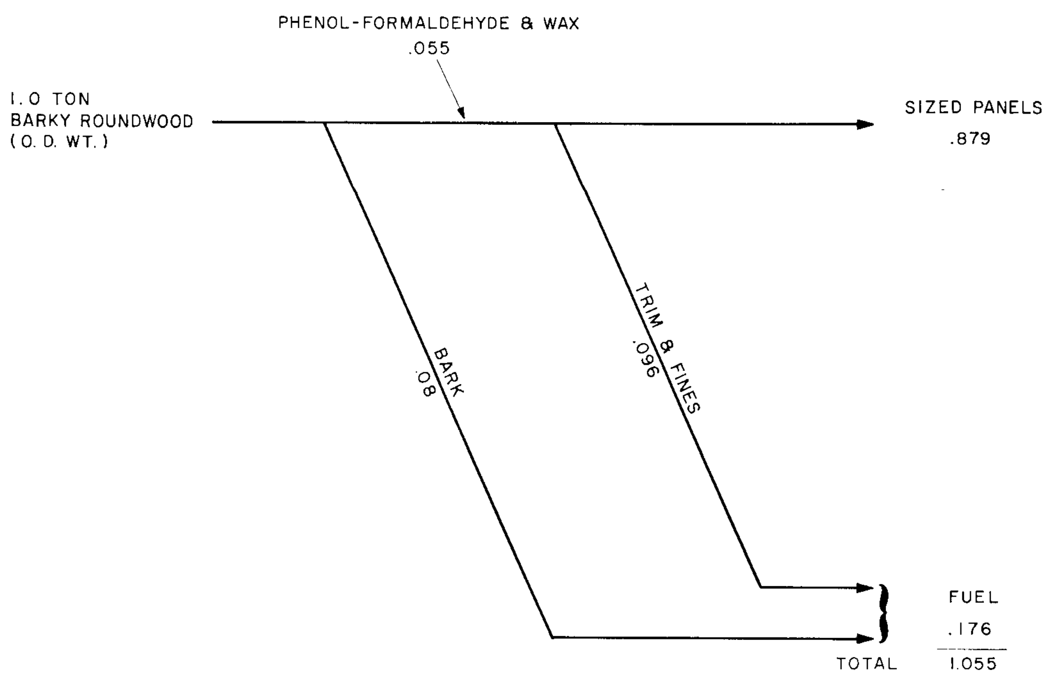
Net total energy represents supplementary energy needs after deducting energy available through fuel use of residues from gross manufacturing energy. For example, net energy required for softwood lumber was calculated as 0.943 (logging) + 4.846 (gross manufacture) − 4.846 (maximum allowable from residue) + 1.966 (transport) = 2.909 (net total) million BTU (oil equivalent) per OD ton.

To provide a base for comparison between alternative structures, designs were developed for four roof, eight exterior wall, three interior wall, and six floor constructions. This array includes the most important designs of these components in use today and, additionally, several feasible designs which are not yet commonly used. The designs were selected to provide a realistic comparison between the use of wood-based components and alternative materials. Sections with an area of 100 square feet were selected for analysis in order to provide easy comparison, and to eliminate the effect of door and window openings. Weights of materials required for each 100-square-foot section were calculated.



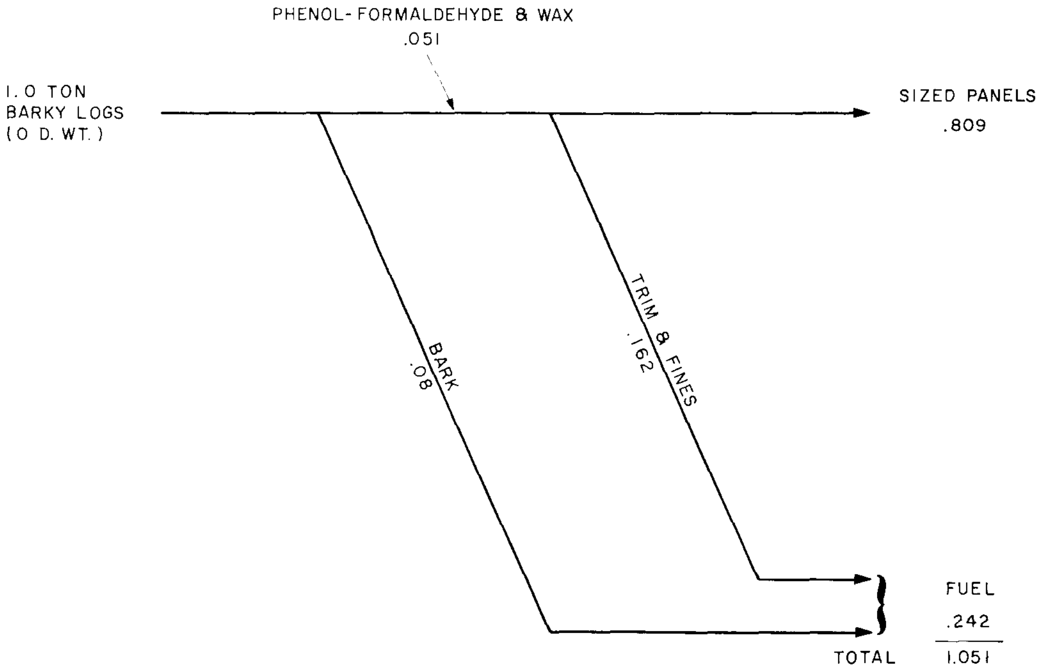
[1] Not in production 1970. Information from industrial source.

FIG. 12. Materials balance for reconstituted structural wood based on oven-dry (OD) weight—whole log flaking of wood with substantial rot.[1]



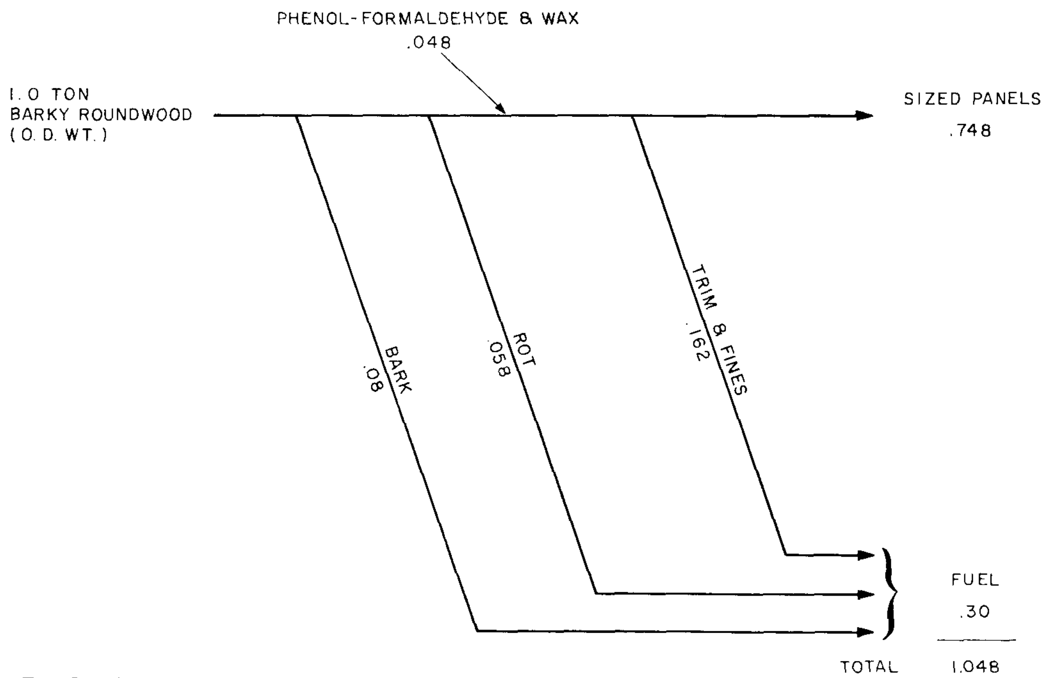
[1] Not in production 1970. Information from National Particleboard Association.

FIG. 13. Materials balance for structural particleboard based on oven-dry (OD) weight—whole log flaking of sound wood.[1]



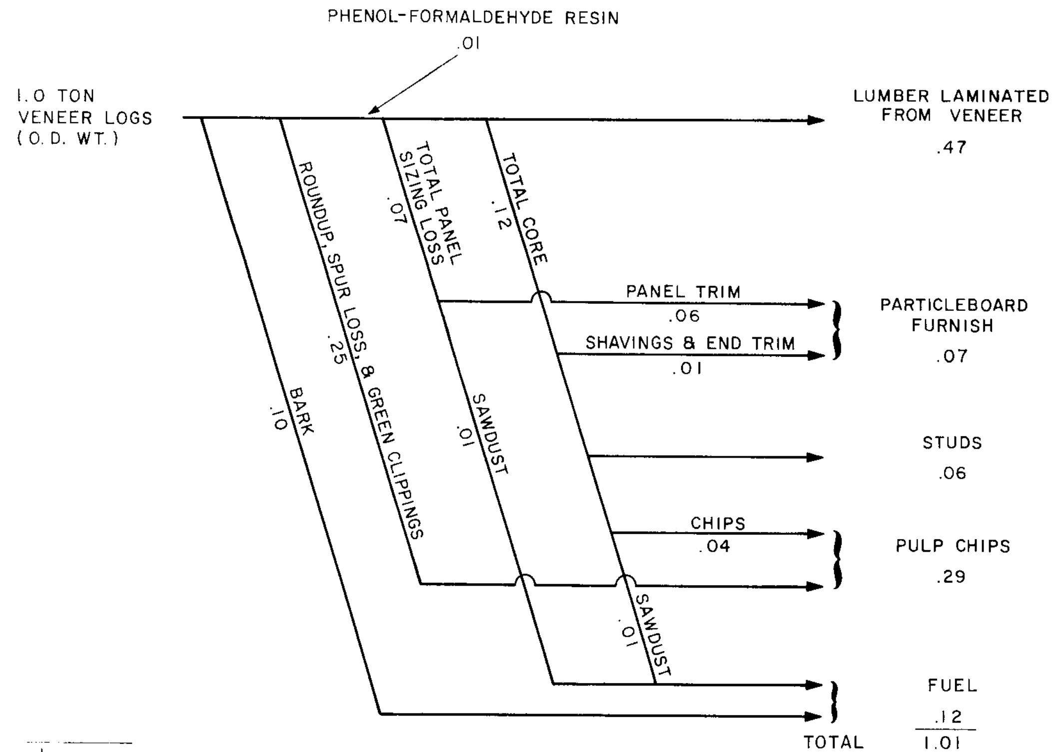
[1] Not in production 1970. Information from National Particleboard Association.

FIG. 14. Materials balance for structural particleboard based on oven-dry (OD) weight—chipping and flaking sound wood.[1]



[1] Not in production 1970. Information from National Particleboard Association.

FIG. 15. Materials balance for structural particleboard based on oven-dry (OD) weight—chipping and flaking wood with some rot.[1]



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

FIG. 16. Materials balance for dimension lumber laminated from ¼-inch softwood veneer based on oven-dry (OD) weight. Veneer log weight includes bark.[1]

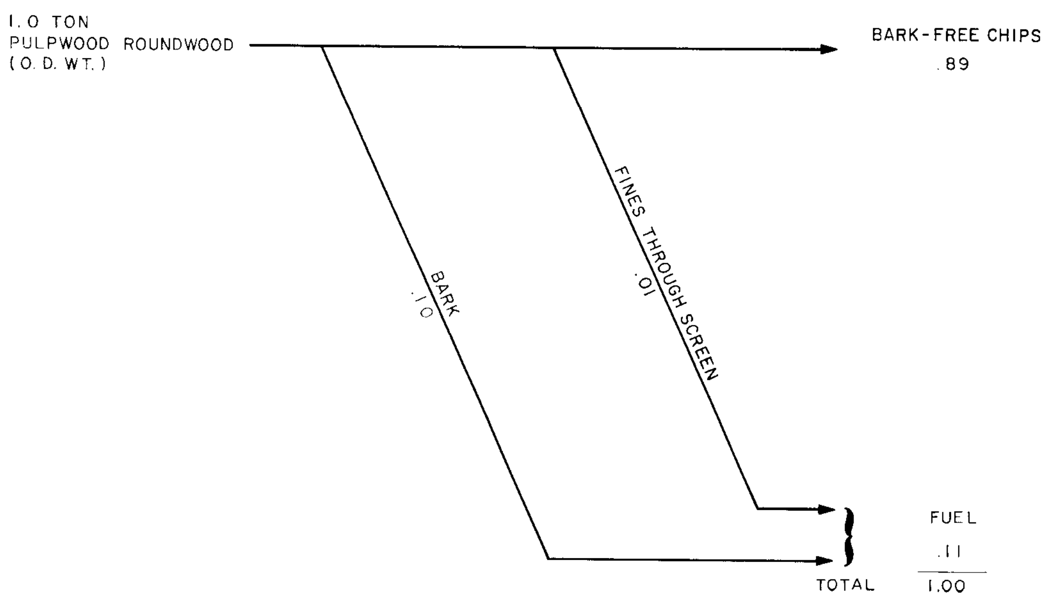


FIG. 17. Materials balance for softwood pulp chips from chip mill with debarker based on oven-dry (OD) weight. Roundwood weight includes bark.

TABLE 4. *Requirements for manpower, energy, and capital depreciation in the manufacture of softwood lumber (Based on 1.0 ton oven-dry (OD) weight input of barky logs - 1970)*

Product	Manpower	Mechanical Energy	Steam Energy	Depreciation of Capital Facilities
OD Tons	*Man-Hours*	*HP-Hours*	*Pounds*	*Dollars*
Dry Planed Lumber 0.35	0.67	21.98	977	0.86
Pulp Chips 0.29	0.56	18.21	0	0.70
Particle-board Furnish 0.15	0.29	9.42	419	0.36
Fuel 0.21	0.40	13.19	0	0.51
1.00	1.92	62.80	1396	2.43

Descriptions of floor, roof, and wall constructions[3]:

Floors

1. Wood joists (2 × 10 inch, 16 inches on center); plywood subfloor (½ inch); particleboard underlayment (⅝ inch); carpet and pad. Total weight—0.312 ton
2. Wood joists (2 × 10 inch, 24 inches on center); plywood subfloor (¾ inch); oak strip flooring. Total weight—0.293 ton
3. Wood joists (2 × 10 inch, 16 inches on center; plywood combination subfloor underlayment (⅝ inch); carpet and pad. Total weight—0.260 ton
4. Concrete slab (4 inches thick on 6-inch gravel base); vapor barrier; carpet and pad. Total weight—4.860 tons
5. Steel joists ("C" section, 48 inches on center); plywood subfloor (1⅛ inches); carpet and pad. Total weight 0.614 ton
6. Lumber-laminated-from-veneer joists (1.5 × 7.5 inches, 16 inches on center); structural flakeboard subfloor (⅝ inch); carpet and pad. Total weight—0.260 ton

Exterior walls[4]

1. Plywood siding (⅝ inch) without sheathing. Total weight—0.290 ton
2. Medium-density fiberboard siding (½ inch); plywood sheathing (⅜ inch). Total weight—0.342 ton
3. Medium-density fiberboard siding (½ inch); insulation-board sheathing (½ inch) with plywood (½ inch) corner bracing. Total weight—0.377 ton
4. Concrete block without additional siding or insulation. Total weight—1.999 tons
5. Aluminum siding (0.02 inch); insulation board sheathing (½ inch). Total weight—0.265 ton
6. Medium-density fiberboard siding (½ inch); steel framing; insulation board sheathing (½ inch) with plywood (½ inch) corner bracing. Total weight—0.323 ton
7. Aluminum framing with siding and sheathing as in number 6. Total weight—0.293 ton
8. Brick siding; insulation board sheathing (½ inch) with plywood (½ inch) corner bracing. Total weight—2.01 tons

Interior walls[5]

1. Wood framing (2 × 3 inches, nominal). Total weight—0.311 ton
2. Aluminum framing. Total weight—0.217 ton
3. Steel framing. Total weight—0.231 ton

[3] Oven-dry weights of individual components in each design are shown in Appendix III-1.

[4] All walls except numbers 4, 6, and 7 are standard framed walls with 2- × 4-inch (nominal) studs, 24 inches on center; with top and bottom plates; building paper, and gypsum board interior panels. All constructions are nailed. With the exception of number 4, all walls contain 2-inch mineral wool insulation batts which conformed to building standards in the base year (1970).

[5] All interior walls are with ½-inch gypsum board on both sides, and nonload-bearing framing on 24-inch centers.

TABLE 5. *Man-hour requirements for extraction, manufacture, and transport to building site of primary commodities*[a]

Wood-Based Commodities	Logging or Extraction	Manufacture	Transport (Mill to Bldg. Site)	Total
	Man-Hours per Oven-Dry Ton			
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
Nonwood-Based Commodities	*Man-Hours per Ton*			
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.

Roofs[6]

1. Pitched roof with W-type wood trusses; plywood sheathing (½ inch); roofing felt and wood shingles. Total weight—0.429 ton
2. Same as number 1 but with asphalt shingles. Total weight—0.493 ton
3. Flat roof with steel rafters ("C" section, 7¼ inches in depth); plywood sheathing (½ inch), built-up roofing (⅜ inch). Total weight—0.410 ton
4. Flat roof with lumber-laminated-from-veneer rafters; structural flakeboard sheathing (½ inch); built-up roofing (⅜ inch). Total weight—0.449 ton

For each composite 100-square-foot section, requirements for man-hours, capital depreciation, and energy from material source to building site were computed for

[6] All roofs are with ½-inch gypsum ceilings; 3½-inch mineral wool insulation; nailed construction, and framing members 24 inches on center.

TABLE 6. *Capital depreciation requirements for primary commodities*

Wood-Based Commodities	Extraction	Manufacturing	Transport	Total
	Dollars per Oven-Dry Ton			
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
Nonwood-Based Commodities	*Dollars per Ton*			
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	413.83	30.80	480.43
Percent of Total	8	86	6	
Mean	2.24	25.86	1.93	30.03

all materials in the design. These data provide a basis for assessing the energy, manpower, and capital cost effectiveness of alternative designs incorporating both wood and nonwood materials and for analyzing the contribution of the various components within a given design to the total requirements for manpower, energy, and capital.

The data on which this study is based are the best available within the time frame and resource limitations of this study. It is felt that they are adequate for the purpose of drawing meaningful comparisons and conclusions. It must be recognized, however, that many data lack precision and that all are averages of a highly variable base. Wood-processing industries are characterized by excessive variability in operating efficiency both within and between geographic regions. In many processing plants throughout the country, material that is residual to the primary product has limited or no utilization. Equipment is frequently obsolete and management support is often inadequate. Materials-flow trajectories and manpower, capital, and energy requirements derived from them are considered representative of efficiently operated plants in areas in which the primary processing

TABLE 7. *Energy requirements for extraction, manufacture, and transport to building site of primary commodities*

Wood-Based Commodities	Gross Manufacture					Available	
	Logging	Electric	Heat	Transport	Gross Total	Residue Energy	Net Total[a]
	- - - - - - *Million BTU (Oil Equivalent) per O D Ton* - - -						
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	5.192	7.64

Non-Woodbased 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.

industries are integrated. The data are representative of those processing plants that are economically viable and from which a significant percentage of primary structural and architectural materials flow, and may be considered characteristic of progressive processing plants throughout the United States.

TABLE 8. *Summary of requirements for residential construction including logging (or extraction), manufacture, transport to house site, and erection (Per 100-square-foot section)*

	Manpower	Net Energy[a]	Capital Depreciation
	Man-Hours	*Million BTU*	*Dollars*
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.

Flow of materials in primary processing

Not surprisingly, the panel products reconstituted from fibers that are mechanically derived largely from chips—and underlayment particleboard that is reconstituted from mechanically reduced dry mill residue—show the highest percentages of principal product recovery (Table 3). Also to be noted is that the residue from these principal products does not provide raw material for other manufactured products. Conversely, commodities requiring the greatest tonnage of input material per ton of product—lumber and hardwood plywood—generate in their manufacture substantial quantities of residue suitable for by-product manufacture.

The process selected to illustrate the manufacture of flakeboard is not now in production. The principal product could have with equal validity been considered hardwood lumber. Lumber from that hardwood flakeboard operation would be particularly useful for pallets which are in increasing demand. With the exception of the hardwood flakeboard oper-

TABLE 9. *Some comparisons of requirements for components in 100 square feet of residential construction for alternative designs (From extraction to building site)*

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	0.645
Floor 5	Steel	5.562	10.13	21.134
	Subfloor (Single-Layer)			
Floor 3	Softwood Plywood	0.997	1.63	0.546
Floor 6	Hardwood Flakeboard	1.192	1.99	0.268
Floor 4	Concrete Slab	4.469	5.01	19.849
	Interior Wall Studs			
Interior Wall 1	2 x 3 Lumber	0.423	0.43	0.123
Interior Wall 2	Aluminum	0.376	0.39	1.423
Interior Wall 3	Steel	0.278	0.51	1.056
	Exterior Wall Framing			
Exterior Wall 1,2,3,5	Wood	0.593	0.60	0.172
Exterior Wall 7	Aluminum	0.795	0.80	3.007
Exterior Wall 6	Steel	0.596	1.09	2.264
	Roof Trusses or Rafters			
Roof 1	Lumber (pitched) & Plates	1.111	1.17	0.457
Roof 3	Steel (flat)	0.751	1.37	2.868
Roof 4	LVL (flat)	0.789	1.31	0.426
	Siding			
Exterior Wall 2,3,6,7	1/2-inch Medium-Density Fiberboard	0.728	2.90	0.739
Exterior Wall 5	Aluminum	0.795	0.80	3.007
Exterior Wall 1	5/8-inch Plywood	0.997	1.63	0.546
Exterior Wall 8	Brick, 3-1/4 inch	7.688	4.56	15.932
	Flooring			
Floor 2	Oak, 3/4 inch	1.901	4.09	0.381
Floors 1,3,4,5,6	Carpet	2.752	3.22	1.041
	Sheathing			
Exterior Wall 3,5,6, 7,8	1/2-inch Insulation Board plus Plywood Corners	0.548	1.28	0.483
Exterior Wall 2	Plywood, 3/8 inch	0.603	0.98	0.330

ation (Fig. 11), lumber and plywood recovery from hardwood is considerably lower than that from softwood, reflecting the generally lower quality of hardwood logs.

Man-hour, capital, and energy requirements for primary products

Tables 5, 6, and 7 summarize, for wood-based and nonwood-based primary commodities, man-hour, capital, and energy requirements for extraction of the raw material, manufacture of the product, and transportation to the building site. This provides a basis for comparison within and between products from renewable and nonrenewable resources.

Wood products are, with few exceptions, more homogeneous in man-hour and capital requirements than are the nonwood-based commodities. Without exception, harvesting the forest resource and transporting it to the mill are more demanding in labor than is extraction of nonwood raw materials. Although highly variable, average man-hour and capital requirements for nonrenewable resources exceed those for wood-based materials.

The most notable differences between wood-based and nonwood-based commodities appear in total energy requirements. Commodities based on nonrenewable materials are appreciably more energy-intensive than are their wood-based counterparts. Among the wood-based commodities, wet-formed hardboard is the most energy-intensive[7], but, even so, it is considerably superior to metal and petrochemical-derived building materials in this respect. In a related area, Sarkanen (1976) has noted a similar energy efficiency for paperboard versus synthetic polymers.

A comparison of manpower, energy, and capital requirements for some examples of construction designs

Manpower, energy, and capital depreciation requirements on the basis of 100-square-foot sections for alternative designs of roofs, exterior walls, interior walls, and floors are summarized in Table 8. The man-hour requirements which are tabulated include those involved in erection of the building. Detailed design data for each system are presented in Appendix III. (For erection man-hours for each design, see Tables III-8, III-11, III-14, and III-15.)

The most striking difference between alternative constructions is in energy requirements. In roofs, the design incorporating steel rafters requires approximately twice the energy of the constructions in which wood trusses or rafters are used. Exterior walls sided with brick or constructed with concrete block require seven to eight times the energy of all-wood constructions, and exterior and interior walls incorporating metal require approximately twice the energy of counterpart wood-framed constructions. Floors constructed from wood materials require only approximately ten percent as much energy as the concrete slab construction or that with steel supporting members.

With the exception of wall constructions incorporating concrete block and brick veneer which require two to three times the labor man-hours of wood constructions, manpower requirements do not differ appreciably between designs. No clear pattern emerges from capital requirements. It may be observed, however, that wood constructions in floor systems appear to be approximately one-half as capital-intensive as their nonwood counterparts.

For the purpose of comparison, several alternative components serving major functions in the various designs are summarized in Table 9. Values in this table are for the labor, capital, and energy input of individual components involved in constructing 100 square feet of the indicated design. The most striking fact revealed by this table is the very substantially lower energy requirements for wood versus alternative mineral-based components. Steel floor joists, for example, require approximately 50 times as much energy as do wood counterparts. Aluminum framing for exterior walls is approximately 20 times as energy-intensive as wood framing. Energy required for steel framing is approximately two-thirds that for aluminum. Similarly, aluminum and steel studs for interior walls require, respectively, twelve and eight times the energy of wood studs to perform the same function. Steel rafters exceed wood trusses sevenfold in energy requirements and aluminum siding requires approximately five times the energy of its plywood and fiberboard counterparts. The energy requirement for brick siding is strikingly high—approximately 5 times that of aluminum and 25 times that of wood-based siding materials. No clear overall patterns emerge from labor and capital depreciation requirements. It may be seen, however, that steel floor joists are very substantially higher than wood counterparts in these two requirements, and that brick is more labor- and capital-intensive than all alternative siding materials in house construction.

[7] The high total energy requirement for wet-formed hardboard (Table 7) might be explained by our source's inclusion of the secondary operations of prefinishing and sizing in the manufacturing operation.

TABLE 10. *Summary of materials flow from gross annual growth (million oven-dry tons)*

Year	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

Similar conclusions with respect to commercial structures may be drawn from a well-documented study by Bingham (1975).

CHANGING PATTERNS IN WOOD USE AS A STRUCTURAL AND ARCHITECTURAL MATERIAL

Wood is renewable and, as is apparent from the results of this study, has substantial advantages—particularly from the standpoint of energy requirements—over alternative materials. This strongly suggests that it is in the nation's best interest to move positively toward a continued high reliance on wood for building construction. To accomplish this, the effect of those factors that influence economic availability and utility of the forest resource as raw material for structural products must be recognized and dealt with.

Materials flow trajectories comparable to those shown in Fig. 1 have been developed for 1985 and 2000 based on the Timber Outlook Study (USDA Forest Service 1974) data on growth and potential for commodity removals (Figs. 18 and 19). In these trajectories, timber in all commercial sizes is pooled in recognition of the fact that sawtimber and pulpwood and pole-size timber distinctions have largely lost meaning. Roundwood totals available for commodities as well as logging and other forest residues, under the assumptions of the model, are summarized in Table 10. The possibilities for increasing available supply through more intensive management as foreseen by another CORRIM panel are discussed by Spurr and Vaux (1976).

It is becoming increasingly clear that continuing replacement of old-growth timber stands with second-growth, managed forests and plantations is resulting in a substantially higher percentage of trees of smaller diameter and of hardwoods. Additionally, economic forces dictate a substantially higher degree of utilization of that component of the resource from old-growth forests which has in the past been considered residual, and of a more complete recovery of the total woody biomass from all forests. These forces act to create an increasing reliance on reconstituted primary products in the forms of both structural support members and panels (Jahn and Preston 1976).

Additionally, the increasing costs and decreasing size and quality of raw material, together with an increasing concern for environmental quality, tend to increase manpower, energy, and capital requirements in converting the forest raw material to structural and architectural commodities. The degree to which future requirements of labor, capital, and energy will increase will be largely dependent upon the level of research and development directed toward the harvesting, manufacture, transportation, and structural design of wood products.

To assess the possible influence of research and development on manpower, energy, and capital requirements for wood-based structural materials, certain external forces have been identified that impinge upon these requirements, and predictions have been made of their combined impact on each of the requirements under the conditions of 1) continuation of current levels of research and development; and alternatively, 2) substantially increasing the levels of research and development.

Important forces identified are:

Forest Harvest
Tree Size
Natural Stands vs. Plantations
Species Mix
Location of Forest Relative to Mill
Specification of Forest Utilization Standard

Fuel Constraints
Availability and Cost of Fossil Fuel

Societal Changes
Type of Product Demanded
Environmental Awareness
House Size

Legislative Constraints
Forest Practices
Manufacturing and Processing (e.g., OSHA)
Building Codes

The assessment is that the level of research and development will influence the impact of these forces on manpower, capital, and energy requirements and that most of the changes will occur by 1985. Changes in the input requirements under the two levels can be expected by 1985 as follows:

	Man-Hours	*Capital*	*Energy*
A. Current Levels of Research and Development	Little change	Substantial increase	Small decrease
B. Substantial Increase in Research and Development	Substantial decrease	Small increase	Possible substantial decrease

In the judgment of CORRIM Panel II, substantial additional change accompanying the two research levels is unlikely between the years 1985–2000.

Although it can be assumed that technological advances will move toward increasing recovery in the form of primary product, it appears probable that the changing quality of available raw material will largely offset these gains. Predictably, more accurate sawing in combination with reduced saw kerf will increase lumber yield from a given log size. Improved centering devices may slightly increase veneer yield. Accurate sawing, market acceptance of partially surfaced lumber, increased application of abrasive planing, and improved surfacing with equipment based on cutter heads will substantially decrease the loss of lumber in surfacing. Improved control in manufacture throughout will work toward reducing residuals from the primary product. Because of the anticipated decrease in log size and quality, however, the materials-flow trajectories that have been developed on the basis of current operations are not likely to change significantly except in the case of softwood lumber in which a higher yield of primary product can be expected, as shown in Fig. 3.

Several scenarios have been developed by CORRIM to span a wide range of anticipated demand for wood-based products derived from domestic timber sources in the years 1985 and 2000. Two of them are shown here. Scenario I is derived essentially from the medium-level projection of the Outlook Study[8] based on constant relative prices for wood-based commodities (Table 11). A major departure from the Outlook Study assumptions holds dwelling-unit size constant at 1970 levels rather than projecting a continuing increasing size based on past trends. We feel that a watershed has been reached in this regard.

Scenario II assumes constant relative prices but at a slower rate of population

[8] Although the Forest Service's 1975 Assessment (USDA Forest Service 1976) report differs from the Outlook Study in several of its underlying assumptions, the projected demands for roundwood are changed very little from the Outlook Study report.

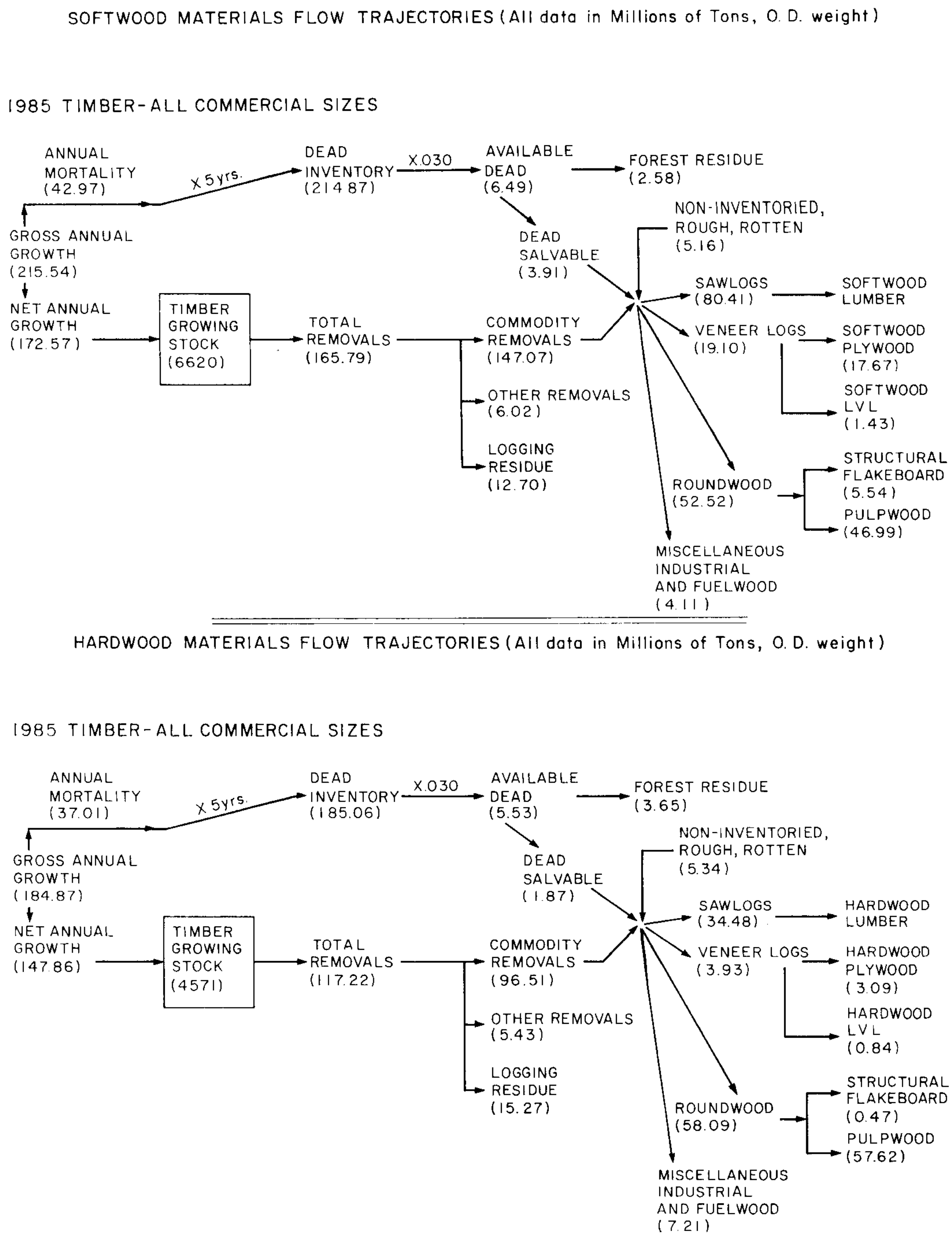


FIG. 18. Softwood (upper) and hardwood (lower) materials flow trajectories for 1985.

Based essentially on data provided in the Outlook Study (USDA Forest Service 1974). Conversion of cu ft to tons (OD) has been through multiplication by 0.0137 for softwoods and by 0.0164 for hardwoods. All values include bark. Data on growth and removal reflect current inventory standards. Complete tree utilization, according to Keays (1971), would permit a commodity removal increase of 35% from the same growing stock.

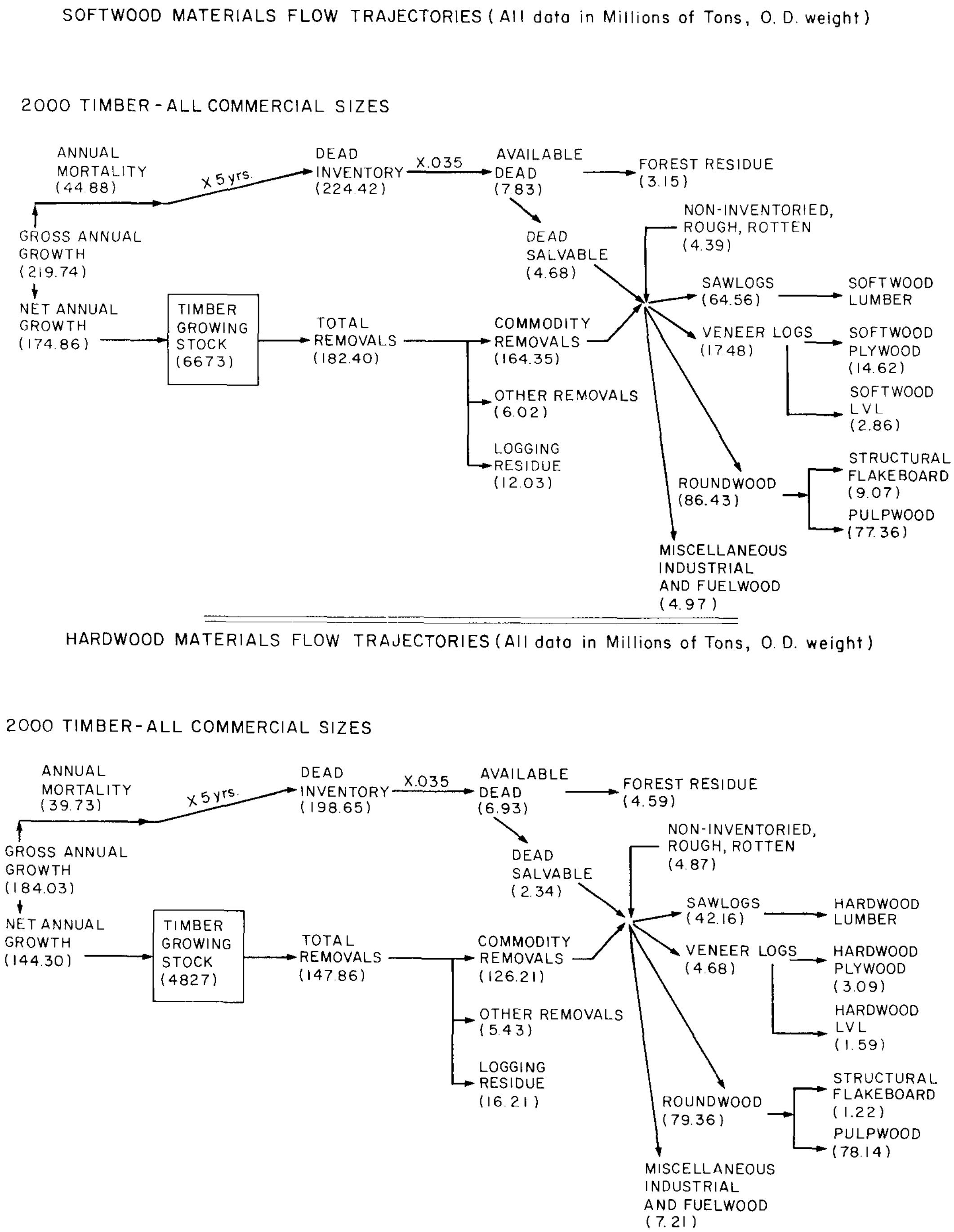


FIG. 19. Softwood (upper) and hardwood (lower) materials flow trajectories for 2000.

Based essentially on data provided in the Outlook Study (USDA Forest Service 1974). Conversion of cu ft to tons (OD) has been through multiplication by 0.0137 for softwoods and by 0.0164 for hardwoods. All values include bark. Data on growth and removal reflect current inventory standards. Complete tree utilization, according to Keays (1971), would permit a commodity removal increase of 35% from the same growing stock.

TABLE 11. *Wood requirements from domestic timber sources in 1985 and 2000 according to Scenario I*

SCENARIO NO. I

WOOD REQUIREMENT

COMMODITY	1985 MM O.D. TONS		2000 MM O.D. TONS	
	FROM ROUNDWOOD	FROM BY-PRODUCT	FROM ROUNDWOOD	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

[1] Yielding flakeboard cores equivalent to veneer from 5.9 MM tons of veneer logs in 1985 and 9.7 tons in 2000. These equivalents have consequently been subtracted from projected roundwood demand for softwood plywood.

[2] Of which 1.5 MM OD tons are converted to finished softwood lumber and 0.8 MM OD tons are converted to finished hardwood lumber.

[3] Of which 2.8 MM OD tons are converted to finished softwood lumber and 1.6 MM OD tons are converted to finished hardwood lumber.

growth than Scenario I—a population of 266 million by 2000 vs. 281 million as is assumed in the Outlook Study medium-level projection (Table 12).

Other CORRIM Scenarios assume that prices of nonrenewable substitutes increase by 20 to 60% relative to structural and fibrous renewable resources by the year 2000 with population growth at the same low rate as in Scenario II. CORRIM Scenarios I and II, largely on the basis of the Committee's interpretation of foreseeable utilization changes, project increased demands on domestic timber supplies for 2000 ranging from 53 to 59% (Scenarios II and I, respectively) over 1970 levels at constant relative prices. The most recent Forest Service update of such projections (USDA Forest Service 1976) is for an increase of 73% over 1970 in total U.S. demand for timber products by the year 2000. Zivnuska and Vaux (1975) have reviewed other reports including that of Resources for the Future (Fischman 1974) and Vaux (1973) which project increased demand by 2000 on the order of 50–70% over that of 1970. An earlier projection (Nathan 1968) prepared for the Public Land Law Review Commission foresaw consumption by 2000 at a level 87% above that actually achieved in 1970.

Requirements under Scenarios I and II can be achieved under the supply schedules of the materials-flow trajectories summarized in Table 10. The assumptions of the scenarios based on higher relative prices for nonrenewable substitutes were considerably less realistic, and requirements under those conditions could not be met without sub-

TABLE 12. *Wood requirements from domestic timber sources in 1985 and 2000 according to Scenario II*

SCENARIO NO. II

WOOD REQUIREMENT

COMMODITY	1985 MM O.D. TONS		2000 MM O.D. TONS	
	FROM ROUNDWOOD	FROM BY-PRODUCT	FROM ROUNDWOOD	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

[1] Yielding flakeboard cores equivalent to veneer from 5.9 MM tons of veneer logs in 1985 and 10.0 MM tons in 2000. These equivalents have consequently been subtracted from projected roundwood demand for softwood plywood.

[2] Of which 1.5 MM OD tons are converted to finished softwood lumber and 0.7 MM OD tons are converted to finished hardwood lumber.

[3] Of which 3.4 MM OD tons are converted to finished softwood lumber and 1.2 MM OD tons are converted to finished hardwood lumber.

stantially augmenting supply by imports and/or capital depletion in anticipation of future productivity, in addition to complete utilization of residues. *The potential of the forest resource to meet realistic demands through the next twenty-five years is evident, but the realization of this potential presents a challenge to the makers of forest policy, to resource managers, and to the forest-based industries.* Much more research in the closer utilization of residues at the mill and in the forest will be needed to achieve the potentials suggested by our scenarios and trajectories.

Apart from the trend toward an increase in overall demand for wood products, the most notable changes that are predictable within the next quarter century will be in the increasing replacement of lumber and plywood with products reconstituted from fibers and small wood components and a trend toward building up structural members of large dimension from smaller pieces through lamination.

Lumber-laminated-from-veneer, which is now technologically feasible and for which trajectories have been developed, holds considerable promise. Even more promising are reconstituted structural products assembled from flakes or strands, which can be derived from essentially all woody components of trees of any species, size, and quality. As in the case of lumber-laminated-from-veneer, technology now exists for such products, and their movement into the market is on the immediate horizon. In fact, an oriented-strand reconstituted wood panel product has very recently entered the market. These products are promising not only in the form of structural panels or panel components to be used as alternatives for plywood or veneer but, additionally, for structural supporting members as alternatives to lumber.

In another sphere of technological development—that of improved design concepts —current research in wood structural systems gives promise of a potential saving in material of as much as one-third without sacrificing structural performance (Goodman et al. 1974). This is equivalent to a gain—for this purpose—of 50%, and overall of at least 15%, in forest productivity. This gain can be achieved without any departure whatsoever from conventional construction materials or practice. It simply involves the development of a rational model that permits the designer to take advantage of the capability of the system to accommodate load sharing among the individual components and recognizes the effective transfer of stress achieved by means of the common nail. Still greater efficiencies can be demonstrated through the application of suitable elastomeric adhesives in the further development of stress transference (Hoyle 1976).

With an assumed high level of technology resulting from advances through research and development and, furthermore, assuming an adequate, technically trained manpower pool, it appears safe to forecast that the nation's needs for structural and architectural materials based on the forest resource can be met, but that they will be met with a mix that is substantially different from that in current use.

Information developed during the course of this study strongly suggests that, on the basis of the man-hours, the capital, and particularly the energy required for their production, transportation, and installation, structural wood products have clear advantages over nonwood alternatives. Large quantities of wood have been used for these purposes for years. There are indications that wood may regain markets that it has earlier lost to nonrenewable materials if the cost of technical energy continues to increase.

A long-established trend toward whole-tree or at least whole-stem utilization could result in an improvement in the cost of wood relative to the cost of competing nonrenewable materials. Another result of this trend will likely be a change in the structural product mix in which reconstituted wood products will make up a larger fraction of the total. Essential to this development is the emergence of improved timber harvesting technology.

If a nonpetroleum-based exterior adhesive were to be produced, competitive with phenol-formaldehyde adhesives in performance and price, the opportunity to conserve petroleum would be enhanced, and the prospects for wider use of reconstituted wood products would be improved.

The industries that produce structural and architectural materials from wood are in a particularly favorable position to become substantially energy-independent. This energy-independence will be fostered if improved furnaces are designed to use green wood and bark residues to generate the heat required for kilns, driers, and presses.

Because wood has been a plentiful material, designs using it in structures have tended to be inefficient in terms of weight of material used in a specific application. Improved designs that are structurally more efficient are feasible and will contribute to materials conservation.

SUMMARY AND CONCLUSIONS

On the basis of the studies of several of its panels each concerned with its particular area of utilization of renewable resources—structural products, fiber products, extractive materials, chemicals, and fuels and energy—the Committee on Renewable Resources for Industrial Materials (National Research Council 1976) concluded that:

The materials available and potentially available from renewable resources can be used as alternatives to materials currently obtained from nonrenewable resources to augment national and world materials supplies, to improve energy conservation in materials supply and use, and to relieve dependence upon foreign sources of energy and materials and accompanying balance of payment problems. The orderly and rational development of a national policy for the achievement of these objectives requires refinement of methods of evaluating alternative materials supply systems in terms of resource supply, available technology, energy requirements, manpower requirements, and capital requirements. The quantitative data base essential to the assessment of viable alternatives needs to be improved, particularly in relation to the utilization, durability and maintenance of materials in specific applications. The development of new technology will increase the options for substitution.

The nation has not given the attention to science and technology in the field of renewable materials that has been devoted to nonrenewable materials and fuels, nor is there a focal point in government for such policy issues. The diverse character of land and factory ownership in the renewable materials sector makes it unlikely that major advances in science and technology in this field will quickly emerge unless fostered by the federal government. The number of universities engaged in significant research on the renewable materials is small and these programs are underfinanced. Industrial research in this field is modest in comparison with that pursued in nonrenewable fields. Most companies are too small to justify the creation and operation of research programs. The few relatively large companies in the field confine their research efforts to developments that can be protected on a proprietary basis. Some of these corporate research resources are very good and should be utilized to advance national goals through research contracted for by the federal government.

Perhaps the most important resource for any industry is competent manpower. The level of research and development by the renewable materials industries needs improvement by attracting and employing more well-educated young people. Needed are professional scientists and technologists soundly educated in the disciplines underlying renewable materials. To back up the scientists and technologists and to carry out technical as well as mill operations, there will be an increasing need for technicians with various levels of education. There is a great need for continuing education programs and this need will increase in the future because of the increasing tempo of knowledge and change in the field.

More specifically in the domain of CORRIM Panel II—wood as structural material—the Committee's report (National Research Council 1976) summarizes:

Timber finds its largest use in the production of structural wood products, including not only lumber but also plywood, particleboard, flakeboard and insulating board, which serve in primary forms as building materials and from which innumerable secondary products are made. In 1970 about 63% of all wood produced in the United States was used for primary structural materials. We concur in the estimate that this will drop to about 50% by the year 2000 (Cliff 1973). Over half of the lumber and panel products produced in 1970 were used for the construction of housing and light industrial buildings, and only a slight decrease in this percentage of the total demand for these products by the year 2000 is projected for building construction (Fig. 2).

In 1970, approximately 62% of the structural wood consumed in the United States entered the market as lumber. Reconstituted products are gaining a larger share of the market at the expense of lumber because of the trend toward smaller sizes and poorer qualities of the raw material, improvements in processing technology, and modifications in techniques of building construction. This trend will continue.

Structural wood products have remained competitive in the U. S. economy. While lumber consumption remained fairly constant from about 1908 until the mid-1960s, annual lumber consumption has risen about 20% since that latter time. The (relative) price of lumber has risen more or less steadily since 1800 at a rate averaging about 1.7% annually, compounded.

Structural wood products should continue to be competitive. Their technical suitability in residential and commercial building construction is widely recognized. Not only are potential supplies available to allow for modest increases in production, but . . . wood-based structural materials demonstrate, on a weight basis, a clear superiority over most nonwood products in energy efficiency. More importantly . . . they show a striking superiority in energy efficiency over nonwood alternatives in . . . the construction of roofs, walls, and floors. For example, steel floor joists require 50 times as much energy as their wood counterparts performing the same function; aluminum framing for exterior walls is approximately 20 times as energy-intensive as wood framing; aluminum siding requires approximately five times the energy of its plywood and fiberboard counterparts, and brick siding requires 25 times the energy of wood-based siding materials. . . . It appears clear that, where the conservation of energy is of prime importance, wood is the preferable material for residential and light commercial construction. . . .

The degree of energy self-sufficiency of many wood products is very striking. Softwood and hardwood lumber and hardwood plywood are not only completely self-sufficient in the manufacturing process but additionally generate a substantial surplus of fuel that can be used elsewhere for industrial or domestic energy. Structural flakeboards, at least one of which is now coming into production, will similarly be energy self-sufficient. Softwood plywood and laminated veneer lumber both generate adequate processing residue for fuel to supply over half of the demands for energy required in manufacturing.

The diminishing supply of large logs suitable for lumber of large dimensions and for plywood, the necessity of using an increasingly higher percentage of that part of the forest biomass that has previously been considered forest residue, and the economic desirability of complete utilization of all raw material entering processing, combine as strong incentives for the development of new reconstituted structural products alternative to lumber and plywood. . . . The use of structural flakeboard for sheathing in building construction—a function now served largely by plywood—is particularly promising. . . .

A long-established trend toward the increasing utilization of every type of tree and species can be expected to continue through the year 2000, with the upper limit of removal to be determined from site and economic considerations. This trend, in combination with the driving forces influencing the use of wood as structural material, will result in a structural-product mix in which new and reconstituted wood products will contribute an ever-increasing share toward meeting the total anticipated needs for structural and architectural wood products. Cost-effective methods should be developed to recover logging residues with the ultimate goal of attaining minimum tolerable levels of residue established by site considerations.

RECOMMENDATIONS

Panel II of CORRIM concludes its report with the following recommendations, which appear also 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 driers and wood-fired boilers.
- Additionally, research and development must be directed toward developing driers, 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 that 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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APPENDIX I

Man-Hour, Energy, and Capital Depreciation Requirements for Primary Wood-Based Commodities[1]

Table No.

[1] Manufacturing phase only; does not include expenditures for harvesting or transport.
[2] Computations of man-hours, energy, and capital depreciation listed in these commodity tabulations *do not* include man-hours, energy, or capital depreciation required for manufacture of resins, waxes or other chemical additives.
[3] Because of the predictable future importance of these products, several examples of alternative processes that may emerge are included. Variations in output products and by-products reflect differences in the amount of bark removed from and the amount of rot in the input raw material and the process used to reduce the input raw materials to flakes, strands, or particles. With the exception of 10a, processing deails are not available or have not been fully developed.
[4] Man-hours, energy, and capital requirements for reconstituted structural wood (Fig. 12) are not available.

TABLE I-1. *Softwood lumber: Product output and manpower, energy, and capital depreciation requirements based on 1.0 ton oven-dry (O D) weight input of unbarked sawlogs*

Product	Manpower[a]	Mechanical Energy[b]	Steam Energy[c]	Depreciation of Capital Facilities[d]
OD tons	*Man-Hours*	*HP-Hours*	*Pounds*	*Dollars*
Dry Planed Lumber 0.35	0.67	21.98	977	0.86
Pulp Chips 0.29	0.56	18.21	0	0.70
Particle-board Furnish 0.15	0.29	9.42	419	0.36
Fuel[e] 0.21	0.40	13.19	0	0.51
1.00	1.92	62.80	1396	2.43

[a]Based on 5.5 man-hours per M bd ft average required to manufacture surfaced kiln-dried lumber. Data supplied by industrial sources.

[b]Connected hp-hrs at 300 per M bd ft of lumber is an industry-wide average. A demand average of 60% of connected horsepower, 180 hp-hrs per M bd ft of lumber sawed and planed, was used.

[c]An industry average of 4 lbs of low-pressure steam per bd ft of lumber was used for computations.

[d]Based on industrial statistics of $17.5 million for 5 mills with aggregate 8-hr capacity of 647 M bd ft, operating two shifts per day, 243 days per year, for annual capacity of 314 MM bd ft. One-half capital investment is depreciated over 20 years and the remainder over 5 years.

[e]Energy potential from fuel: 0.21 ton of dry fuel corresponds to 840 pounds of green fuel. From 840 pounds of green fuel are produced 134.0 (via non-condensing turbine) hp-hrs of mechanical work with 2,184 lbs of exhaust steam for heating or drying.

TABLE I-2. *Hardwood lumber (i.e., oak flooring): Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of unbarked sawlogs*

Product	Manpower[a]	Mechanical Energy[b]	Steam Energy[c]	Depreciation of Capital Facilities[d]
OD tons	*Man-Hours*	*HP-Hours*	*Pounds*	*Dollars*
Dry, 3/4-inch Planed Flooring 0.28	1.44	16.6	933	4.01
Pulp Chips 0.29	.60	17.2	0	4.15
MDF Furnish 0.20	.72	11.9	667	2.86
Fuel[e] 0.23	.82	13.6	0	3.29
1.00	3.58	59.3	1600	14.31

[a]Based on flooring manufacturer's data: An average of 16 man-hours of labor, maintenance, and supervision required to produce sufficient flooring to cover 1000 sq ft.

[b]Based on flooring manufacturer's data: 37,400 total connected hp-hours with 60 percent demand required to produce 86,000 sq ft of floor covering; energy for lighting added.

[c]Based on estimate of 4.0 pounds of steam required to dry one bd ft of rough lumber.

[d]Based on plant and equipment cost of $2.3 million for annual production of 4.5 million sq ft of floor coverage. Depreciation based on one-half over 20 years and one-half over five years.

[e]Energy potential from fuel: 0.23 ton of dry fuel corresponds to 920 lbs of green fuel which will produce (via a non-condensing steam turbine) 146.8 hp-hrs of mechanical work with 2,392 lbs of residual exhaust steam available for drying and heating.

TABLE I-3. *Softwood plywood (unsanded sheathing): Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of unbarked veneer logs*

Product	Manpower[a]	Mechanical Energy[b]	Steam Energy[c]	Depreciation of Capital Facilities[d]
OD tons	*Man-Hours*	*HP-Hours*	*Pounds*	*Dollars*
Unsanded Sheathing Plywood 0.45	1.63	6.31	2056	4.13
Studs 0.06	.21	.84	274	.55
Pulp Chips 0.30	1.08	4.20	57	2.75
Particleboard Furnish 0.08	.29	1.12	365	.73
Fuel[e] 0.12	.41	1.68	23	1.10
1.01[f]	3.62	14.15	2775	9.26

[a]Based on industrial data: Average of 4 man-hours of labor plus 10 percent of labor for supervision required per 1000 sq ft of plywood (3/8-inch basis).

[b]Based on industrial data: 17 hp-hrs, including forklifts, required to produce 1000 sq ft of plywood (3/8-inch basis); demand is 60 percent of connected horsepower. Energy for lighting is additional at 7.0 hp-hrs demand per 1000 sq ft of plywood produced (3/8-inch basis) for a total demand of 17.2 hp-hrs per 1000 sq ft.

[c]Based on industrial data: 3,140 pounds of steam per 1000 sq ft of plywood (3/8-inch basis) for the hot-press and dryer and 191 pounds per ton (O D basis) for heating veneer bolts. Steam requirements for drying allocated proportionately by weight to plywood, studs, and particleboard furnish.

[d]Based on plant cost of $9 million for capacity (three shifts) of 100 million sq ft (3/8-in) annual production. One-half is depreciated over 20 years and one-half over five years.

[e]Energy potential from fuel: 0.12 ton of dry fuel corresponds to 480 lbs of green fuel which will produce (via non-condensing turbine) 76.6 hp-hrs of mechanical work with 1248 lbs of residual exhaust steam available for heating and drying.

[f]Including phenol-formaldehyde resin.

TABLE I-4. *Hardwood plywood: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of unbarked veneer logs*

Product	Manpower[a]	Mechanical Energy[b]	Steam Energy[c]	Depreciation of Capital Facilities[d]
OD tons	*Man-Hours*	*HP-Hours*	*Pounds*	*Dollars*
Interior Paneling 0.30	1.4	5.1	2000	3.00
Fuel[e] 0.23	1.0	3.9	60	2.30
Pulp Chips 0.48	2.1	8.0	440	4.70
1.01[f]	4.5	17.0	2500	10.00

a-b-c-d
These values are adjusted from softwood plywood values; they are not based on plant surveys.

[e]Energy potential from fuel: 0.23 ton of oven-dry fuel corresponds to 920 lbs of green fuel. If all fuel is assumed to be green (actually, .13 ton is dried to manufacturing requirements), it will produce (via non-condensing turbine) 146.8 hp-hrs of mechanical work with 2392 lbs of exhaust steam available for drying and heating.

[f]Including resin adhesive.

TABLE I-5. *Underlayment particleboard: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of shavings, sawdust, and plywood trim*

Product	Manpower[a]	Electrical Energy[b]	Heat Energy[c] Natural Gas / Steam	Depreciation of Capital Facilities[d]
OD tons	*Man-Hours*	*KWH*	*MM BTU / Pounds*	*Dollars*
Sanded Particle-board, 5/8-inch 0.979	2.29	210	2.46 / 1718	11.07
Sander Dust 0.094 (Fuel[e])	.22	20	.24 / 165	1.06
Saw-dust 0.014 (Fuel[e])	.01	1	.01 / 25	.07
1.087[f]	2.52	231 (= 310 Hp-hrs)	2.71 / 1908	12.20

[a] Based on 1973 National Particleboard Association survey of manufacturers. Values ranged from 1.85 to 3.73 man-hours/1000 sq ft 3/4-inch basis.

[b] Based on 1974 National Particleboard Association survey of manufacturers. Average electrical usage was 284 KWH/1000 sq ft 3/4-inch basis. Converting to account for greater productivity when producing 5/8-inch board, the value becomes 231 KWH, equivalent to 310 hp-hrs per ton input.

[c] Process steam plus natural gas used in operating driers. Based on 1974 survey of National Particleboard Association manufacturers. Values are 1,908 lb steam and 2,681 cu ft natural gas.

[d] Based on investment of $12 million for a plant with a capacity of 100 million sq ft/year, 3/4-inch basis. Depreciation computed one-half depreciated over 20 years and one-half over five years.

[e] Energy potential from fuel: .108 ton of dry fuel (actually produced dry) will produce 79.5 hp-hrs of mechanical work with a residual of 1,296 lb of exhaust steam available for heating and drying.

[f] Including resin and wax.

TABLE I-6. *Medium-density fiberboard: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of 50-50 mixture of chips and barky roundwood*

Product	Manpower[a]	Electrical Energy[b]	Heat Energy[c]	Depreciation of Capital Facilities[d]
OD tons	*Man-Hours*	*HP-Hours*	*MM BTU*	*Dollars*
MDF 42-lb Panel 0.86	1.88	322.5	4.334	17.92
Loss 0.06	.13	22.5	.302	1.25
Fuel[e] 0.17	.37	63.7	.857	3.54
1.09[f]	2.38	408.7	5.493	22.71

[a] Based on average of three industrial operations (3.6 man-hours per 1000 sq ft of 3/4-inch panel).

[b] Based on average of three industrial operations (462 kw-hours per 1000 sq ft of 3/4-inch panel).

[c] Based on requirements for a plant with 91,000-ton annual production capacity.

[d] Based on $19.125 million to build a plant with 91,000-ton annual capacity, one-half depreciated over 20 years and one-half over five years.

[e] Energy potential from fuel: .17 ton of dry fuel corresponds to 680 lbs of green fuel, which will produce (via non-condensing steam turbine) 108.5 hp-hrs of mechanical work with 1,768 lbs of residual steam available for drying and heating.

[f] Including resin and wax.

TABLE I-7. *Wet-formed insulation board: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of mixed chips*[a]

Product	Manpower[b]	Energy[c] (Demand)	Heat[d]	Depreciation of Capital Facilities[e]
OD tons	*Man-Hours*	*HP-Hours*	*MM BTU*	*Dollars*
Insulation Board, 1/2 in. 1.04	5.85	565.68	5.04	20.23
Fuel[f] 0.05	.28	27.20	.24	.97
Solubles and Volatiles 0.10	.56	54.39	.49	1.95
1.19[g]	6.69	647.27	5.77	23.15

[a]Assumes maximum of 5 percent bark.

[b]Based on averages from two industrial sources (2.68 man-hours per 1000 sq ft, 1/2-inch basis).

[c]Based on averages from three industrial sources (259.3 HP-hours per 1000 sq ft, 1/2-inch basis).

[d]Based on one industrial estimate (2.31 MM BTU per M sq ft, 1/2-inch basis).

[e]Based on two estimates (average $16.205 million) for plants with 91,000-ton annual capacity. One-half depreciated over 20 years and one-half over five years.

[f]Energy potential from fuel: 0.05 ton of dry fuel corresponds to 200 lbs of green fuel, which will produce (via non-condensing turbine) 31.9 hp-hrs of mechanical work with 520 lbs of residual steam which can be used for heating.

[g]Including additives.

TABLE I-8. *Wet-formed primary hardboard: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of mixed chips*[a]

Product	Manpower[b]	Mechanical[c] Horsepower (Demand)	Steam[d]	Depreciation of Capital Facilities[e]
OD tons	*Man-Hours*	*HP-Hours*	*MM BTU*	*Dollars*
45-lb. Hard-board, 1/8-in. 0.87	10.90	940.13	7.22	35.44
Fuel[f] 0.05	.63	54.03	.42	2.04
Solubles and Volatiles 0.10	1.25	108.06	.83	4.07
1.02[g]	12.78	1102.21	8.47	41.55

[a]Assumes a maximum of 5 percent bark.

[b]Assumes 3.44 man-hours per 1000 sq ft (1/8-inch basis); average from three industrial sources adjusted to include maintenance and supervision.

[c]Assumes 296.93 hp-hr demand per 1000 sq ft (1/8-inch basis); average from three industrial sources.

[d]Assumes 2.28 MM BTUs required per 1000 sq ft (1/8-inch basis); estimated from one industrial source for a plant with an annual capacity of 91,000 tons.

[e]Based on data from industrial sources for two recently built plants (average cost $26.855 million) with an annual capacity of 300,000 sq ft of 1/8-inch board. One-half depreciated over 20 years and one-half over five years.

[f]Energy potential from fuel: 0.05 ton of dry fuel corresponds to 200 lbs of green fuel, which will produce (via non-condensing turbine) 31.9 hp-hrs of mechanical work with 520 lbs of residual steam which can be used for heating.

[g]Including resin and additives.

TABLE I-9. *Dimension lumber laminated from veneer (1/4-inch softwood): Product output and man-hour , energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of unbarked veneer logs*

Product	Manpower[a]	Mechanical Horsepower[b] (Demand)	Steam[c]	Depreciation of Capital Facilities[d]
OD tons	*Man-Hours*	*HP-Hours*	*Pounds*	*Dollars*
Lumber Laminated from Veneer 0.47	1.69	6.59	2057	4.32
Particleboard Furnish 0.07	.25	.99	365	.64
Studs 0.06	.21	.83	274	.55
Pulp Chips 0.29	1.04	4.06	56	2.65
Fuel[e] 0.12	.43	1.68	23	1.10
1.01[f]	3.62	14.15	2775	9.26

[a]Based on industrial data: Average of 4 man-hours of labor plus 10 percent of labor for supervision required per 1000 sq ft of plywood (3/8-inch basis).

[b]Based on industrial data: 17 hp-hrs, including forklifts, required to produce 1000 sq ft of plywood (3/8-inch basis); demand is 60 percent of connected horsepower. Energy for lighting is additional at 7.0 hp-hrs demand per 1000 sq ft of plywood produced (3/8-inch basis) for a total demand of 17.2 hp-hrs per 1000 sq ft.

[c]Based on industrial data: 3,140 lbs of steam per 1000 sq ft of plywood (3/8-inch basis) for the hot-press and drier and 191 lbs per ton (O D basis) for heating veneer bolts. Steam requirement for drying is allocated proportionately by weight to plywood, studs, and particleboard furnish.

[d]Based on plant cost of $9 million for capacity (three shifts) of 100 million sq ft (3/8-inch basis) annual production. One-half is depreciated over 20 years and one-half over five years.

[e]Energy potential from fuel: 0.12 ton of dry fuel corresponds to 480 lbs of green fuel which will produce (via non-condensing turbine) 76.6 hp-hrs of mechanical work with 1248 lbs of residual exhaust steam available for heating and drying.

[f]Including phenol-formaldehyde resin.

TABLE I-10a. *Hardwood structural flakeboard[a]-- pallet lumber: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of unbarked roundwood*

Product	Manpower[b]	Mechanical Horsepower[c] (Demand)	Steam Energy[d]	Depreciation Capital Facilities[e]
OD tons	*Man-Hours*	*HP-Hours*	*Pounds*	*Dollars*
Flakeboard Panels, 1/2 in. 0.354	1.08	19.22	1590	2.81
Rough Lumber 0.45	1.37	24.44	0	3.57
Fuel[f] 0.22	.67	11.94	210	1.74
1.024[g]	3.12	55.6	1800	8.12

[a]Not in production 1970. Data developed by USDA Forest Service, Southern Forest Experiment Station, for process utilizing shaping-lathe headrig to make flakeboard weighing 45.3 lb per cu ft (O D basis).

[b]Based on plant requiring 120 workmen (total for all three shifts) with daily consumption of 308 O D tons of unbarked roundwood; i.e., 3.12 man-hours per O D ton input.

[c]Based on total of 1188 connected horsepower with an average demand of 60 percent for the above plant.

[d]Includes flake-drier requirement (1200 lbs steam) based on wood at 75 percent moisture content and two lbs of steam required to evaporate one pound of water, and hot-press steam (600 lbs) based on 1600-pound requirements per 1000 sq ft of 1/2-inch board.

[e]Assumes plant and equipment cost of $7 million, operating 350 days per year with 308 O D tons of roundwood consumed per day. One-half is depreciated over 20 years and one-half over five years.

[f]Energy potential from fuel: 0.22 ton of dry fuel corresponds to 880 lbs of green fuel, which will produce (via non-condensing turbine) 140.4 hp-hrs of mechanical work with 2288 lbs of residual steam available for heating and drying.

[g]Including phenol-formaldehyde resin and wax.

TABLE I-10b. *Structural particleboard -- whole log flaking: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of unbarked logs*[a]

Product	Manpower	Electrical Energy	Energy Natural Gas / Steam	Depreciation of Capital Facilities[c]
OD tons	Man-Hours	KWH	MM BTU / Pounds	Dollars
Structural Board[b] 0.879	1.12	200	4.12 / 2747	10.13
Bark 0.08 (d)	.10	18	.38 / 250	.92
Trim, Process Losses 0.096 (d)	.12	21	.45 / 300	1.11
1.055[e]	1.34	239	4.95 / 3297	12.16

[a]Data developed by the National Particleboard Association.

[b]Unsanded sheathing board, 40 lb per cu ft density.

[c]Based on plant with annual capacity of 68 million sq ft of 3/4-inch board. Total plant investment $7.8 million, one-half depreciated over 20 years and one-half over five years.

[d]Available as fuel: 0.176 ton.

[e]Including resin and wax.

TABLE I-10c. *Structural particleboard -- chipping and flaking sound wood: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of unbarked logs*[a]

Product	Manpower	Electrical Energy	Energy Natural Gas / Steam	Depreciation of Capital Facilities[c]
OD tons	Man-Hours	KWH	MM BTU / Pounds	Dollars
Structural Board[b] 0.809	1.14	250	3.79 / 2528	9.33
Bark 0.08 (d)	.11	25	.37 / 250	.92
Process Losses 0.162 (d)	.23	50	.76 / 506	1.87
1.051[e]	1.48	325	4.92 / 3284	12.12

[a]Data developed by the National Particleboard Association.

[b]Unsanded sheathing board, 40 lb per cu ft density.

[c]Based on plant with annual capacity of 68 million sq. ft of 3/4-inch board. Total plant investment $7.8 million, one-half depreciated over 20 years and one-half over five years.

[d]Available as fuel: 0.242 ton.

[e]Including resin and wax.

TABLE I-10d. *Structural particleboard -- chipping and flaking wood with some rot: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of unbarked logs*[a]

Product	Manpower	Electrical Energy	Energy: Natural Gas / Steam	Depreciation of Capital Facilities[c]
OD tons	*Man-Hours*	*KWH*	*MM BTU / Pounds*	*Dollars*
Structural Board[b] 0.748	1.05	231	3.50 / 2337	8.63
Bark 0.08 }[d]	.11	25	.37 / 250	.92
Process Losses 0.22 }[d]	.31	68	1.03 / 687	2.54
1.048[e]	1.47	324	4.90 / 3274	12.09

[a]Data developed by the National Particleboard Association.

[b]Unsanded sheathing board, 40 lb per cu ft density.

[c]Based on plant with annual capacity of 68 million sq ft of 3/4-inch board. Total plant investment $7.8 million, one-half depreciated over 20 years and one-half over five years.

[d]Available as fuel: 0.30 ton.

[e]Including resin and wax.

TABLE I-11. *Softwood pulp chips from chip mill: Product output and man-hour, energy, and capital depreciation requirements in manufacture based on 1.0 ton (O D weight) input of unbarked roundwood*

Product	Manpower[a]	Mechanical[b] Horsepower (Demand)	Steam Energy	Depreciation of Capital Facilities[c]
OD tons	*Man-Hours*	*HP-Hours*	*Pounds*	*Dollars*
Pulp Chips 0.89	.62	10.83	0	1.28
Fuel 0.11	.08	1.34	0	.16
1.00	.70	12.17	0	1.44

[a]Assumes 100 percent moisture content of wood and bark. Based on one mill producing 500 tons green chips (250 tons O.D.) per day (two shifts) with productivity of 0.70 man-hours per O D ton of chips.

[b]Based on average requirements for two plants.

[c]Based on data from two plants with approximate capital requirements of $750 thousand and annual chip production of 65,000 O D tons. One-half depreciated over 20 years and one-half over five years.

TABLE I-12. *Adhesives and additives -- phenol formaldehyde, urea formaldehyde and wax: man-hours, energy, and capital cost requirements per ton of production*

Product	Manpower	Mechanical Horsepower (Demand)	Steam Energy	Depreciation of Capital Facilities[a]
	Man-Hours	*HP-Hours*	*Pounds*	*Dollars*
Urea-Formaldehyde Resin	0.74	36	419	15
Phenol-Formaldehyde Resin	1.02	34	196	21
Wax	1.60	35	267	7

[a]Depreciation estimated at one-half of investment in 20 years and one-half in five years. Capital investment assumed was $1 million for a resin plant and $50,000 for a wax plant.

TABLE I-13. *Summary of yield, energy, man-hours and depreciation in manufacture for ten primary wood-based products*[a-f]

Commodity	Form of Raw Material	Input of Woody Furnish to Yield 1.0 ton of Primary Product	Motor Energy Demanded in Conversion to Yield 1.0 ton of Product		Process Steam Needed to Yield 1.0 ton of Product		Man-Hours Allocated to Product and Residual Fuel	Capital Depreciation Allocated to Primary Product and Residual Fuel
			Gross	Net[c]	Gross	Net[c]		
		OD Tons	*HP-Hours*		*Pounds*		*Man-Hours*	*Dollars*
Softwood Lumber	Barky long logs	2.86	179	(203)	3,989	(2,251)	3.06	3.91
Lumber Laminated from Veneer[f]	Barky logs	2.13	30	(133)	5,904	3,249	4.51	11.53
Oak Flooring	Barky logs	3.57	212	(313)	5,714	(2,829)	8.07	26.07
Softwood Sheathing Plywood[f]	Barky logs	2.22	31	(139)	6,167	3,393	4.53	11.62
Hardwood Plywood[f]	Barky logs	3.33	57	(433)	8,333	360	8.00	17.67
Underlayment Particle-board[f]	Planer shavings, sawdust, plywood trim	1.02	316	235	1,948[d]	625[d]	2.57	12.46
Structural Flakeboard[f]	Barky logs	2.82[e]	157	(240)	5,084	(1,379)	4.94	12.85
Insulation[f] Board	Mixed species chips	.96	622	592	3,814	3,314	5.89	20.38
Wet-Formed Hardboard[f]	Mixed species chips	1.15	1,267	1,230	6,693	6,095	13.25	43.08
Medium-Density Fiberboard[f]	50% chips 50% barky roundwood	1.16	475	349	4,391	2,335	2.62	24.95

[a]Oven-dry weight basis of both input and product.

[b]These data apply to the process of manufacture from logs (or chips) in yard through loading product on carrier for shipment: they do not include manpower, energy, or capital depreciation involved in manufacture of product additive (i.e. resins, wax, starch, or asphalt). See Table I-12 for such information.

[c]Assumes that green bark and sawdust are burned at 66.5 percent efficiency to generate steam to drive a non-condensing turbine connected to an A.C. generator driving electric motors, and that low-pressure exhaust steam is utilized for process heat. Net energy is that required in addition to energy produced from residue fuel. Values in parentheses represent energy generated from residue fuel in excess of that required for plant operation.

[d]In addition to this process steam, 2.77 million BTU of natural gas are needed to produce 1.0 ton (O D weight basis) of product.

[e]In addition, 1.27 tons (O D weight basis) of pallet lumber are yielded from these logs.

[f]Energy balances for these products do not include energy consumed in manufacture of resins or waxes.

APPENDIX II

Man-Hour, Energy, and Capital Depreciation Requirements for Forest Harvesting

Table No.

TABLE II-1. *Forest harvesting: Man-hour requirements (1972)*[a]

Activities	Pacific Northwest Man-Hours per O D ton	Pacific Northwest Percent	South Man-Hours per O D ton	South Percent
Harvest Planning & Layout	.08	4.5	.06	2
Road Construction & Maintenance	.19	10.0	.06	2
Stump-to Mill Handling	1.12	58.0	2.21	74
Equipment Maintenance	.38	19.5	.55	19
Supervision	.15	8.0	.10	3
Totals	1.92	100.0	2.98	100

[a]Based on industrial data.

TABLE II-2. *Forest harvesting: Capital depreciation requirements (1972)*[a]

Activities	Pacific Northwest Dollars per O D ton	South Dollars per O D ton
Road Construction & Maintenance	.07	
Stump-to-Mill Handling	1.54	2.21
Equipment Maintenance	.03	
Totals	1.64	2.21

[a]Based on industrial data.

TABLE II-3. *Forest harvesting: Primary fuel consumption (1972)*[a]

Activities	Pacific Northwest Gals. Diesel per O D ton	South Gals. Diesel per O D ton
Stump-to-Mill Handling	3.85	4.00
Road Construction & Maintenance	.20	.20
Supervision	.12	.15
Totals	4.17	4.35

[a]Based on industrial data.

TABLE II-4. *Summary of forest harvesting: Man-hour, energy, and capital depreciation requirements per O D ton of roundwood from stump to mill (1972)*

	Pacific Northwest	South	Average
Man-Hours	1.92	2.98	2.45
Capital Depreciation (Dollars)	1.64	2.21	1.93
Diesel Fuel (Gallons)	4.17	4.35	4.26
(Million BTU)[a]	.576	.601	.589

[a]Based on 138,336 BTU/gallon.

TABLE II-5. *Forest harvesting: Man-hour, capital depreciation and energy requirements per O D ton of intermediate and final product*[a]

	Manpower *Man-Hours*	Capital *Dollars*	Energy *MM BTU*
Barky Roundwood	2.45	1.93	.589
Forest Residual (Barky) Chips	1.29	4.39	.536
Bark-Free Chips	3.45	3.60	.757
Softwood Lumber	3.92	3.09	.943
Hardwood Flakeboard	3.97	3.13	.956
Hardwood Lumber	4.46	3.51	1.073
Lumber Laminated from Veneer	3.08	2.42	.740
Softwood Plywood	3.10	2.44	.747
Hardwood Plywood	4.33	3.41	1.041
Underlayment Particleboard[b]	5.04	6.72	4.617
Medium-Density Fiberboard[c]	3.43	3.21	.783
Wet-Formed Insulation Board[d]	2.28	3.84	.622
Wet-Formed Primary Hardboard[d]	2.72	4.59	.743

[a]Man-hour, capital depreciation, and energy requirements for input raw materials from the stump to the manufacturing plant are those assigned to the primary product and the fuel derived in processing. Requirements include chipping where chips are the raw material input to the manufacturing process (See Figures 3-16).

[b]Assumes furnish derived one-third from planer shavings, one-third from sawdust, and one-third from plywood trim.

[c]Assumes furnish derived one-half from barky roundwood and one-half from bark-free chips.

[d]Assumes furnish derived one-half from forest residual chips and one-half from bark-free chips.

APPENDIX III

Materials, Man-Hours, Energy, and Capital Requirements for Alternative Floor, Roof, and Wall Constructions (100 Square Feet)

Table No.

TABLE III-1. *Descriptions of floor, roof, and wall constructions (Material requirements per 100 sq ft)*

Floors

1. Wood joist, subfloor and underlayment. 2 x 10 joists, 16 in. OC,[a] 1/2-in. plywood subfloor, 3/8-in. particleboard underlayment, carpet.

Joists	0.139	ton
Plywood	0.073	"
Particleboard	0.070	"
Carpet & pad	0.028	"
Nails	0.0019	"

2. Wood joist, subfloor, oak finish floor. 2 x 10 joists, 24 in. OC, 1/2-in. plywood subfloor, 3/4-in. oak strip flooring.

Joists	0.093	ton
Plywood	0.073	"
Oak Flooring	0.125	"
Nails	0.0019	"

3. Wood joist, single layer floor. 2 x 10 joists, 16 in. OC, 5/8-in. plywood underlayment, carpet.

Joist	0.139	ton
Plywood	0.091	"
Carpet & pad	0.028	"
Nails	0.0019	"

4. Concrete slab, 4 in. thick, on 6 in. gravel base.

Concrete	2.33	tons
Gravel	2.50	"
Vapor barrier	0.0015	"
Carpet & pad	0.028	"

5. Steel joist, 2-4-1 plywood. Steel "C" joists, 48 in. OC simple span, 1 1/8-in. plywood combination.

Joist	0.42	ton
Plywood	0.164	"
Carpet & pad	0.028	"
Nails	0.0019	"

6. Construction same as Floor No. 3 except LVL[b] joist, 16 in. OC, and 5/8 inch flakeboard instead of plywood.

1.5 in. x 7.5 in. joist	0.112	ton
Flakeboard, 5/8 in.	0.118	"
Carpet & pad	0.028	"
Nails	0.0019	"

Exterior Walls

1. Plywood siding (no sheathing), 2 in. x 4 in. frame

Siding - 5/8-in. plywood	0.091	ton
Building paper	0.0075	"
Framing, 24 in. OC, top-bottom plates	0.059	"
Insulation, mineral wool 2-in. batts	0.027	"
Gypsum board, 1/2 in.	0.027	"
Nails	0.0019	

TABLE III-1, *continued*

Exterior walls, cont.

2. Medium-density fiberboard siding, plywood sheathing, 2 in. x 4 in. frame.

Siding, 1/2-in. MDF[c] 42 lbs/cu ft	0.087	ton
Sheathing 3/8-in. plywood	0.055	"
Building paper	0.0075	"
Framing, 24 in. OC, top-bottom plates	0.059	"
Insulation, mineral wool 2-in. batts	0.027	"
Gypsum board, 1/2 in.	0.104	"
Nails	0.0025	"

3. Medium-density fiberboard siding, 1/2-in. insulation board, 1/2-in. plywood corner bracing, 2 in. x 4 in. frame

Siding, 1/2-in. MDF	0.087	ton
Sheathing, plywood (25 sq ft)	0.018	"
Sheathing, insulation board, 20 lbs/cu ft (75 sq ft)	0.032	"
Building paper	0.0075	"
Framing, 24 in. OC	0.059	"
Insulation, mineral wool 2-in. batts	0.027	"
Gypsum board, 1/2 in.	0.104	"
Nails	0.0025	"

4. Concrete building block, no insulation.

Wall, 2-core building block 8 in. thick	1.887	tons
Furring strips - six 1 in. x 2 in.	0.0066	ton
Gypsum board, 1/2 in.	0.104	"
Nails	0.0013	"

5. Aluminum siding, over sheathing, 2 in. x 4 in. frame.

Siding - .020 in. thick, 168 lb/cu ft	0.015	ton
Building paper	0.0075	"
Sheathing, plywood 1/2 in. corner bracing (25 sq ft)	0.018	"
Sheathing, insulation board 1/2 in. (75 sq ft)	0.032	"
Framing, 24 in. OC	0.059	"
Insulation, mineral wool 2-in. batts	0.027	"
Gypsum board, 1/2 in.	0.104	"
Nails	0.0025	"

6. Medium-density fiberboard siding, sheathing, steel studs.

Siding, MDF	0.087	ton
Building paper	0.0075	"
Sheathing, plywood, 1/2 in. corner bracing (25 sq ft)	0.018	"
Sheathing, insulation board, 1/2 in. (25 sq ft)	0.032	"
Framing, steel, 24 in. OC	0.045	"
Insulation, mineral wool 2-in. batts	0.027	"
Gypsum board, 1/2 in.	0.104	"
Nails	0.0025	"

TABLE III-1, *continued*

Exterior walls, cont.

7. Medium-density fiberboard siding, sheathing, aluminum framing.

All components same as Nos. 3 and 6 above except

Framing, aluminum, 24 in OC in place of other framing	0.015	ton

8. Brick veneer.

Brick veneer	1.76	tons
Sheathing: insulation board, 1/2 in.	0.032	ton
Plywood corner bracing, 1/2 in.	0.018	"
Building paper	0.0075	"
Framing 2 in. x 4 in., 24 in. OC	0.059	"
Insulation 2-in. batts mineral wool	0.027	"
Gypsum board, 1/2 in.	0.104	"
Nails	0.0025	"

Interior Walls

1. Wood framing, 24 in. OC.

Gypsum board, 1/2 in. both sides	0.208	ton
Framing 2 in. x 4 in. -- load bearing	0.059	"
or 2 in. x 3 in. -- non-load bearing	0.042	"
Nails	0.0019	"

2. Aluminum framing, 24 in. OC

Gypsum board, 1/2 in. both sides	0.208	ton
Framing, non-load bearing	0.0071	"
Nails	0.0019	"

3. Steel framing, 24 in. OC.

Gypsum board, 1/2 in. both sides	0.208	ton
Framing, non-load bearing	0.021	"
Nails	0.0019	"

Roofs
(30 lb/sq ft live load)

1. W-type wood truss, 28-ft span, 24 in. OC.

Truss lumber	0.107	ton
Truss plates -- 3.05 lbs/truss	0.0029	"
Roof sheathing 114 sq ft 1/2-in. plywood	0.083	"
Roofing felt	0.0086	"
Wood shingles -- 1.14 squares @ 128 lbs/sq	0.073	"
Gypsum board ceiling, 100 sq ft	0.104	"
Insulation, 3.5 in. loose mineral wool	0.048	"
Nails	0.0025	"

2. Same as No. 1 above except asphalt instead of wood shingles.

Asphalt shingles -- 1.14 squares @ 240 lbs/sq	0.137	ton

TABLE III-1, *continued*

Roofs, cont.

3. Steel rafters (Flat roof).

Rafters, "C" beam, 7 1/2 in. deep, 14 ft simple span, 24 in OC	0.057	ton
(Load bearing center, 2 in. x 4 in.)	0.017	"
Sheathing, 1/2-in. plywood	0.073	"
Built-up roofing, 3/8-in. thick 70 lbs/cu ft	0.109	"
Gypsum board ceiling, 100 sq ft	0.104	"
Insulation, 3.5 in. loose mineral wool	0.048	"
Nails	0.0025	"

4. Laminated veneer lumber joists (Flat roof).

1.5 in. x 7.6 in., 14-ft span, 24 in. OC joists	0.074	ton
(Load bearing center wall, 2 in. x 4 in. framing)	0.017	"
Flakeboard sheathing 45.3 lb/cu ft, 1/2 in.	0.094	"
Built-up roofing, 3/8 in.	0.109	"
Gypsum board ceiling	0.104	"
Insulation, 3.5 in. loose mineral wool	0.048	"
Nails	0.0025	"

[a] On center.

[b] Laminated veneer lumber.

[c] Medium-density fiberboard.

TABLE III-2. *Summary of requirements for 100 square feet of construction for alternative designs (including extraction, manufacture, transport to building site and erection[a])*

	Manpower	Net Energy[b]	Capital Depreciation
	Man-Hours	*Million BTU*	*Dollars*
Floors (all with carpet and pad, except No. 2)			
1. Wood joist, plywood subfloor, and particle-board 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[c] joist and flakeboard[d]	7.76	2.05	7.23
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-in. 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
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[c] and flakeboard[d]	9.36	2.45	6.59

[a]For design descriptions, see III-1.

[b]Energy from wood residues credited only against gross energy requirements of manufacturing phase, not against logging or transport of wood components.

[c]Laminated veneer lumber.

[d]Erection man-hours unavailable. Approximations based on similar constructions.

TABLE III-3. *Some comparisons of requirements for 100 square feet of construction for alternative designs (from extraction to the building site, but not including erection)*

Design from Table III-1	Function and Material	Labor	Capital Depreciation	Net Energy
		Man-Hours	*Dollars*	*Million BTU*
	Floor Joists			
Floor 1,3	Softwood Lumber	1.395	1.42	.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 Slab	4.469	5.01	19.849
	Interior Wall Studs			
Interior Wall 1	2 x 3 Lumber	.423	.43	.123
Interior Wall 2	Aluminum	.376	.39	1.423
Interior Wall 3	Steel	.278	.51	1.056
	Exterior Wall Framing			
Exterior Wall 1,2,3,5	Wood	.593	.60	.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	Medium-Density Fiberboard, 1/2 inch	.728	2.90	.739
Exterior Wall 5	Aluminum	.795	.80	3.007
Exterior Wall 1	Plywood, 5/8 inch	.997	1.63	.546
Exterior Wall 8	Brick, 3-1/4 inch	7.688	4.56	15.932
	Flooring			
Floor 2	Oak, 3/4 inch	1.901	4.09	.381
Floor 1,3,4,5,6	Carpet and pad	2.752	3.22	1.041
	Sheathing			
Exterior Wall 3,5,6,7,8	1/2-inch Insulation Board plus Plywood Corners	.548	1.28	.483
Exterior Wall 2	Plywood, 3/8 inch	.603	.98	.330

TABLE III-4. *Shipping distances and modes from fabrication plant to retail yard -- wood products*

Commodity	Rail		Truck		Ship & Other	
	Average Distance	Quantity	Average Distance	Quantity	Average Distance	Quantity
	Miles	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*
Softwood Lumber[a]	1,750	52.4	670	44.4	5,000[e]	3.2
Softwood Plywood[a]	1,560	73.5	1,170	24.7	5,000[e]	1.8
Oak Flooring[a]	1,200	40.0	700	60.0	0	0
Particleboard[b]	742	58.0	425	42.0	0	0
Insulation Board[c]	976	58.0	385	42.0	0	0
Medium-Density Fiberboard[d]	870	70.0	400	30.0	0	0
Wet-Formed Hardboard[b]	870	70.0	400	30.0	0	0
Structural Flakeboard[e]	1,000	50.0	400	50.0	0	0
Lumber Laminated from Veneer	---------------------Same as softwood lumber ---------------------					
Hardwood Plywood	---------------------Same as oak flooring -----------------------					

[a]Based on data from the National Forest Products Association.

[b]Based on data from National Particleboard Association.

[c]From a knowledgeable industrial source.

[d]Assumed to be the same as wet-formed hardboard.

[e]Estimate from knowledgeable industrial source.

TABLE III-5. *Man-hours, capital depreciation, and energy requirements per ton-mile from mill to retail yard*[a]

Transport mode	Capital Depreciation	Manpower	Energy (diesel fuel)
	Dollars	*Man-Hours*	*MM BTU*
Rail[b]	0.0009785	0.001253	0.000652
Truck[c]	.00331	.00230	.00280
Ship[d]	.0005	.0006	.0003

[a]Off-loading at the retail yard increases these values (multiplied by miles hauled):

Capital depreciation per ton:	$ .41
Man-Hours per ton:	.20
Energy per ton:	.125 million BTU

[b]Based on data for all railroads from Association of American Railroads.

[c]Based on data from a knowledgeable industrial source.

[d]Estimated values.

TABLE III-6. *Shipping distances and modes from fabrication plant to retail yard -- non-wood products*[a]

Commodity	Rail Average Distance	Rail Quantity	Truck Average Distance	Truck Quantity	Ship Average Distance	Ship Quantity
	Miles	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*
Nails (steel)	532	35	282	64	1,518	1
Steel Studs	653	22	367	77	721	1
Steel Joists	-----Same as steel studs-----					
Concrete Slab	-----Same as gravel (i.e., pit to ready-mix plant)-----					
Carpet and Pad	969	19	634	81	0	0
Gypsum Board	349	17	120	81	189	2
Concrete Block	-----Same as gypsum board-----					
Asphalt Shingles	335	15	171	68	559	17
Aluminum Siding	-----Same as steel studs-----					
Clay Brick	458	25	163	75	0	0
Glass Fiber Insulation	739	54	285	40	79	6
Tar Paper (impregnated felt)	-----Same as asphalt shingles-----					
Liquid Asphalt	-----Same as asphalt shingles-----					
Blown Insulation (vermiculite)	-----Same as glass fiber insulating batts-----					
Gravel[b]	100	40	25	40	100	20
Plastic Vapor Barrier (6-mil)	533	45	221	37	498	18

[a]Based on data from the Bureau of Census.

[b]Knowledgeable estimate.

TABLE III-7. *Capital depreciation, energy, and man-hours required per ton of product to deliver wood commodities from retail yard to building site*[a]

	Yard Number 1	2	3	4	5	6	7[b]	8[c]	9	Weighted Average
Depreciation per O D ton of Commodity Transported, Dollars	2.21	.74	.79	.69	.26	.46	.26	.83	.28	.68
Million BTU per O D ton[d]	.256	.200	.189	.240	.092	.070	.140	.643	.167	.214
Man-Hours per O D ton	1.24	1.06	.86	1.2	.50	.35	.28	1.3	.28	.74

[a]Based on survey of geographically widely dispersed retail yards (District of Columbia, California, Idaho, Louisiana, Michigan, Minnesota, New Jersey, Rocky Mountain states, Utah)

[b]Composite of yards in Los Angeles, New Jersey, and Seattle.

[c]Composite of many Rocky Mountain yards.

[d]Gasoline has BTU content of $\frac{21,400\ \text{BTU/lb}}{.1711\ \text{gal/lb}} = 125,073\ \text{BTU/gal}$.

TABLE III-8. *Man-hour requirements for components in 100 square feet of each floor system*

Component	O D Weight	Extraction	Manufacture	Transport[a]	Erection	Total
	Tons	*Man-Hours*				
Floor No. 1: Wood joist, subfloor and underlayment						
Joists	0.139	0.545	0.425	0.425		1.395
Plywood	.073	.226	.332	.242		.800
Particleboard	.070	.353	.185	.139		.677
Carpet & pad	.028	.045	2.624	.083		2.752
Nails	.0019	.002	.019	.004		.025
Total	0.3119	1.171	3.585	0.893	3.500	9.149
Percent		12.8	39.2	9.7	38.3	100.0
Floor No. 2: Wood joist, subfloor, oak finish floor						
Oak flooring	0.125	0.558	1.009	0.334		1.901
Plywood	.073	.226	.332	.242		.800
Joists	.093	.365	.285	.285		.935
Nails	.0019	.002	.019	.004		.025
Total	.2929	1.151	1.645	0.865	4.850	8.511
Percent		13.5	19.3	10.2	57.0	100.0
Floor No. 3: Wood joist, "single layer" floor						
Joists	0.139	0.545	0.425	0.425		1.395
Plywood	.091	.282	.414	.301		.997
Carpet & pad	.028	.045	2.624	.083		2.752
Nails	.0019	.002	.019	.004		.025
Total	0.2599	0.874	3.482	0.813	2.600	7.769
Percent		11.2	44.8	10.5	33.5	100.0
Floor No. 4: Concrete slab						
Concrete	2.33	0.221	1.848	2.400		4.469
Gravel	2.50	.195	0	2.575		2.770
Vapor barrier	.0015	.061	.145	.002		.149
Carpet & pad	.028	.045	2.624	.083		2.752
Total	4.860	0.462	4.617	5.060	1.480	11.619
Percent		4.0	39.7	43.6	12.7	100.0
Floor No. 5: Steel joist, 2-4-1 plywood						
Joists	0.42	0.375	4.242	0.945		5.562
Plywood	.164	.508	.746	.543		1.797
Carpet & pad	.028	.045	2.624	.083		2.752
Nails	.0019	.002	.019	.004		.025
Total	0.6139	0.930	7.631	1.575	1.830	11.966
Percent			7.8	63.8	13.1	100.0
Floor No. 6: LVL joist and flakeboard plus carpet and pad						
Joists	0.112	0.345	0.507	0.343		1.195
Flakeboard	.118	.468	.471	.253		1.192
Carpet and pad	.028	.045	2.624	.083		2.752
Nails	0019	.002	.019	.004		.025
Total	0.2599	0.860	3.621	0.683	3.500[b]	8.664
Percent		9.9	41.8	7.9	40.4	100.0

[a]Commodity from the factory to retail yard to house site.

[b]Not in production. Assumed to be the same as Floor No. 1.

TABLE III-9. *Energy requirements for components in 100 square feet of each floor system*

Component	OD Weight	Extraction	Manufacture Electric	Manufacture Heat	Transport[a]	Gross Total	Available Residue Energy	Net Total[b]
	Tons	*Million BTU (oil equivalent)*						
	Floor No. 1: Wood joist, subfloor and underlayment							
Joists	0.139	0.131	0.109	0.564	0.273	1.077	1.156	0.404
Plywood	.073	.055	.011	.491	.152	.709	.270	.439
Particle-board	.070	.323	.175	.392	.084	.974	.107	.867
Carpet & pad	.028	.185	-----.803-----		.053	1.041	.000	1.041
Nails	.0019	.005	-----.088-----		.003	.096	.000	.096
Total	0.3119	0.699	2.633		0.565	3.897		2.847
Percent (of gross)		17.9	67.6		14.5	100.0		
	Floor No. 2: Wood joist, subfloor, oak finish floor							
Oak flooring	0.125	0.134	0.106	0.605	0.247	1.092	1.424	0.381
Plywood	.073	.055	.011	.491	.152	.709	.270	.439
Lumber joists	.093	.088	.073	.378	.183	.722	.773	.271
Nails	.0019	.005	-----.088-----		.003	.096	0	.096
Total	0.2929	0.282	1.752		0.585	2.619		1.187
Percent (of gross)		10.8	66.9		22.3	100.0		
	Floor No. 3: Wood joist, "single layer" floor							
Joist	0.139	0.131	0.109	0.564	0.273	1.077	1.156	0.404
Plywood	.091	.068	.013	.612	.189	.882	.336	.546
Carpet & pad	.028	.185	-----.803-----		.053	1.041	0	1.041
Nails	.0019	.005	-----.088-----		.003	.096	0	.096
Total	0.2599	0.389	2.189		0.518	3.096		2.087
Percent (of gross)		12.6	70.7		16.7	100.0		
	Floor No. 4: Concrete slab							
Concrete	2.33	1.21	17.70		0.930	19.84	0	19.84
Gravel	2.50	.129	-------.0------		.998	1.127	0	1.127
Vapor barrier	0.0015	0.007	0.038		0.001	0.046	0	0.046
Carpet & pad	.028	.185	-----.803------		.053	1.041	0	1.041
Total	4.859	1.531	18.54		1.982	6.439		22.054
Percent (of gross)		6.9	84.1		9.0	100.00		
	Floor No. 5: Steel joist, 2-4-1 plywood							
Joist	0.42	1.029	--19.404-----		0.701	21.134	0	21.134
Plywood	.164	.123	.024	1.103	.341	1.501	.606	.985
Carpet & pad	.028	.185	----.803-----		.053	1.041	0	1.041
Nails	.0019	.005	----.088-----		.003	.096	0	.096
Total	0.6139	1.342	21.422		1.098	23.862		23.256
Percent (of gross)		5.6	89.8		4.6	100.0		
	Floor No. 6: LVL joist and flakeboard plus carpet and pad							
Joist	0.112	0.083	0.016	0.722	0.220	1.041	0.396	0.645
Flakeboard	.118	.113	.068	.818	.155	1.154	1.017	.268
Carpet & pad	.028	.185	-----.803-----		.053	1.041	0	1.041
Nails	.0019	.005	-----.088-----		.003	.096	0	.096
Total	0.2599	0.386	2.515		0.431	3.332		2.050
Percent (of gross)		11.6	75.5		12.9	100.0		

[a]Commodity from the factory to retail yard to house site.

[b]Assumes energy from residuals can be internally used or exchanged in manufacturing phase only (not logging or transport).

TABLE III-10. *Capital depreciation requirements for components in 100 square feet of each floor system*

Component	O D Weight	Extraction	Manufacture	Transport[a]	Total
	Tons	*Dollars*			
Floor No. 1:	Wood joist, subfloor and underlayment				
Joists	0.139	0.43	0.54	0.45	1.42
Plywood	.073	.18	.88	.25	1.31
Particleboard	.070	.47	.96	.15	1.58
Carpet & pad	.028	.23	2.91	.08	3.22
Nails	.0019	.01	.03	.01	.05
Total	0.3119	1.32	5.32	0.94	7.58
Percent		17.4	70.2	12.4	100.0
Floor No. 2:	Wood joist, subfloor, oak finish floor				
Oak flooring	0.125	0.44	3.26	0.39	4.09
Plywood	.073	.18	.88	.25	1.31
Lumber joists	.093	.29	.36	.30	.95
Nails	.0019	.01	.03	.01	.05
Total	0.2929	0.92	4.53	0.95	6.40
Percent		14.4	70.8	14.8	100.0
Floor No. 3:	Wood joist, "single layer" floor				
Joists	0.139	0.43	0.54	0.45	1.42
Plywood	.091	.22	1.10	.31	1.63
Carpet & pad	.028	.23	2.91	.08	3.22
Nails	.0019	.01	.03	.01	.05
Total	0.2599	0.89	4.58	0.85	6.32
Percent		14.1	72.5	13.4	100.0
Floor No. 4:	Concrete slab				
Concrete	2.33	0.43	1.85	2.73	5.01
Gravel	2.50	.46	0	2.93	3.39
Vapor barrier	0.0015	.1	.18	0	.19
Carpet & pad	.028	.23	2.91	.08	3.22
Total	4.860	1.13	4.94	5.74	11.81
Percent		9.6	41.8	48.6	100.0
Floor No. 5:	Steel joist, 2-4-1 plywood				
Joists	0.42	2.01	6.97	1.15	10.13
Plywood	.164	.40	1.98	.56	2.94
Carpet & pad	.028	.23	2.91	.08	3.22
Nails	.0019	.01	.03	.01	.05
Total	0.6139	2.65	11.89	1.80	16.34
Percent		16.2	72.8	11.0	100.0
Floor No. 6:	LVL joist and flakeboard plus carpet and pad				
Joists	0.112	0.27	1.34	0.36	1.97
Flakeboard	.118	.37	1.34	.28	1.99
Carpet & pad	.028	.23	2.91	.08	3.22
Nails	.0019	.01	.03	.01	.05
Total	0.2599	0.88	5.62	0.73	7.23
Percent		12.2	77.7	10.1	100.0

[a]Commodity from the factory to retail yard to house site.

TABLE III-11. *Man-hour requirements for components in 100 square feet of each exterior wall system*

Component	O D Weight	Extraction	Manufacture	Transport[a]	Erection	Total
	Tons			*Man-Hours*		
Exterior Wall No. 1: Plywood siding (no sheathing), 2 x 4 frame						
Siding	0.091	0.282	0.414	0.301		0.997
Building paper	.0075	.005	.030	.010		.045
Framing	.059	.231	.181	.181		.593
Insulation	.027	.030	.473	.046		.549
Gypsum	.104	.036	.181	.129		.346
Nails	.0019	.002	.019	.004		.025
Total	0.2904	0.586	1.298	0.671	5.430	7.985
Percent		7.3	16.3	8.4	68.0	100.0
Exterior Wall No. 2: Medium-density board siding, plywood sheathing, 2 x 4 frame						
Siding	0.087	0.298	0.249	.181		0.728
Sheathing	.055	.171	.250	.182		.603
Building paper	.0075	.005	.030	.010		.045
Framing	.059	.231	.181	.181		.593
Insulation	.027	.030	.473	.046		.549
Gypsum	.104	.036	.181	.129		.346
Nails	.0025	.002	.025	.006		.033
Total	0.3420	0.773	1.389	0.735	6.960	9.857
Percent		7.8	14.1	7.5	70.6	100.0
Exterior Wall No. 3: Medium-density board, 1/2 inch insulation board and plywood corner bracing						
Siding	0.087	0.298	0.249	0.181		0.728
Sheathing, plywood	.018	.056	.082	.060		.198
Sheathing, insulation board	.032	.073	.209	.068		.350
Building paper	.0075	.005	.030	.010		.045
Framing, lumber	.059	.231	.181	.181		.593
Insulation	.027	.030	.473	.046		.549
Gypsum board	.104	.036	.181	.129		.346
Nails	.0025	.002	.025	.006		.033
Total	0.3370	0.731	1.430	0.681	6.420	9.262
Percent		7.9	15.4	7.4	69.3	100.0
Exterior Wall No. 4: Concrete building block, no insulation						
Building block	1.887	0.179	3.302	2.340		5.821
Furring strips	.0066	.026	.020	.020		.066
Gypsum	.104	.036	.181	.129		.346
Nails	.0013	.001	.013	.003		.017
Total	1.9989	0.242	3.516	2.492	12.200	18.450
Percent		1.3	19.1	13.5	66.1	100.0
Exterior Wall No. 5: Aluminum siding over sheathing						
Siding	0.015	0.009	0.752	0.034		0.795
Building paper	.0075	.005	.030	.010		.045
Sheathing, plywood	.018	.056	.082	.060		.198
Sheathing, insulation board	.032	.073	.209	.068		.350
Framing	.059	.231	.181	.181		.593
Insulation	.027	.030	.473	.046		.549
Gypsum	.104	.036	.181	.129		.346
Nails	.0025	.002	.025	.006		.033
Total	0.2650	0.442	1.933	0.534	6.920	9.828
Percent		4.5	19.7	5.4	70.4	100.0

TABLE III-11, *continued*

Component	O D Weight	Extraction	Manufacture	Transport[a]	Erection	Total
	Tons			*Man-Hours*		
		Exterior Wall No. 6: Siding, sheathing, steel studs				
Siding, MDF	0.087	0.298	0.249	.181		0.728
Building paper	.0075	.005	.030	.010		.045
Sheathing, plywood	.018	.056	.082	.060		.198
Sheathing, insulation board	.032	.073	.209	.068		.350
Framing, steel	.045	.040	.455	.101		.596
Insulation	.027	.030	.473	.046		.549
Gypsum	.104	.036	.181	.129		.346
Nails	.0025	.002	.025	.006		.033
Total	0.3230	0.540	1.704	0.601	7.040	9.885
Percent		5.5	17.2	6.1	71.2	100.0
		Exterior Wall No. 7: Siding, sheathing, aluminum framing				
Siding, MDF	0.087	0.298	0.249	.181		0.728
Building paper	.0075	.005	.030	.010		.045
Sheathing, plywood	.018	.056	.082	.060		.198
Sheathing, insulation board	.032	.073	.209	.068		.350
Framing, aluminum	.015	.009	.752	.034		.795
Gypsum	.104	.036	.181	.129		.346
Nails	.0025	.002	.025	.006		.033
Insulation	.027	.030	.473	.046		.549
Total	0.2930	0.509	2.001	0.534	8.220	11.264
Percent		4.5	17.8	4.7	73.0	100.0
		Exterior Wall No. 8: Brick veneer				
Bricks (clay)	1.76	0.137	5.157	2.394		7.688
Sheathing, plywood corners	.018	.056	.082	.060		.198
Sheathing, insulation board	.032	.073	.209	.068		.350
Framing, lumber	.059	.231	.181	.181		.593
Building paper	.0075	.005	.030	.010		.045
Insulation	.027	.030	.473	.046		.549
Gypsum board	.104	.036	.181	.129		.346
Nails	.0025	.002	.025	.006		.033
Total	2.0100	0.570	6.338	2.894	12.200[b]	22.002
Percent		2.6	28.8	13.2	55.4	100.0

[a]Commodity from the factory to retail yard to house site.

[b]Assumed to be the same as for concrete or cinder block.

TABLE III-12. *Energy requirements for components in 100 square feet of each exterior wall system*

Component	OD Weight	Extraction	Manufacture Electric	Manufacture Heat	Transport[a]	Gross Total	Available Residue Energy	Net Total[b]
	Tons	*Million BTU (oil equivalent)*						
Exterior Wall No. 1: Plywood siding (no sheathing), 2 x 4 frame								
Siding	0.091	0.068	0.013	0.612	0.189	0.882	0.336	0.546
Building paper	.0075	.001	-----.038-----		.005	.044	0	.044
Framing	.059	.056	.046	.240	.116	.458	.490	.172
Insulation	.027	.017	-----.721-----		.025	.763	0	.763
Gypsum	.104	.015	-----.284-----		.068	.367	0	.367
Nails	.0019	.005	-----.088-----		.003	.096	0	.096
Total	0.2904	0.162	2.042		0.406	2.610		1.988
Percent (of gross)		6.2	78.2		15.6	100.0		
Exterior Wall No. 2: Medium-density fiberboard siding, plywood sheathing, 2 x 4 frame								
Siding	0.087	0.068	0.326	0.483	0.100	0.977	0.238	0.739
Sheathing	.055	.041	.008	.370	.114	.533	.203	.330
Building paper	.0075	.001	-----.038-----		.005	.044	0	.044
Framing	.059	.056	.046	.240	.116	.458	.490	.172
Insulation	.027	.017	-----.721-----		.025	.763	0	.763
Gypsum	.104	.015	-----.284-----		.068	.367	0	.367
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	0.3420	0.204	2.632		0.432	3.268		2.541
Percent (of gross)		6.3	80.5		13.2	100.0		
Exterior Wall No. 3: Medium-density fiberboard, 1/2 inch insulation board and plywood corner bracing								
Siding	0.087	0.068	.326	0.483	0.100	0.977	0.238	0.739
Sheathing, plywood	.018	.013	.003	.121	.037	.174	.067	.107
Sheathing, insulation board	.032	.020	.157	.180	.040	.397	.021	.376
Building paper	.0075	.001	-----.038-----		.005	.044	0	.044
Framing	.059	.056	.046	.240	.116	.458	.490	.172
Insulation (2-inch batts)	.027	.017	-----.721-----		.025	.763	0	.763
Gypsum board	.104	.015	-----.284-----		.068	.367	0	.367
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	0.3370	0.196	2.715		0.395	3.306		2.694
Percent (of gross)		5.9	82.1		12.0	100.0		
Exterior Wall No. 4: Concrete building block, no insulation								
Building block	1.887	0.98	---14.34-----		1.223	16.543	0	16.543
Furring strips	.0066	.006	.005	.027	.013	.051	.055	.019
Gypsum	.104	.015	-----.284 ---		.068	.367	0	.367
Nails	.0013	.006	-----.116----		.004	.126	0	.126
Total	1.9989	1.007	14.767		1.313	17.087		17.087
Percent (of gross)		5.9	86.4		7.7	100.0		

TABLE III-12, *continued*

Component	OD Weight	Extraction	Manufacture Electric	Manufacture Heat	Transport[a]	Gross Total	Available Residue Energy	Net Total[b]
	Tons	*Million BTU (oil equivalent)*						
Exterior Wall No. 5: Aluminum siding over sheathing								
Siding	0.015	0.402	----2.580-----		0.025	3.007	0	3.007
Building paper	.0075	.001	-----.038-----		.005	.044	0	.044
Sheathing, plywood	.018	.013	.003	.121	.037	.174	.067	.107
Sheathing, insulation board	.032	.020	.157	.180	.040	.397	.021	.376
Framing	.059	.056	.046	.240	.116	.458	.490	.172
Insulation	.027	.017	-----.721-----		.025	.763	0	.763
Gypsum	.104	.015	-----.284-----		.068	.367	0	.367
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	0.2650	0.530	4.486		0.320	5.336		4.953
Percent (of gross)		9.9	84.1		6.0	100.0		
Exterior Wall No. 6: MDF siding, sheathing, steel studs								
Siding	0.087	0.068	0.326	0.483	0.100	0.977	0.238	0.739
Building paper	.0075	.001	-----.038----		.005	.044	0	.044
Sheathing, plywood	.018	.013	.003	.121	.037	.174	.067	.107
Sheathing, insulation board	.032	.020	.157	.180	.040	.397	.021	.376
Framing	.045	.110	----2.079-----		.075	2.264	0	2.264
Insulation	.027	.017	-----.721-----		.025	.763	0	.763
Gypsum	.104	.015	-----.284-----		.068	.367	0	.367
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	0.3230	0.250	4.508		0.354	5.112		4.786
Percent (of gross)		4.9	88.2		6.9	100.0		
Exterior Wall No. 7: MDF siding sheathing, aluminum framing								
Siding	0.087	0.068	0.326	0.483	0.100	0.977	0.238	0.739
Building paper	.0075	.001	-----.038----		.005	.044	0	.044
Sheathing, plywood	.018	.013	.003	.121	.037	.174	.067	.107
Sheathing, insulation board	.032	.020	.157	.180	.040	.397	.021	.376
Framing	.015	.402	----2.580-----		.025	3.007	0	3.007
Insulation	.027	.017	-----.721-----		.025	.763	0	.763
Gypsum	.104	.015	-----.284-----		.068	.367	0	.367
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	0.2930	0.542	5.009		0.304	5.855		5.529
Percent (of gross)		9.3	85.5		5.2	100.0		
Exterior Wall No. 8: Brick veneer								
Bricks (clay)	1.76	0.996	---13.605-----		1.331	15.932	0	15.932
Sheathing, plywood	.018	.013	.003	.121	.037	.174	.067	.107
Sheathing, insulation board	.032	.020	.157	.180	.040	.397	.021	.376
Framing	.059	.056	.046	.240	.116	.458	.490	.172
Building paper	.0075	.001	-----.038-----		.005	.044	0	.044
Insulation	.027	.017	-----.721-----		.025	.763	0	.763
Gypsum	.104	.015	-----.284-----		.068	.367	0	.367
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	2.0100	1.124	15.511		1.626	18.261		17.887
Percent (of gross)		6.2	84.9		8.9	100.00		

[a] Commodity from the factory to retail yard to house site.

[b] Assumes energy from residuals can be internally used or exchanged in manufacturing phase only (not logging or transport).

TABLE III-13. *Capital depreciation requirements for components in 100 square feet of each exterior wall system*

Component	O D Weight	Extraction	Manufacture	Transport[a]	Total
	Tons		*Dollars*		
Exterior Wall No. 1:	Plywood siding (no sheathing), 2 x 4 frame				
Siding	0.091	0.22	1.10	0.31	1.63
Building paper	.0075	.01	.04	.01	.06
Framing	.059	.18	.23	.19	.60
Insulation (2-inch batts)	.027	.03	.89	.05	.97
Gypsum	.104	.04	.65	.15	.84
Nails	.0019	.01	.03	.01	.05
Total	0.2904	0.49	2.94	0.72	4.15
Percent		11.8	70.8	17.4	100.0
Exterior Wall No. 2:	Medium-density board siding, plywood sheathing, 2 x 4 frame				
Siding	0.087	0.28	2.43	.19	2.90
Sheathing	.055	.13	.66	.19	.98
Building paper	.0075	.01	.04	.01	.06
Framing	.059	.18	.23	.19	.60
Insulation	.027	.03	.89	.05	.97
Gypsum	.104	.04	.65	.15	.84
Nails	.0025	.01	.04	.01	.06
Total	0.3420	0.68	4.94	0.790	6.41
Percent		10.6	77.1	12.3	100.0
Exterior Wall No. 3:	Medium-density board, 1/2 inch insulation board and plywood corner bracing				
Siding	0.087	0.28	2.43	.19	2.90
Sheathing, plywood	.018	.04	.22	.06	.32
Sheathing, insulation board	.032	.12	.77	.07	.96
Building paper	.0075	.01	.04	.01	.06
Framing	.059	.18	.23	.19	.60
Insulation (2-inch batts)	.027	.03	.89	.05	.97
Gypsum	.104	.04	.65	.15	.84
Nails	.0025	.01	.04	.01	.06
Total	0.3370	0.71	5.27	0.73	6.71
Percent		10.6	78.5	10.9	100.0
Exterior Wall No. 4:	Concrete building block, no insulation				
Building block	1.887	0.35	1.50	2.77	4.62
Furring strips	.0066	.02	.03	.02	.07
Gypsum	.104	.04	.65	.15	.84
Nails	.0013	.01	.02	.0	.03
Total	1.9989	0.42	2.20	2.94	5.56
Percent		7.5	39.6	52.9	100.0
Exterior Wall No. 5:	Aluminum siding over sheathing				
Siding	0.015	0.03	.73	.04	0.80
Building paper	.0075	.01	.04	.01	.06
Sheathing, plywood	.018	.04	.22	.06	.32
Sheathing, insulation board	.032	.12	.77	.07	.96
Framing, lumber	.059	.18	.23	.19	.60
Insulation	.027	.03	.89	.05	.97
Gypsum	.104	.04	.65	.15	.84
Nails	.0025	.01	.04	.01	.06
Total	0.2650	0.46	3.57	0.58	4.61
Percent		10.0	77.4	12.6	100.0

TABLE III-13, *continued*

Component	O D Weight	Extraction	Manufacture	Transport[a]	Total
	Tons		*Dollars*		
Exterior Wall No. 6: Siding, sheathing, steel studs					
Siding	0.087	0.28	2.43	0.19	2.90
Building paper	.0075	.01	.04	.01	.06
Sheathing, plywood	.018	.04	.22	.06	.32
Sheathing, insulation board	.032	.12	.77	.07	.96
Framing	.045	.22	.75	.12	1.09
Insulation	.027	.03	.89	.05	.97
Gypsum	.104	.04	.65	.15	.84
Nails	.0025	.01	.04	.01	.06
Total	0.3230	0.75	5.79	0.66	7.20
Percent		10.4	80.4	9.2	100.0
Exterior Wall No. 7: Siding, sheathing, aluminum framing					
Siding	0.087	0.28	2.43	.19	2.90
Building paper	.0075	.01	.04	.01	.06
Sheathing, plywood	.018	.04	.22	.06	.32
Sheathing, insulation board	.032	.12	.77	.07	.96
Framing, aluminum	.015	.03	.73	.04	.80
Insulation	.027	.03	.89	.05	.97
Gypsum	.104	.04	.65	.15	.84
Nails	.0025	.01	.04	.01	.06
Total	0.2930	0.56	5.77	0.58	6.91
Percent		8.1	83.5	8.4	100.0
Exterior Wall No. 8: Brick veneer					
Bricks (clay)	1.76	0.33	1.40	2.83	4.56
Sheathing, plywood	.018	.04	.22	.06	.32
Sheathing insulation board	.032	.12	.77	.07	.96
Framing, lumber	.059	.18	.23	.19	.60
Building paper	.0075	.01	.04	.01	.06
Insulation	.027	.03	.89	.05	.97
Gypsum	.104	.04	.65	.15	.84
Nails	.0025	.01	.04	.01	.06
Total	2.0100	0.76	4.24	3.37	8.37
Percent		9.1	50.6	40.3	100.0

[a]Commodity from the factory to retail yard to house site.

TABLE III-14. *Man-hour, energy, and capital depreciation requirements for components in each interior wall system*

Component	O D Weight	Extraction	Manufacture	Transport[a]	Erection	Total
	Tons		*Man-Hours*			
Interior Wall No. 1: Wood framing						
Gypsum	0.208	0.071	0.362	0.258		0.691
Framing	.042	.165	.129	.129		.423
Nails	.0019	.002	.019	.004		.025
Total	0.2519	0.238	0.510	0.391	2.730	3.869
Percent		6.2	13.2	10.1	70.5	100.0
Interior Wall No. 2: Aluminum framing						
Gypsum	0.208	0.071	0.362	0.258		0.691
Framing	.0071	.004	.356	.016		.376
Nails	.0019	.002	.019	.004		.025
Total	0.2170	0.077	0.737	0.278	2.900	3.992
Percent		1.9	18.5	7.0	72.6	100.0
Interior Wall No. 3: Steel Framing						
Gypsum	0.208	0.071	0.362	0.258		0.691
Framing	.021	.019	.212	.047		.278
Nails	.0019	.002	.019	.004		.025
Total	0.2309	0.092	0.593	0.309	2.540	3.534
Percent		2.6	6.8	8.7	71.9	100.0

Component	Extraction	Manufacture Electric	Manufacture Heat	Transport[a]	Gross Total	Available Residue Energy	Net Total[b]
		Million BTU (oil equivalent)					
Interior Wall No. 1: Wood framing							
Gypsum	0.029	----0.568-----		0.135	0.732	0	0.732
Framing	.040	.033	.171	.083	.327	.350	.123
Nails	.005	-----.088-----		.003	.096	0	.096
Total	0.074	0.860		0.221	1.155		0.951
Percent (of gross)	6.4	74.5		19.1	100.0		
Interior Wall No. 2: Aluminum framing							
Gypsum	0.029	----0.568-----		0.135	0.732	0	0.732
Framing	.190	----1.221-----		.012	1.423	0	1.423
Nails	.005	-----.088-----		.003	.096	0	.096
Total	0.224	1.877		0.150	2.251		2.251
Percent (of gross)	9.9	83.4		6.7	100.00		
Interior Wall No. 3: Steel framing							
Gypsum	0.029	----0.568-----		0.135	0.732	0	0.732
Framing	.051	-----.970-----		.035	1.056	0	1.056
Nails	.005	-----.088-----		.003	.096	0	.096
Total	0.085	1.626		0.173	1.884		1.884
Percent (of gross)	4.5	86.3		9.2	100.0		

TABLE III-14, *continued*

Component		Extraction	Manufacture	Transport[a]	Total
			Dollars		
	Interior Wall No. 1: Wood framing				
Gypsum		0.08	1.30	0.31	1.69
Framing		.13	.16	.14	.43
Nails		.01	.03	.01	.05
	Total	0.22	1.49	0.46	2.17
	Percent	10.1	68.7	21.2	100.0
	Interior Wall No. 2: Aluminum framing				
Gypsum		0.08	1.30	.31	1.69
Framing		.02	.35	.02	.39
Nails		.01	.03	.01	.05
	Total	0.11	1.68	0.34	2.13
	Percent	5.2	78.9	15.9	100.0
	Interior Wall No. 3: Steel framing				
Gypsum		0.08	1.30	.31	1.69
Framing		.10	.35	.06	.51
Nails		.01	.03	.01	.05
	Total	0.19	1.68	0.38	2.25
	Percent	8.4	74.7	16.9	100.0

[a]Commodity from the factory to retail yard to house site.

[b]Assumes energy from residuals can be internally used or exchanged in manufacturing phase only (not logging or transport).

TABLE III-15. *Man-hour requirements for components in 100 square feet of each roof system*[a]

Component	O D Weight	Extraction	Manufacture	Transport[b]	Erection	Total
	Tons	*Man-Hours*				
Roof No. 1: W-type wood truss, wood shingles						
Truss lumber	0.107	0.419	0.327	0.327		1.073
Truss plates	.0029	.003	.029	.006		.038
Roof sheathing	.083	.257	.378	.275		.910
Roofing felt	.0086	.005	.034	.011		.050
Wood shingles	.073	.286	.223	.223		.732
Gypsum ceiling	.104	.036	.181	.129		.346
Insulation	.048	.004	.514	.082		.600
Nails	.0025	.002	.025	.006		.033
Total	0.4290	1.012	1.711	1.059	5.180	8.962
Percent		11.3	19.1	11.8	57.8	100.00
Roof No. 2: Same as No. 1, but shingles are asphalt						
Truss lumber	0.107	0.419	0.327	0.327		1.073
Truss plates	.0029	.003	.029	.006		.038
Roof sheathing	.083	.257	.378	.275		.910
Roofing felt	.0086	.005	.034	.011		.050
Asphalt shingles	.137	.025	.603	.182		.810
Gypsum Ceiling	.104	.036	.181	.129		.346
Insulation	.048	.004	.514	.082		.600
Nails	.0025	.002	.025	.006		.033
Total	0.4930	0.751	2.091	1.018	5.180	9.040
Percent		8.3	23.1	11.3	57.3	100.0
Roof No. 3: Steel rafters (flat roof)						
Rafters	0.057	0.051	0.576	0.124		0.751
Load-bearing center wall-lumber	.017	.067	.052	.052		.171
Sheathing	.073	.226	.332	.242		.800
Built-up roofing[c]	.109	.040	.452	.145		.637
Gypsum ceiling	.104	.036	.181	.129		.346
Insulation	.048	.004	.514	.082		.600
Nails	.0025	.002	.025	.006		.033
Total	0.4105	0.426	2.132	0.780	5.830	9.168
Percent		4.6	23.3	8.5	63.6	100.0
Roof No. 4: Flat roof with LVL and flakeboard						
LVL horizontal rafters	0.074	0.228	0.335	0.226		0.789
Load bearing center wall-lumber	.017	.067	.052	.052		.171
Flakeboard	.094	.373	.375	.201		.949
Built-up roofing[c]	.109	.040	.452	.145		.637
Gypsum ceiling	.104	.036	.181	.129		.346
Insulation	.048	.004	.514	.082		.600
Nails	.0025	.002	.025	.006		.033
Total	0.4485	0.750	1.934	0.841	5.830[d]	9.355
Percent		8.0	20.7	9.0	62.3	100.0

[a]Horizontal projection of roof structures.

[b]Commodity from the factory to retail yard to house site.

[c]50% roofing felt and 50% asphalt by weight.

[d]Not in production. Assumed to be the same as Roof No. 3.

TABLE III-16. *Energy requirements for components in 100 square feet of each roof system*[a]

Component	O D Weight	Extraction	Manufacture Electric	Manufacture Heat	Transport[b]	Gross Total	Available Residue Energy	Net Total[c]
	Tons	*Million BTU (oil equivalent)*						
	Roof No. 1: W-type wood truss, wood shingles							
Truss lumber	0.107	0.101	0.084	0.434	0.210	0.829	0.889	0.311
Truss plates	.0029	.007	-----.134-----		.005	.146	0	.146
Roof sheathing	.083	.062	.012	.558	.173	.805	.307	.498
Roofing felt	.0086	.002	-----.043-----		.006	.051	0	.051
Wood shingles	.073	.069	.057	.296	.144	.566	.607	.213
Gypsum ceiling	.104	.015	-----.284-----		.068	.367	0	.367
Insulation	.048	.002	-----.682-----		.044	.728	0	.728
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	0.4290	0.264	2.700		0.654	3.618		2.440
Percent		7.3	74.6		18.1	100.0		
	Roof No. 2: Same as No. 1, but shingles are asphalt (not wood)							
Truss lumber	0.107	0.101	0.084	0.434	0.210	0.829	0.889	0.311
Truss plates	.0029	.007	-----.134-----		.005	.146	0	.146
Roof sheathing	.083	.062	.012	.558	.173	.805	.307	.498
Roofing felt	.0086	.002	-----.043-----		.006	.051	0	.051
Asphalt shingles	.137	.113	-----.781-----		.100	.994	0	.994
Gypsum ceiling	.104	.015	-----.284-----		.068	.367	0	.367
Insulation	.048	.002	-----.682-----		.044	.728	0	.728
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	0.4930	0.308	3.128		0.610	4.046		3.221
Percent		7.6	77.3		15.1	100.0		
	Roof No. 3: Steel rafters (flat roof)							
Rafters	0.057	0.140	----2.633-----		0.095	2.868	0	2.868
Load-bearing center wall-lumber	.017	.016	.013	.069	.033	.131	.141	.049
Sheathing	.073	.055	.011	.491	.152	.709	.270	.439
Built-up roofing[d]	.109	.011	-----.447-----		.079	.537	0	.537
Gypsum ceiling	.104	.015	-----.284-----		.068	.367	0	.367
Insulation	.048	.002	-----.682-----		.044	.728	0	.728
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	0.4105	0.245	4.746		0.475	5.466		5.114
Percent		4.5	86.8		8.7	100.0		
	Roof No. 4: Flat roof with LVL and flakeboard							
LVL horizontal rafters	0.074	0.055	0.011	0.477	0.145	0.688	0.262	0.426
Load bearing center wall-lumber	.017	.016	.013	.069	.033	.131	.141	.049
Flakeboard	.094	.090	.054	.652	.124	.920	.810	.214
Built-up roofing[d]	.109	.011	-----.477-----		.079	.537	0	.537
Gypsum ceiling	.104	.015	-----.284-----		.068	.367	0	.367
Insulation	.048	.002	-----.682-----		.044	.728	0	.728
Nails	.0025	.006	-----.116-----		.004	.126	0	.126
Total	0.4485	0.195	2.805		0.497	3.497		2.447
Percent		5.6	80.2		14.2	100.00		

[a] Horizontal projection of roof structures.

[b] Commodity from factory to retail yard to house site.

[c] Assumes energy from residuals can be internally used or exchanged in manufacturing phase only (not logging or transport).

[d] 50% roofing felt and 50% asphalt by weight.

TABLE III-17. *Capital depreciation requirements for components in 100 square feet of each roof system*[a]

Component	O D Weight	Extraction	Manufacture	Transport[b]	Total
	Tons		*Dollars*		
Roof No. 1:	W-type wood truss, wood shingles				
Truss lumber	0.107	0.33	0.42	0.35	1.10
Truss plates	.0029	.01	.05	.01	.07
Roof sheathing	.083	.20	1.00	.28	1.48
Roofing felt	.0086	.01	.05	.01	.07
Wood shingles	.073	.23	.29	.24	.76
Gypsum ceiling	.104	.04	.65	.15	.84
Insulation	.048	.01	1.66	.09	1.76
Nails	.0025	.01	.04	.01	.06
Total	0.4290	0.84	4.16	1.14	6.14
Percent		13.7	67.7	18.6	100.00
Roof No. 2:	Same as No. 1, but shingles are asphalt				
Truss lumber	0.107	0.33	0.42	0.35	1.10
Truss plates	.0029	.01	.05	.01	.07
Roof sheathing	.083	.20	1.00	.28	1.48
Roofing felt	.0086	.01	.05	.01	.07
Asphalt shingles	.137	.11	1.01	.22	1.34
Gypsum ceiling	.104	.04	.65	.15	.84
Insulation	.048	.01	1.66	.09	1.76
Nails	.0025	.01	.04	.01	.06
Total	0.4930	0.72	4.88	1.12	6.72
Percent		10.7	72.6	16.7	100.0
Roof No. 3:	Steel rafters (flat roof)				
Rafters	0.057	0.27	0.95	0.15	1.37
Load bearing center wall -- lumber	.017	.05	.07	.06	.18
Sheathing	.073	.18	.88	.25	1.31
Built-up roofing[c]	.109	.11	.58	.17	.86
Gypsum ceiling	.104	.04	.65	.15	.84
Insulation	.048	.01	1.66	.09	1.76
Nails	.0025	.01	.04	.01	.06
Total	0.4105	0.67	4.83	0.88	6.38
Percent		10.5	75.7	13.8	100.0
Roof No. 4:	Flat roof with LVL and flakeboard				
LVL horizontal rafters	0.074	0.18	0.89	0.24	1.31
Load bearing center wall -- lumber	.017	.05	.07	.06	.18
Flakeboard	.094	.29	1.07	.22	1.58
Built-up roofing[c]	.109	.11	.58	.17	.86
Gypsum ceiling	.104	.04	.65	.15	.84
Insulation	.048	.01	1.66	.09	1.76
Nails	.0025	.01	.04	.01	.06
Total	0.4485	0.69	4.96	0.94	6.59
Percent		10.5	75.3	14.2	100.0

[a] Horizontal projection of roof structures.
[b] Commodity from the factory to retail yard to house site.
[c] 50 percent roofing felt and 50 percent asphalt by weight.