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Potential for Producing Ponderosa Pine Plywood in the Black Hills

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Dennis M. Donnelly and Harold E. Worth

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Abstract

This study describes possible plywood production opportunities for Black Hills ponderosa pine in terms of kinds of plywood and advantageous market areas. The resource analysis examines current and future uses of the area's timber. Economic evaluation includes analyses of discounted cash flow and operating costs and revenues.

The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

Acknowledgments

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Potential for Producing Ponderosa Pine Plywood in the Black Hills

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MANAGEMENT IMPLICATIONS

MARKETING

A major advantage of producing plywood in the Black Hills area of South Dakota and Wyoming is proximity to major markets. Plywood produced there could be delivered to Great Plains and upper Midwest markets at a freight cost lower than that from other major softwood plywood producing regions. Market potentials for softwood plywood in the United States are very strong for the foreseeable future. However, because ponderosa pine is not a well established plywood species, there is some question about the share of the market it can command. Because Black Hills ponderosa pine yields primarily C and D grade veneers, its utilization would be limited mainly to plywood products made from these grades, such as roof and wall sheathing, siding, or flooring. Other special plywood products for use in new residential, homeowner, nonresidential construction, and industrial markets seem promising also. Small volumes of B Patch and better veneer might be marketed as stock for products where appearance is of some importance, such as cabinets.

In addition, recent developments in performance standards for sheathing panels, including plywood, may have expanded market possibilities for woods such as ponderosa pine. Performance-rated sheathing panels are "designed, manufactured and identified for specific construction end uses" (American Plywood Association 1980). Such panels conform to "criteria for panel strength, stiffness, durability, stability and other properties relevant to the end-use." If structural criteria are met, panels can be made entirely from veneer faces bonded to a reconstituted wood core, or from reconstituted wood.

In the case of plywood manufactured from ponderosa pine in the Black Hills, the provisions of Product Standard 1-74 (American Plywood Association 1974) remain applicable. However, it is possible that such plywood could now obtain upgraded span ratings through testing for sheathing end-use applications. See the appendix for details about sheathing applications and span ratings. Plywood variables such as veneer thickness and orientation, along with inherent wood properties, would determine in part how well such panels meet the standards for performance-rated sheathing.

TIMBER RESOURCE

The Black Hills National Forest Timber Management Plan for the 10-year period ending in 1986 shows that enough timber of the required size² is available to support a plywood plant with an annual capacity of about 60-65 million square feet (MM ft²), 3/8-inch basis. However, a very tentative projection for the following 10-year period indicates sawtimber volume from 1987 to 1996 may be about 23 million board feet less than volume for the current 10-year period—a 21% reduction. This reduction of volume in sawtimber size trees may mean a smaller potential supply of logs suitable for plywood.

The size of logs required for any potential plywood plant is roughly the same as for the established Black Hills lumber industry. The supply of timber of this size appears to be adequate to serve both the present industry and a new plywood plant until 1986. However, in the 10 years after 1986, reduced volumes of timber in this size class may not support both industries.

Estimated veneer block supply is concentrated largely in the 8- to 12-inch d.i.b.³ range. A plywood plant would also have to deal with a substantial volume of logs smaller than 8 inches d.i.b. to utilize the tops of larger trees and any smaller trees purchased in multiproduct timber sales.

ECONOMICS

At early 1978 cost levels, the break-even price for 1,000 square feet of 1/2-inch C-D Interior plywood with external glue (C-D-X) sheathing, f.o.b. mill, was about \$142. For a 20% rise in total costs, break-even price for 1/2-inch C-D-X sheathing rose 28%. Break-even price is also sensitive to other factors, to a lesser degree. In decreasing order of sensitivity, internal rate of return, log cost, labor cost, and energy cost are of greatest importance. All costs are those incurred before the plywood leaves the mill.

The economic aspects of plywood manufacture in the Black Hills area appear favorable except for the uncer-

²The "required size" in this report is assumed to be trees whose diameter at 4.5 feet above the ground (diameter at breast height) is 9 inches or greater. Diameters of the timber resource analyzed in this report are grouped into 2-inch classes for which the nominal diameter is the mid-value (e.g., the 10-inch d.b.h. class includes all trees whose diameter is between 9.0 and 10.9 inches).

³Usually the small end of the log is specified for the diameter inside bark (d.i.b.) measurement.

tainty surrounding supplies of logs for veneer. The analysis showed that under 1978 conditions, supplies of stumpage could be critical for both plywood and lumber. However, current total sawmill demand for stumpage has decreased significantly. It is possible that plywood manufacture would be economically attractive at this time.

CONCLUSIONS

The timber resource projected for harvest in the Black Hills area, during the next 15 years, is not adequate to support a plywood plant of economic size in addition to a sawmill industry of the size operating in early 1978. Under conditions existing at that time, competition for available sawtimber could be expected to intensify during the period, particularly after 1986. More recently, however, mill closures have resulted in substantial reductions in overall sawmill production, which could make plywood an attractive alternative for utilizing a potential surplus of sawtimber.

Markets do not appear to be a major problem, because the north-central part of the United States should provide good end-use outlets for plywood of the types that could be produced. Economic costs and returns would probably be favorable for a plywood producer at least until 1986, when the expected reduction in sawtimber volume could significantly increase competition and the cost of stumpage.

STUDY OBJECTIVES

The goal of this study was to evaluate marketing, timber resource and economic factors that determine whether plywood could be profitably manufactured in the Black Hills area of South Dakota and Wyoming. Specifically the study objectives were to:

1. Determine market potentials for selected plywood products that can be manufactured from Black Hills ponderosa pine.
2. Evaluate the timber resource of the Black Hills area in terms of its current utilization, its availability and suitability for veneer, and the log size classes available under current timber management plans.
3. Analyze the operating economics of a potential plywood plant/sawmill complex under several assumptions about product prices and plant costs.

MARKETS FOR BLACK HILLS PLYWOOD

U.S. PLYWOOD MARKET CHANGES

Since 1945, many new end uses have been developed for softwood plywood in the United States. The largest single use is structural sheathing for residential construction. In response to this increase in uses, the softwood plywood industry now has 10 times the production capacity of 30 years ago (Gregory 1972, Lambert 1977, U.S. Department of Commerce 1978a).

In 1950, the plywood industry manufactured about 2.7 billion square feet (MMM ft²)⁴ at a relative wholesale price index of 180 (1967 = 100). Until 1968, the plywood industry provided increasing supplies at decreasing relative prices because of efficiencies of scale, productivity gains, and increased industry competition (Gregory 1972). This relationship through the years until 1967 is shown in figure 1 by the steadily decreasing relative wholesale price index as production increased. However, starting in 1968, the relationship between relative wholesale price index and softwood plywood production became erratic because of several economic factors—primarily inflation, rising raw material costs and, especially, highly variable housing markets.

Production of sanded grades⁵ was about 2.6 MMM ft² in 1976, 18% of total production (American Plywood Association 1977b). Production of specialty grades⁶ was about 1.5 MMM ft² in 1976, 10% of total production. Production of sheathing grades⁷ was about 10.7 MMM ft² in 1976, 72% of total production.

During the past 30 years, plywood, especially sheathing, has been substituted for lumber in housing

⁴All plywood production and volume figures in this report are based on 3/8-inch thickness unless otherwise noted.

⁵Sanded grades include B-D and better sanded grades (American Plywood Association 1974).

⁶Specialty grades include siding, and other specialty products like T 1-11, 303 sidings and overlays, and Plyron (American Plywood Association 1974).

⁷Sheathing grades include sheathing and touch sanded grades such as C-D-X, Underlayment, C-C, 2-4-1, Structural I and II, and C-D P & TS (American Plywood Association 1974).

Figure 1.—Production of softwood plywood from 1950 to 1977 relative to its wholesale price index. Data Source: Phelps (1977), and U.S. Department of Commerce (1978b). Acknowledgement is made of the original form of this graph appearing in Gregory (1972).

construction. This shift accounts for the dominance of sheathing grades among all types of softwood plywood.

NATIONAL PLYWOOD OUTLOOK

Although the maturing plywood industry may not continue to experience the spectacular growth rate of the 25-year post-World War II period, industry sources expect continued expansion of production to meet increasing demand (Anderson 1977, Baldwin 1977). Housing growth is expected to continue to increase up to the late 1980's. However, wide cyclic swings may continue unless effective institutional means are adopted to even out production (Young 1978). New floor, foundation, and wall applications for plywood, such as the All Weather Wood Foundation or under-floor plenum heating-cooling systems, will probably strengthen plywood demand. Non-housing markets such as use by homeowners also are expected to create new plywood demand.^a

Current (1980) plywood industry plant capacity,^a based on 3-shift, 5-day operation, is estimated at 24.46 MMM ft². This current total capacity is slightly higher than a conservatively projected demand for the mid-1980's of about 22 MMM ft².

End-Use Markets

The five principal markets for softwood plywood, as defined by the American Plywood Association (APA) (Anderson 1977) are:

Residential construction.—Including single and multifamily homes, manufactured housing, and mobile homes.

Nonresidential construction.—Including most buildings not used as homes, such as commercial, industrial, and institutional buildings; hotels; motels; agricultural buildings; and applications such as barricades, signs, shoring, dams, bridges, and highways. Highrise apartment construction also is included in this end-use market.

Industrial.—Encompassing a wide variety of uses, such as manufactured products including furniture, fixtures, and toys. Pallets, crates, bins, and other containers, categorized as materials handling devices, are also included. The transportation industry uses plywood in truck bodies, cargo containers and liners, rail cars, ships, boats, and travel trailers. General industrial applications are for plant repair and maintenance, and for tools, jigs, and patterns.

Distribution (homeowner).—Including home repair and remodeling, home additions and alterations, and miscellaneous homeowner projects.

Miscellaneous.—The fifth market segment, including international markets, government and military markets, and any use not included in the other market sectors.

Of interest, is the projected change in demand for each of the five principal markets. Average growth or decline in each principal end-use market is indicated by a compound annual rate of demand change (table 1). For example, an estimated market share loss of 8.1% from 1977 to 1986 in the residential end-use market is taken up by market share gains in the other four end-use markets.

End-Use Markets and Plywood Grades

Some indication of future demand for individual plywood grades can be obtained by combining demand forecasts for end-use markets with information about plywood grades most used in those markets. Table 2 shows main segments of the five major plywood end-use markets along with plywood grades used predominantly in each market segment.

A Black Hills plywood plant, manufacturing panels with C and D grades of veneer, would have access to several market segments. Some degree of protection from market fluctuations would be afforded by this diversity.

Grades other than C-D-X that could be made from Black Hills ponderosa pine are Exterior C-C and Structural II C-C, C-C Plugged, and C-D; also Interior Structural II C-D, C-D Plugged, and Underlayment; also 2-4-1 and 2-4-1 T&G. These grades have wide application by market sector, as shown in table 2, and are relatively high in value; however, market demand is much smaller than for C-D or C-D-X grades.

In addition, new grade specifications for 303 siding may allow use of ponderosa pine for this product. Also, enough B Patch and better veneer can be recovered (Yerkes and Woodfin 1972) so that decorative panel products and cabinet grade plywood are production possibilities.

PONDEROSA PINE PLYWOOD—POTENTIAL APPLICATIONS

Ponderosa pine (*Pinus ponderosa* Laws.) is classified in U.S. Product Standard PS 1-74 as a Group 3 softwood plywood species (American Plywood Association 1974), based on stiffness and strength properties. Plywood characteristics and properties important in marketing and application are discussed in the appendix. Based on these characteristics and the APA classification, some of the uses for which ponderosa pine plywood should be suitable include sheathing, subflooring, underlayment, siding, soffits, signs, billboards, boxes, crates, movable partitions, interior paneling, and kitchen cabinets, furniture, fixtures, and decorative paneling. The following applications are discussed for each major end-use category that utilizes mostly C and D grades of veneer.

Residential Construction

Softwood plywood is primarily used in roof sheathing, subflooring, underlayment, combination flooring,

^aPersonal communication from Robert G. Anderson, Marketing Group, American Plywood Association, Tacoma Wash.

Table 1.—Comparison of demand and market share in plywood end-use markets¹

Major end-use market	1977 demand	1986 estimated demand	Estimated average annual demand change 1977-1986	1977 market share	1986 estimated market share
	----- MMM ft ² -----		----- percent -----		
Residential	9.10	8.85	- 0.28	46.8	38.7
Distribution (homeowner)	3.60	4.55	2.37	18.5	19.9
Industrial	3.00	4.10	3.17	15.4	17.9
Nonresidential	2.25	3.10	3.26	11.6	13.6
Other	1.50	2.25	4.14	7.7	9.8
Total	19.45	22.85	² 1.62	100.0	100.0

¹Source: Anderson (1977).²This figure is the average for all major end-use markets.

wall sheathing, siding, and combination siding. These uses make up almost 90% of the plywood sold in the residential construction market. Most of the potential construction uses for ponderosa pine plywood are subject to local building codes, which establish the minimum physical requirements for a particular use. Applications must therefore be considered within requirements of building codes and other characteristics of the end use.

Industrial, Nonresidential, and Other Uses

The uses in the industrial market that were considered in this study are van interiors, boxes and crates, pallets, and air cargo containers—the total of which represents approximately 25% of the industrial market. However, there are many diverse end uses for softwood plywood in the industrial market, each requiring a unique set of physical properties. Unlike requirements for the residential construction market, characteristics other than strength and stiffness are important in many industrial uses of softwood plywood. For example, the weight of the material from which a container is made can be more significant than the material strength. Ponderosa pine could have an advantage over some other species used in plywood because of its combination of moderate strength and light weight. Because many uses in the industrial market require a face veneer of A or B grade, some Black Hills ponderosa pine plywood could fit these requirements.

The nonresidential construction market uses plywood in many ways, such as concrete forms and temporary structures.

Homeowner and miscellaneous uses would cover applications ranging from home remodeling to furniture. For structural use, ponderosa pine plywood would be subject to conditions similar to residential construction.

MARKETING BLACK HILLS PLYWOOD

Production and Demand in Relation to Geography

The distribution of plywood plants in the United States is shown in table 3. Plywood production in the South has risen dramatically since the first plant was established there in 1964. The number of plants has increased in the South and decreased in the Northwest. Although production capacity figures for some states and individual plants are available in the trade literature, estimates of total industry plant capacity from 1970 to 1978 are less certain. It is expected, however, that most future industry growth will occur in the South.

Relative volumes of plywood shipped from each producing region to various Rand McNally Major Trading Areas (Rand McNally and Company 1963) offer some insight into comparative advantages each region may have.

Shipment data on sheathing plywood for 1976 (American Plywood Association 1977b) indicate that shipments from producers in the South went to all but seven of 52 Rand McNally Major Trading Areas (including Alaska, Honolulu, and Export); shipments from producers in the West went to all Major Trading Areas; shipments from the producers Inland went to all but three Major Trading Areas (table 4). The regional pattern of shipments from the South is most apparent, while shipments from the West and Inland Regions appear to be more widely distributed.

Within the range of sheathing grades produced, certain producing regions manufacture a disproportionately large share of certain grades (table 5). The Inland Region, for example, shipped slightly less than 18% of the industry's sheathing production in 1976. However, of the total C-D Interior sheathing produced, the Inland

Table 2.—Softwood plywood applications by grade in major end use market segments¹

	Panel use ²	Residential				Nonresidential			Industrial				Distribution ³		Miscellaneous ³			
		Floor structures	Roof structures	Siding	Other residential uses	Mobile homes	Roof decks	Concrete forms	Other nonresidential uses	Material handling	Transportation equipment	Products made for sale	Plant repair, maintenance	Home modifications ⁴	Other homeowner uses	International	Military and government	
Engineered grades:																		
C-D, C-D-X	I	X	X		X	X		X	X	X		X	X	X	X		X	X
Structural I C-D	I					X		X			X		X					
Structural II C-D	I										X		X					
Underlayment	I	X			X	X			X				X		X		X	
T&G Underlayment ⁵	I	X											X		X		X	
2-4-1	I	X			X			X		X			X					
C-D Plugged	I												X					
C-C	E								X	X	X		X				X	
Underlayment C-C Plugged	E	X											X		X		X	
C-C Plugged	E		X	X				X	X	X			X					
Structural I C-C	E					X		X			X		X					
B-B Plyform I & II	E								X				X					
Appearance grades:																		
N-N, N-A, N-B	I										X		X		X			
N-D	I										X		X		X			
A-A	I										X		X		X			
A-B	I										X		X		X			
A-D	I				X	X				X	X	X	X		X	X	X	
B-B	I										X		X		X			
B-D	I										X		X		X			
A-A	E										X		X		X			
A-B	E										X		X		X			
A-C	E		X	X	X	X			X	X	X	X	X		X		X	X
B-B	E										X		X		X			
B-C	E	X	X	X			X	X	X	X	X	X	X		X	X	X	X
Specialty grades:																		
Decorative panels	I				X								X					
Plyron	I				X								X					
HDO	E							X				X	X					
MDO	E	X	X	X				X		X	X	X		X				
303 siding, T 1-11	E	X	X	X	X			X				X	X		X		X	X
Plyron	E												X					
Marine	E									X	X	X						

¹Sources: Anderson (1977), American Plywood Association (1976).²Panel use: I = Interior, E = Exterior.³Distribution is also called the homeowner market. For both Distribution and Miscellaneous market segments, almost all grades are in demand; only the principal grades are indicated.⁴Includes home repairs, additions, alterations.⁵T&G = Tongue and Groove.

Table 3.—Distribution of North American softwood plywood plants for selected years¹

Area	1970	1974	1976	1977	1978
South and Southeast					
Alabama	3	7	8	8	9
Arkansas	6	8	8	8	9
Florida	1	2	1	—	—
Georgia	5	5	7	5	6
Louisiana	10	11	13	13	13
Maryland	1	1	1	1	1
Mississippi	5	6	6	5	6
North Carolina	5	5	5	6	8
Oklahoma	—	1	1	1	1
South Carolina	1	2	2	3	4
Texas	7	7	9	7	9
Virginia	2	1	2	2	2
Total	46	56	63	59	68
Pacific Northwest and Coast					
California	16	17	23	16	13
Oregon	84	79	85	79	69
Washington	32	28	28	25	27
Total	132	124	136	120	109
Inland					
Idaho	5	4	5	5	5
Montana	5	5	7	6	5
Total	10	9	12	11	10
Other States²					
	4	3	4	2	2
Total U.S.	192	192	215	192	189
Total Canada	28	30	28	28	33
TOTAL NORTH AMERICA	220	222	243	220	222

¹Source: *Directory of the Forest Products Industry* for each year, published by Miller Freeman Publications, Inc., San Francisco, Calif.

²Number of softwood plywood plants in states not typically associated with any of the three recognized producing regions.

Region shipped almost 96%, and of the total C-C Plugged Exterior sheathing produced, the Inland Region shipped almost 43%.

Freight Rates

Freight rates are a large factor in delivered price and, given a commodity type product like sheathing, can often determine where plywood is purchased. There are numerous market areas where a Black Hills producer might ship plywood with a freight advantage, or at least with a freight parity, compared to existing production centers.

Current freight regulations require plywood producers to separate the f.o.b. mill price from freight charges and permit customers to pay freight costs on the basis of actual weights. Consequently, ponderosa pine plywood, would have significant freight cost advantage over Douglas-fir or southern pine plywood due to its lighter weight.

Newcastle, Wyo., and Rapid City and Whitewood, S. Dak., were selected as representative Black Hills locations on which to base freight rate computations in this study. Of all other southern and western rail shipping points considered, one or more of the three Black Hills locations have the lowest rates to the following cities: Denver, Des Moines, Kansas City, Milwaukee, Minneapolis, Omaha, and Wichita. Freight rates to Chicago from the Black Hills locations were slightly higher than the lowest rate from the South, but remained competitive.

Of all truck shipping points considered, one or more of the three Black Hills locations have the lowest rates to the following cities: Chicago, Denver, Des Moines, Kansas City, Minneapolis, Omaha, and Wichita.

Table 7 shows how these truck and rail rates compare. In almost all cases, truck rates are highly competitive with rail; in a few instances they are lower. With the exception of Rapid City and Whitewood to Wichita and of Newcastle to Omaha, rail transport is less than \$2.00 cheaper than truck transport. For

Table 4.—Shipments to major trade areas receiving 1% or more of total production from each producing region¹

Southern			Inland			Western		
Trade area destination	Amount shipped ²	Percent of production from region	Trade area destination	Amount shipped ²	Percent of production from region	Trade area destination	Amount shipped ²	Percent of production from region
Charlotte	486,665	9.03	Spokane	185,318	9.85	San Francisco/		
Atlanta/			Salt Lake City	176,869	9.40	Oakland	505,237	14.80
Chattanooga	334,102	6.20	Denver	151,156	8.03	Portland	493,472	14.45
Chicago	293,543	5.45	New York	131,522	6.99	Los Angeles	482,389	14.13
Dallas/			Minneapolis/			Seattle	306,435	8.98
Fort Worth	289,767	5.38	St. Paul	127,871	6.79	Export	247,908	7.26
Memphis	238,737	4.43	Seattle	115,410	6.13	New York	201,433	5.90
Houston	234,824	4.36	San Francisco/			Chicago	127,535	3.74
Detroit/			Oakland	104,011	5.53	Boston/		
Toledo	229,093	4.25	Boston/			Providence	124,209	3.64
New York	203,471	3.78	Providence	76,779	4.08	Phoenix	103,941	3.04
Richmond/			Milwaukee	71,793	3.81	Minneapolis/		
Norfolk	198,767	3.69	Export	65,978	3.51	St. Paul	102,751	3.01
Philadelphia	195,488	3.63	Detroit/			Salt Lake City	86,199	2.52
New Orleans	163,130	3.03	Toledo	64,832	3.44	Milwaukee	76,331	2.24
Washington/			Philadelphia	63,046	3.35	Philadelphia	70,043	2.05
Baltimore	153,333	2.85	Los Angeles	62,378	3.31	Detroit/		
St. Louis	149,583	2.78	Portland	51,952	2.76	Toledo	54,635	1.60
Miami	143,574	2.66	Des Moines/			Denver	51,843	1.52
Jacksonville	123,056	2.28	Sioux City	34,627	1.84	Washington/		
Birmingham	118,499	2.20	Washington/			Baltimore	47,538	1.34
Kansas City	111,850	2.08	Baltimore	30,807	1.64	Kansas City	42,759	1.25
Cleveland	110,724	2.05	St. Louis	29,804	1.58	Spokane	42,447	1.24
Milwaukee	110,320	2.05	Buffalo/			Des Moines/		
Pittsburgh	105,464	1.96	Rochester	26,391	1.40	Sioux City	36,403	1.07
Little Rock	104,171	1.93	Kansas City	20,543	1.09			
Knoxville	95,807	1.78	Omaha	19,635	1.04			
San Antonio	94,103	1.76						
Indianapolis	89,924	1.76						
Tampa/								
St. Petersburg	84,574	1.57						
Cincinnati/								
Dayton	83,974	1.56						
Boston/								
Providence	79,752	1.48						
Des Moines/								
Sioux City	68,994	1.28						
Nashville	63,832	1.18						
Shreveport	58,641	1.09						
Oklahoma City	57,110	1.06						
Columbus	53,622	1.00						

¹Data Source: American Plywood Association (1977b).²In thousand square feet (M ft²), 3/8-inch basis.

customers not located on rail sidings, any surcharge added to rail rates to cover truck delivery would likely overcome the slight cost advantage of rail shipment.

In the period since these figures were originally compiled (1977), several across-the-board, percentage freight rate increases have increased the rate advantage of Black Hills locations, compared to the Pacific Northwest and Southern Regions, when shipping to the Great Lakes States.

Market Potentials

Based on freight costs and trade patterns, the trade areas represented by the cities listed in table 7 probably comprise the prime potential market for a poten-

tial Black Hills plywood producer. Data for 1976, assembled in table 8, support the concept that plywood manufactured in the Black Hills can be marketed successfully in northern and central Great Plains, the upper Midwest, and the Great Lakes area.

Rough Grades

The total industry column in table 8 shows the proportion of total industry production of sheathing grades that was shipped to the prime Black Hills market area. For example, the total volume of sheathing that was shipped to the prime market area is about 1.75 MMM ft², 3/8-inch basis. This volume is about 16% of sheathing production of the entire plywood industry.

Table 5.—Distribution of 1976 sheathing plywood shipments by grade and producing region¹

Sheathing plywood grade or group	Industry total production ²	Percent of shipments from each region		
		Inland	Southern	Western
Interior				
C-D	56,161	95.71	0.47	3.82
C-D-X	7,350,432	15.64	55.54	28.83
Structural I & II	157,380	7.88	0.81	91.31
C-D Plugged	1,132	8.83	13.62	77.55
C-D-X Plugged	368,621	14.14	42.24	43.62
Underlayment	324	45.18	—	54.82
Underlayment Exterior glue	1,226,010	22.35	48.82	28.83
2-4-1	4,750	0.23	—	99.77
2-4-1-X	106,023	31.05	3.53	65.41
Miscellaneous	41,621	56.62	3.19	40.19
Total Interior	9,312,454	17.16	52.01	30.83
Exterior				
C-C	109,978	29.15	16.94	53.91
C-C Plugged	201,193	42.70	3.89	53.41
Total Exterior	311,172	37.91	8.50	53.48
Mill stamp	633,120	18.23	40.09	41.69
Rejects	397,876	11.31	63.55	25.13
TOTAL SHEATHING	10,684,622	17.62	50.43	31.95

¹Data source: American Plywood Association (1977b).²In thousand square feet (M ft²), 3/8-inch basis.Table 6.—Weight (pounds per M ft², surface area basis) for selected species, thicknesses, and constructions of sheathing plywood panels¹

Nominal thickness	Number of double glue lines, typical panel construction ²	Douglas-fir Coast	Douglas-fir Interior North	Western larch	Southern pine		Ponderosa pine
					Loblolly/ Shortleaf	Longleaf/ Slash	
5/16	1.0	928	918	997	966	1,103	777
3/8	1.0	1,105	1,093	1,188	1,151	1,315	924
1/2, 3 ply	1.0	1,459	1,443	1,569	1,521	1,739	1,218
1/2, 4 ply	1.5	1,480	1,465	1,590	1,542	1,761	1,239
1/2, 5 ply	2.0	1,501	1,486	1,612	1,563	1,782	1,260
5/8	2.0	1,855	1,836	1,993	1,933	2,207	1,554
3/4	2.0	2,209	2,186	2,375	2,302	2,631	1,848

¹Computed using wood density figures at 12% moisture (USDA Forest Products Laboratory 1974) and glue weight of 60 lb/M ft² of double glue line. Glue assumed to have 5/6 resin component with 65% solids and 1/6 hardener. Dried glue weight is 42.5 lb/M ft² of double glue line.²From American Plywood Association (1974).

Table 7.—Freight rates¹ (dollars per M ft³) for 1/2-inch, 4-ply sheathing from Black Hills points of origin to selected destinations representative of market trade areas (Rand McNally and Company 1963)

Destinations	Rapid City, S. Dak.		Whitewood, S. Dak.		Newcastle, Wyo.	
	Truck	Rail	Truck	Rail	Truck	Rail
Chicago ²	19.08	17.22	20.07	17.72	18.71	18.21
Denver	10.53	9.66	10.53	10.66	8.80	9.29
Des Moines	14.12	12.02	14.99	13.51	14.99	14.99
Kansas City	15.49	14.99	15.86	15.49	16.48	14.99
Minneapolis	14.00	12.02	14.00	12.51	14.74	15.36
Omaha	12.64	11.15	13.75	11.77	14.00	11.77
Wichita ³	16.35	11.52	15.49	11.89	15.49	14.99
Milwaukee ⁴	—	16.97	—	17.35	—	17.97

¹Commodity rate for truck and rail transport, 1977 prices.

²Only one rail rate to Chicago lower than those shown was identified, \$16.44 from Birmingham, Ala.

³Diboll, Tex., had a lower rail rate of \$15.21 to Wichita.

⁴For comparison, Birmingham, Ala. had a rate of \$17.97 to Milwaukee, equivalent to that for Newcastle, Wyo.

Table 8 also shows the proportion of total industry production shipped to the prime market area from each major plywood region. For example, the Western and Southern Regions each shipped just under 14% of their total production to the prime market area in 1976. However, the Inland Region shipped about 29% of its production to the same trade areas. This relationship could be expected from comparing relative freight costs between regions.

Within each grade listed in table 8, the proportion shipped from each producing region reflects both freight cost influences and preferences in consuming regions for certain plywood types based on species or other wood characteristics. For example, of the total Underlayment volume shipped to the prime market area, the Inland Region supplied about 35%, the Southern Region about 47%, and the Western Region about 18%. Table 8 further indicates that several grades which could be produced in the Black Hills would have a good chance of market success in the eight trade areas of the prime market area. For example, plywood from Black Hills ponderosa pine could be manufactured in C-C, C-D, C-C Plugged, C-D Plugged, Underlayment, and 2-4-1 grades, with either interior or exterior glue. Even allowing for APA species group differences, ponderosa pine plywood in these grades would probably be acceptable.

Siding

Siding panels currently are manufactured from plywood species groups 1 through 4. As shown in table 8, the prime market area in 1976 received slightly less than 15% of all siding manufactured under the American Plywood Association's specifications for 303 siding products. Table 8 also shows that about 25% of siding

made from species groups 2, 3, and 4 was shipped to the prime market area. Of this volume, virtually all (99.85%) 303 siding originated in the Western Region. Of the minute amount produced in the Inland Region, most (96%) was shipped to the prime market area.

Recently, the American Plywood Association revised its specifications for 303 siding (see appendix). Given the diversity of classes and grades defined in the new APA specifications, C grade veneer in the Black Hills could have increased technical potential for utilization in siding panels. Also, the prime market area for the Black Hills appears to accept enough 303 siding of all species groups for a market to be established for modest quantities of siding manufactured from Black Hills ponderosa pine.

TIMBER RESOURCES AND PLYWOOD

The Black Hills area is about 20,600 square miles of forested mountains located along the boundary between western South Dakota and northeastern Wyoming (U.S. Department of Agriculture and U.S. Department of Interior 1967). Surrounded by short grass prairie for at least 100 miles in all directions, the Black Hills is a uniquely isolated mix of federal, state, and private land (fig. 2). State land is largely concentrated in Custer State Park, located in the southeastern part of the Black Hills. Private land is scattered throughout the federal land, usually in small tracts.

To evaluate any proposed forest products venture, such as a plywood plant in the Black Hills, it is necessary to estimate the amount of timber required. Further, it is important to know how much material is available, what part of this material is used currently, and what part is suitable for the proposed product.

Table 8.—Quantity (square feet, 3/8-inch basis) of softwood plywood sheathing and siding shipped in 1976 from the three major producing regions to the prime market area for Black Hills production¹

Plywood grade	Inland			Southern			Western			Total industry ²	
	Quantity	Percent of total industry production shipped	Percent of regional production shipped	Quantity	Percent of total industry production shipped	Percent of regional production shipped	Quantity	Percent of total industry production shipped	Percent of regional production shipped	Quantity	Percent of total industry production shipped
SHEATHING											
Product standard sheathing											
Interior:											
C-D	17,393,038	97.67	32.36	509,168,100	--	--	414,787	2.33	19.33	17,807,825	31.71
C-D-X	343,884,670	29.27	29.92	219,872	43.33	12.47	321,981,349	27.40	15.20	1,175,034,119	15.99
Struc. I and II	1,570,433	53.78	12.66	11,307	7.53	17.16	1,129,558	38.69	0.79	2,919,863	1.86
C-D Plugged	16,000	49.34	16.02	27,786,853	34.87	7.34	5,120	15.79	0.58	32,427	2.87
C-D-X Plugged	16,586,055	30.41	31.82	--	50.95	17.84	10,169,172	18.64	6.32	54,542,080	14.80
Underlayment	143,616	100.00	98.08	--	--	--	--	--	--	143,616	44.31
Underlayment Exterior											
glue	120,122,950	35.09	43.83	161,679,888	47.23	27.01	60,490,545	17.67	17.12	342,293,383	27.92
2-4-1	--	--	--	--	--	--	285,824	100.00	5.61	265,824	5.60
2-4-1 Exterior Glue	1,111,296	29.26	3.38	--	--	--	2,686,368	70.74	3.87	3,797,664	3.58
Miscellaneous	1,806,570	94.95	7.67	--	--	--	96,000	5.05	0.57	1,902,570	4.57
Total Interior	502,634,628	31.44	31.45	698,866,020	43.71	14.43	397,238,723	24.85	13.84	1,598,739,271	17.17
Exterior:											
C-C	2,783,873	54.73	8.68	609,238	11.98	3.27	1,693,523	33.29	2.86	5,086,634	4.63
C-C Plugged	7,094,324	62.58	8.26	870,240	7.68	11.12	3,372,040	29.74	3.14	11,336,604	5.63
Total Exterior	9,878,197	60.15	8.37	1,479,478	9.01	5.59	5,065,563	30.84	3.04	16,423,238	5.28
Total product standard sheathing	512,512,825	31.73	29.86	700,345,498	43.36	14.38	402,304,286	24.91	13.24	1,615,162,609	16.78
Total mill stamp sheathing	32,426,097	28.59	26.83	20,243,352	17.85	7.62	60,765,858	53.57	12.98	113,435,307	17.11
Total rejects sheathing	3,871,056	14.86	8.60	19,156,334	73.54	7.58	3,022,067	11.60	3.02	26,049,457	6.55
TOTAL SHEATHING	548,809,978	31.28	29.16	739,755,184	42.16	13.75	466,092,211	26.56	13.65	1,754,657,373	16.42
SIDING											
Group 1	709,546	0.70	7.08	12,059,250	11.97	6.74	88,001,083	87.33	12.27	100,769,879	11.12
Group 2-4	117,493	0.15	96.13	--	--	--	78,293,922	99.85	25.15	78,411,415	25.18
TOTAL SIDING	827,039	0.46	8.15	12,059,250	6.73	6.74	166,295,005	92.81	16.16	179,181,294	14.71

¹The prime market area consists of the following trade areas: Chicago, Denver, Des Moines, Kansas City, Milwaukee, Minneapolis, Omaha, and Wichita.

²This is the quantity and proportion of all industry shipments to the prime market.

Figure 2.—Black Hills National Forest and adjacent area.

THE FOREST RESOURCE

Land

Total forest land area in all ownerships is about 2.1 million acres, and of this area, 1.9 million acres (88%) are classified as productive nonreserved forest land.⁹ Of this productive nonreserved forest land, 1.1 million acres are in the Black Hills NF, 627,000 acres are in private ownership, and 131,000 acres are administered by state agencies and federal agencies other than USDA Forest Service.

Growing Stock

Ponderosa pine is the predominant species in the Black Hills, with minor amounts of white spruce (*Picea glauca*), aspen (*Populus tremuloides*), and other hardwoods present. Table 9 shows the distribution of growing stock among areas and timber types. Ponderosa pine is the only species considered in this study. Any small volumes of spruce harvested with pine would likely be processed for plywood with pine or sold for sawlogs. Major harvests of aspen are not planned, although small amounts may occasionally become available.

The Black Hills NF contains about 68% of the growing stock volume; private owners, 25%; and other public agencies, 7%. Sawlog volume in the Black Hills NF is also 68% of the total, with 27% on private lands and 5% in other holdings.

Nearly two-thirds of the ponderosa pine growing stock in diameter classes 5 inches d.b.h. and greater, on the Black Hills NF, have diameters between 5.0 and 8.9 inches. However, these diameter classes contain only about 22% of the net cubic foot volume. About half the cubic foot volume is in diameter classes from 9.0 to 14.9 inches. The complete distribution¹⁰ is as follows:

D.b.h.	Live stems	Net volume
inches	percent	percent
5.0-8.9	65.2	21.9
9.0-14.9	29.9	49.6
15.0-20.9	4.5	23.9
21.0+	0.4	4.6

RESOURCES FOR PLYWOOD

Current Utilization

Sawmills are now the primary users of logs 8 inches d.b.h. and larger. A small volume (about 4%) of

⁹Productive nonreserved forest land is defined as forest land capable of producing industrial wood crops. This requires a minimum growth rate of 20 cubic feet per acre per year, and the land must not be withdrawn from timber utilization because of statute or administrative regulation.

¹⁰These figures are based on data from computer program GROW that was used as part of the timber management process. The data were supplied by the Black Hills National Forest.

sawtimber size material is used for commercial poles (Setzer and Barrett 1977). Many sawmills are now equipped to saw logs smaller than those previously classified as sawlog size material. Sawmill output in the Black Hills is currently about 80% board lumber and about 20% dimension lumber.¹¹

Estimated future sawmill requirements for sawtimber are based on past experience. Mill capacity figures are based on directories for the forest products industry in South Dakota and Wyoming (South Dakota Department of Game, Fish and Parks 1974, Wyoming Department of Economic Planning and Development 1974), as updated by unpublished data.¹² Based primarily on 1-shift operation, the estimated sawmill capacity in the Black Hills as of early 1978 was 200 million board feet lumber tally (MM fbm (LT)).

For a variety of reasons, sawmill production has been less in the past than suggested by the estimated capacity figures. Table 10 shows an effective capacity figure that estimates the degree to which sawmills have used their total capacity in utilizing the timber actually cut. The underutilization of production capacity indicated in table 10, together with the general lumber market conditions from 1972 to 1975, imply that in relatively poor years, production averaged only about 60-70% of total capacity. Effective capacity of 82% in 1974 indicates a relatively good year for Black Hills lumber producers.

Figures in table 10 suggest that a 75% effective capacity is a reasonable estimate of sawmill utilization for purposes of this analysis. Then, assuming a recovery factor¹³ of 1.3, based on present USDA Forest Service Appraisal Guidelines, and assuming that these figures will hold for the next 10 years, the estimated log supply required to sustain sawmills at an average production level during this period is as follows:

200 MM fbm lumber tally current total capacity

× 0.75 effective capacity proportion of total capacity

= 150 MM fbm lumber tally effective capacity

÷ 1.3 MM fbm lumber tally/MM fbm log scale recovery factor

= 115.4 MM fbm net log scale

Thus, the current estimated average annual sawmill requirement for timber is about 115 MM fbm (LS).

¹¹Personal communication from F. P. Smedley, USDA Forest Service, Black Hills NF, Custer, S. Dak. (On file at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.)

¹²Report of Black Hills Industry Mix Task Force. 1974. Unpublished report on file at Rocky Mountain Forest and Range Experiment Station.

¹³Recovery factor is the lumber output measured in foot board measure lumber tally (fbm (LT)) divided by the net log volume measured in board feet Scribner Decimal C log scale (fbm (LS)). All log volumes are given as net rather than gross, unless otherwise noted.

Table 9.—Total sawtimber and growing stock, Black Hills area, 1974

Forest type	South Dakota		Wyoming		Black Hills total	
	Sawtimber	Growing stock	Sawtimber	Growing stock	Sawtimber	Growing stock
	<i>M fbm (LS)</i>	<i>M ft³</i>	<i>M fbm (LS)</i>	<i>M ft³</i>	<i>M fbm (LS)</i>	<i>M ft³</i>
Ponderosa pine	5,212,922	1,542,243	2,141,742	644,683	7,354,664	2,186,926
White spruce	230,173	50,357	55,533	12,436	285,706	62,793
Hardwoods	133,251	39,388	115,518	57,309	248,769	96,697
Total	5,576,346	1,631,988	2,312,793	714,428	7,889,139	2,346,416

Table 10.—Estimates of available timber compared with effective capacity of Black Hills sawmills

Year	NF total cut all size classes ¹	NF total cut sawtimber ²	All ownerships total cut sawtimber ³	Mill capacity ⁴ lumber tally	Lumber recovery factor ⁵	Mill capacity, ⁶ Scribner log scale	Effective capacity ⁷
	<i>MM fbm (LS)</i>			<i>MM fbm (LT)</i>		<i>MM fbm (LS)</i>	Percent
1972	96.969	66.414	88.552	152.1	1.20	127.8	69.3
1973	89.170	61.073	81.430	152.1	1.19	127.8	63.7
1974	112.011	76.716	102.288	152.1	1.22	124.7	82.0
1975	76.796	52.598	70.130	152.1	1.49	102.1	68.7

¹Source: Black Hills NF Timber Management Plan 1977-1986.

²Board foot volume in all size classes multiplied by a factor of 0.6849, the proportion of sawtimber in 1974.

³Computed by dividing Black Hills NF sawtimber cut by 0.75 because this sawtimber was three-fourths of total cut.

⁴Source: Black Hills Task Force Report, 1974. In 1976, capacity increased by 30 MM fbm (LT), all in one mill.

⁵Source: USDA Forest Service, Rocky Mountain Region Appraisal Bulletins for the respective time periods.

⁶Computed by dividing lumber tally mill capacity by lumber recovery factor.

⁷Percentage of total sawmill capacity (net log scale—column 7) that was used in processing sawtimber from all ownerships (column 4).

10-Year Future Supply, 1977-1986

The Black Hills NF plans to treat annually about 39,600 acres of forest land with a variety of silvicultural cuts. Most of this acreage is in the Standard Component¹⁴ with the remainder in the Special Component.¹⁵

¹⁴Standard Component is the component of the regulated, suitable, forested land on which crops of industrial wood can be grown and harvested with adequate protection of the forest resources under the usual provisions of the timber sale contract. This area includes stands of immature trees or areas not yet accessible, but which will be in the normal course of events. This area is capable of producing timber crops that have a reasonable probability of use, given the accessibility and economic conditions projected for a 10-year plan period, even though portions of the area may not be developed during this period.

¹⁵Special Component is the component of the regulated, forested land that is recognized in the multiple use plan as needing specially designed treatment of the timber resource to achieve landscape or other key resource objectives. For example, these are areas where timber management activities are informally delayed pending multiple use planning studies and management decisions, travel and water influence zones, peripheral portions of developed sites, and developed recreation areas.

Harvest treatment in the Marginal Component¹⁶ is not planned for the current 10-year period.

Under the 1977-1986 National Forest Timber Management Plan, programmed annual sawtimber harvest will be about 118 MM fbm (LS) from trees 8 inches d.b.h. or larger.¹⁷ Planned utilization limits are to a 6-inch top. Trees 9 inches d.b.h. and larger are considered suitable for plywood because they can supply

¹⁶Marginal Component is the component of the regulated, suitable, forested land that does not qualify as a standard or special components, primarily because of excessive development cost, low product values, or resource protection constraints. Included may be drainages requiring unusual logging techniques, such as helicopters, skyline logging systems; areas where harvesting is blocked until government constructed roads are in place; or areas supplying a particular product or particular species type not presently in demand. Also included is the backlog of nonstocked areas which would otherwise be classed as standard, but are in need of reforestation that cannot be accomplished with Knutson-Vandenberg funds.

¹⁷Timber Management Plan, Black Hills National Forest. 1977. Unpublished document on file at Rocky Mountain Forest and Range Experiment Station or available from Supervisor's Office, Black Hills NF, Custer, S. Dak.

an 8-inch d.i.b. small end veneer log. Volume scheduled to be cut in trees 9 inches d.b.h. and larger is about 110.7 MM fbm (LS).

Timber harvested from non-national forest lands in South Dakota contributes significant amounts of roundwood. Estimated annual allowable harvest from these lands is about 57,290 cunits, with sawtimber amounting to about 15.6 MM fbm (LS).¹⁸ Volume figures for Wyoming show an annual allowable cut of 22 MM fbm (LS) on private and other public land (U.S. Department of Agriculture and U.S. Department of Interior 1967). Past experience suggests that in both South Dakota and Wyoming, about half the allowable cut from non-national forest land will be harvested.

Timber available from state and private land in both states can be expected to range from a minimum of 19 MM fbm (LS), representing the historical level of actual cuts, to a maximum allowable cut of about 38 MM fbm (LS). These volumes in trees 9 inches d.b.h. and larger are an important potential resource in determining the timber volume available for plywood.

Availability for Plywood

A surplus sawtimber volume that may be available for plywood manufacture is estimated by deducting current sawtimber usage from total volumes that are available (table 11).

¹⁸Personal communication from South Dakota Department of Fish, Game, and Parks, Division of Forestry. Figures from timber management plan for the period 1974-1984.

Total estimated supply of sawtimber in the Black Hills available for forest products, is in a range of 137 to 156 MM fbm (LS), depending on volume cut from state and private lands. The supply in the Black Hills NF is divided into two parts: volume in trees equal to or greater than 9 inches d.b.h., and volume in trees less than 9 inches d.b.h. The supply of sawtimber from state and private land is assumed to be in trees 9 inches d.b.h. and larger.

In the use section of table 11, Black Hills NF volume in trees less than 9 inches d.b.h. is subtracted from total supply, because it is assumed trees smaller than 9 inches d.b.h. would not be suitable for plywood manufacture. When this volume is subtracted from the estimated total sawmill demand of 115 MM fbm (LS), the remaining 108 MM fbm (LS) of demand is in trees 9 inches d.b.h. and larger.

The 1977 sawmill usage of 108 MM fbm (LS) in trees 9 inches d.b.h. and larger is subtracted from 130 and 149 MM fbm (LS), respectively; so, the minimum volume available for plywood manufacture ranges from 22 to 41 MM fbm (LS). The computations shown are based on a relatively stable sawmill capacity and suggest that total wood volume available for plywood manufacture may not be as large as desirable. Any significant additions or reductions in total sawmill capacity would inversely alter the volume available for plywood manufacture.

Another factor that might further limit the availability of timber for plywood manufacture is the requirements of the Small Business Set Aside Program.¹¹ For the 5-year period ending December 31,

Table 11.—Computation of timber volume (MM fbm (LS)) available for plywood¹

	Expected	Maximum
Supply of sawtimber		
USDA Forest Service		
≥9 inches	111	111
< 9 inches	+ 7	+ 7
Total Forest Service	118	118
State and private	+ 19	+ 38
Total, all ownerships	137	156
Use of sawtimber		
Sawmill (115 MM fbm (LS))		
< 9 inches (7 MM fbm (LS))	- 7	- 7
	130	149
≥9 inches (115-117 MM fbm (LS))	- 108	- 108
Volume available after satisfying estimated sawmill demand	22	41

¹Assumptions: (1) Entire Black Hills NF programmed harvest is available.

(2) Sawmills are able, if not willing, to take material less than 9 inches d.b.h.

(3) State and private harvest is not less than half the allowable cut and does not exceed allowable cut.

(4) Total sawtimber volume is in trees 8 inches d.b.h. or larger.

1980, the Set Aside Program required preferential treatment of bids from small business on 67% of the sawtimber volume sold. In the next 5-year period the proportion of sawtimber allotted to small business set asides could increase or decrease slightly. However, the potential impact of the Set Aside Program would depend on the size of the firm operating a plywood plant.

In addition, a combination of existing Black Hills operators has announced plans to construct a waferboard plant in the Black Hills area (Forest Industries 1979). This plant is expected to utilize primarily small diameter roundwood not generally suitable for veneer blocks. There would not likely be much direct competition for timber between this waferboard plant and a plywood plant, with the possible exception of logs in the 8- to 10-inch d.i.b. range.

The Second 10 Years, 1987-1996

Under the non-declining, even-flow timber harvest policy of the USDA Forest Service, total cubic volume in the second decade of the Timber Management Plan is expected to be about the same as during the first decade. However, the proportion of sawtimber of larger sizes will probably decrease. The following tabulation shows the relation between sawtimber board foot volume and total cubic volume for the first two decades:¹⁹

Volume cut	Decade 1	Decade 2
Cubic-foot volume, M cunits, all size classes	364.14	363.14
Sawtimber volume, MM fbm (LS), trees 10-inch d.b.h. class and larger	110.67	87.61
Sawtimber volume, MM fbm (LS), trees 8-inch d.b.h. class and larger	117.99	Not available

Volume for trees 10 inches d.b.h. and larger is different for the two decades. Although total sawtimber volume includes trees down to 8 inches d.b.h., the assumption is that only trees 9 inches d.b.h. and greater (i.e., the 10-inch d.b.h. class using 2-inch d.b.h. classes) will be eligible for veneer blocks. Total sawtimber volume for the second decade is not available, but the figure pertinent to plywood manufacture is shown under decade 2 for sawtimber volume in trees in the 10-inch d.b.h. class and larger. Clearly, raw material for plywood would be less available in the second decade.

¹⁹Sources: Timber Management Plan, Black Hills National Forest 1977-1986. Final Environmental Statement for Timber Management Plan, Appendix Q, Black Hills NF. Computer printed output from Program GROW used in Ram Run 37 for the Timber Management Plan, on file at Rocky Mountain Forest and Range Experiment Station.

QUALITY

In addition to the gross amounts of raw material available, feasibility analyses must consider indicators of quality. In this study, the general aspects of quality were considered in terms of timber sale characteristics, log size distribution, and the main products available from Black Hills ponderosa pine.

Efficient plywood plant operation depends largely on having a favorable mix of log sizes available for manufacture; therefore, gross volumes alone do not adequately portray the suitability of the log supply. Estimates must be made of the material size likely to be in the plywood plant woodyard during a year of operation. The log mix that will actually be available to a plywood operation depends on a number of complex logistic factors and is somewhat indeterminate. However, for this study, a log mix was chosen to reflect the tree sizes most likely to be cut as part of the current 10-year Timber Management Plan.

Timber Sale Characteristics

The assumed characteristics of timber sales are based on the Black Hills NF Timber Management Plan. The current 10-year Timber Management Plan for the Black Hills NF, as well as the planning for later 10-year periods, is based on timber classes. Timber classes define growing stock by size, density, and species (USDA Forest Service 1977). Timber is classified as sawtimber trees (8 inches d.b.h. or larger), poletimber trees (5-7.9 inches d.b.h.), and seedling and sapling trees (less than 5 inches d.b.h.). Density of stands is ranked in terms of basal area classes: less than 60 square feet per acre, 60-119 square feet per acre, and 120 square feet per acre and greater. Species groups are ponderosa pine and mixed species. The mixed species group is further classified into pine-spruce, spruce-pine, pine-aspen, and aspen-pine subgroups, depending on the predominant timber type.

The current Plan calls for harvesting timber from 395,525 acres over a 10-year period ending in 1986. Thirteen timber classes are specified for harvest in this period (table 12). Each timber class and its silvicultural prescription is described in the appendix. Of the 13 timber classes, seven comprise almost 97% of the total acreage to be harvested in the current Timber Management Plan period. Thus, these seven classes will be encountered in timber sales to a much greater degree than the remaining six timber classes. These seven timber classes, therefore, were analyzed by proportion of trees in each 2-inch diameter class. From this analysis three major groups of timber classes were developed as shown in figure 3.

One group, timber classes P61 and P21, has mostly small trees 8 inches d.b.h. and smaller scheduled for harvest. This group is not of major interest for plywood production. Timber class P21, with trees in the 10-inch class, is considered a sawtimber stand, but note that the largest d.b.h. class is only 10 inches. Timber class

Table 12.—Timber class characteristics, Black Hills National Forest

Timber class designation ¹	Acres to be cut, 1977-1986	Basal area class ²	Stand size class ³	Dominant species ⁴	Site index ⁵
P21 ⁶	108,787	60-120	S	PP	55
PB1	73,492	60-120	S	PP	55
P31	68,813	120 +	S	PP	65
P61	48,104	120 +	P	PP	58
PA1	35,788	60 —	S	PP	52
SB1	35,774	120 +	S	PS	62
SC1	11,117	120 +	S	SP	75
WZS	5,150	120 +	S	SP	75
TZB	4,000	60-120	S	PP	60
TZN	1,500	60-120	S	PP	60
TZA	1,000	60-120	S	PP	60
N60	1,000	60-120	S	PP	55
NOR	1,000	n.d.	S	PP	55
Total	395,525				

¹Explained in appendix.

²120 + means 120 square feet or greater; 60 — means 60 square feet or less.

³S—sawtimber is predominant size; P—poletimber is predominant size.

⁴PP—ponderosa pine; PS—mixed ponderosa pine and spruce with pine dominant; SP—mixed ponderosa pine and spruce with spruce dominant.

⁵Site index—100-year base.

⁶Timber class P21 is classified by Black Hills NF as sawtimber. However, the largest diameter class represented is 10 inches. For the purposes of this study, it is classified in the pole-timber group.

P61 is classified as poletimber even though it has trees in the 8-inch class, which are considered sawtimber. Consequently, these two timber classes are referred to here as the poletimber group.

The second group, timber classes PA1 and PB1, contains trees in d.b.h. classes 12 inches and larger. Timber sales featuring these two timber classes would have raw material of highest value for a plywood plant. These timber classes are referred to as the sawtimber group.

The third group, timber classes SC1, SB1, and P31, has both pole and sawtimber diameter classes. These timber classes are called the all-size group. Sales having these timber classes would contain raw material of value for plywood but would also include tree diameter classes too small for plywood. Under the multiproduct sale format of the Black Hills NF, purchasers must buy all timber included in the sale, not just certain size classes. Utilizing these small trees poses a challenge for some sawmill operators in the Black Hills, and likely would similarly affect a plywood plant.

Having established the proportions of trees, a timber buyer for a plywood mill would likely give highest priority to the sawtimber group. Next in desirability would be sales featuring the all-size group. Finally, the buyer might consider the poletimber group because it does contain some 9- and 10-inch d.b.h. trees but would probably avoid sales featuring this group if at all possible.

As indicated in the previous discussion, these seven timber classes make up the vast majority of acreage in timber sales until 1986. Acreage for the three groups of timber classes is shown as follows:

Group (timber classes)	Acreage
Sawtimber (PB1, PA1)	109,280
All-size (P31, SB1, SC1)	115,704
Poletimber (P21, P61)	156,891

Acreage is roughly equal in the two groups most useful for plywood. Assuming sales in the poletimber group are of little interest, there is about an equal chance of encountering sales composed of the sawtimber and all-size groups, which together represent about 57% of the total area to be harvested under the current Timber Management Plan.

Log Size Distribution

An estimate of the distribution of log sizes that reasonably could be expected to come from each of the two groups of primary interest is extremely important in the operating economics of a plywood plant. The timber class with the largest acreage from each group was selected to represent the group—class P31 represents the all-size group, and timber class PB1 represents the sawtimber group.

Small end diameters inside bark (d.i.b.) for 8.5-foot veneer blocks were grouped into 1-inch d.i.b. classes for each timber class. Because the two timber class groups—sawtimber and all-size—had about equal acreage, the numbers of 8.5-foot veneer blocks in each d.i.b. class were averaged without weighting. It was assumed that, on an annual basis, a plywood plant would have access to a variety of sales from each timber class group, and that the d.i.b. distribution of veneer blocks would be similar to the computed values. A more complete discussion of methods involved in computing the veneer block distribution is contained in the appendix.

The curve for all 8.5-foot logs in figure 4 is a composite of proportions of logs from the all-size group and sawtimber group. Logs 4 and 5 inches d.i.b. come only from the all-size group. Logs 6 inches and larger come from both timber class groups. There are few logs less than 6 inches d.i.b. cut from large ponderosa pine trees because of the form of the upper bole.

The 6-inch division point also reflects a utilization limit prescribed by the Black Hills NF.²⁰ This limit

²⁰USDA Forest Service, Rocky Mountain Region. 1978. *Supplement to the Forest Service Manual, Title 2400, Timber Management. R-2 Suppl. 236. Page 2451.22—3.*

Figure 3.—Proportional distribution of trees in 2-inch d.b.h. classes for timber management tree classes on the Black Hills National Forest.

Figure 4.—Proportions of logs in 1-inch classes for small end, diameter inside bark (d.i.b.). Results based on tree distribution data from Black Hills National Forest timber classes PB1 and P31: a = logs ≤ 8 inches d.i.b. from small trees; b = logs ≤ 8 inches and less d.i.b. from large trees; c = logs in all d.i.b. classes from all trees; d = logs in study of veneer recovery (Yerkes and Woodfin 1972), ≥ 6 inches d.i.b. at the small end; e = logs in this study ≥ 6 inches d.i.b.

specifies that sawtimber trees, those with d.b.h. 8 inches or larger, must be cut to a 6-inch d.i.b. top or less, provided the tree contains at least one 8-foot log. However, the utilization limits specify that poletimber trees, those with d.b.h. between 5 and 8 inches, must be cut to a 4-inch d.i.b. top or less, and must contain at least two "pieces" (logs) of 8.33 feet each (i.e., one log of 16.67 feet).

Note in figure 4 that both timber class groups contribute substantial numbers of 8-inch logs, and when combined, the proportion of logs in this d.i.b. class is the largest of all d.i.b. classes.

In d.i.b. classes larger than 8 inches, the proportion of logs decreases with an increase in diameter. Logs 20 inches d.i.b. or greater are few, but some can be expected.

Superimposed on figure 4 is the proportional distribution of small end d.i.b.'s for 8.5-foot veneer blocks measured by Yerkes and Woodfin (1972) in their veneer recovery study. Large logs are heavily represented, because large trees were deliberately included to insure an adequate number of peelable blocks in the sample. Logs processed in that veneer recovery study were 6 inches or larger, d.i.b., so comparable log sizes in this study are shown in figure 4.

Product Characteristics

Given the expected numbers of multiproduct timber sales offered by the Forest Service in the Black Hills, purchasers must expect that they will have to handle material that does not fit the mainstream of their

operations. In the case of a projected plywood plant, this material would include logs too small for peeling, veneer block cores, and various kinds of residue, such as clipper trim, lily pads, or bark. To help estimate the amounts and kinds of products and by-products that would be generated, a general assessment of the characteristics of plywood, lumber, and residue product classes was made.

Veneer

The amounts and grades of veneer recoverable from Black Hills ponderosa pine are described in previous research (Yerkes and Woodfin 1972). Conclusions drawn from that research are:

1. A sample of 144 Black Hills ponderosa pine trees, from six d.b.h. classes, meeting defect criteria of the study, yielded veneer in a proportion of grades and sizes that was more than adequate to produce C-D grade, 3/8-inch, 3-ply plywood.
2. Trees in larger diameter classes yielded a higher percentage of veneer but lower percentages of C and better (C+) grades than trees in smaller diameter classes.
3. Larger diameter veneer blocks yielded slightly higher percentages of C+ grades than did smaller diameter blocks.
4. Blocks in lower tree positions yielded larger proportions of C+ grades of veneer than blocks in higher tree positions.
5. Recovery ratios appeared favorable for conversion of trees to plywood, except for trees and blocks of small diameters.²¹
6. More than enough full width sheets of C+ and D grades of veneer were recovered to provide one-piece face plies, even if all plywood that could have been produced in this study were 3/8-inch, 3-ply panels.
7. Knot size, as visually estimated on the veneer blocks, was a useful means of separating the blocks into two classes yielding significantly different proportions of C+ veneer.
8. Recovery data varied widely with all classes of trees and blocks. However, it is believed that any large sample of Black Hills trees in these diameters would give nearly the same veneer recovery as those in this study.

Lumber

Boards and dimension lumber, including studs, are the principal products now manufactured from Black Hills ponderosa pine. Because many plywood plants are associated with a sawmill, log allocation for use in lumber or plywood is influenced by product recovery

²¹"Small diameters" means trees of 9 and 10 inches d.b.h. and veneer blocks smaller than 9 inches d.i.b. When this cited research was done in 1968, the existing "state-of-the-art" in plywood manufacture made this statement generally true. However, recent advances in green end technology for small diameter blocks have made this constraint much less binding on raw material supply.

and value. For purposes of this study, it was assumed that the associated sawmill would exist only as an auxiliary to the plywood operation and would utilize only the logs that could not be profitably utilized in veneer.

The most recent lumber grade recovery study published for the Black Hills found a high proportion of the volume in Common grades of boards (Mueller and Kovner 1967). Log diameters in the study were typical of the Black Hills area—from 8 to 20 inches—and log grades were mostly Number 3 and Number 5. Approximately 75% of the lumber volume was about evenly divided between lumber grades 1 and 2 Common, 3 Common, and 4 Common. Lumber volume in grade 5 Common, as reported in the study, resulted only from downgrading of the higher grade lumber in the seasoning and surfacing operations. Some grade 5 Common lumber was discarded in the green state because it was considered unmerchantable.

The most likely lumber product from a plywood plant-sawmill complex will be 2- by 4-inch or possibly 2- by 6-inch dimension stock. However, no published data currently exist describing grade recovery of dimension products from Black Hills ponderosa pine.

Residue

Most residue from current sawmill operations in the Black Hills is underutilized. Some chips are shipped to pulp mills in the Great Lakes region. The market for salable residue, however, is sporadic. Another outlet for much of this residue could be particleboard, if this commodity were to be manufactured in the Black Hills (Markstrom et al. 1976). There is considerable interest in the Black Hills area in promoting some type of composition board plant. Such a facility could provide an outlet for mill residue and/or large volumes of small roundwood of less than 8 inches d.b.h.¹¹

Another utilization opportunity in the Black Hills area is some type of composite panel product with veneer face plies over a particleboard core.²² A product of this type could advantageously utilize C and D grade veneer for faces and backs while reducing the D grade veneer required for interior plies. Plant residues possibly could be utilized for the composition board core.

OPERATING ECONOMICS

Economic estimates in this section are necessarily based on a number of informed judgments, since no history of plywood production exists for the Black Hills. However, most economic factors are expected to be similar to those for plants of comparable size and type in other areas. This section is based on an economic analysis conducted within projected technology, and coupled with the previous assessment of markets and raw material conditions.²³

²²Personal communication from R. F. Baldwin, Camden, Tex.

²³Unless otherwise noted all cost estimates in this section are based on an engineering analysis, "Black Hills Plywood Study" by Frank Hahn, Senior Consultant, formerly with H. C. Mason and Associates, Inc. 1978. This analysis was performed under contract 43-82-FT-7-556.

Plant Size

The size of plywood plants that can operate economically has increased steadily over the years to spread rising fixed costs over greater plywood output. Figure 5 shows the production capacity distribution of U.S. softwood plywood plants in early 1977. The minimum capacity for an operating U.S. plant is about 40 MM ft² annually (3/8-inch basis).

The range of plant sizes that were considered in this study runs from about 40 to 70 MM ft² capacity, 3/8-inch basis. A smaller plant probably is not economical, and log volume is not available for a sufficient time to amortize a large plant. Capital equipment required under the assumed operating format is about the same for whichever plywood level is produced—40 MM or 70 MM ft². The largest difference in the two production capacities is the number of operating shifts per day and the resulting direct labor cost. Consequently, the only plant size discussed here is in the range of 60-70 MM ft² annual production.

Although no mills have been built in the last 10 years with less than 100 MM ft² capacity,⁸ it should be noted that job counts, equipment, and variable operating costs for a plant with 70 MM ft² capacity are not much different than for a larger plant.²⁴

²⁴Personal communication from R.F. Baldwin, Camden, Tex.

In the assumed operating format, logs are delivered from the woodyard to the debarker deck by front-end grapple loader. After debarking, logs are conveyed to the cut-off saw and cut to 102-inch blocks. Blocks of less than peelable diameter are diverted to a chipping headrig for stud manufacture.

Veneer blocks are sorted into several diameter classes, steamed,²⁵ and delivered to the lathe-charger system. The veneer green chain is close coupled with a veneer scanner triggering the clipper. Clipped, green veneer is manually pulled and stacked. The jet dryer has drying capacity (sections) proportional to plant capacity, plus two cooling sections. A patch and reclip system is used for veneer repair. Hand layup of dry veneer uses a spreader, prepress, press sequence.

Panels are trimmed, repaired (if product requires), bundled, palletted, and stored for shipment by truck or rail.

Wood waste in the form of short blocks, lily pads, slabs, edgings, bark, and fishtails is chipped and sold, or hogged to fuel a wood-fired boiler, depending on the relationship between energy needs and alternative outlets. Chips from the sawmill and plywood plant are sold in the most advantageous markets.

The associated sawmill produces mostly stud lumber from cores and logs not suitable for veneer. Lumber is sold kiln dried or rough green, depending on markets.

²⁵Conditioning logs in hot water vats instead of in steam tunnels is frequently preferred, but because of the possibility of water pollution problems, steam tunnels were assumed for the plant configuration.

Figure 5.—Production capacity distribution of U.S. softwood plywood plants, 1977 (Forest Industries 1977).

Product Output

It might be assumed that all log sizes not suitable for peeling could be sold or traded to others, but such an arrangement does not conform to current industry patterns and therefore is not assured. It may be more realistic to assume that the plywood mill would be responsible for processing or otherwise disposing of all timber it purchased. If so, products likely to be produced are plywood (veneer), studs, chips, bark, and coarse and fine residues.

To estimate total volumes of these products, figures were compiled on expected recovery of each product, by diameter, for veneer blocks or stud logs. These recoveries were applied to the expected log size distribution and volume to estimate total product output.²⁶

Veneer and Residue Recovery Per Log

Veneer yields by block diameter were computed by regression equations based on published material (Yerkes and Woodfin 1972, Woodfin 1973). This approach allows estimates of veneer recovery and residue generation for block diameters slightly larger than those listed in the reported research. Table 13 shows

²⁶The three possible outputs of this plywood complex—plywood panels, lumber, and residue—each have units of measure commonly associated with the product such as square feet, board feet, lumber tally and oven-dry tons, respectively. Logs, in turn, are commonly measured in board feet, Scribner Decimal C log scale, in the Black Hills. To achieve consistency in measurement this economic analysis is expressed in terms of cubic feet, with the corresponding volume measurements in the usual units shown as companion figures.

the material volume allocation for veneer blocks of various diameters, estimating total block volume, tangible loss volume, veneer shrinkage volume, and finally, green and dry veneer volumes for three target core sizes.²⁷ Tangible losses consist of round-up volume, end spur, and clipper loss. Details about the derivation of this table are found in the appendix.

Stud and Residue Recovery Per Log

There are no published data for stud recovery from Black Hills ponderosa pine logs. Consequently, stud recovery and residue generation was estimated by considering theoretical sawing diagrams for 8.5-foot stud logs.

It is assumed that three classes of logs based on log taper would be available to a sawmill auxiliary to the assumed plywood plant. First are logs without taper; that is, cores from the veneer lathe. Second are small logs with taper not greater than 1 inch per 8.5 feet. These logs tend to originate in trees smaller than 9 inches d.b.h., the lower limit set for trees with peelable blocks. Third are small logs that originate in the upper bole of trees cut for veneer blocks. Generally, these logs will have numerous large knots and severe taper resulting from the growth characteristics and stem form of Black Hills ponderosa pine. (See appendix sections, "Computation of Log Taper" and "Lumber and Residue Recovery.")

²⁷One way to increase veneer recovery is to install 4-foot core lathe equipment. However, the economic impact of this option was not analyzed in this study.

Table 13.—Veneer block material allocation (cubic feet) by block diameter class (inches) and target core diameters¹

Block diameter class	Total volume in one block (8.5 feet)	Loss volume	Veneer and core volume	Shrinkage volume	Target core diameters					
					6 inches		5 inches		4 inches	
					Green	Dry	Green	Dry	Green	Dry
6	3.0828	1.0528	2.0300	0.0120	0.3611	0.3491	0.8710	0.8590	1.2883	1.2763
7	3.3054	1.0354	2.2700	0.0132	0.6011	0.5879	1.1110	1.0978	1.5283	1.5151
8	3.6120	1.1020	2.5100	0.0347	0.8411	0.8064	1.3510	1.3163	1.7683	1.7336
9	3.9925	1.2526	2.7399	0.0719	1.0710	0.9991	1.5809	1.5090	1.9982	1.9263
10	5.1558	1.4872	3.6686	0.1114	1.9997	1.8883	2.5096	2.3982	2.9269	2.8155
11	6.4031	1.8058	4.5973	0.1665	2.9284	2.7619	3.4383	3.2718	3.8556	3.6891
12	7.7344	2.2084	5.5260	0.2197	3.8571	3.6374	4.3670	4.1473	4.7843	4.5646
13	9.1497	2.6950	6.4547	0.2782	4.7858	4.5076	5.2957	5.0175	5.7130	5.4348
14	10.6490	3.2656	7.3834	0.3376	5.7145	5.3769	6.2244	5.8868	6.6417	6.3041
15	12.2323	3.9202	8.3121	0.3963	6.6432	6.2469	7.1531	6.7568	7.5704	7.1741
16	13.8996	4.6588	9.2408	0.4323	7.5719	7.1396	8.0818	7.6495	8.4991	8.0668
17	15.6509	5.4814	10.1695	0.5180	8.5006	7.9826	9.0105	8.4925	9.4278	8.9098
18	17.4862	6.3880	11.0982	0.5403	9.4293	8.8890	9.9392	9.3989	10.3565	9.8162
19	19.4005	7.3786	12.0269	0.6055	10.3580	9.7525	10.8679	10.2624	11.2852	10.6797
20	21.4088	8.4532	12.9556	0.6455	11.2867	10.6402	11.7966	11.1501	12.2139	11.5674
21	23.4961	9.6118	13.8843	0.7378	12.2154	11.4776	12.7253	11.9875	13.1426	12.4048
22	25.6674	10.8544	14.8130	0.8060	13.1441	12.3381	13.6540	12.8480	14.0713	13.2653
23	27.9227	12.1810	15.7417	0.8768	14.0728	13.1960	14.5827	13.7059	15.0000	14.1232
24	30.2620	13.5916	16.6704	0.9502	15.0015	14.0513	15.5114	14.5612	15.9287	14.9785

¹Discussion of the derivation of table values is found in the appendix. Four decimal places are carried here to insure that subsequent use of these figures will not introduce significant error caused by rounding.

Table 14.—Theoretical 2- by 4-inch stud lumber and residue recovery from three classes of small diameter logs

Log class	Small end d.i.b. class	Total volume	Chips	Saw kerf	Lumber rough, green untrimmed	Trim	Lumber rough, green trimmed	Shrink	Planer, sander volume	Lumber dry, dressed	Nominal lumber tally	Number of pieces recovered
	<i>inches</i>	<i>cubic feet</i>									<i>fbm</i>	
Lathe cores (no taper)	4	0.742	0.377	--	0.365	0.021	0.344	0.024	0.028	0.292	5.333	1
	5	1.159	0.396	0.033	0.730	0.043	0.687	0.048	0.056	0.583	10.667	2
	6	1.669	0.517	0.066	1.086	0.064	1.022	0.072	0.084	0.866	16.000	3
Small tree logs (low taper)	4	0.950	0.585	--	0.365	0.021	0.344	0.024	0.028	0.292	5.333	1
	5	1.414	0.651	0.033	0.730	0.043	0.687	0.048	0.056	0.583	10.667	2
	6	1.970	0.808	0.066	1.096	0.064	1.032	0.072	0.084	0.876	16.000	3
	7	2.619	1.058	0.100	1.461	0.086	1.375	0.097	0.112	1.166	21.333	4
	8	3.361	1.004	0.166	2.191	0.129	2.062	0.145	0.168	1.749	32.000	6
Large tree logs (high taper)	6	2.883	1.721	0.066	1.096	0.064	1.032	0.072	0.084	0.876	16.000	3
	7	3.272	1.711	0.100	1.461	0.086	1.375	0.097	0.112	1.166	21.333	4
	8	3.811	1.444	0.166	2.191	0.129	2.062	0.145	0.168	1.749	32.000	6

Lathe cores.—For the veneer recovery study (Yerkes and Woodfin 1972), core size averaged close to 6 inches for all block diameters. However, current industry practice, especially in high-volume, small-log veneer plants, tends toward the 4-inch diameter target core size.

The core size decision not only affects veneer recovery, but also determines stud recovery. Table 14 shows the theoretical possibilities for lumber recovery from core logs in each diameter class and estimates of residues generated.

Low-taper logs.—As mentioned in the section on timber resources, logs in the 8-inch small end d.i.b. class will likely occur in greater proportion than other d.i.b. classes. The engineering analysis, however, recommends peeling only logs 9 inches and larger. This would mean allocating the largest proportionate log class, originating in both multiproduct and sawlog timber sales, to lumber manufacture. In turn, volumes of logs 9 inches and larger would need to be increased to maintain plywood production at capacity. Peeling 8-inch logs may increase operating costs, but this potential negative effect is less than that introduced by having to purchase significantly more stumpage. Also, making studs from the large volume of 8-inch logs would, in effect, require a sizable sawmill with an associated plywood plant. This runs counter to the original purpose of this study, which was to determine the feasibility of a plywood plant with a small sawmill added to upgrade utilization.

Table 14 lists stud lumber and residue recovery for 8.5-foot logs with d.i.b.'s from 4 to 8 inches. While the larger logs could yield lumber other than studs, considering a wider range of possibilities for this study would have obscured the main comparisons. The assumed sawn product, therefore, was restricted to stud lumber.

High taper logs.—Taper in these logs is much more variable, because the logs are cut from trees with a wide variety of diameters and heights. Assumptions for taper are as follows:

Log d.i.b. class	Taper per 8.5-foot log
<i>inches</i>	<i>inches</i>
6	3.4
7	2.6
8	2.0

Small end log diameters in table 14 range from 6 to 8 inches for this taper class. Few high taper logs should be less than 6 inches d.i.b., because they come from sawtimber size trees that have a 6-inch top utilization limit.

Bark Recovery

Bark volume was not computed on a per-log basis, as was done for veneer and lumber, because no published data were available to support such computations. Instead, data were used that estimate the bark produced per cubic foot of wood processed for each 4-inch diameter class (Krier and River 1968).

Complete computations for bark volume are given in the appendix section "Bark Volume." The basic approach was to segment the assumed log distribution into diameter classes compatible with those for which data were available. The result is that bark volume generated is 100 cubic feet for each group of 100 logs 8.5 feet in length distributed with respect to small end d.i.b., as previously assumed.

Log Distribution and Index Volumes

Tables 13 and 14 show how individual logs of each size class would contribute to product output, bark excepted. The essential question, then, is to determine whether the proportionate log size mix discussed earlier would yield sufficient veneer to support the plant target annual output of 62.5 MM ft², 3/8-inch basis.

To compute total requirements, a quantity called "index log volume" was defined. This index volume is for 100 logs with small end diameters distributed as in figure 4. For example, of the 100 logs, 15.2082 logs have diameters in the 8-inch class, 6.5903 logs have diameters in the 12-inch class, etc. Dealing with such precise decimal parts of logs is theoretical but will result in a more accurate estimate when transformed to a basis of total number of logs required annually.

The following part of the analysis is based on assumptions about future plywood management decisions with respect to the veneer block lower diameter limit and to the target core size.

Three levels each of block diameters and core diameters have been considered—9, 8, and 7 inches (d.i.b. small end) for veneer block lower size limit, and 6, 5, and 4 inches for target core size. The analysis for each of the nine combinations has been carried to the point of illustrating log volumes required and product volumes generated under each combination.

Complete tables for product and residue volumes are given in the appendix (tables A-4, A-5, A-6) for each of the nine combinations of veneer block size lower limit and target core diameter. Some of this information is summarized in figure 6 which shows how plywood and lumber volumes, obtained from an index log volume, will vary depending on the assumed combination of lower veneer block limit and core size. Note the relationship between plywood and lumber volumes. For example, peeling veneer blocks 9 inches and larger to a 6-inch core yielded the lowest cubic foot plywood volume but the highest cubic foot lumber volume per 100 index logs.

Total Product and Residue Volumes

The final step in analysis of estimated product output is to divide the index volumes based on log size distribution into the total volumes required to achieve an annual plywood production level of 62.5 MM ft², 3/8-inch basis, which is equivalent to 1,953,125 cubic feet or to 19.53 M cunits.²⁸ This assumed cubic volume of finished plywood can be traced back to the beginning of the production process to determine what volume of logs will supply the veneer volume required.

Figure 7 traces the flow of wood material through the plywood complex as conceived. Two primary flows

are necessary to process all logs—one for plywood and one for lumber. In addition, veneer block cores enter the lumber flow.

As shown in figure 7, the 19.53 M cunits of finished plywood—banded, stacked, ready for shipment—is net of trim and other dry veneer loss incurred from veneer dryer output to shipping dock.

Two veneer recovery studies (Hunt and Woodfin 1970, Woodfin and Pong 1972), each found that approximately 16% of dry, untrimmed veneer is lost in the dry chain and panel layup. Losses at this step in plywood production are largely dependent on mill efficiency and production technology. Because two independent studies reported similar results, it was assumed that the proposed mill would experience a similar loss of 16%.

To provide the required plywood volume (62.5 MM ft², 3/8-inch basis), allowing for a dry veneer loss of 16%, the annual gross veneer volume from the dryer must be 2,325,149 cubic feet, or 23,250 cunits.

To produce 23,250 cunits of dry veneer annually requires an input log volume that depends on target core size and lower veneer block diameter limit. Total required log volume increases dramatically as target core size increases or as veneer block lower limit increases (fig. 8). Methods used to compute these alternative volumes are presented in the appendix.

An interesting consequence of decisions about the minimum block diameter and target core diameter is

Figure 6.—Plywood and lumber product volume per 100 log index unit as a function of target core size and veneer block lower diameter limit.

²⁸One cunit is 100 cubic feet of wood; one M cunit is 100,000 cubic feet of wood. Although the cunit generally is used to measure roundwood products such as sawlogs or pulpwood, it is used here as a convenient, product-independent measure of solid volume.

Figure 7.—Primary process steps and resulting intermediate products and by-products for plywood and lumber manufacture: (a) can also be measured in terms of board foot log rule volume; (b) traditional measurement unit is oven-dry tons (O.D.T.); (c) traditional measurement unit is a ratio-square foot, 3/8-inch basis, per board foot; (d) traditional measure unit is square feet, 3/8-inch basis; (e) has no traditional measurement unit; (f) traditional measurement unit is foot board measure, lumber tally basis (fbm (LT)).

the change in potential lumber output in the form of 2-by 4-inch studs. As the lower limit of veneer block diameters increases, lumber volume increases significantly. This happens because small logs not peeled must be disposed of at the sawmill. Product volumes for all nine combinations of target core sizes and veneer block lower limit can be computed from tables A-4, A-5, A-6. In figure 8, the distance between curves for total lumber and plywood volumes and total required wood volume represents residues of various kinds.

For the remainder of this analysis, plywood operations are based on peeling veneer blocks 8 inches and greater to a 4-inch target core. This assumption is an economic compromise between the two extreme combinations of 9-inch blocks to a 6-inch core and 7-inch blocks to a 4-inch core. It allocates to plywood the large supply of 8-inch logs and incorporates capabilities of modern plywood technology to peel blocks to a 4-inch

core. Annual material requirements for the assumed management option are presented in table 15.

Economics

In this analysis, costs that are largely uncontrollable by plant management, such as log and energy costs, were separated for detailed analysis of their effects. For controllable costs it was assumed that the experience of producers with similarly configured plants in other areas was representative of the Black Hills. Some variation in labor cost can be expected with location, but most in-plant processing costs would be nearly the same whether the plant is located in South Dakota, Wyoming, or elsewhere. The engineering study mentioned previously supplied the basic data for in-plant costs.

The Cash Flow Analysis (CFA) Approach

A computer program was used to provide an analysis of discounted cash flows (Harpole 1978). The CFA computer program computes the after-tax value of investment cash flows over time. Results are presented in terms of present value of investment and internal rate of return. Also available is the total unit cost of production, or break-even price, under varying levels of input variables.

When analyzing cash flow with the CFA computer program, the only serious, but not insurmountable, limitation concerns units of measure for dealing with multiple products from the same facility. Because apportioning fixed and variable costs to several products was not practical in this case, a method was needed to realistically assign costs to plywood, lumber, and salable residues. The method used initially figures costs in units appropriate to each product and then

converts these costs in terms of cost per cubic foot of wood equivalent. After analysis by the CFA program, prices and costs are then converted back into units characteristic of each product.

Cost of Operation

All costs are discussed in the order in which they are entered on the CFA program data sheet (Harpole 1978).

Selling expense.—The factor used represents the ratio of sales cost to gross sales, not an absolute value. The selling expense factor is assumed to remain constant for the analysis period.

Selling expense for plywood is composed of trade discounts of 5% and 3%, a 2% cash discount on invoiced amount, and a 3% sales cost allowance on invoiced amount. The resulting composite factor is 0.1246 or 12.46%.

Selling expense for lumber is composed of a 5% trade discount plus a 2% cash discount on invoiced amount. The resulting composite factor is 0.0690 or 6.9%.

No selling expense factor is assumed for salable residue, because any such costs in the Black Hills region are built into chip and residue contracts.

Because the CFA program does not accommodate individual product cost analyses in integrated operations, the above factors were combined in a weighted average to reflect overall product selling expense. Representative market prices and the assumed product outputs for plywood, lumber, and salable residue were combined to derive a sales cost factor of 0.1125 based on total gross sales of all products.

Working capital.—Typical sources and uses of working capital are accounts receivable, timber sale and road deposits, accounts payable, and raw material and operating costs invested in goods-in-process or in unsold finished products inventory.

For this analysis, it was conservatively assumed that working capital requirements are equivalent to about 2 months' or 40 working days' production. For a base working year of 242 days, the computed working capital factor is 0.1653.

Tax rate.—The federal income tax rate for this enterprise is assumed to be 48%. South Dakota and Wyoming do not impose state corporate income taxes.

Discount rate.—The expected rate of return on investment is represented in the analysis by assumed discount rates. These rates are used to determine the present value of future cash flows included in the break-even analysis. As part of the analysis to determine limits on plant operating parameters, the discount rate is varied from a minimum value of 6%, through an average value of 15%, to a maximum value of 25%.

Time span of CFA.—The time period considered in the CFA is 10 years, chosen for reasons explained in the paragraphs on depreciation.

Unit manufacturing costs.—For the plywood plant, these are variable costs, such as wood procurement costs and glue and chemical costs that vary directly with output; for the sawmill, only wood procurement

Figure 8.—Plywood and lumber volumes produced and total wood volume required on an annual basis. (Plywood is constant at 19,530 cunits, corresponding to 62.5 MM ft² (3/8-inch basis).

Table 15.—Annual material budget (cubic feet) for plywood complex¹

Material type (product volume)	Material volume
Total volume (wood + bark)	6,386,445
Minus: Bark volume	1,222,993
Total wood volume	5,163,452
Wood to plywood ²	4,215,760
Minus: Green losses	1,287,079
Lathe cores	501,419
Green veneer	2,427,262
Minus: Dryer shrink	102,108
Dry veneer	2,325,154
Minus: Trim & dry loss	372,024
Plywood (62.5 MM ft ² , 3/8-inch basis)	1,953,130
Wood to lumber (from logs)	947,693
Minus: Chips	469,579
Saw kerf	23,342
Lumber, rough green untrimmed	454,772
Minus: End trim	26,629
Lumber, rough green trimmed	428,143
Minus: Drying shrink	29,991
Planer, sander loss	34,869
Lumber, dry dressed (6,641,707 fbm)	363,283
Wood to lumber (from lathe cores)	501,419
Minus: Chips	254,867
Saw kerf	—
Lumber, rough green untrimmed	246,552
Minus: End trim	14,197
Lumber, rough green trimmed	232,355
Minus: Drying shrink	16,188
Planer, sander loss	18,929
Lumber, dry dressed (3,605,326 fbm)	197,237

¹Total values may be in error by 1 cubic foot because of rounding errors after multiplying index volumes (table A-5) by the "blow-up" factor (table A-7).

²Logs 8 inches and larger, d.i.b., peeled to a 4-inch core.

costs vary directly with output. In an integrated operation, wood procurement cost is shared between plywood, lumber, and salable residue.

The CFA program used in this analysis considers only one product per computer run, but this limitation is not critical, because diverse outputs like plywood, lumber, and residue can be analyzed simultaneously when computed on a cubic foot product basis. Table 16 has unit cost data for various levels of log procurement cost. The final unit cost figure includes a charge of \$23.20 per cunit of plywood for glue and chemicals, which translated into an equivalent of \$9.87 per cunit of composite product output.

Other variable costs.—These costs are mixtures of fixed and variable elements, but are predominantly variable. Labor, energy, and utilities are examples of

these costs. In this analysis "other variable cost" categories for year 1 are as follows:

Plywood	
Direct labor	\$ 930,286
Operating supplies	48,750
Association dues	37,500
Power-electric (from commercial sources)	178,560
Power-steam (from residue fuels)	128,414
	1,323,510
Lumber, residue	128,668
Total of other variable costs	1,452,178

Fixed manufacturing costs.—Although regarded as constant regardless of output level, these costs can have some variable elements. However, for purposes of

this analysis, they are considered joint costs dependent primarily on the rated capacity of the plywood/sawmill complex.

Costs in this category are maintenance, supplies and expenses, and mill supervision. Amounts for these fixed manufacturing costs are as follows:

Plywood	
Maintenance, supplies and expense	\$103,125
Mill supervision	115,128
	<u>218,253</u>
Lumber	31,140
	<u>249,393</u>
Total fixed manufacturing costs	249,393

Overhead costs.—Included are costs expected to vary as a constant proportion of facilities costs, such as insurance and taxes. Office and miscellaneous costs are also included in overhead costs.

Insurance is estimated to be 1.5% of total facilities capital investment. Taxes include ad valorem property taxes and other local assessments. Corporate income taxes are not considered here. Office costs are made up of staff salaries including the mill sales function, supplies, telephone, and travel expenses. Estimates of these costs are as follows:

Plywood	
Insurance	\$297,284
Taxes, local	16,951
Office	74,852
Miscellaneous	10,000
	<u>399,087</u>
Lumber	308,436
	<u>707,523</u>
Total overhead costs	707,523

Facilities costs.—These costs are made up of all investments necessary to provide physical resources for production. Items include costs for land, site preparation, buildings, engineering, processing machinery, mobile equipment, and other like expenses.

Table 17 shows the major capital expenditures necessary for the physical facilities. Included in addition to these costs are pre-start up charges for interest on capital during construction and for salaries of key personnel during the construction period.²⁹

Physical facilities	\$ 9,909,450
Interest on capital (15%)	1,486,418
Salaries	<u>116,776</u>
Total facilities costs	11,512,664

It was assumed that all mobile equipment would be replaced after 5 years of use. The original capital cost of \$250,000 was increased to \$367,332 to cover an inflation rate of 8% annually for 5 years.

Depreciation.—Depreciation charges account for expiration of fixed assets. Harpole (1978) has excerpted data from the 1971 Revenue Act to illustrate ranges in the time periods allowed for depreciation of various capital assets. Land improvements typically are allowed a 20-year depreciation period, and buildings are allowed 45- or 60-year depreciation periods depending on type of building. Processing equipment for primary and secondary manufacturing of plywood, lumber, and particleboard is allowed a depreciation period of 8 to 12 years with an average of 10 years.

²⁹These cost estimates as well as all others in this report are based on 1977 prices. A more recent estimate for cost of similar facilities, current as of mid-1979, is \$20-25 million. Personal communication from R. F. Baldwin, Camden, Tex.

Table 16.—Unit manufacturing costs (dollars) for Black Hills plywood, lumber, and chip mill

Stumpage cost (per M fbm (LS))	Stumpage cost ¹ (per cunit, log scale)	Stumpage cost ² (per cunit, plywood)	Stumpage cost plus glue and chemicals ³ (per cunit)	Unit cost ⁴ (per cunit of composite product)
130	57.85	153.04	176.24	75.002
110	48.95	129.50	152.70	64.982
90	40.05	105.95	129.15	54.962
70	31.15	82.41	105.61	44.943
50	22.25	58.86	82.06	34.922
30	13.35	35.32	58.52	24.903

¹Cost per M fbm (LS) $\times$ 0.445 $\frac{M \text{ fbm (LS)}}{\text{cunit, log scale}}$

²Cost per cunit log scale $\times$ 2.646 $\frac{\text{cunit, log scale}}{\text{cunit, plywood}}$

³Cost per cunit plywood + \$23.20/cunit for glue and chemicals = unit cost in terms of plywood cubic volume.

⁴Cost per cunit plywood $\times$ 0.42556 $\frac{\text{cunit, plywood}}{\text{cunit, composite product}}$ = unit cost in terms of total cubic volume of salable product.

Table 17.—Capital investment (1977) (dollars) for plywood production facilities in the Black Hills (62.5 MM ft² annually, 3/8-inch basis)

Land	24,000
Site preparation	25,000
Foundations	411,200
Buildings	1,880,000
Utilities	1,948,000
Plant equipment and machinery	3,242,750
Miscellaneous and mobile equipment	250,000
Design and Engineering	412,000
Contingencies	750,000
Auxiliary sawmill, including kiln	966,000
Total facilities cost	9,909,450

Table 18 shows the flow of depreciation charges over the 10-year analysis period. In this analysis, site preparation, buildings, and mobile equipment were written off with straight line depreciation for the total period appropriate to each asset. Processing machinery is depreciated by the double declining balance method for the first 5 years, then switched to straight line depreciation for the remaining 5 years of its investment life. Accelerated depreciation in the early years of the capital investment assumes that benefits from the asset are greatest when it is new and that technical progress increases the risk of early obsolescence for machinery.

Investment tax credit.—This credit is incorporated into the feasibility analysis, because it is a currently available stimulus to investment. A credit of 10% of the cost of processing machinery and mobile equipment is shown below:

Plywood process equipment	\$324,275
Lumber process equipment	75,300
Mobile equipment	25,000
Total investment tax credit	424,575

Rising costs.—The CFA computer program was modified to enable subsequent users to enter estimated changes in prices and costs into updates of the analysis. To allow for rising costs, the wholesale price index was selected as an indicator of general cost levels for industry. This index is available from the U.S. Department of Labor, Bureau of Labor Statistics, and is also tabulated in the series on demand and price situation for forest products published by the USDA Forest Service (Phelps 1977). The years 1967 to 1976 were chosen as the base period. During this period the Wholesale Price Index rose from 100 to 183. This increase is equivalent to a 6.95% compound annual interest rate. This rate was applied to estimated 1977 costs to compute future costs over the subsequent 10-year period.

Revenues

Cash revenue was projected from the sale of plywood, stud lumber, chips, and sawdust. While plywood revenues are the focal point of this report, economic feasibility also depends on sale of these other products.

Prices were assumed for lumber and salable residue, and then were used to determine the plywood price that would be needed to break even, with all costs considered. Lumber and residue prices were assumed to increase at a 7.2% annual rate based on data for 1967 to 1976 (Phelps 1977).

Base prices for 2- by 4-inch stud lumber were the average prevailing mill prices in 1977 and 1978. Chip and sawdust prices, oven dry (o.d.), were based on 1978 levels at rail loading points in the Black Hills. Base prices used were as follows:

Product and units	Product dollars/unit	Cubic volume price
		dollars/cunit
2- by 4-inch stud lumber (M fbm (LT))	175.00	320.00
Chips, (o.d. tons)	17.50	21.00
Sawdust, (o.d. tons)	4.00	4.80

These cubic volume unit prices, multiplied by the cubic volume output of each respective product, give total revenue from all nonplywood production.

The typical definition of break-even point is that level of business operation where total revenues and total expenses are equal. Part of total expenses is the implicit alternative cost of capital and operating funds that could have been invested elsewhere. This alternative cost is covered by the specified rate of return. Thus, break-even plywood price, as used here, is the amount per thousand square feet required to make total revenue match total costs plus the specified rate of return.

One additional factor of importance in computing break-even plywood price is the mix of plywood grades and thicknesses. However, this price, as computed by the CFA program, must be in terms of dollars per hun-

Table 18.—Depreciation schedule (dollars) for plywood plant and associated auxiliary lumber/chip mill

Depreciable capital asset	Initial book value	Year					
		1	2	3	4	5	6-10
Site preparation ¹	25,000	1,250	1,250	1,250	1,250	1,250	1,250
Buildings—PW ²	5,401,700	120,038	120,038	120,038	120,038	120,038	120,038
Buildings—LMCP ²	213,000	4,733	4,733	4,733	4,733	4,733	4,733
Process machinery, PW ³	3,242,750	648,550	518,840	415,072	332,058	265,646	
Book value, ⁴	1,062,584						147,662
Process machinery, LMCP ³	753,000	150,600	120,480	96,384	77,107	61,686	
Book value, ⁴	246,743						34,289
Mobile equipment ⁵							
Years 1-5	250,000	45,000	45,000	45,000	45,000	45,000	
Years 6-10 ⁶	367,332						66,120
Total depreciation		970,171	810,341	682,477	580,186	498,353	374,092

¹Straight line depreciation over 20 years with no salvage.

²Straight line depreciation over 45 years with no salvage; includes building, foundation, utilities, design and engineering, and contingencies. PW-Plywood mill. LMCP-Lumber/Chip mill.

³Double declining balance depreciation first 5 years, straight line depreciation last 5 years with salvage of 10% of initial book value. Includes all in-plant machinery for each mill and installation.

⁴Remaining book value at beginning of last 5 years.

⁵Straight line depreciation over 5 years with 10% salvage.

⁶Cost is amount in year 0 inflated over 5 years at 8%.

dred cubic feet of plywood, regardless of grade or thickness. Further analysis is needed to break down the composite cubic-foot price into a representative mix of plywood grades and thicknesses. In this study, the composite price was based on five thicknesses of C-D-X grade plywood. Although other grades of plywood were discussed as good production opportunities, only commodity grades were used for this economic analysis, because their market prices can be more accurately established. Any error resulting from this assumption would be on the conservative side. Output proportion and average mill price for the five thicknesses included in the analysis are shown below:

C-D-X thickness	Proportion of output	Assumed mill price
inch	percent	dollars/M ft ²
5/16, 3 ply	1.2	160
3/8, 3 ply	13.9	164
1/2, 4 ply	68.7	223
5/8, 5 ply	12.8	263
3/4, 5 ply	3.4	327

These were used to establish the price spread between thicknesses in computing prices for individual plywood thicknesses.

Profitability

The values given in the preceding discussion of costs of operation are assumed to be base figures for the CFA. In addition, for the base run, log cost is assumed

to be \$70 per thousand board feet, Scribner log scale, and internal rate of return is 15%. CFA output for these assumed values is shown in table 19. As an example of how values in table 19 are computed, table 20 shows the flow of computations necessary to get an after-tax net cash flow of \$2,199,782 for year 1.

Table 19 shows that the break-even unit price must average \$180.48 per hundred cubic feet of composite product. Lumber mill value is assumed to be \$175 per thousand board feet, and chip and sawdust mill value is assumed to be \$17.50 and \$4.00 per o.d. ton, respectively. Mill realization for 1/2-inch C-D-X sheathing must then be \$141.41 per thousand square feet (M ft², surface area basis). Required mill realizations for the remaining C-D-X thicknesses are computed by applying market price spreads to the 1/2-inch C-D-X realization. Results are shown in the following tabulation:

C-D-X thickness	Price spread factor	Plywood mill realization
inch	$\frac{\text{price, given thickness}}{\text{price, 1/2-inch thickness}}$	dollars/M ft ² , surface area basis
5/16	0.717	101.46
3/8	0.735	104.00
1/2	1.000	141.41
5/8	1.179	166.77
3/4	1.466	207.36

To estimate market break-even prices, freight costs as shown in table 7 plus other handling charges must be added.

ALTERNATIVE OPERATING FORMATS

The preceding analysis portrayed operation of an integrated plywood plant, sawmill, and chip mill facility. All input and output factors described previously were set at values considered reasonable based on late 1977 and early 1978 price levels. Break-even prices computed under these circumstances indicated economic feasibility, given current market conditions. However, because market conditions in the forest products industry, and, therefore, production factors, vary widely over time, the effect on break-even prices of changes in selected input or output factors needs further investigation.

Effect on Break-even Price

Given the input factor values used in the previous sections, the effects of a change in various production costs and a change in stud price on the break-even price for plywood were computed (fig. 9). For example in A, an increase in labor cost of 20% would raise break-even price from about \$141 to about \$147 per thousand square feet area basis. The slope of the graph line for a specific factor indicates the sensitivity of break-even price to percent changes in the responsible factor—the steeper the slope, the greater the sensitivity.

In example B (fig. 9), the graph line for stud price shows that a 40% decrease from \$175 to \$105 per thousand board feet would result in a rise in break-even price for 1/2-inch C-D-X plywood to about \$152. Typically, however, the prices of sheathing plywood and studs move in the same direction at the same time, because they are complementary commodities in the housing construction materials market.

All relationships are linear except for changes in "Production below capacity." If the plant has to operate at 20% or 40% below capacity, for example, fixed costs are spread over lower output and, consequently, the break-even price must rise rapidly for revenues to cover expenses.

Total costs affect break-even price most dramatically and give a general idea of inflationary effects on a plant of this size. Because the capacity of this plant is the size of smaller plywood plants currently operating, fixed costs are a higher proportion of the total. Increases in general cost levels, therefore, can be expected to impact this plant more severely than a larger operation.

The relative lack of sensitivity of break-even price to energy costs is noteworthy. Energy costs are not as high as they otherwise might be, because it was assumed that the plant would depend on its own residue for process steam. Such residue was valued at current salable residue prices or at zero price depending on

Figure 9.—Sensitivity of break-even price, 1/2-inch C-D-X plywood, area basis, to percent changes in selected cost and plant operation factors.

alternative uses. Therefore, although electricity is purchased commercially, total residue-based energy costs do not form a large proportion of total costs.

Effect on Raw Material Need

Although not discussed here in detail, log cost is sure to receive serious management attention. For this plant it was conservatively assumed that 8-inch and larger blocks would be peeled to a 4-inch core. Instead, management could decide, for example, to peel 7-inch, or even 6-inch and larger logs, to a 3-inch core. The rationale might be that because blocks of this size are generated from multiproduct sales, they might better go into plywood than lumber, and thus reduce the total mill log supply required to produce annually 62.5 MM ft² (3/8-inch basis) of plywood. In this case, rather than produce lumber as the only secondary product, cores might be treated with a suitable preservative and sold for fence posts. Logs not suitable for peeling might be sawn for lumber, or chipped for pulp or fuel, depending on relative needs and prices.

Table 19.—Discounted cash-flow analysis of assumed expense and revenue base values¹

Initial investment—Year 0		Effective tax rate		0.4800		Original cash equity		\$		0		Variable costs/sales =	
Facilities cost		Borrowing rate		.0000		Ending value of equity		16,947,218		Fixed costs/sales =		.05410	
Working capital		Reinvestment rate		.0000		Facilities salvage value		6,468,008		Tax costs/sales =		.1695	
Total investment		Internal rate of return		.1500		Present value of investment		3		After tax profits/sales =		.1351	
						(I = .1500)						.1544	
10-Year financial summary with break-even adjusted unit prices ²													
Year-end values	1	2	3	4	5	6	7	8	9	10			
Unit sales	43,597	43,597	43,597	43,597	43,597	43,597	43,597	43,597	43,597	43,597			
Unit price	\$ 180.48	\$ 193.48	\$ 207.41	\$ 222.34	\$ 238.35	\$ 255.51	\$ 273.91	\$ 293.63	\$ 314.77	\$ 337.43			
Gross sales	7,868,534	8,435,068	9,042,393	9,693,445	10,391,373	11,139,552	11,941,600	12,801,395	13,723,095	14,711,158			
Interest income or expense	0	0	0	0	0	0	0	0	0	0			
Gross revenues	7,868,534	8,435,068	9,042,393	9,693,445	10,391,373	11,139,552	11,941,600	12,801,395	13,723,095	14,711,158			
Variable manufacturing cost	1,959,399	2,095,578	2,241,220	2,396,985	2,563,575	2,741,744	2,932,295	3,136,090	3,354,048	3,587,154			
Selling expense	885,210	948,945	1,017,269	1,090,513	1,169,029	1,253,200	1,343,430	1,440,157	1,543,848	1,655,005			
Other variable cost	1,452,178	1,553,104	1,661,045	1,776,488	1,899,954	2,032,000	2,173,224	2,324,264	2,485,800	2,658,563			
Total variable cost	4,296,787	4,597,627	4,919,535	5,263,985	5,632,559	6,026,944	6,448,950	6,900,510	7,383,696	7,900,723			
Unit variable cost	98.56	105.46	112.84	120.74	129.19	138.24	147.92	158.28	169.36	181.22			
Profit contribution	3,571,746	3,837,441	4,122,858	4,429,460	4,758,815	5,112,608	5,492,650	5,900,885	6,339,399	6,810,436			
Fixed manufacturing cost	249,393	266,726	285,263	305,089	326,293	348,970	373,224	399,163	426,904	456,574			
Overhead cost	707,523	756,696	809,286	865,532	925,686	990,021	1,058,828	1,132,416	1,211,119	1,295,292			
Total fixed cost	956,916	1,023,422	1,094,549	1,170,621	1,251,979	1,338,991	1,432,051	1,531,579	1,638,023	1,751,866			
Facilities cost	0	0	0	0	367,332	70,225	75,106	80,326	85,908	91,922			
Working capital investment	50,187	53,675	57,405	61,395	65,662	70,225	75,106	80,326	85,908	91,922			
Depreciation	970,171	810,341	682,477	580,186	498,353	374,092	374,092	374,092	374,092	374,092			
After tax profit	1,279,798	1,041,913	1,219,833	1,392,900	1,564,411	1,767,753	1,916,984	2,077,511	2,250,188	2,435,928			
After tax earnings	2,249,969	1,852,254	1,902,310	1,973,086	2,062,764	2,141,845	2,291,076	2,451,603	2,624,280	2,810,020			
After tax net cash flow	2,199,782	1,798,579	1,844,904	1,911,691	1,629,770	2,071,620	2,215,970	2,371,278	2,538,371	2,715,029			
Accumulated net cash flow (M dollars)	-10,035.0	-8,236.4	-6,391.5	-4,479.8	-2,850.0	-778.4	1,437.5	3,808.8	6,347.2	16,947.2			
Internal rates of return—at adjusted input values													
Unit sales	80%	90%	100%	110%	120%								
Unit price	0.090	0.121	0.150	0.178	0.205								
Unit variable cost	.065	.109	.150	.189	.227								
Total fixed costs	.201	.175	.150	.124	.098								
Facilities cost	.161	.155	.150	.145	.139								
	.184	.165	.150	.137	.126								

¹Investment tax credit of \$424,575 considered.²Figures in this table are reproduced from computer printout and are rounded off.

LITERATURE CITED

Table 20.—Example of computations used in table 19

Unit sales, cunits		43,597
Unit price, dollars per cunit	(x)	180.48
Gross sales revenue		\$7,868,534
Less: Variable manufacturing cost		
Selling expense		\$1,959,399
Other variable cost		885,210
Total variable cost		1,452,178
Profit contribution (gross)		
Less: Fixed manufacturing cost		249,393
Overhead cost		707,523
Total fixed cost		956,916
Depreciation		970,171
Total fixed cost (including depreciation)		
Before tax profits	(-)	1,927,087
Tax allowance (1.00 - 0.48)		1,644,659
After tax profit	(x)	0.52
Plus: Investment credit	(+)	855,223
After tax profit (adjusted)		(+) 424,575
Plus: Depreciation		1,279,798
After tax earnings	(+)	970,171
Less: Working capital allowance		2,249,969
After tax net cash flow	(-)	50,187
		2,199,782

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MARKETS

Plywood Properties Important in Marketing

Various plywood applications require different panel characteristics or different combinations of characteristics. The following summary describes some of the more important properties of sheathing and associated types of plywood related to particular end uses.¹

Stiffness.—The ability of a panel to resist deformation in the plane of the panel results from the inherent elasticity of the wood and the panel thickness. Stiffness is of primary importance in such applications as roof sheathing, subflooring, combination floor, wall sheathing, boxes, pallets, and air cargo containers.

Bending strength.—The ability of a panel to support a load without breaking. This characteristic is significant in such applications as sheathing, subflooring, combination floor, wall sheathing, boxes, pallets, and air cargo containers.

Rigidity.—The ability of a panel to resist racking, or deformation "out-of-square." This property is important when the plywood is used as subflooring or wall sheathing and in boxes and pallets.

Weight.—Because panels manufactured from different species vary considerably in weight, this significantly affects ease of handling, dead loads of structures, and tare weight of packaging. Weight becomes important in uses such as roof sheathing, combination flooring, and air cargo containers.

Thermal insulation.—The ability of the material to restrict the flow of heat. This characteristic is particularly important for wall and roof sheathing.

Workability.—The ease with which various woods can be worked with hand or machine tools in such operations as sanding, sawing, grooving, etc. Workability of plywood is very significant when plywood is used in applications such as cabinets, boxes, and air cargo containers.

Fastening strength.—The ability of the plywood to hold mechanical fasteners, such as nails or screws. Fastener-holding capacity is important in all plywood applications but is especially critical in van linings, boxes, pallets, and air cargo containers.

Color.—The general appearance of a panel as to whether it is light or dark and the overall effect of the grain pattern caused by the growth rings. A light

uniform color is usually considered to be desirable for plywood, even when it serves no specific functional purpose.

Integrity of surface.—The degree to which defects (knots, knotholes, bark pockets, and pitch pockets) are found in the face plies of plywood. This characteristic is most important when plywood is used for underlayment, combination floor, siding, combination siding, and van linings, where holes or voids in the surface may show through coatings or coverings or make the panel more subject to mechanical damage or weathering.

Surface hardness.—The resistance of the wood to abrasion and puncture. This property is significant in plywood used for underlayment, combination flooring, siding, combination siding, van lining, boxes, pallets, and air cargo containers.

Dimensional stability.—The ability of a panel to maintain the same dimensions through fluctuations in climate or moisture content. This property is most important for plywood used for underlayment, combination flooring, siding, and combination siding. Dimensional stability is slightly less important for roof sheathing, subflooring, wall sheathing, and van linings.

Weathering.—Warping and change in color, roughening, or checking of the surface caused by exposure to the elements. Because of plywood's exceptional dimensional stability, the problem of cupping and twisting from uneven stresses on the face and back of solid wood are largely eliminated. However, surface checking and roughening is often a problem. Good weathering characteristics are critical in siding and combination siding, but considerably less important in covered sheathing, boxes, pallets, and air cargo containers.

Painting quality.—This property reflects how well a material will take paint or stain and the frequency of maintenance required. Painting characteristics of plywood are similar but usually somewhat inferior to those of solid lumber of the same species. It is extremely important in considering the use of plywood for siding and combination siding, but not for sheathing and other "hidden" structural applications.

Gluing quality.—The ability of the wood to form good glue bonds with other structural elements over a wide range of glue types and gluing conditions. It is important in using plywood for subflooring, underlayment, and combination flooring.

Appearance.—The general visual characteristics of the plywood panel. Appearance plays an important role in utilization of panels for siding and combination siding.

Acoustical insulation.—The ability of the material to restrict sound from passing through it. It is an important consideration in selecting plywood panels for wall sheathing, siding, and combination siding.

¹Information in the following titled paragraphs is taken from F. F. Wangaard et al. (1971). *Potential markets for plywood made from Rocky Mountain ponderosa pine and Engelmann spruce. Unpublished Report, Department of Forest and Wood Science, Colorado State University, Fort Collins, Colo. (On file at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.)*

Applications in Residential Construction

Roof sheathing.—The most critical property of roof sheathing is stiffness. In this market, ponderosa pine plywood would compete mainly with plywood made from Douglas-fir and southern pine, which have the highest strength properties of any commercial softwood plywood species. Code standards for roof sheathing specify the minimum strength and stiffness required for a given span. In many cases, ponderosa pine plywood would be able to satisfy the minimum requirements and, at a given thickness, could be used interchangeably with Douglas-fir or southern pine, although its strength and stiffness may be less.² It is common practice for builders to use plywood roof sheathing thicker than required by building codes to provide an additional measure of stiffness desired by roofing applicators. Because thickness contributes more to stiffness than species, 1/2-inch ponderosa pine plywood roof sheathing may not only be acceptable under the code, but also about equally acceptable to builders when compared with Douglas-fir or southern pine. As an example, ponderosa pine 1/2-inch sheathing has an Identification Index³ of 24/0, while 1/2-inch sheathing of Group 1 species like Douglas-fir has an Identification Index of 32/16. However, the most common roof joist spacing in light frame construction (housing) is 24 inches, no matter which plywood group is applied as sheathing. Subject to local building code restrictions and builder and consumer acceptance, ponderosa pine 1/2-inch plywood sheathing may be competitive with plywood sheathing of higher groups on an equal thickness basis.

Subflooring.—Stiffness and bending strength are the most important properties for subflooring, with rigidity, nail holding ability, dimensional stability, and gluing ability also rated as important characteristics. On the basis of physical properties, the suitability of species for subflooring follows the same general principles as for roof sheathing: Douglas-fir and southern pine have the highest ratings with ponderosa pine falling below western hemlock and above white fir and Englemann spruce. For a plywood species to be accepted in the flooring market, it must be suitable for

spanning at least 16 inches, the most usual joist spacing. The APA has found that about 80% of plywood subfloors are 1/2-inch thick. Underlayment in double floor systems is usually 5/8-inch. However, the major trend in flooring systems has been toward concrete slabs and single layer wood floors instead of toward double floor systems.⁴

Underlayment.—It is important for underlayment plywood to have integrity of surface, surface hardness, dimensional stability, and gluing ability. Because floor coverings are applied directly to the underlayment, the face of the plywood must be free of voids and resistant to puncture. Veneer of C Plugged or better grade may be suitable for face plies in ponderosa pine underlayment. Also of importance is the contrast in hardness between early and late wood (grain pattern) which may show through thin flexible floor coverings. Ponderosa pine has less grain contrast than either Douglas-fir or southern pine and might be preferred for that reason.

Combination floor.—This application is often referred to as a single layer floor system because it is one sheet of plywood which serves the dual function of subfloor and underlayment. The important properties for this use are stiffness, bending strength, light weight, integrity of surface, surface hardness, and gluing ability. Although Douglas-fir is rated as the best species because of its stiffness, strength, and surface integrity, ponderosa pine of 5/8-inch thickness can be used over 16-inch spans. With more than 90% of the floor joists in single-family and multi-family homes having a 16-inch span, ponderosa pine plywood should be competitive in this market if it satisfies the other requirements for subflooring and underlayment.

Wall sheathing.—Physical requirements for wall sheathing are less demanding than for roof sheathing or flooring. As a result, the market potential for woods of lower strength and stiffness, such as ponderosa pine, is greater. Specifications for wall sheathing are established on the basis of minimum requirements for specific stud spacings. A 5/16-inch ponderosa pine panel carries an index of 16/0, well over the minimum 12/0 index required for 16-inch stud spacing. For 2- by 4-inch or 2- by 6-inch studs spaced 24 inches o.c.,⁵ the panel identification index can range from 16/0 to 32/16, depending on panel thickness and construction.

Siding.—The most important properties for siding are integrity of surface, surface hardness, dimensional stability, weathering, painting ability, and appearance. Of the species considered in this study, white fir, Douglas-fir, spruce, and hemlock were rated as the most acceptable species. Appearance, which is prob-

²Personal communication from R. F. Baldwin, Camden Tex. As of midyear 1979, the Industry Standard Committee of the American Plywood Association were considering an amendment to Product Standard 1-74 (American Plywood Association 1974). The amendment allows marking 1/2-, 5/8-, and 3/4-inch C-C-X, C-D, and Structural panels of Group 3 woods with the same Identification Index (Reference footnote 3 in appendix) as Group 1 woods if they are manufactured 1/32-inch thicker than standard nominal thickness and if they have 1/16-inch thick minimum face and back plies. This amendment, if accepted, would assist acceptance of ponderosa pine plywood in applications where the Identification Index for sheathing panels is specified.

³Identification Index or Span Rating (American Plywood Association 1974) serves as an indicator of allowable roof and floor spans for which a particular plywood panel is mechanically suited. For example, in an Identification Index of 48/24, the 48 indicates that when used for roof sheathing, the panel may have supports spaced up to 48 inches apart, center to center; the 24 indicates that the panel may be used for structural floors with supports spaced up to 24 inches apart, center to center.

⁴Personal communication from Robert G. Anderson, Marketing Group, American Plywood Association, Tacoma, Wash., and personal communication from J. L. Bowyer, Department of Forest Products, College of Forestry, University of Minnesota, St. Paul, Minn.

⁵The distance from the center of one stud to the center of the next stud is 24 inches o.c. (on center). For more information on panel index and wall sheathing, read the American Plywood Association Tacoma, Wash., publications A30, Plywood Sheathing for Walls and Roofs, and W405, Mod 24 Building Guide. Application Data For 24-inch Framing.

ably the most important property, is almost entirely dependent on individual tastes, and an adequate rating system for appearance has not been established. It may be possible to develop a siding product from ponderosa pine plywood by taking advantage of the rustic appearance of knotty veneer. Two basic types of plywood siding offer either textured veneer surfaces for painting or staining or smooth medium density overlay faces (MDO grade) for painting. Any commercial softwood species is technically acceptable for plywood siding material, subject to proven durability under exterior exposure and appropriate surface treatment.

Combination siding.—This type of siding combines the important technical functions of both siding and sheathing. Although ponderosa pine is rated lower for this use than some other species because of its lower strength values, there are no standards or specifications which would restrict the use of ponderosa pine in single wall construction. A major reason for significant increases in demand for combination siding has been the modular home concept, where a single panel of plywood serving as both a sheathing and siding material can provide the additional stiffness required in transportable units. There is still a problem of gaining building code acceptance for the single wall system in some areas as well as convincing builders that a separate sheathing material is not necessary. These attitudes should change as the public becomes more aware of the technical acceptability of this system.

The ability of ponderosa pine to penetrate this market depends largely on the ingenuity of producers in developing attractive siding products.

Some Industrial Applications

Van interiors.—Although there are no standard specifications for plywood used as the interior lining of truck vans, most of the grades used are A-D, B-C, and A-C. Each van manufacturer establishes its own standards. In some cases, plywood is also used as a floor covering in vans. Important physical characteristics for van interiors are fastener holding capability and surface hardness. All plywoods are rated in approximately the same range for these properties.

Plywood overlaid with fiberglass or metal is being used more often in this application. This material is also important in the construction of marine cargo containers. Ponderosa pine plywood would be an excellent substrate for these overlays.

Because of the high grade surface veneer required, it might be difficult to sell ponderosa pine plywood that is not overlaid for interior lining material. However, a potential may exist for van lining because of the lighter weight of pine plywood.

Boxes and crates.—Ponderosa pine plywood belongs to a group of species with the following properties: lightness in weight, freedom from splitting when nailed, moderate nail holding capacity, and fairly soft (Anderson and Heebink 1964). One of the main reasons for using such plywood for boxes and crates is that it is stronger and more durable than lumber, but this ad-

vantage may be offset in some cases by the lower cost of lumber. Although penetration of plywood into the container market has been slow, it is increasing, and pine plywood could be in a particularly good position to supply an increasing proportion of this market.

Pallets.—Softwood plywood is increasingly used in pallet production, but substantial price differential over alternative materials largely limits its use to bin pallets and other specialized types. For example, an oak lumber pallet costs about one-third as much as a plywood pallet of comparable size and strength. Pallets, therefore, do not appear to offer a particularly promising market for ponderosa pine plywood, but the large size of the pallet industry means that ponderosa pine plywood might have specialized uses.

Air cargo containers.—Because light weight is a critical factor for this use, ponderosa pine plywood might be rated as one of the most suitable species. However, the American Plywood Association, after studying this application, feels that plywood does not have a good opportunity in this use.⁶

APA 303 Siding Specifications

APA siding is produced in four classes, based on number of panel face patches permitted, as shown below (American Plywood Association 1978a):

Class	Face patches
303-0 (Special Series)	none
303-6	6 maximum
303-18	18 maximum
303-30	30 maximum

Within each class there are provisions for different grades.

The characteristics of the four grades for the Special Series 303-0 class, which differ from those for the other three classes, are shown below (American Plywood Association 1978b):

Class and grade	Description
303-OC	Clear
303-OL	Overlaid (e.g., medium density overlaid siding)
303-NR	Natural rustic (e.g., permits open knotholes)
303-SR	Synthetic rustic (e.g., permits natural-defect shaped synthetic repairs)

Within each of the other three classes, the following three grades may be designated:

-W	Wood repairs only
-S	Synthetic repairs only
-S/W	Both wood and synthetic repairs

⁶Personal communication from Robert G. Anderson, Marketing Group, American Plywood Association, Tacoma, Wash.

Specifications for the APA "303" series siding include, but are not limited to, permissible levels for knots, knotholes, patches, splits, shims, and voids (American Plywood Association 1977a). The size and number of knots in C-grade ponderosa pine veneer may limit the class and grade of siding panels that could be manufactured in the Black Hills. However, APA "303-NR and -SR (rustic)" panels are permitted to have tight or pin knots up to 1 1/2-inches in maximum size and no limit in number. Also, APA "303-30-S and S/W" grades permit tight knots of 1 1/2 inches maximum, and pin knots of 3/8 inch maximum. Patches are permitted in all grades except "Special Series 303."

TIMBER RESOURCE

Black Hills National Forest Timber Classes

Timber classes specified in the current 10-year Timber Management Plan of the Black Hills NF are described below, along with a concise statement of the probable silvicultural treatment for each timber class.⁷

P21 is an uneven-aged stand of ponderosa pine sawtimber in the standard component with an inadequately stocked pine understory. This stand has 60 to 120 square feet of growing stock basal area. Enter this stand with the first cut of the three-cut shelterwood system to establish regeneration.

PB1 is a two-storied ponderosa pine stand in the standard component. This stand has 60-120 square feet of growing stock basal area. It has an adequately stocked sawtimber overstory and a fully stocked pine understory. The overstory will be removed in two cuts to minimize damage to the established understory. Because of the size of the understory, it is assigned a managed age of 10. The second cut (seed cut) will be made in the overstory.

P31 is an overstocked, uneven-aged stand of ponderosa pine sawtimber in the Standard Component. This stand has more than 120 square feet of growing stock basal area, which requires immediate entry. This entry will be by a multiproduct cut to reduce density. Trees will be cut from all diameter classes to a growing stock level (GSL) of 80.

P61 is an overstocked ponderosa pine poletimber stand in the Standard Component. This stand has in excess of 120 square feet of growing stock basal area. Enter this stand with an intermediate cut to a GSL of 80.

PA1 is a two-storied ponderosa pine stand in the Standard Component. This stand has less than 60 square feet of growing stock (all live trees ≥ 5 inches d.b.h.) basal area. It has a sparse sawtimber overstory age 150 and a fully stocked pine understory. The overstory will be removed in two cuts to minimize damage to the established understory. Because of the size of the understory, it is assigned a managed age of 10.

⁷Timber Management Plan, Black Hills National Forest. 1977. Unpublished document on file at Rocky Mountain Forest and Range Experiment Station or available from Supervisor's Office, Black Hills NF, Custer, S. Dak.

SC1/SB1: SC1 is a spruce-pine mix sawtimber stand in the Standard Component, and SB1 is a pine-spruce sawtimber stand in the Standard Component. Enter these stands, cutting in all size classes to a GSL of 90 to retain the uneven-aged character of these stands. GSL's of 120+ are acceptable, because beetle populations are not a problem in these stands.

WZS is a spruce-pine sawtimber stand in the Special Component. Cut in all size classes to a GSL of 90 to retain the uneven-aged character of this stand. GSL's of 120+ are acceptable, because beetle populations are not a problem in these stands.

TZB/TZN: TZB is an uneven-aged ponderosa pine sawtimber stand outside the Norbeck Wildlife Preserve Special Component. TZN is an uneven-aged ponderosa pine sawtimber stand within the Norbeck Special Component. These stands have adequately stocked understories which vary from 60 to 120 square feet of growing stock basal area. Intermediate cut to a GSL of 80.

TZA is an uneven-aged ponderosa pine sawtimber stand with an adequately stocked understory in the special component. This stand varies from 60 to 120 square feet of growing stock basal area. Intermediate cut to a GSL of 80.

N60 is an uneven-aged ponderosa pine sawtimber stand to be managed for wildlife habitat within the Norbeck Wildlife Preserve in the Special Component. This stand has 60-120 square feet of growing stock basal area. Enter this stand with an intermediate cut to a GSL of 60.

NOR is a two-storied ponderosa pine stand in the Norbeck Wildlife Preserve Special Component. It has an adequately stocked overstory and understory. The overstory will be removed in two cuts to minimize damage to the understory. The second cut (seed cut) will be made in the overstory.

Computation of Log Size Distribution

As mentioned in the main text, timber class P31 is representative of the all-size group of timber classes, and timber class PB1 is representative of the sawtimber group of timber classes. Each of these timber classes is composed of trees with a distinctive distribution of diameters (figure 3). If a tree height distribution is available or can be reasonably estimated, then the diameters of logs cut from such trees may be estimated by means of taper tables. This was essentially the process used here to estimate one possible distribution of veneer block diameters.

To start, construct a probable estimated tree height distribution based on stand type and mean height for each tree diameter class. Table A-1 shows the results for timber class P31, and table A-2 shows the same information for timber class PB1.

Relative tree height within a diameter class in a timber stand depends largely on the age structure of the stand. In contrast, relative tree height for cut trees in a harvested timber stand depends on the silvicultural

Table A-1.—Average tree heights and one possible distribution of estimated tree heights for timber class P31

Tree d.b.h. classes (2-inch classes)	Average tree height		Trees per acre	Tree heights in distribution ¹				
	feet ²	logs ³						
6	43.9	0.5	40.0000		0 (0.25)	0.5 (0.5)	1.0 (0.25)	
8	51.9	1.0	33.0000		0.5 (0.25)	1.0 (0.5)	1.5 (0.25)	
10	55.4	1.5	28.6591	0.5 (0.1)	1.0 (0.2)	1.5 (0.4)	2.0 (0.3)	
12	62.3	2.0	17.6607	1.0 (0.1)	1.5 (0.2)	2.0 (0.4)	2.5 (0.2)	3.0 (0.1)
14	66.8	2.5	9.1672	1.5 (0.1)	2.0 (0.2)	2.5 (0.4)	3.0 (0.2)	3.5 (0.1)
16	70.0	3.0	4.3085	2.0 (0.1)	2.5 (0.2)	3.0 (0.4)	3.5 (0.2)	4.0 (0.1)
18	76.6	3.5	2.1053	2.5 (0.1)	3.0 (0.2)	3.5 (0.4)	4.0 (0.2)	4.5 (0.1)
20	78.1	3.5	0.7068	2.5 (0.1)	3.0 (0.2)	3.5 (0.4)	4.0 (0.2)	4.5 (0.1)
22	85.0	4.0	0.3304	3.0 (0.1)	3.5 (0.2)	4.0 (0.4)	4.5 (0.2)	5.0 (0.1)
24	88.1	4.5	0.1222	3.5 (0.1)	4.0 (0.2)	4.5 (0.4)	5.0 (0.3)	
*26	88.0	4.5	0.0769					

¹Two numbers appears in each column. The first number, without parentheses, tells the number of 16-foot logs found in that tree d.b.h. class. The second number, within parentheses, tells what proportion of trees in the given d.b.h. class are assumed to have that number of 16-foot logs. For example, trees in the 10-inch d.b.h. class are assumed to have 40% of their number with 1.5 16-foot logs.

²Source: Computer program GROW printout. Information used as input to Black Hills NF Timber Management Plan, 1977-1986. On file, Rocky Mountain Forest and Range Experiment Station.

³Conversion from tree height in feet to tree height in merchantable 16-foot logs based on information in Van Deusen (1967).

*Taper information was not available for this diameter class. Effects of dropping this class are negligible.

Table A-2.—Average tree heights and one possible distribution of estimated tree height for timber class PB1

Tree d.b.h. classes (2-inch classes)	Average tree height		Trees per acre	Tree heights in distribution ¹				
	feet ²	logs ³						
12	56.3	1.5	13.9867	0.5 (0.05)	1.0 (0.20)	1.5 (0.50)	2.0 (0.20)	2.5 (0.05)
14	61.9	2.0	11.6958		1.5 (0.25)	2.0 (0.50)	2.5 (0.20)	3.0 (0.05)
16	68.1	2.5	6.4858	1.5 (0.05)	2.0 (0.20)	2.5 (0.50)	3.0 (0.20)	3.5 (0.05)
18	72.2	3.0	2.9654	2.0 (0.05)	2.5 (0.20)	3.0 (0.50)	3.5 (0.20)	4.0 (0.05)
20	79.1	3.5	1.6948	2.5 (0.05)	3.0 (0.20)	3.5 (0.50)	4.0 (0.20)	4.5 (0.05)
22	83.7	4.0	0.7296	3.0 (0.05)	3.5 (0.20)	4.0 (0.50)	4.5 (0.20)	5.0 (0.05)
24	88.3	4.5	0.3106	3.5 (0.05)	4.0 (0.20)	4.5 (0.50)	5.0 (0.25)	
*26	93.3	5.0	0.1725					

¹Two numbers appears in each column. The first number, without parentheses, tells the number of 16-foot logs found in that tree d.b.h. class. The second number, within parentheses, tells what proportion of trees in the given d.b.h. class are assumed to have that number of 16-foot logs. For example, trees in the 10-inch d.b.h. class are assumed to have 40% of their number with 1.5 16-foot logs.

²Source: Computer program GROW printout. Information used as input to Black Hills NF Timber Management Plan, 1977-1986. On file, Rocky Mountain Forest and Range Experiment Station.

³Conversion from tree height in feet to tree height in merchantable 16-foot logs based on information in Van Deusen (1967).

*Taper information was not available for this diameter class. Effects of dropping this class are negligible.

tural prescription for the stand and on the judgment of the timber cruiser in selecting trees to match the prescription.

Height data from about 400 trees from timber sales in the Black Hills NF suggests that distributions of cut tree height on that National Forest are approximately symmetric about the mean height for a particular tree diameter class. In addition, while data are not available, it is assumed that the distribution of tree heights within a diameter class is wider for an uneven-aged stand than for an even-aged stand. Thus, timber class P31, an uneven-aged stand, is given a wider distribution than timber class PB1, a two-storied, even-aged stand.

Based on the information in tables A-1 and A-2, the next step is to consult a taper table for the sawtimber trees (Woodfin 1960) and for the poletimber trees (Myers 1963). For each tree diameter and height combination, the taper table will supply data on number and small end diameter, inside bark, of veneer blocks, each 8.5 feet long, that can be bucked from the tree.

A tree from a given height and diameter class would supply veneer blocks in several small end d.i.b. classes, based on the taper tables cited above. When these numbers of veneer blocks are multiplied by trees per acre in the height and diameter class, the result is number of logs per acre, by small end d.i.b. class, from trees within the given height and diameter class. Then logs per acre in each d.i.b. class are summed for all tree height and diameter classes. The result is an estimate of the distribution, by small end d.i.b. class, of the veneer blocks and other logs that can be obtained from the timber class.

The d.i.b. distribution of logs from each timber class is weighted by the acreage of each timber class to arrive at an overall d.i.b. distribution of available logs. In this case, as stated in the main text, the acreage of timber classes P31 and PB1 are about equal, so the distributions from each timber class were merged with equal weights. The net result is an estimate of a likely distribution of small end d.i.b.'s shown in figure 4 for 8.5-foot logs.

ECONOMICS

Computation of Veneer Recovery

To estimate veneer recovery volumes and associated residue volumes, a set of relationships was developed to relate total veneer block volumes to published veneer recovery studies. The basic relationship is that volumes for all losses, such as roundup and clipper losses, volumes for green veneer, and volumes for the block core must sum to the total block volume. In addition, estimates for each volume component of the block must conform reasonably well with volumes reported in published recovery studies (Yerkes and Woodfin 1972, Woodfin 1973).

Residue Volume

Green residue volume results mainly from block roundup and from losses at the clipper. Roundup loss is mainly a function of tree form, log diameter, and resultant taper. Clipper loss can result from a wide variety of physical and biological factors that degrade green veneer. This loss volume is also a function of block diameter to the degree that some veneer degrade factors are functions of block size, or position in the tree. In addition, some good veneer occasionally is lost by clipper malfunction. Published loss data (Yerkes and Woodfin 1972) shown in figure A-1 suggest that a quadratic equation might fit the data. A linear regression analysis resulted in the equation

$$V_{\text{loss}} = 0.0420d^2 - 0.5634d + 2.912$$

Figure A-1.—Veneer block component volumes by diameter class, Black Hills ponderosa pine (Yerkes and Woodfin 1972). Legend for the respective curves: a1 = sum of regressions for veneer, core, and loss volumes; a2 = data points for sum of veneer, core, and loss volumes; b1 = regression for veneer plus core volumes; b2 = data points for veneer plus core volumes; c = regression for residue loss volume; d1 = data points for residue loss volume; d2 = regression for core volume; e = data points for core volume. Dotted portion of lines a1 and b1 show break between two separate regressions.

where d is veneer block small end diameter inside bark^a and V_{loss} is cubic foot volume lost.

Total of Veneer and Core Volume

This volume is the block volume net of all losses discussed above. Again, published recovery data were obtained from Yerkes and Woodfin (1972). The resulting regression equations are

$$V_{\text{vc}9+} = 0.9287d - 5.6184 \quad d \geq 9 \text{ inches}$$

$$V_{\text{vc}6-8} = 0.2400d + 0.5900 \quad d = 6, 7, 8 \text{ inches}$$

where $V_{\text{vc}9+}$ is cubic foot volume in veneer (v) plus core (c) from blocks 9 inches and greater, and $V_{\text{vc}6-8}$ is cubic foot volume in veneer (v) plus core (c) from blocks 6 to 8 inches in diameter. The published data points for veneer and core (curve b2 in fig. A-1) show a distinct break between 8 and 9 inches. On each side of this break, the data points are almost linear. The simplest way to approximate these data points is by two linear equations for the block diameter ranges noted above.^a

Total Volume

Total block volume is found by adding the respective volumes for losses and for veneer plus core, as computed by regression. Thus, total volume is completely accounted for and is expressed by the following equations:

$$V_{+9+} = 0.0420d^2 + 0.3653d - 2.6972 \quad d \geq 9 \text{ inches}$$

$$V_{+6-8} = 0.0420d^2 - 0.3234d + 3.5112 \quad d = 6, 7, 8 \text{ inches}$$

where d is veneer block small end diameter inside bark in inches and V_{+xx} is total veneer block cubic volume. An alternative method is to compute a regression equation for total veneer block volume as a function of block diameter. Data for this method would not be the sum of veneer, core, and residue; instead the data would be total block volume as reported by Yerkes and Woodfin (1972). This method, however, would lead to small discrepancies between total block volume computed by a regression formula and total block volume as the sum of the block component volumes. To be consistent total volume was computed on the basis of the sum of component volumes.

^aThis regression and all following equations are based on published summaries of recovery data. The equations are used here as computational aids for analysis of the timber resource. As seen in figure A-1, the regressions generally fit the data points. The authors do not suggest that these equations are necessarily applicable beyond the analysis reported here.

^aA single regression equation may fit these data points with a high coefficient of determination (r^2). However, such an equation would erroneously estimate volume for 8-inch veneer blocks. Because this size block is represented in the diameter distribution to a far greater extent than other diameters, this defect is serious. For this reason, two separate equations were used.

Core Volume and Green Veneer Volume

Core volume is based on the formula for a cylinder. Length assumed is 8.5 feet for each veneer block. After allowing for the appropriate unit conversion factors the following equation results:

$$V_c = 0.046359d_c$$

where d_c is the target core diameter in inches, and V_c is cubic foot volume in the core. Target diameters used in this study and the corresponding volumes for veneer lathe cores are shown below.

Target core diameter	Core volume
inches	cubic feet
6	1.6689
5	1.1590
4	0.7417

Green veneer volume is computed by subtracting the respective core volume from the volume for green veneer and core.

Veneer Shrinkage and Dry Veneer Volume

Shrinkage volume is based on percent factors published by Woodfin (1973). The percent shrinkage of veneer by block diameter class is applied to the total block volume, computed as indicated above. The resultant cubic volume of shrinkage is then subtracted from each appropriate green veneer volume to arrive at the figure in table 13 for cubic volume of dry veneer.

Computation of Log Taper

Low-taper logs.—Work completed by Myers (1963) for ponderosa pine in the Southwest is the source of taper data for pole-sized trees that most closely resemble Black Hills ponderosa pine. Taper for 8-foot logs ranged from 0.4 to 1.9 inches, depending on diameter, tree height, and log position in the bole. Average taper for each 1-inch class of log diameter, inside bark, varies from 0.95 to 1.18 inches per 8-foot log. Average taper for all logs is 1.01 inch per 8-foot log. Based on the above information, it was assumed that taper in logs from poletimber trees averages 1 inch per 8.5-foot log.

High-taper logs.—As noted in the main text, these logs are bucked mostly from the top of the bole of sawtimber-sized trees. Taper data for ponderosa pine sawtimber trees in the Black Hills was compiled by Woodfin (1960). Analysis of these data reveal a wide variation in taper, as would be expected. When the data for 8.5-foot logs are aggregated by 1-inch small end d.i.b. classes, average taper is shown in the following tabulation:

Log small end diameter class	Taper per 8.5-foot log
inches	inches
6	3.4
7	2.6
8	2.0
9	1.8

These results are consistent with expectation. Six-inch logs are located in the rapidly tapering bole top. Logs of larger diameter would be located farther down the bole where taper is less than at the top.

Lumber and Residue Recovery

Smalian's formula, modified to reflect the assumed taper per 8.5-foot log, was used to compute total log volume. The resulting formula is:

$$V_L = 0.046359(d^2 + dt + 0.5t^2)$$

where V_L is log volume in cubic feet, d is log small end d.i.b. in inches, t is log taper in inches per 8.5 feet, and 0.046359 is the appropriate conversion factor for units computed as 0.005454 square feet per square inch $\times$ 8.5 feet. Six decimal places does not imply extreme accuracy, but rather, minimizes rounding error.

Dimension 2- by 4-inch lumber produced by the auxiliary sawmill with chipping headrig is assumed to have the following cross sectional dimensions, depending on its degree of manufacture:

Condition	Size
	inches
Rough, green	1.65 $\times$ 3.75
Rough, dry	1.59 $\times$ 3.63
Dressed, dry	1.50 $\times$ 3.50

Saw kerf, where it applies, is assumed to be 0.15 inch. Williston's (1976) recommended standard saw kerf of 0.125 inch was adjusted upward to assure a conservative estimate. Saw kerf sawdust volume is computed for the full log length of 8.5 feet because the 2- by 4-inch lumber is not yet trimmed to 8 feet.

Chip volume is the log volume net of rough green lumber and saw kerf volumes.

Trim volume is the 0.5 foot of ends trimmed to make an 8-foot long stud. Shrinkage is volume lost during the drying process. Planer shaving volume includes planer shavings plus sander dust. Both shrinkage and planer shaving volumes are based on changes in cross sectional dimension shown in the tabulation above.

Bark Volume

Bark volumes per cubic unit of roundwood volume were estimated using factors published by Krier and

River (1968). These factors were given by 4-inch diameter classes for logs with diameters ranging from 7.6 to 35.5 inches. Because log diameter in the Black Hills is as small as 4 inches, the factor values were extrapolated to cover the entire range of Black Hills log sizes. Proportions of logs in each 4-inch diameter class were computed from data incorporated in figure 4. Assuming that log diameters are distributed as shown in the figure, the weighted average bark volume factor is computed as shown in table A-3.

The total volume of 100 index logs, defined in the main text, is 424.4980 cubic feet. Multiplying this volume by the weighted average bark factor (0.236724) results in a bark volume of 100.4889 cubic feet per 100 index logs.

Product Recovery for Index Log Volumes and Total Volume Required

Units of one hundred logs, each log 8.5 feet long, whose small end diameters are distributed as shown in figure 4, are estimated to provide the product volumes shown in tables A-4, A-5, and A-6.

Each table is organized to relate product recovery to three levels of target core diameter and to three levels of veneer block lower size limit. For example, the relationships illustrated in figure 6 are amplified in these tables. Lumber recovery from small logs shown in table A-5 depends only on choice of a lower diameter limit for veneer blocks, but lumber recovery from veneer block cores depends on both the lower veneer block diameter limit and on the target core size.

A most important question for the analysis of material flow is how many units of 100 index logs are required to support the plywood plant at the assumed capacity.

Dry veneer is used as the base product for computing volumes. The annual dry veneer requirement is 2,325,149 cubic feet. The column in table A-4 for dry veneer lists cubic volume per 100 index logs. For example, when peeling 8-inch and larger logs to a 4-inch core, the number of units of 100 index logs required is computed by dividing 2,325,149 cubic feet required per year by 191.03 cubic feet per 100 index logs. The result is that 12,172 units of 100 index logs are required annually. Similar results are shown in table A-7 for each of the nine combinations of veneer block lower diameter limit and target core size.

The numbers of index units in table A-7 are termed blow-up factors. When the appropriate blow-up factor is multiplied by index volumes from tables A-4, A-5, and A-6, the annual requirements for raw material can be determined, as well as the annual production volumes of the various products and residues. The annual material volume flow is shown in table 15 for the analysis presented in this report, assuming a target core size of 4 inches and veneer block lower limit of 8 inches.

Table A-3.—Computation of average bark volume factor weighted by proportions of log diameters

Midpoint, d.i.b. class	D.i.b. class range	Bark factor ¹	(×)	Percent of logs in d.i.b. class	(=)	Weighted bark factor
----- inches -----						
5	3.6-7.5	.20260		36.0989		0.093857
9	7.6-11.5	.234		47.7529		.111742
13	11.6-15.5	.192		13.3195		.025573
17	15.6-19.5	.201		2.4870		.004999
21	19.6-23.5	.162		0.3250		.000526
25	23.6-27.5	.158		0.0168		.000026
Total weighted average bark factor -----						0.236724

¹Cubic feet of bark per cubic foot of wood in log volume. Source: Krier and River (1968).
²Estimated by extrapolation of tabulated values for the 9- to 25-inch d.i.b. classes.

Table A-4.—Veneer and plywood recovery and losses per 100 index logs¹

Target core diameter	Veneer block lower diameter limit	Total veneer log volume	Core volume	Tangible losses	Green veneer	Shrink	Dry veneer	Dry losses and panel trim	Cubic volume	Area volume (3/8-inch basis)
----- inches -----										
4	9	291.4266	29.9157	88.9845	172.5264	7.8613	164.6648	26.3464	138.3184	square feet 4,426.1894
	8	346.3586	41.1956	105.7439	199.4191	8.3890	191.0297	30.5648	160.4649	5,134.8779
	7	373.9881	47.3954	114.3987	212.1940	8.4993	203.6943	32.5911	171.1032	5,475.3023
5	9	291.4266	46.7471	88.9845	155.6948	7.8613	147.8334	23.6532	124.1802	3,973.7620
	8	346.3586	64.3734	105.7439	176.2411	8.3890	167.8517	26.8562	140.9958	4,511.8620
	7	373.9881	74.0614	114.3987	185.5278	8.4992	177.0281	28.3244	148.7040	4,758.5236
6	9	291.4266	67.3134	88.9845	135.1285	7.8613	127.2672	20.3629	106.9043	3,420.9424
	8	346.3586	92.6944	105.7439	147.9201	8.3890	139.5311	22.3251	117.2060	3,750.5960
	7	373.9881	106.6446	114.3987	152.9446	8.4993	144.4453	23.1114	121.3339	3,882.6897

¹Four decimal places are carried here to insure that subsequent use of these figures will not introduce significant error caused by rounding.

Table A-5.—Lumber and residue recovery and losses per 100 index logs for veneer block cores and for small logs sent directly to the lumber mill¹

Target core diameter	Veneer block lower limit	Total core and log volume	Chips	Saw kerf	Lumber rough, green untrimmed	Trim	Lumber rough, green trimmed	Shrink	Planer, sander volume	Lumber dry, dressed	Nominal lumber tally	Number of pieces recovered
		inches	cubic feet									
			fbm									
4	9	29.9278	15.2059	--	14.7219	0.8470	13.8749	0.9680	1.1294	11.7775	215.1012	40.3340
	8	41.2123	20.9394	--	20.2729	1.1664	19.1065	1.3330	1.5552	16.2183	296.2066	55.5422
	7	47.4146	24.0907	--	23.3239	1.3419	21.9820	1.5336	1.7892	18.6591	340.7846	63.9011
5	9	46.7471	15.9723	1.3310	29.4438	1.7344	27.7095	1.9360	2.2587	23.5147	430.2428	80.6680
	8	64.3734	21.9947	1.8329	40.5458	2.3883	38.1575	2.6660	3.1104	32.3811	592.4686	111.0844
	7	74.0614	25.3048	2.1087	46.6478	2.7477	43.9001	3.0673	3.5785	37.2543	681.6330	127.8022
6	9	67.3174	20.8527	2.6620	43.8027	2.5814	41.2213	2.9040	3.3881	34.9262	645.3440	121.0020
	8	92.6999	28.7153	3.6658	60.3188	3.5547	56.7641	3.9990	4.6655	48.0995	888.6752	166.6266
	7	106.6509	33.0369	4.2175	69.3966	4.0897	65.3069	4.6009	5.3677	55.3384	1,022.4176	191.7033
Small logs ²	9	132.5256	57.3990	4.4422	70.6843	4.1497	66.5346	4.6692	5.4198	56.4459	1,032.3321	193.5629
	8	77.8606	38.5797	1.9177	37.3632	2.1878	35.1753	2.4640	2.8648	29.8468	545.6697	102.3137
	7	50.5099	24.2775	1.0817	25.1507	1.4689	23.6817	1.6531	1.9286	20.1002	367.3472	68.8777

¹Four decimal places are carried here to insure that subsequent use of these figures will not introduce significant error caused by rounding.

²Recoveries from small logs do not depend on target core diameter, but do depend on the choice of a lower diameter limit for veneer blocks.

Table A-6.—Lumber and residue recovery and losses per 100 index logs for veneer block cores and small logs combined¹

Target core diameter	Veneer block lower limit	Total core or log volume	Chips	Saw kerf	Lumber rough, green untrimmed	Trim	Lumber rough, green trimmed	Shrink	Planer sander volume	Lumber dry, dressed	Nominal lumber tally	Number of pieces recovered
		inches	cubic feet									
			fbm									
4	9	162.4534	72.6049	4.4422	85.4062	4.9967	80.4095	5.6372	6.5492	68.2234	1,247.4333	233.8969
	8	119.0729	59.5191	1.9177	57.6361	3.3542	54.2818	3.7970	4.4200	46.0651	841.8763	157.8559
	7	97.9245	48.3682	1.0817	48.4746	2.8108	45.6637	3.1867	3.7178	38.7593	708.1321	132.7788
5	9	179.2727	73.3713	5.7732	100.1281	5.8841	94.2441	6.6052	7.6785	79.9606	1,462.5749	274.2309
	8	142.2340	60.5744	3.7506	77.9090	4.5761	73.3328	5.1300	5.9752	62.2279	1,138.1383	213.3975
	7	124.5713	49.5823	3.1904	71.7985	4.2166	67.5818	4.7204	5.5071	57.3545	1,048.9802	196.6799
6	9	199.8430	78.2517	7.1042	114.4870	6.7311	107.7559	7.5732	8.8079	91.3751	1,677.6761	314.5649
	8	170.5605	67.2950	5.5835	97.6820	5.7425	91.9394	6.4630	7.5303	77.9463	1,434.3449	268.9403
	7	157.1608	57.3144	5.2992	94.5473	5.5586	88.9886	6.2540	7.2963	75.4386	1,389.7648	260.5810

¹Four decimal places are carried here to insure that subsequent use of these figures will not introduce significant error caused by rounding.

Table A-7.—Number of units of 100 index logs required to supply dry veneer required for capacity plywood plant operation

Veneer block lower limit (inches)	Target core size (inches)		
	6	5	4
9	18,269.8198	15,728.1698	14,120.4970
8	16,664.0183	13,852.3748	12,171.6613
7	16,097.0887	13,134.3265	11,414.8938

Donnelly, Dennis M., and Harold E. Worth. 1981. Potential for producing ponderosa pine plywood in the Black Hills. USDA Forest Service Resource Bulletin RM-4, 43p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

This study describes possible plywood production opportunities for Black Hills ponderosa pine in terms of kinds of plywood and advantageous market areas. The resource analysis examines current and future uses of the area's timber. Economic evaluation includes analyses of discounted cash flow and operating costs and revenues.

Keywords: *Pinus ponderosa*, plywood, forest products, Black Hills, ponderosa pine, markets, economics

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Rocky Mountain Forest and Range Experiment Station

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