NON-PULP UTILIZATION OF ABOVE-GROUND BIOMASS OF MIXED-SPECIES FORESTS OF SMALL TREES

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ABSTRACT

This solution proposes to rehabilitate annually—by clear felling, site preparation, and planting—25,000 acres of level to rolling land averaging about 490 cubic feet per acre of stemwood in small hardwood trees 5 inches in diameter at breast height (dbh) and larger, and of many species, plus an equal volume of above-ground biomass in stembark and tops, and in trees smaller than 5 inches in dbh. By usual utilization procedures, such wood is an unmerchantable residue from the harvest of merchantable southern pines.

On an annual basis, 398,265 tons (oven-dry basis) of such wood and bark will be harvested and converted in an energy self-sufficient plant to the following: 208,688 tons of structural flakeboard sheathing and decking (sold at $200/ton), 16,298 tons of decorative hardwood plywood ($400/ton), and 20,191 tons of long fabricated joists with parallel-laminated veneer flanges and flakeboard webs ($600/ton), for a total product yield of about 60%—all on a dry-weight basis.

Following are projected operating results and other essential data for a three-shift operation:

Capital investment, including working capital	$50,000,000
Operating costs, annual	$40,000,000
Sales, annual	$60,371,400
Net profit, annual (before income taxes)	$20,371,400
Return on sales	33.7%
Return on investment	40.7%
Number of mill employees (harvesting and planting are contracted)	250
Electrical energy purchased annually	0 kWh
Diesel fuel and propane for front-end loaders and lift trucks (oil equivalent)	150,000 gallons
Wood residues burned annually (oven-dry-weight basis), all available from mill residues	168,186 tons

Keywords: Low-grade hardwoods, small hardwoods, harvesting, utilization, flakeboard, feasibility study, decorative plywood, fabricated joists.

INTRODUCTION

In north temperate, temperate, sub-tropical, and tropical climates of the world, there are extensive mixed-species forests comprised largely of small trees. These trees have, in many cases, defied economic utilization except as pulpwood—and only then with significant restrictions on species and diameters admitted—and as low-value fuelwood.

Hardwoods in the United States on sites economically better suited for growth of southern pine are one example of such woodlands (Fig. 1). In this paper their characteristics are scrutinized, and a model utilization solution is developed to suit these characteristics. The solution, with some modifications, should be widely applicable to other forests comprised of mixed species of small trees on level to rolling terrain.

The total hardwood resource of the South recently was estimated at 113.7 billion ft^3, which amounts to 2,051 million tons of oven-dry wood and bark. This

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FIG. 1. A typical scene in the southern United States after merchantable southern pines have been harvested. The residual pine logging slash, unmerchantable hardwoods of numerous species, and some small pines have a total above-ground biomass of about 980 cubic feet per acre. On industrial lands this residual wood is commonly windrowed and burned prior to replanting. Small private landowners, however, often cannot afford the costs of site preparation and planting, so the land frequently goes unplanted and remains stocked mainly with slow-growing small hardwoods of poor quality.

resource, spread over twelve states, can be divided into two site categories: southern pine and hardwood. Pine sites are defined—for the purposes of this paper—as forested uplands, excluding those growing cove-type hardwoods, that support southern pine or show evidence, e.g., stumps, of having done so. Hardwoods on pine sites total about 49.2 billion ft^3 of wood (888 million tons of wood and bark, oven-dry) or 43% of the total hardwood inventory (Table 1).

Since southern pines grow on about 100 million acres of commercial forestland, the southwide average volume of hardwoods 5 inches and larger in dbh growing among the southern pines is about 490 cu ft of wood per acre in these stems to a top diameter of 4 inches outside bark. Stembark on these trees may total an additional 73 cu ft per acre.

Tops and branches of these hardwood trees, together with pine logging slash and above-ground portions of trees smaller than 5 inches in diameter, probably average about 417 cu ft of additional wood and bark per acre. Above-ground components of hardwood trees of all diameters together might total about 17.4 tons (oven-dry basis) per acre on an average, or 31 tons on a green-weight basis—half of which is in stemwood 5 inches and larger in dbh.

How have pine sites become so heavily invaded by hardwoods? In most of the South, plant succession—the replacement of one plant community by another—

TABLE 1. *Volume of all hardwoods on pine sites and hardwood sites in twelve Southern states (Christopher et al. 1976).*[1]

	All sites	Pine sites	Hardwood sites
	Million cubic feet		
Alabama	10,886	6,456	4,430
Arkansas	11,174	4,926	6,248
Florida	5,461	1,078	4,383
Georgia	12,999	6,600	6,399
Louisiana	9,879	3,085	6,794
Mississippi	8,416	3,827	4,589
North Carolina	17,074	6,838	10,236
Oklahoma	1,601	633	968
South Carolina	8,093	3,358	4,735
Tennessee	10,255	3,724	6,531
Texas	4,222	2,593	1,629
Virginia	13,651	6,118	7,533
	113,711	49,236	64,475

[1] From source data gathered during 1964–1974 on systematic sample plots 2 to 4 miles apart. The volume is expressed in cubic feet inside bark of trees from stump to a minimum 4-inch top diameter (outside bark) of stem. All trees 5 inches in dbh and larger are included.

climaxes with a hardwood forest (Billings 1938; Quarterman and Keever 1962). Establishment of pine stands requires the absence of heavy litter and freedom from competing plant cover; wildfires often provide these conditions and check the succession to hardwoods. However, man has largely eliminated fire from the forest, thus favoring the shade-tolerant hardwoods.

TABLE 2. *The major hardwood species on pine sites.*

Common name	Botanical name
Ash, green	*Fraxinus pennsylvanica* Marsh.
Ash, white	*F. americana* L.
Elm, American	*Ulmus americana* L.
Elm, winged	*U. alata* Michx.
Hackberry	*Celtis* sp.
Hickory	*Carya* sp.
Maple, red	*Acer rubrum* L.
Oak, black	*Quercus velutina* Lam.
Oak, blackjack	*Q. marilandica* Muenchh.
Oak, cherrybark	*Q. falcata* Michx. var. *pagodaefolia* Ell.
Oak, chestnut	*Q. prinus* L.
Oak, laurel	*Q. laurifolia* Michx.
Oak, northern red	*Q. rubra* L.
Oak, post	*Q. stellata* Wangenh.
Oak, scarlet	*Q. coccinea* Muenchh.
Oak, Shumard	*Q. shumardii* Buckl.
Oak, southern red	*Q. falcata* Michx.
Oak, water	*Q. nigra* L.
Oak, white	*Q. alba* L.
Sweetbay	*Magnolia virginiana* L.
Sweetgum	*Liquidambar styraciflua* L.
Tupelo, black	*Nyssa sylvatica* Marsh.
Yellow-poplar	*Liriodendron tulipifera* L.

TABLE 3. *Species volumes on pine sites in the 12 southern states.*[1]

Species	Volume	Proportion of pine site hardwood volume
	Million cubic feet	*Percent*
Sweetgum	6,508	13.2
Oak, white	6,058	12.3
Hickory, sp.	4,173	8.5
Oak, southern red	3,994	8.1
Oak, post	3,444	7.0
Yellow-poplar	3,421	7.0
Tupelo, black	2,710	5.5
Oak, water	2,332	4.7
Oak, chestnut	2,102	4.2
Oak, black	1,949	4.0
Oak, scarlet	1,799	3.6
Maple, red	1,751	3.6
Oak, northern red	1,169	2.4
Oak, laurel	683	1.4
Elm, sp.	668	1.4
Oak, cherrybark	579	1.2
Ash, sp.	441	.9
Sweetbay	300	.6
Oak, Shumard	120	.2
Hackberry, sp.	57	.1
Other hardwoods	4,978	10.1
Total hardwoods	49,236	100.0

[1] Compiled from data of Christopher et al. (1976).

About 90% of the total hardwood volume on southern pine sites is composed of twenty-two species or species groups representing ten genera (Table 2). Stemwood of the inventoried hardwoods (Table 3) is probably less than half the total hardwood biomass (excluding foliage) grown on these sites. The remainder is in stembark, roots, stumps, and branches of inventoried stems and in trees smaller than 5 inches dbh.

Oaks comprise 47% of the twelve-state volume of hardwoods on pine sites. Sweetgum and white oak are the leading species, each with an inventory of more than 6 billion ft^3. The hickories, third in abundance, are widespread, although their quality on pine sites tends to be poor. The five most abundant pine site hardwoods—sweetgum, white oak, hickory, southern red oak, and post oak—and the seventh—black tupelo—are well represented in all twelve states. Yellow-poplar, scarlet oak, and chestnut oak are scarce or absent west of the Mississippi and in Florida. Black oak is plentiful except in Florida, Texas, Louisiana, and Oklahoma. Among other species making up 2% or more of the hardwood on pine sites, red maple is well distributed except in Oklahoma, water oak is scarce only in Tennessee and Oklahoma, and northern red oak is scarce in the Gulf States.

Many factors make use of these hardwoods difficult. Trees are often scarred and defective from fires and from previous pine harvesting. They are slow growers because the sites are not right for them—trees 6 inches in dbh are typically 40 years of age (Manwiller 1974). Hardwood growth rate on these sites is generally one-half cord per acre per year or less. Typically, the trees are short and crooked in bole.

The low cubic content per stem, the highly variable species mix from stand to stand and even from site to site within stands, and the low volume per acre all combine to raise harvest costs. However, there are some advantages. The resource is distributed throughout the southern pinery and is available near many potential consumers. Because the volumes are substantial, they can supply a market of almost any realizable size—and at a variety of locations. A supply will always exist because on many sites hardwoods replace southern pines in natural succession, and certain sites, such as areas bordering intermittent streams in uplands, will remain in hardwoods for environmental reasons. Stumpage cost is low, so much of the final product value is left for harvest and manufacture. New industries based on these hardwoods can be located in depressed rural areas where labor is readily available, and local communities are frequently eager to help establish plants. Finally, factories utilizing these hardwoods can be energy self-sufficient (Barber 1975).

Improved utilization of hardwoods from all sites should hasten the time when wood production can be maximized by concentrating hardwood management on sites best suited for hardwoods and pine production on lands best suited for pines. Hardwood sites intermingled with pine lands will permit a desirable pattern of diversity in most areas. Moreover, substantial acreages suitable for high production of either hardwoods or pine are available. These lands can be allocated to either species group as needed to balance demands, not only for industrial wood products, but for wildlife habitat, recreational areas, visually pleasing landscapes, and water management.

PHYSICAL CHARACTERISTICS

Pine-site hardwoods are small. Of volume in trees 5 inches and larger in dbh, nearly half (46%) is in trees 5.0 to 10.9 inches in diameter, about 29% in trees measuring 11.0 to 14.9 inches in dbh, and only 25% is in trees 15.0 inches or larger in diameter (Murphy and Knight 1974). Stems of these trees taper about 1¼ inches per 8 feet of stem length.

Stembark of 6-inch trees of the eleven oaks averages about 20% of the weight of the stemwood; the eleven non-oaks have a lower percentage of stem-bark—about 15% of stemwood (oven-dry basis) in 6-inch trees. Larger trees have a smaller percentage of bark. Weighted by species volume, average stembark content is 13.5% of above-ground biomass of 6-inch trees, foliage excepted. Stembark of these trees ranges in specific gravity from 0.34 in winged elm to 0.64 in black-jack and northern red oak, with weighted average of 0.507 (based on oven-dry and green volume). Stembark moisture content averages 70.4% (weighted dry basis).

In trees measuring 6 inches dbh, stemwood specific gravity based on oven-dry weight and green volume ranges from 0.40 in yellow-poplar to 0.67 in post oak; weighted average for all the species is 0.569. Density of stemwood (weighted oven-dry basis), therefore, averages 35.5 pounds per cubic foot. Sweetgum has the highest moisture content at 120.4% of oven-dry weight and green ash the lowest at 47.4%; weighted average for stemwood of all the species is 79.3%.

MECHANICAL PROPERTIES

Mechanical properties of some of the woods are exceptional. Nine species (including five oaks and hickories: *Carya glabra* (Mill.) Sweet, *C. tomentosa* Nutt., *C. ovata* (Mill.) K. Koch, and *C. laciniosa* (Michx. f.) Loud.) have modulus of elasticity values higher than the average for loblolly pine (*Pinus taeda* L.)—a premium structural wood, as follows at wood moisture content of 12% (Bendtsen and Ethington 1975):

Species	Modulus of elasticity	Modulus of rupture	Crushing strength parallel to grain
		Pounds/sq inch	
Oak, cherrybark	2,280,000	18,100	8,740
Hickory, pignut	2,260,000	20,100	9,190
Hickory, mockernut	2,220,000	19,200	8,940
Hickory, shagbark	2,160,000	20,200	9,210
Oak, water	2,020,000	15,400	7,440
Oak, scarlet	1,910,000	17,400	8,330
Hickory, shellbark	1,890,000	18,100	8,000
Oak, northern red	1,820,000	14,300	6,760
Oak, white	1,780,000	15,200	7,440
Pine, loblolly	1,750,000	12,600	6,940

Average modulus of elasticity of stemwood of all twenty-two of these hardwoods (at 12% moisture content), weighted by the proportions in which they occur on southern pine sites, is 1,705,000 pounds/sq inch.

LAND BASE AND MANAGEMENT OBJECTIVES

In addition to earning an acceptable profit on the required investment—as well as providing needed products—a major purpose of the proposed general solution is systematic and large-scale rehabilitation of portions of the southern pinery invaded by slow-growing hardwoods that are, by most standards, unmerchantable. A major obstacle to such rehabilitation is the cost of site preparation and replanting—commonly in excess of $100 per acre. The proposed solution calls for the landowner—after having sold and removed his merchantable southern pine—to trade the residual stumpage in hardwoods of all sizes, plus cull and small unmerchantable pines, in return for preparation and planting of his acres. Under this plan, a new forest can be established at no cost to the landowner. Species composition will be based on the landowner's needs as determined by environmental, silvicultural, and economic analyses. (See Koch 1980 for one such prescription.) By nature of the harvesting and site preparation procedures, tracts as small as 40 acres can be rehabilitated.

The enterprise contemplated will clear (harvest), site-prepare, and plant 25,000 acres annually. Each acre considered for rehabilitation will have an average above-ground biomass (predominantly hardwood) of about 17.4 tons, oven-dry basis, or 31 tons on a green-weight basis. Virtually all of such acreage is presently considered economically inoperable by usual utilization procedures.

FIG. 2. Three-layer structural flakeboard of several southern hardwood species. The board has randomly oriented flakes throughout, and weighs about 44.5 pounds per cubic foot, oven-dry basis. Face flakes are 3 inches long and 0.015 inch thick; core flakes are 3.0 inches long and 0.025 inch thick.

In 35 years, the area reforested will total 875,000 acres (1,367 square miles), or nearly 1% of the southern pinery. With a procurement radius of 100 miles, the new forests will total 4.4% of this area. Because nearly three-fourths of the commercial forestland in the South is under private, nonindustrial ownership, it seems likely that a procurement area of this size can be located where terrain is capable of supporting 10 pounds/sq inch ground pressure and is mostly level to rolling—terrain limitations imposed by harvesting procedures.

The analysis is perhaps oversimplified by assuming no land ownership by the company; a company contemplating an investment of this size would likely want to control a significant share of the land-base required. The analysis, as presented, is intended to suggest a method of increasing wood production on privately owned non-industrial land.

THE UTILIZATION CONCEPT

The products

After studying the array of species and their physical and mechanical properties, two major commodities come to mind—pallet shook and railroad crossties[1]—but

[1] See Koch (1978) and Anderson (1981) for economic analyses of a utilization concept to use southern pines as well as pine-site hardwoods to make crossties, pallet parts, framing lumber, and sheathing.

are rejected in this analysis because their market value is low. Pallet shook has fob mill value of $100 to $150 per ton and untreated railroad crossties about $110 to $140 per ton (oven-dry weight basis).

Instead, the selected solution concentrates on products that capitalize on the unusual esthetic, physical, and mechanical properties of the various species and that thereby command a high price per ton. The solution tolerates the available mix of tree sizes and species, and converts about 60% of the above-ground biomass into these valuable products. The remaining 40% supplies virtually all the energy needs of the manufacturing facility.

The three products (other than fuel) yielded from the proposed general solution—structural panels, long-span joists for building, and esthetically pleasing hardwood panels for residential and industrial furniture and fixtures—have expanding and potentially large world markets. These products all can be made from hardwoods growing on southern pine sites, with estimated values as follows:

Product	Approximate value fob mill in the United States in 1981
Structural flakeboard panel in thickness from ⅜- to ¾-inch and sizes up to 8 by 24 feet (Fig. 2)	200
4- by 4-foot panels of decorative many-layered plywood with clear faces of thin rotary-peeled premium-hardwood veneer (or cut-to-size plywood parts)	400
Long structural joists of I-beam section constructed with flakeboard webs, and flanges made from parallel-laminated veneer of high strength (Fig. 3)	600

Harvest

It would be simple for this analysis to specify procurement limits calling for delivery of the required tons of tree-length stems with butt-end diameter not smaller than that suitable for a small veneer log. But such an approach avoids the question of how to remove unmerchantable wood from the forest so that a new and more productive forest can be established.

It is common practice throughout the southern pinery to harvest the merchantable pine (Fig. 1) and then clear-fell, windrow, and burn the residual above-ground biomass—on average near 30 tons per acre. To avoid such waste of raw material, it is proposed that all above-ground portions of all residual trees of all diameters and species be harvested from the 25,000 acres of the southern pinery to be rehabilitated annually.

Primary breakdown equipment in the mill will consist of three disk flakers designed to accept 26-inch-long round or split wood generally not larger than 9½ inches in diameter, two ring flakers designed principally to convert selected forest residual chips into essentially bark-free flakes, and one roundup shaping lathe to prepare 52-inch-long bolts for a 52-inch veneer lathe. The veneer lathe will accept rounded-up cylinders 8 to 24 inches in diameter.

To serve these machines, each acre will be harvested as follows:

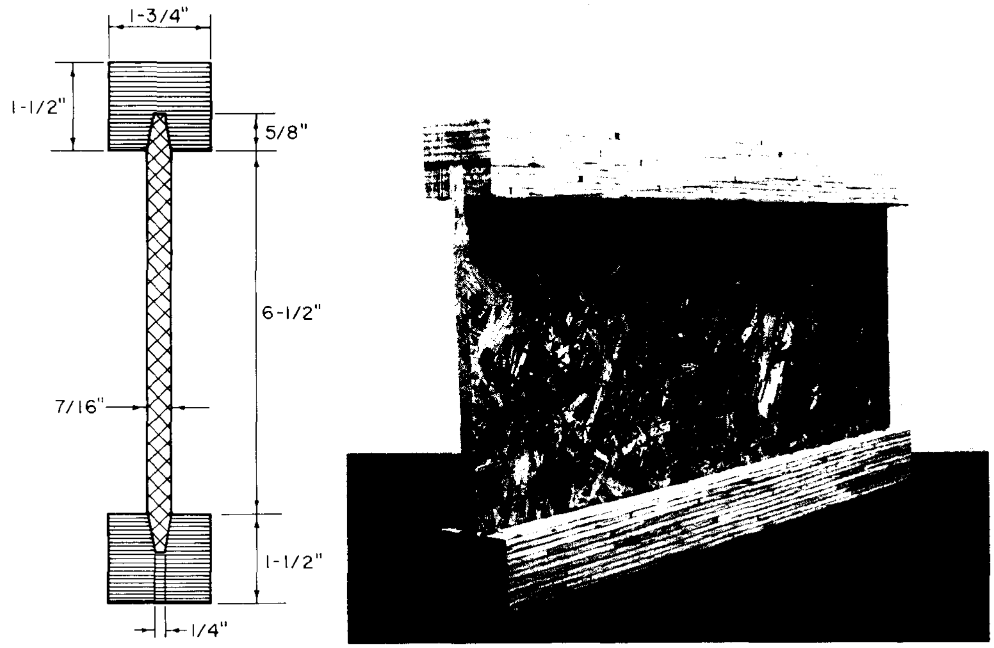

FIG. 3. Fabricated joist available in long lengths, to order. (Right) The webs are flakeboard and the flanges are parallel-laminated rotary-peeled hardwood veneer of high modulus of elasticity. For this analysis, a 7/16-inch-thick web with tapered edges has been utilized. (Left) Fabricated joist sized to compete with a 2- by 10-inch solid wood joist. (Drawing adapted from Woodson 1981.)

- Trees 5 inches in dbh and larger will be felled, delimbed, and topped for tree-length transport to the mill. These tree stems will yield about 490 cu ft of wood per acre, of which about 40% (196 cu ft) will be in stems with butt diameters smaller than 9½ inches inside bark. Of the stems with butt diameter inside bark 9½ inches and larger, about half their volume can be bucked into 52-inch veneer bolts with small-end diameter inside bark of 8 inches or larger.
- All residual wood, including tops and branches severed from the harvested trees and all above-ground portions of smaller trees and culls left standing, will be harvested with swathe-felling mobile chippers (Fig. 4). Of the 417 cu ft of residual wood and bark available per acre, about 80%, or 334 cu ft will be delivered to the mill. Of this, half (167 cu ft) will go to the fuel pile and half will be flaked for use in cores of structural panels.

Total volume from the 25,000 acres harvested annually and delivered to the mill will therefore be about as shown in Table 5. Contractors should be able to harvest this wood and bark in the manner described and deliver it to the mill at a price

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FIG. 4. For the harvesting schedule proposed a swathe-felling mobile chipper is required that will retrieve about 10 tons, green basis, of forest residual chips from the average acre at a cost delivered to the mill not in excess of $19 per ton. (Top) Drawing after Koch and Savage (1980). (Bottom) Commercial prototype.

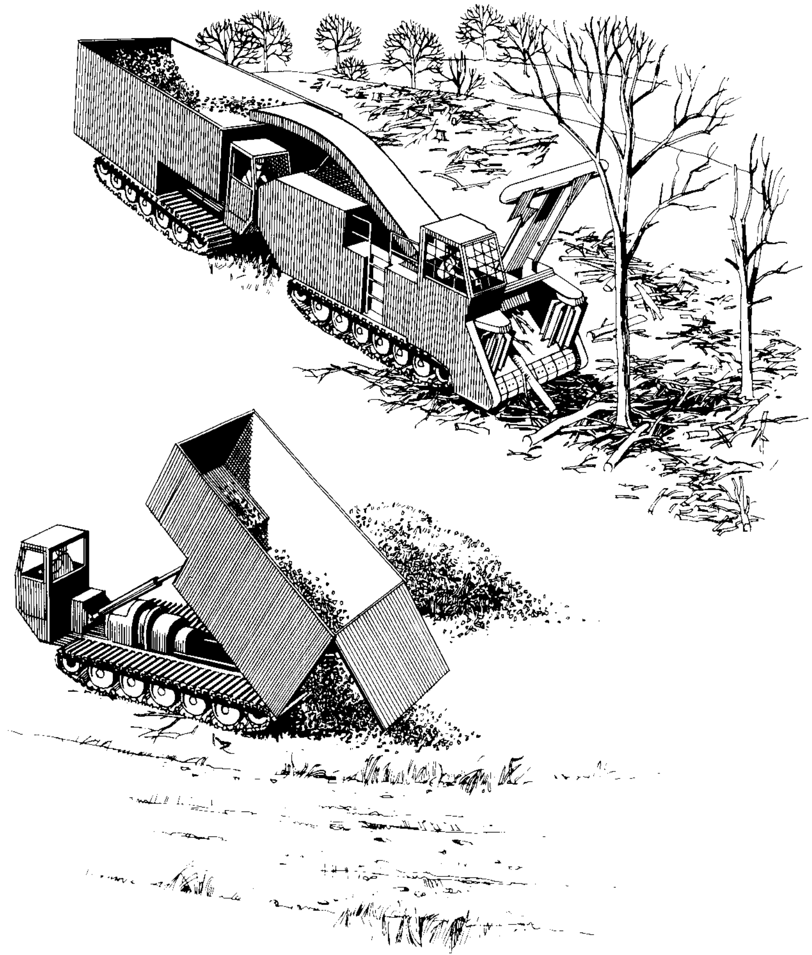

TABLE 4. *Specific gravity, moisture content, and green wood weight of stemwood and bark from 6-inch hardwoods on southern pine sites.*

Species	Percent of total volume[1]	Stemwood specific gravity[2]	Stembark specific gravity[2]	Stemwood moisture content[3]	Stembark moisture content[3]	Weight of bark-free green stemwood
				Percent		*Pounds/ cu ft*
Ash, green	0.9	0.561	0.407	47.4	75.9	51.6
Ash, white		0.582	0.397	47.5	68.4	53.6
Elm, American	1.4	0.536	0.395	75.5	86.9	58.7
Elm, winged		0.623	0.341	65.6	76.0	64.4
Hackberry	0.1	0.525	0.601	72.6	55.5	56.5
Hickory, true	8.5	0.643	0.522	51.5	72.9	60.8
Maple, red	3.6	0.496	0.535	69.9	74.4	52.6
Oak, black	4.0	0.620	0.612	69.2	56.2	65.5
Oak, blackjack	<0.1	0.638	0.642	74.2	43.6	69.4
Oak, cherrybark	1.2	0.633	0.622	66.6	54.1	65.8
Oak, chestnut	4.2	[4]	[4]	[4]	[4]	[4]
Oak, laurel	1.4	0.582	0.630	74.4	57.4	63.3
Oak, northern red	2.4	0.605	0.644	69.7	55.7	64.1
Oak, post	7.0	0.659	0.498	65.6	48.9	68.1
Oak, scarlet	3.6	0.622	0.618	69.4	55.6	65.7
Oak, Shumard	0.2	0.625	0.644	69.1	52.2	65.9
Oak, southern red	8.1	0.609	0.601	70.1	52.9	64.6
Oak, water	4.7	0.587	0.628	73.6	54.4	63.6
Oak, white	12.3	0.665	0.543	61.9	58.1	67.2
Sweetbay	0.6	0.437	0.440	100.8	102.1	54.8
Sweetgum	13.2	0.453	0.369	120.4	89.3	62.3
Tupelo, black	5.5	0.500	0.428	90.0	69.8	59.3
Yellow-poplar	7.0	0.395	0.390	111.7	125.8	52.2
Other hardwoods	10.1	—	—	—	—	—
	100.0					

[1] Data from Christopher et al. (1976).
[2] Basis of oven-dry weight and volume when green. Data from Manwiller (1979).
[3] Dry weight basis. Data from Manwiller (1975).
[4] Data not available.

of $34 per ton (oven-dry basis) or $19 per ton green (Koch and Savage 1980). Total annual cost of harvest and transport to mill will therefore be $13,541,000 ($34 × 398,265). Annual planting costs, including seedlings, will be about $28 per acre or $700,000 for the 25,000 acres.

PROCESSING

At the mill, forest residual chips are dumped into a storage pile from whence they are conveyed through a device to remove rocks and metal and then through a screening system to divert large bark-free chips through a ring flaker for the core layer of structural panels (about half of incoming chips). The remaining half are hammer-hogged and put into fuel inventory. Assuming that this facility operates 324 days per year, an average of 457 tons (dry basis) of forest residual chips are received daily.

Incoming tree length stems will not exceed 55 feet, will average about 30 feet in length, and will not be shorter than 8⅔ feet. All stems will be offloaded at the

TABLE 5. *Cubic feet and dry weight of annual harvest of stemwood, stembark, and forest residual chips.*

Class of material and description	Cubic feet	Weight[1] (oven-dry basis)
		Tons
Tree-length stemwood (wood only)		
Portions that can be bucked into 52-inch-long veneer bolts with small-end diameters inside bark of 8 inches and larger	3,675,000[2]	65,231
Portions for conversion with disk flakers, i.e., those stem portions not large enough to be rotary peeled into veneer	8,575,000[3]	152,206
Bark from tree-length stemwood	1,837,500[4]	32,616
Forest residual chips		
Large, bark-free chips suitable for ring flaking	4,175,000[5]	74,106
Suitable for fuel (wood and bark)	4,175,000[5]	74,106
TOTAL	22,437,500	398,265

[1] All weights computed on basis of 35.5 pounds/cu ft, oven-dry-weight basis.

[2] $\frac{490 - 196}{2} \times 25{,}000 = 3{,}675{,}000$ cu ft.

[3] $\left(196 + \frac{490 - 196}{2}\right) \times 25{,}000 = 8{,}575{,}000$ cu ft.

[4] $0.15(3{,}675{,}000 + 8{,}575{,}000) = 1{,}837{,}500$ cu ft.

[5] $\frac{334}{2} \times 25{,}000 = 4{,}175{,}000$ cu ft.

mill by portal crane and species sorted into two specific-gravity classes—high and low, arranged to be equal in volume.

The stems, by specific-gravity class, are crane-transferred from storage under sprinklers to a cutup deck, where they are reduced to 104-inch lengths plus a top cut of variable length. The cutting station is equipped to remove short sections from crooked stems to yield fairly straight 104-inch lengths. The 104-inch lengths plus top cuts and short stem sections are all admitted to a 12- by 45-ft drum debarker. Average daily throughput (two-shift basis, 324 days per year) is 671 tons of bark-free wood and 101 tons of bark (dry basis).

Short stem sections and top cuts shorter than 104 inches are reduced to 26-inch lengths and routed directly to the disk flakers. Very large hollow or highly defective pieces are split to smaller size, reduced to 26-inch lengths, and also routed directly to the disk flakers.

All 104-inch lengths are sorted into two size classes: small-end diameters less than 7½ inches, and small-end diameters 7½ inches and larger. They are placed in hot water to achieve optimum wood temperature for rotary peeling and flaking.

When heated with 160 F water for several hours, the larger logs are conveyed sideways through a set of slashing saws that are arranged to cut all possible 52-inch lengths with small-end diameter of at least 8 inches and sound centers to permit rotary peeling, plus smaller or unsound 26-inch lengths for the disk flakers. The smaller logs, after being heated, are automatically slashed to 26-inch lengths and routed to the disk flakers.

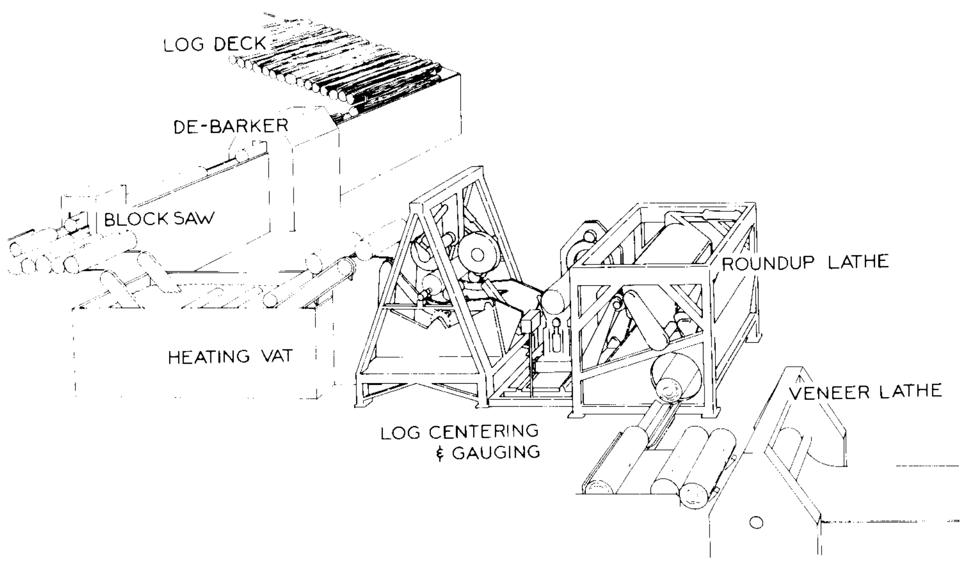

FIG. 5. Schematic layout of round-up lathe with centering and feeding device to produce maximum-diameter cylinders to be rotary peeled. (Drawing from Stetson-Ross after Roubicek and Koch 1981.)

Veneer manufacture

The 52-inch veneer logs are fed to the infeed deck of the round-up lathe (Figs. 5 and 6). Resultant cylinders are collected on the infeed deck of the veneer lathe. They are rotary-peeled into clear $^1/_{20}$-inch veneer where possible (about 6% of total veneer in premium species only) and the balance (about 94%) into $^1/_{10}$-inch veneer. Production through the round-up lathe and veneer lathe averages about four bolts per minute. Spent cores 3.5 inches in diameter are collected in bunks and transported by front-end loader to the disk flakers. Veneer emerging from the veneer lathe is spur-trimmed to 50-inch lengths and clipped to yield 50-inch dry width on a machine close-coupled to the veneer lathe. Full sheets are automatically stacked, $^1/_{20}$ in one pile and $^1/_{10}$ in another. Veneer sheets smaller than 50 × 50 inches are manually stacked on carts. Clippings are chipped to 3-inch lengths and along with veneer spur trim, are fed to the ring flakers.

The green veneer is dried in a jet roller dryer—or possibly a platen dryer—equipped with pneumatic feeder. Dry veneer sheets ($^1/_{10}$-inch only) smaller than 50 × 50 inches are collected on carts and fed into a stitching composer, which assembles them into sheets 50 × 50 inches. Full sheets of $^1/_{20}$-inch veneers are sorted into clears for faces and patchable veneers for backs. All $^1/_{10}$-inch 50- × 50-inch veneers, patched where necessary to eliminate oversize knots or knot holes, are routed through a nondestructive testing machine. Those $^1/_{10}$-inch veneers with modulus of elasticity of 1,700,000 pounds/sq inch or greater, and free of major strength-reducing defects, are pulled for use as flanges of fabricated joists. The remainder—about half—are stacked for use in cores of decorative plywood. The green veneer line and veneer dryer operate 240 days per year, three shifts per day.

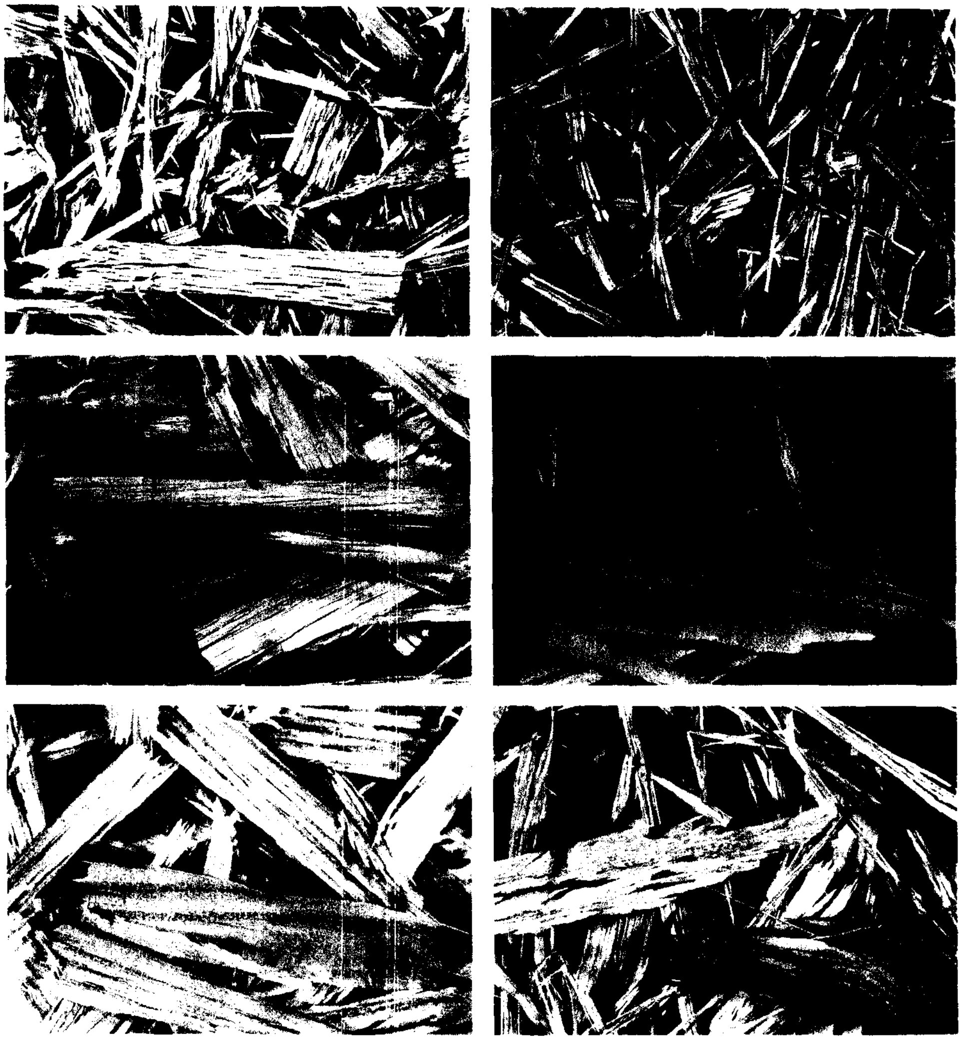

FIG. 6. Face flakes 0.015 inch thick and 3 inches long in random widths as produced on the round-up lathe. Top left, white oak; top right southern red oak; center left, true hickory; center right, sweetgum; bottom left, southern pine; and bottom right, the five species mixed. These flakes have near-optimum geometry for use in structural flakeboard.

Decorative plywood manufacture

Manufacture starts with a layup station at which $^1/_{20}$ face veneers of premium species and $^1/_{20}$ back veneers are assembled with $^1/_{10}$-inch core veneers of randomly assorted species double-spread with adhesive, into sandwiches of sufficient numbers of veneers to yield the desired finished panel thickness. The assembled 50-inch-square sandwiches are paired into twenty 50- by 100-inch layers, cold prepressed, and then hot-pressed in a 20-opening, 4- × 8-foot hot press equipped with automatic loader, offbearer, and stacker. The 50-inch-square panels are conveyed to an automatic sizing saw, patched where required, sanded, and routed

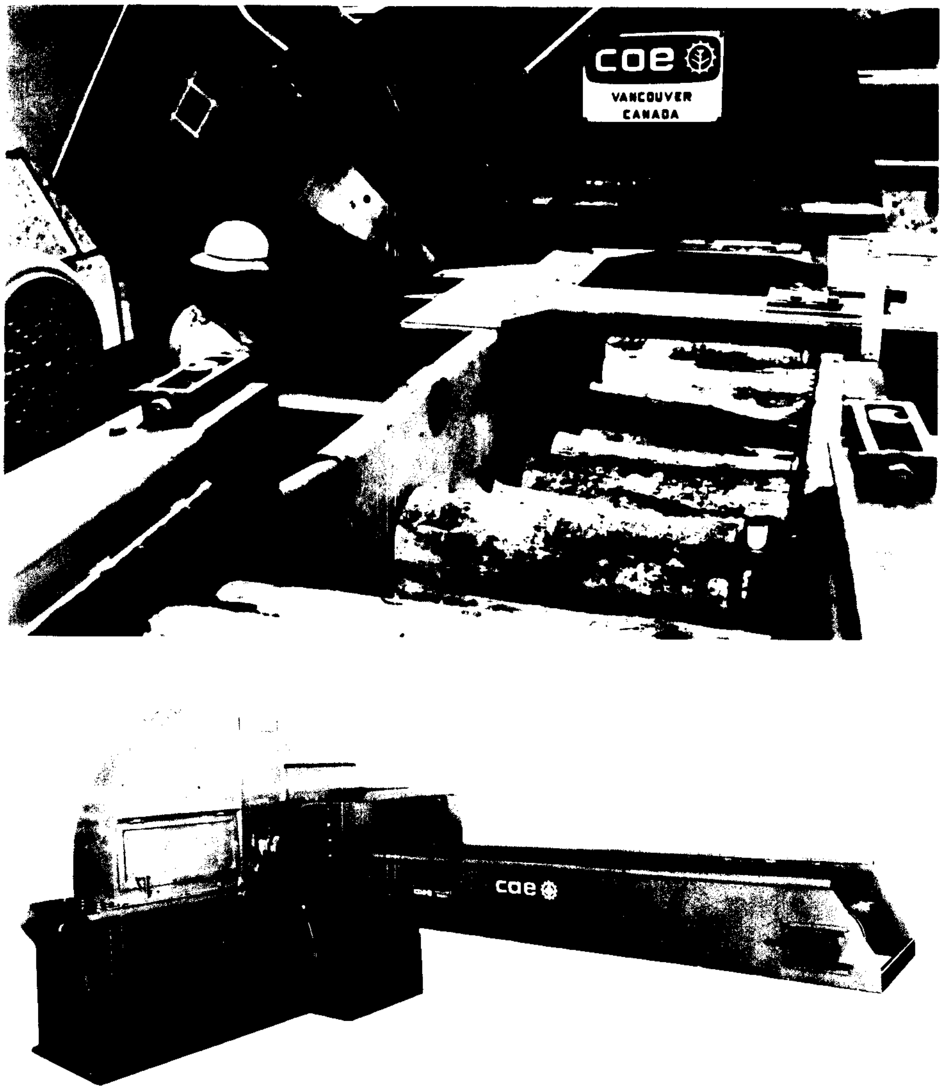

FIG. 7. Disk flaker measuring 93 inches in diameter. (Top) Hopper removed to show disposition of castellated knives mounted in the disk; flake length is determined by the length of each cutting edge. (Bottom) Feed arrangement for 26-inch-long hardwood bolts. (Photo from CAE Machinery Ltd.)

to storage awaiting shipment. Most panels are manufactured in the thicknesses from ½-inch to 1-inch; average thickness is ¾-inch. These decorative plywood panels are intended for residential and industrial furniture and fixtures, cut-to-size as needed. The plywood manufacturing line operates 240 days per year, two shifts per day.

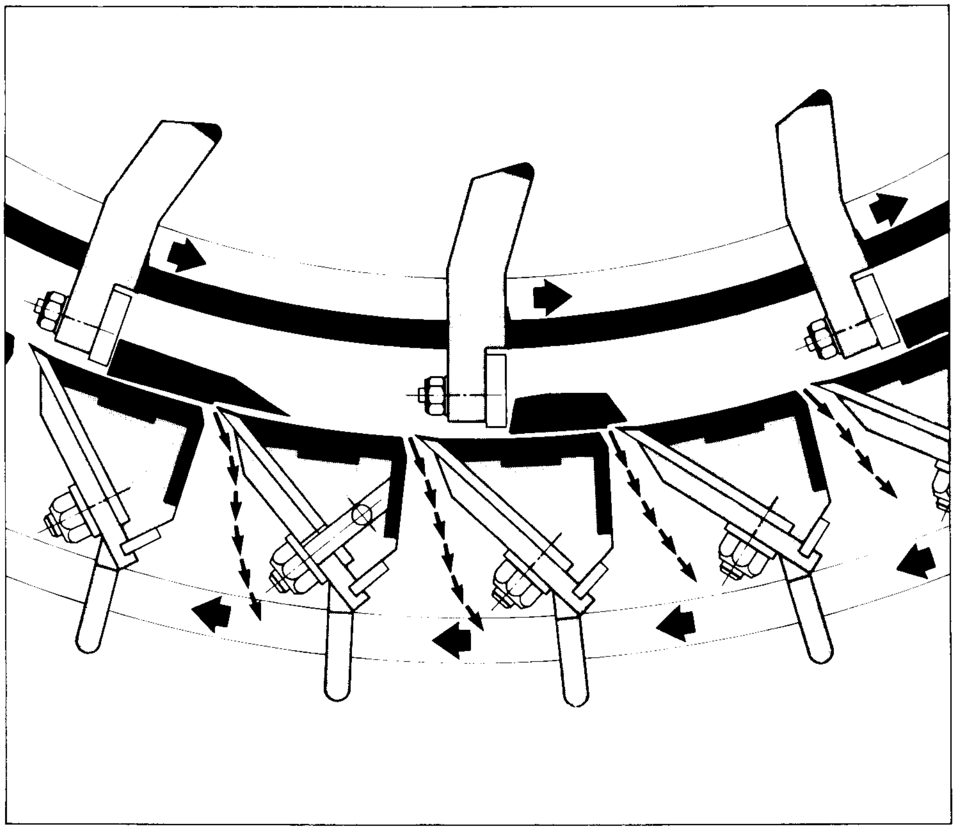

FIG. 8. Cross section through a ring flaker designed to accept wood in chip form. The interior rotating impeller forces the chips against the knives of the outer counter-rotating ring. (Drawing after Pallman Pulverizers Company, Inc.)

Parallel-laminated veneer manufacture

The 50- × 50-inch, 1/10-inch veneers selected for their high modulus of elasticity and absence of serious strength-reducing defects are stacked and heated in a warming compartment to about 100 F. The warmed veneers are hopper-fed through a combination string composer and glue spreader that applies 100 pounds of phenol-formaldehyde resin mix per 1,000 sq ft of double glue line. The spread veneers are composed with two or three strings into laminae 100 feet long, each comprised of 24 butt-jointed sheets with grain aligned along the 100-ft length. As each 100-ft-long strip reaches its designated position to achieve the desired pattern of staggered butt joints, its conveyor is withdrawn from under so that it drops to form a 50-inch-wide sandwich of 16 laminae with joints staggered in a predetermined pattern to minimize their effect on tensile strength. These sandwiches are hot-pressed into 50-inch-wide, 96-foot-long, 1.5-inch-thick flitches of parallel-laminated veneer and stored preparatory to manufacture of fabricated joists. The hot press time is 20 min, and loading and unloading time total 3 min. Press cycle time, and maximum closed assembly time each are 23 min. The hot press therefore discharges about 21 flitches in 8 h. This press line operates 240 days per year, three shifts per day. Such parallel-laminated veneer should have average modulus of elasticity of 1,800,000 psi or more, and modulus of rupture of about 12,500 psi (Woodson 1981).

Structural flakeboard manufacture

Flakes are produced on three classes of machines, for two purposes, as follows (totaling 256,776 tons per year, oven-dry weight basis):

Machine, wood type, and flake tonnage	Purpose and dimensions
One round-up lathe (Fig. 5) for veneer logs (9,785 tons)	Face-layer flakes 3 inches long and 0.015 inch thick (Fig. 6)
Three disk flakers (Fig. 7) for small roundwood (159,442 tons)	Face-layer flakes 3 inches long and 0.015 inch thick and core-layer flakes 3 inches long and 0.025 inch thick
Two ring flakers (Fig. 8) for chips (87,549 tons)	Core-layer flakes about 3 inches long and 0.025 inch thick

Wood to be flaked on the round-up lathe and on the disk flakers is sorted by specific-gravity class prior to flaking, dried by specific-gravity class, and stored separately as follows: face flakes of (1) high density and (2) low density, and core flakes of (3) high density, and (4) low density. Two driers are used, one for face flakes and one for core flakes. Output of of mixed-density flakes from the two ring flakers is routed to the core-flake dryer along with core flakes of specified density from one of the disk flakers.

The dry flakes are screened before they are routed to their respective storage bins. Oversize flakes are circulated through a re-flaker to reduce their size, and fines are removed for fuel. From dry storage bins holding high- and low-density wood, flakes are metered and mixed in equal proportions, blended with liquid resin, and formed into three-layer mats comprised of two face layers of 0.015-inch-thick flakes 3 inches long and one core layer of 0.025-inch flakes 3 inches long. Flakes are randomly oriented in all layers, but the forming heads can be adjusted to lay down face and core flakes oriented at right angles if the market so demands. Flakeboards can be pressed in thicknesses of ⅜- to ¾-inch, but most are produced 7/16-inch thick at a density (oven-dry basis) of about 44.5 pounds per cubic foot.

The formed mat is automatically loaded and unloaded from a 16-opening hot press with 8- × 24-foot platens. The pressed panels are passed through a blister detector, trimmed to sizes specified by customers, automatically stacked, and moved to the shipping dock by front-end loader. The flakeboard forming line, press, and trim line operates 324 days per year, three shifts per day.

Panels produced in this manner from a typical mixture of southern hardwoods should have average modulus of elasticity of about 650,000 psi, modulus of rupture of about 4,700 psi (Hse et al. 1975), and linear expansion of less than 0.10% when subjected to a change from 50 to 90% relative humidity.

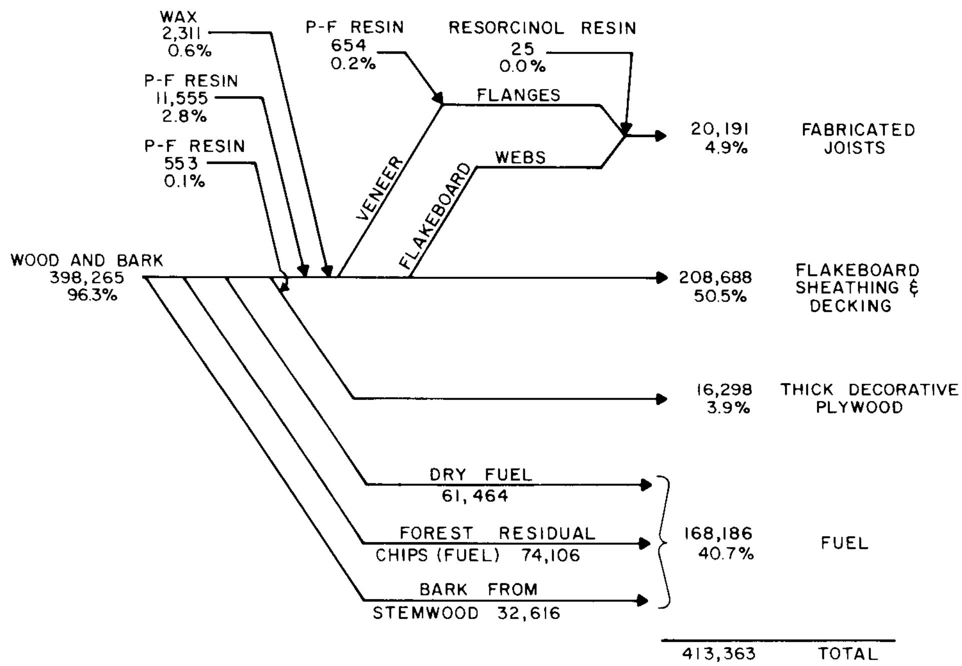

FIG. 9. Simplified annual overall materials-balance diagram; values shown are in tons, oven-dry-weight basis.

Fabricated joist assembly[2]

The veneer flitches are 50 inches wide, 1.5 inches thick, 96 feet long, and parallel-laminated. They are automatically fed through an endless-bed-feed multiple straight-line rip saw to produce 25 flange strips measuring 1.75 inches wide. Preceding the rip saws, a battery of dado cutters mounted on a rail over the infeeding panel machines 25 linear ⅝-inch-deep tapered grooves, $^{5}/_{16}$-inch wide at the top and ⅛-inch wide at the bottom, the full length of each flitch, with one groove centered on each 1.75-inch-wide strip. Between the dado heads and the rip saws, 25 vertical router spindles cam-guided in slow oscillations, machine grooves in a sinusoidal pattern the length of the flitch with amplitude of ⅛-inch and pitch of 24 inches. The grooves, centered on those previously machined by the dado cutters, are designed to receive one edge of a 7.75-inch wide, $^{7}/_{16}$-inch-thick, flakeboard web machined on the two edges to form ⅝-inch-long tapers measuring ¼-inch thick at their outer-most edges. (It is probable that flakeboard webs need be only ⅜-inch thick, but $^{7}/_{16}$-inch has been specified to be conservative.)

[2] The assembly concept described under this heading was provided by Drs. Alan W. Sliker and Otto Suchsland, Michigan State University, East Lansing. Fabricated joists of this, or similar, design are under intensive evaluation in several federal, university, and industrial laboratories. Service and market tests appear favorable.

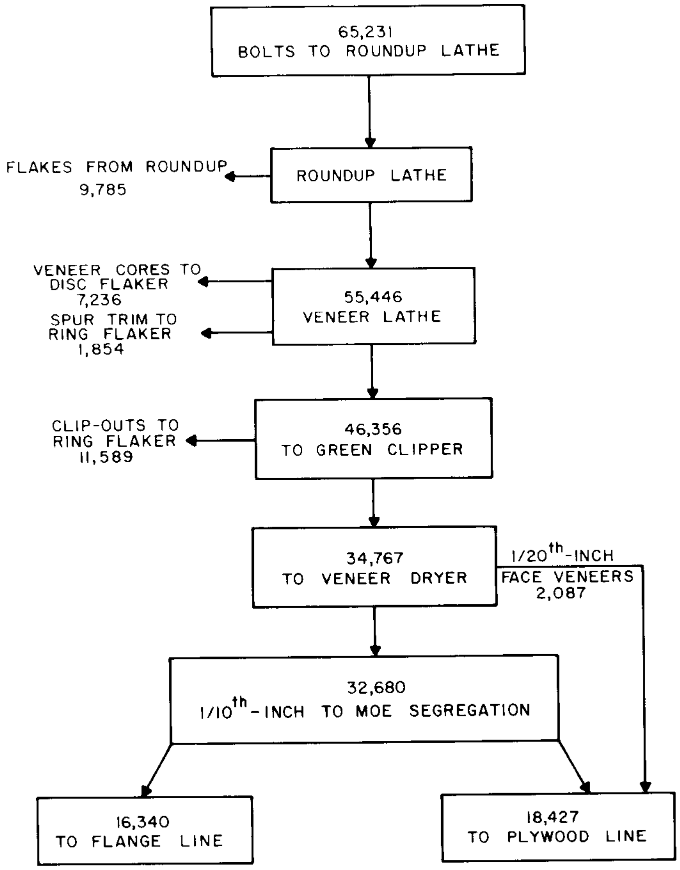

FIG. 10. Annual materials-balance diagram for veneer manufacture. Values shown are in tons, oven-dry-weight basis.

TABLE 6. *Densities of wood, forest residual chips, and products.*

Item	Density (oven-dry basis)
	Pounds/cu ft
Stemwood, weighted average	35.5
Forest residual chips	35.5
Green veneer as peeled for joist flanges[1]	37.0
Green veneer as peeled for decorative plywood[2]	34.0
Pressed flanges (37.0/0.9 × 1.04)	42.8
Pressed decorative plywood (34.0/0.9 × 1.03)	38.9
Pressed flakeboard	44.5
Assembled fabricated joists	43.5

[1] These veneers selected for modulus of elasticity of 1,700,000 pounds/sq inch or more.
[2] These veneers have modulus of elasticity less than 1,700,000 pounds/sq inch.

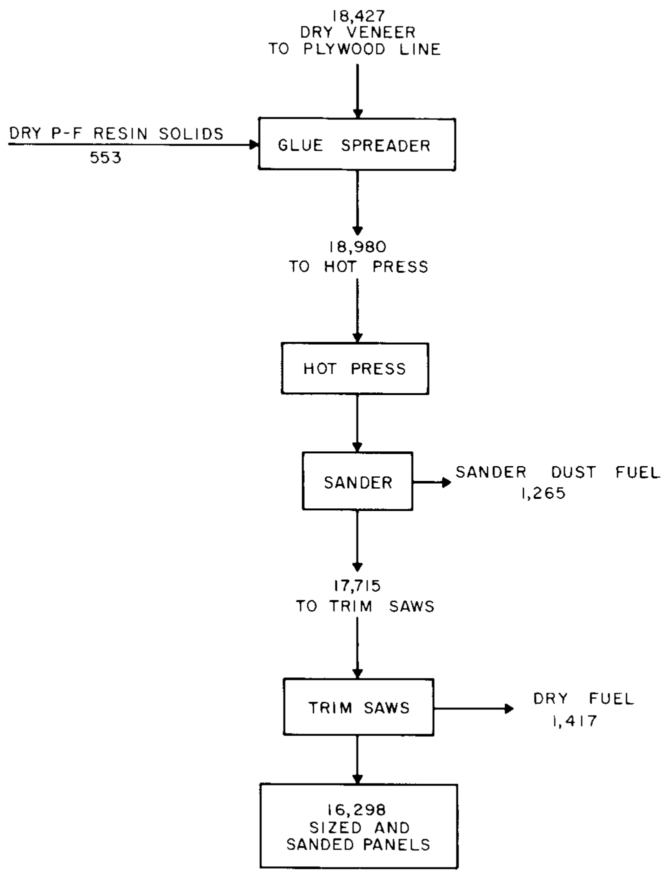

FIG. 11. Annual materials-balance diagram for decorative plywood manufacture. Values shown are in tons, oven-dry-weight basis.

The flakeboard webs are reduced to 8-foot lengths and are loaded into a hopper at the infeed end of the assembly machine. Flanking this hopper on each side are supplies of the grooved 1.5- by 1.75-inch flanges in 96-foot lengths. The flakeboard webs are hopper-fed through rolls that apply resorcinol adhesive to the two edges of each web; from the applicator rolls the webs move into a 12-foot-long assembly machine that continuously accepts pairs of 96-foot-long flanges at about 60 linear fpm and presses the webs into the flange grooves; as the webs seat into the flange grooves they are deformed slightly to sinusoidal pattern. This action locks the assembly sufficiently to permit it to be crosscut to desired length (24 feet for example), offloaded, stacked, and transported to a warm room. After about 8 h, when the adhesive is cured, the fabricated joists are moved to the shipping area. The joist assembly machine operates 3 shifts per day, 240 days per year—possibly less, if the assembly process can be speeded to perhaps 100 linear fpm. These joists are intended to be stock warehouse items for distribution through retail lumber yards. It is recognized that considerable time and effort would be required to achieve acceptance by major building-code bodies.

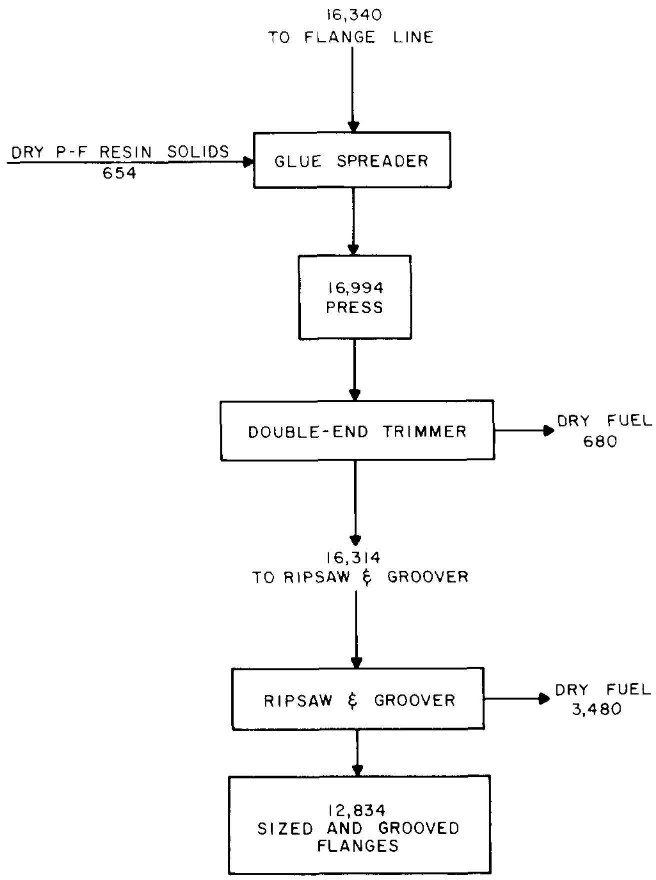

FIG. 12. Annual materials-balance diagram for manufacture of joist flanges made of parallel-laminated high-strength veneer. Values shown are in tons, oven-dry-weight basis.

MATERIALS BALANCE

To construct a simplified materials balance (Fig. 9), it is first necessary to tabulate product densities (Table 6) and to graph materials balances for production of green veneer (Fig. 10), plywood (Fig. 11), parallel-laminated veneer for joist flanges (Fig. 12), flakeboard (Fig. 13), and fabricated joists (Fig. 14).

From Fig. 9, it is seen that 398,265 tons of wood and bark (oven-dry basis) enter the plant annually to produce 20,191 tons of fabricated joists, 208,688 tons of flakeboard sheathing and decking, and 16,298 tons of decorative plywood. Total product yield is therefore 245,177 tons or 61.6% of the weight of wood and bark entering the plant. Resins and wax consumed annually total 15,098 tons.

Additionally, 168,186 tons of fuel (oven-dry basis) containing about 2.7×10^{12} Btu are available annually to generate electrical power and heat energy; this is slightly more than the 2.5×10^{12} Btu required annually to operate the plant (not including harvest and wood transport).

Through use of product densities shown in Table 6, product tonnages and measures can be computed as follows:

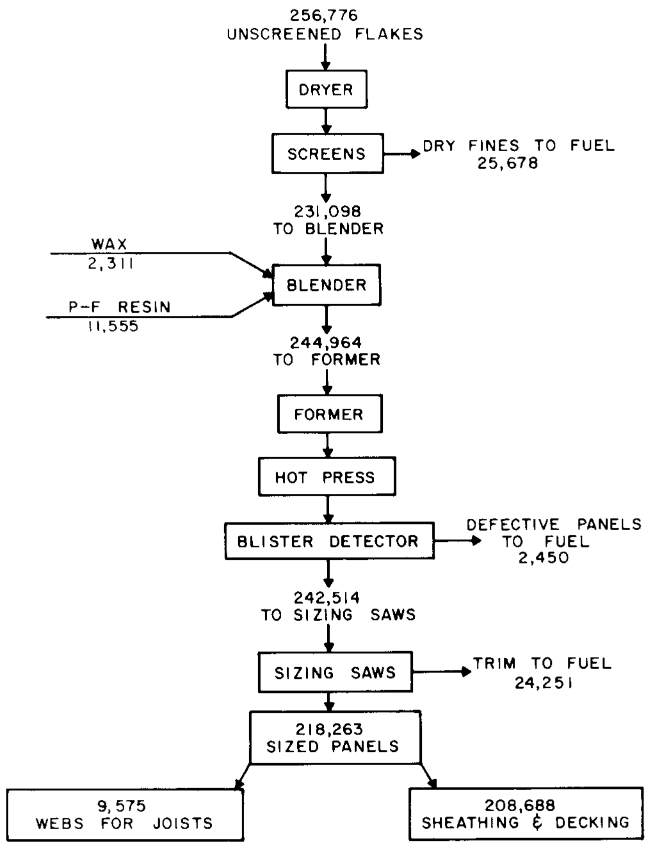

FIG. 13. Annual materials-balance diagram for flakeboard manufacture. Values shown are in tons, oven-dry-weight basis.

Product	Annual production	
	Tons, oven-dry	Other units
Fabricated joists (Fig. 3)	20,191	18,277,152 lineal feet or 30.5 million board feet, nominal
Flakeboard sheathing and decking (Fig. 2)	208,688	300 million square feet of panel, ⅜-inch basis
Thick decorative plywood	16,298	26.8 million square feet of decorative plywood, ⅜-inch basis

FINANCIAL ANALYSIS

Investment required for this enterprise is substantial, but projected earnings appear to warrant it. To compute projected earnings, investment, costs, and receipts must be known.

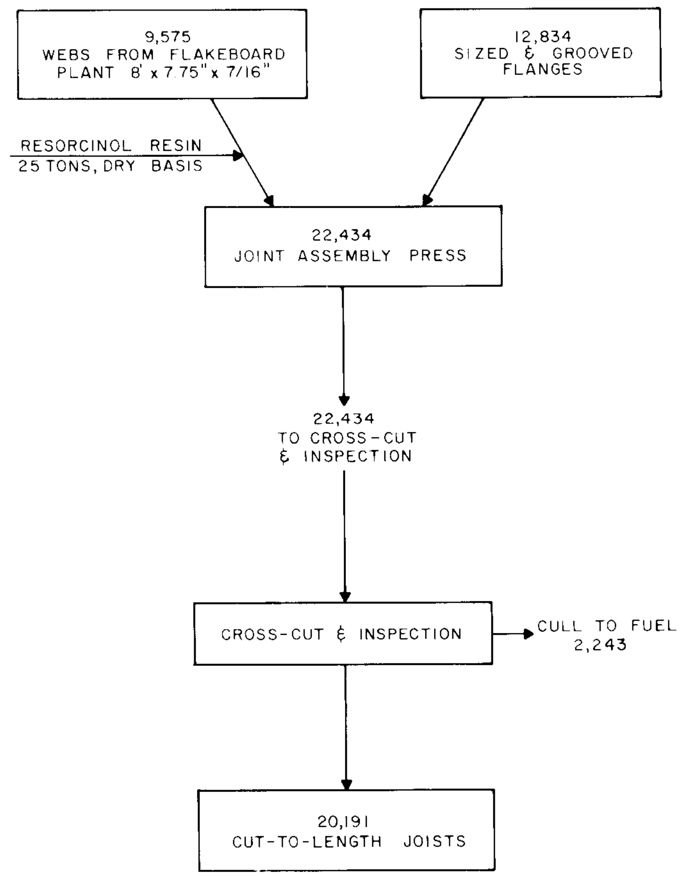

FIG. 14. Annual materials balance diagram for assembly of fabricated joists. Values shown are in tons, oven-dry-weight basis.

Investment

For this analysis, it is assumed that the enterprise owns no forest land and therefore has no forest investment. As harvesting, wood transport, and planting will be done through contractors, investment in woods equipment will be minimal.

The major investment is in the wood receiving yard serviced by a portal crane, merchandising deck, drum debarker, wood-burning power plant, and flakeboard plant capable of producing over 300 million square feet (⅜-inch basis) of structural flakeboard annually. Capital investment for this facility is estimated at $33 million.

Investments in other necessary processing lines are estimated as follows:

Facility	Investment
	Dollars
Green-veneer line	7,000,000
Veneer dryer and nondestructive test setup for modulus of elasticity	2,000,000
Plywood assembly line with hot press	4,000,000
Press line for manufacture of parallel-laminated-veneer joist flanges	2,000,000
Line to fabricate joists	2,000,000

TABLE 7. *Major operations, shifts scheduled per year, and press sizes.*

Operation	Scheduled production		Press size
	Shifts/ day	*Days/ year*	
Portal crane, merchandising deck, drum debarker	2	324	—
Flakeboard flake cutting, drying, forming, and pressing line	3	324	8- × 24-foot, 16 opening
Roundup lathe, veneer-lathe, and clipper	3	240	—
Veneer dryer and line to segregate veneers by modulus of elasticity	3	240	—
Assembly and press line for decorative plywood	2	240	4- × 8-foot, 20 opening
Line to press parallel-laminated-veneer joist flanges and machine them	3	240	4- × 100-foot, single opening
Line to continuously assemble joist flanges and webs	3	240	Average feed speed 60 fpm (possibly faster)
Power plant to generate electricity and process heat[1]	3	365	—

[1] With capacity to burn green and dry wood having heat content (annual) of 2.7×10^{12} Btu.

Total investment is therefore estimated at about $50 million. Brief descriptions of presses required are summarized in Table 7.

Costs

Major elements of costs include raw materials, planting expenditures, depreciation, labor, maintenance, and other overhead items. These costs are estimated as follows:

Item	Estimated cost, annual
	Dollars
Planting of 25,000 acres	700,000
Wood and bark (delivered to mill)	13,500,000
15,098 tons of resin and wax	10,000,000
Depreciation (10-year, straight line)	5,000,000
Labor (250 people)	5,000,000
Maintenance, supplies, and other overhead	5,800,000
TOTAL	40,000,000

These estimates are approximations. A detailed cost analysis could be made only on a site-specific basis.

Receipts

All income from the enterprise results from sales of the three products manufactured; net annual sales after discounts and commissions are estimated as follows:

Product and computation (based on oven-dry weight)	Net annual sales
	Dollars
Flakeboard sheathing and decking 208,688 tons × $200/ton	41,737,600
Decorative plywood 16,298 tons × $400/ton	6,519,200
Fabricated joists 20,191 tons × $600/ton	12,114,600
TOTAL	60,371,400

Profit

Net annual profit before income taxes is estimated at $20,371,400, i.e., $60,371,400 net sales less $40 million costs. This amounts to 40.7% return on the $50 million investment and 33.7% return on sales.

If cost of purchased wood increased to $21 per green ton delivered to the mill instead of $19, annual costs would rise $1,454,862. Should acres available for harvest contain less wood per acre than planned, so that 35,000—instead of 25,000 acres—must be harvested and planted per year, costs would rise $280,000. If product prices were to drop 10% to $180, $360, and $540 per oven-dry ton, annual revenue would decrease by $6,037,140. If all of these developments occurred simultaneously, net annual income would still amount to 25.2% of investment.

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