UTILIZATION AND MARKETING OPPORTUNITIES FOR ALBERTA ASPEN SOLID WOOD PRODUCTS

Virginia Polytechnic Institute &
State University

Eugene M. Wengert[1]

1988

This is a joint publication of Forestry Canada
and the Alberta Forest Service pursuant to the
Canada-Alberta Forest Resource Development Agreement

[1]Brooks Forest Products Center
Virginia Tech.
Blacksburg, VA 24061
U.S.A.

1471-45

DISCLAIMER

The study on which this report is based was funded in part under the Canada/Alberta Forest Resource Development Agreement.

The views, conclusions and recommendations are those of the authors. The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by Forestry Canada or the Alberta Forest Service.

Catalogue No.: FO 42-91/46-1988E
ISBN: 0-662-16269-2

Additional copies for this publication are available at no charge from:

Forestry Canada
Regional Development
5320 - 122nd Street
Edmonton, Alberta
T6H 3S5
Telephone: (403) 435-7210

or

Forestry, Lands and Wildlife
Forest Industry Development Division
108th Street Building
#930, 9942 - 108th Street
Edmonton, Alberta
T5K 2J5
Telephone: (403) 422-7011

UTILIZATION AND MARKETING OPPORTUNITIES FOR ALBERTA ASPEN

EXECUTIVE SUMMARY

Eight general use categories for Alberta aspen (*Populus tremuloides*) were examined for both their technical and marketing potential. The examination was based on published literature, as well as the author's years of personal research and practical experience with both Lake States and Rocky Mountain aspen in the United States. A summary of this report is presented in the following tabulation:

Product	Overall Potential
Veneer and Plywood	Product value is high, but manufacturing costs are very high; market development would be necessary. High quality resource probably lacking.
Construction Lumber (8/4 Dimension)	Very low product value; very low yields; many unsuccessful industrial trials.
Utility Lumber (4/4 through 6/4)	Moderate to high potential for high quality logs over 24 cm (9-inches) in diameter; profitable residue uses are essential.
Furniture Blanks or Parts	High potential for medium and high quality logs; some market development needed; product value is high.
Pallet Stock or Parts	High potential, especially with profitable residue use; already active markets in Alberta.
Fuel	Low potential for development of (industrial) markets; low weight per volume is a problem; briquet manufacturing possible.
Animal Feed & Roughage	Interesting possibilities, but many unanswered questions, including safety of animals and humans.
Animal Bedding	High potential for all grades of logs; markets must be within 100 km (60 miles) of resource.

As an overall summary, the utilization potential for small logs (under 24 cm (9-inches) in diameter, small end) is best for animal bedding and local fuel use. For logs over 24 cm (9-inches) in diameter, the highest potential use is for furniture parts followed by pallet parts, with a moderate potential for use as 4/4 - 6/4 lumber.

Several potential uses are not discussed in this report because of a lack of processing information. These uses include wood flour, wood excelsior or wool, snow fence lath, log cabin logs, and various pressed items from veneer (such as tongue depressors). Manufacturing and marketing opportunities may exist in these areas, as well as other small product and market niches.

In addition, the potential for use of aspen in manufacturing pulp and particleboards (including OSB) was excluded because these two uses are already quite active in Alberta and therefore were considered beyond the scope or objectives of this report. Certainly opportunities may exist for expansion in these two areas.

ABSTRACT

Aspen (Populus tremuloides) is an underutilized resource in Alberta, as in most of North American. The primary reason for this underutilization is aspen's poor economic potential for manufacturing most wood products using conventional processing techniques. The poor economics arise because of poor management practices leading to excessive cull in the harvested logs, poor product choices, and poor processing methods. This report considers the aspen resource and its potential for utilization to manufacture a variety of wood products, including utility lumber, construction lumber, pallet parts, furniture dimension parts, veneer, fuel, and a variety of residue uses. This report is a summary of published and unpublished information from both Canada and the U.S.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I. THE ASPEN RESOURCE

Introduction

Utilization of wood is one of the most important tools for managing any forest tree species or forest type. It not only provides products and other tangible economic benefits; it also finances or helps to finance management for other purposes than timber growing. Yet for aspen[1] in Alberta, utilization for solid wood products (that is, products other than particleboard and pulp) is minimal and therefore in turn optimal management is difficult. It is the emphasis of this report to develop utilization of aspen into a more viable management tool.

Utilization of aspen, as with other species, depends on the species, properties, processing technology, and product markets. Aspen is a unique wood with many characteristics unlike any other species (e.g., splinterless). A summary is presented in Table 1. Unfortunately, markets for solid aspen wood products in Western Canada (and the U.S. as well) are poorly developed, partly because the native conifers have been plentiful and have certain advantages, and partly because the technical properties and advantages of western aspen are not widely known. Although the wood of western aspen differs in some respects from the wood of aspen in the Lake States and Colorado in the U.S., due to climate and soil differences, most processing technology that they have developed appears directly applicable to Alberta.

There are, however, important differences in marketing opportunities between the States and Alberta. For example, there is considerably less population and less manufacturing industry in the West.

This comprehensive report on wood utilization and marketing was prepared with several specific objectives in mind. First, much of the literature on the technology of processing aspen is scattered throughout many different publications, some of which are out-of-print. Therefore, in this report, the technology of processing aspen is reviewed and updated to provide guidance to the potential processor. Second, this report examines the market potential for aspen for various solid wood products, in order to provide insight to the forest manager and the potential processor. It is hoped that this marketing information will assist and encourage broad and long range understanding of the utilization of this species by both land managers and wood processors, and thereby increase employment and value added in the region.

Some of the information in this report is based on published information derived for Lake States or Canadian aspen and is so referenced.

---

[1]Aspen includes trembling or quaking aspen (<u>Populus tremuloides</u>), big-tooth aspen (<u>Populus grandidentatis</u>), and often balsam poplar (<u>Populus balsamifera</u>), also called Balm-of-Gilead. The latter has so many processing problems, that it is not discussed further. The term "poplar" in the eastern U.S. lumber trade refers to yellow-poplar (<u>Liriodendron</u> <u>tulipifera</u> L.) which is not related to aspen poplar.

Table 1. Aspen Characteristics and Properties (Data from Kennedy 1968 and Zasada 1947).

Both bark and wood digestible by ruminants (up to 55% digestible)

Many knots-mostly tight; some loose

White color in normal wood; discoloration frequent in other mature trees

Light weight-0.42 g/cm^3 (26 lb/cu ft) when air dried; green specific gravity 0.37

Odorless when dry

Shrinks and swells very little (after drying) with changes in relative humidity

Splinterless

Warps (cup and crook) during drying due to high tangential to radial shrinkage ratio

Decays easily

Small diameter trees-most boards are 1 x 4 and 1 x 6 inches (25 x 100 mm and 25 x 150 mm); a few larger

Mature trees are typically quite defective-knots, incipient decay

Indistinct grain in sapwood

Weak in bending-MOE is 1.18 million psi (9030 MPa) and MOR is 8400 psi (37.6 MPa) at 12% moisture for clear wood

High in toughness (when green, equal to Douglas-fir; dry, to southern yellow pine)

Weak in nail and screw holding

Nails without splitting even at the end of a board

Glues well

Paints very well

Stains well-some blotchiness without wash coat

Inks well

Wears smoothly

Sapwood and normal heartwood dry very easily

Table 1. continued.

Wetwood, when present, is very difficulty to dry
Machines easily; dulls knives slowly; low energy requirements
Grain tears occasionally, especially end grain, when machining
Surface fuzzes occasionally in sawing, sanding, and machining
Pulps well

Other information is based on the author's experience with Lake States and Rocky Mountain aspen while employed by the U.S. Forest Service (USFS). Much of the data collected in this USFS assignment were never published. (The data are in file reports at the Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO.) Professional judgments based on these data (indicated by unreferenced technical statements) are provided on aspects not covered by published research.

Distribution and Volumes

Aspen, also commonly called "popple", "poplar", "quaking aspen", and "quaky", is the most widespread species in North America, stretching from Mexico to the Arctic Ocean and then the Atlantic to the Pacific (Figure 1). The range is controlled by adequate moisture levels and cool summer temperatures.

Important commercial concentrations of aspen exist in Northeastern United States, the Great Lakes area, central portions of Canada (Figure 2), and in the Central Rockies. In the Central Rocky Mountains, commercial aspen is generally confined to elevations between 7000 to 11,000 feet (2100 to 3500 m).

Alberta, of the three Canadian prairie provinces, has the largest standing aspen sawtimber volume-nearly 20 billion board feet. The aspen-type occupies a significant part of the commercial forest land in Alberta. Much of this aspen-type acreage is public land.

Aspen Management Perspectives

In general, aspen stands have been an unregulated component of many forests. It is recognized that many of these stands cannot be realistically managed solely for the wood fiber they contribute to the forest industry. Rather, because of the species' desirable and unique properties, aspen will be managed primarily for scenic beauty, wildlife habitat, livestock grazing benefits, watershed improvement, and recreational uses. Aspen therefore plays an extremely important role in the overall resource and land use picture (Miller and Choate 1964, Reynolds 1969, Krebill 1972).

In the past, an important "natural" aspen management tool was wildfire-young aspen, sprouting from roots, would quickly reforest a burned conifer area. As these aspen sites matured, they frequently would naturally revert back to conifers in 100 to 200 years. However, with the control of wildfire (and with the present, environmentally stimulated, cutting and logging practices in the conifers that do not open up large areas), conditions are often unfavorable for large scale aspen regeneration (Schier 1975). Yet, as stated above, it is important to keep the aspen forest as a controlled part of the total Alberta forest in widespread locations. The management tool that is available to do this is aspen wood utilization. By logging aspen in small, cleared areas, the aspen will regenerate and the type can be maintained where and when desired (Jones 1975). One of the most definitive works on aspen management in the U.S. has recently been published (DeByle and Winokur 1985).

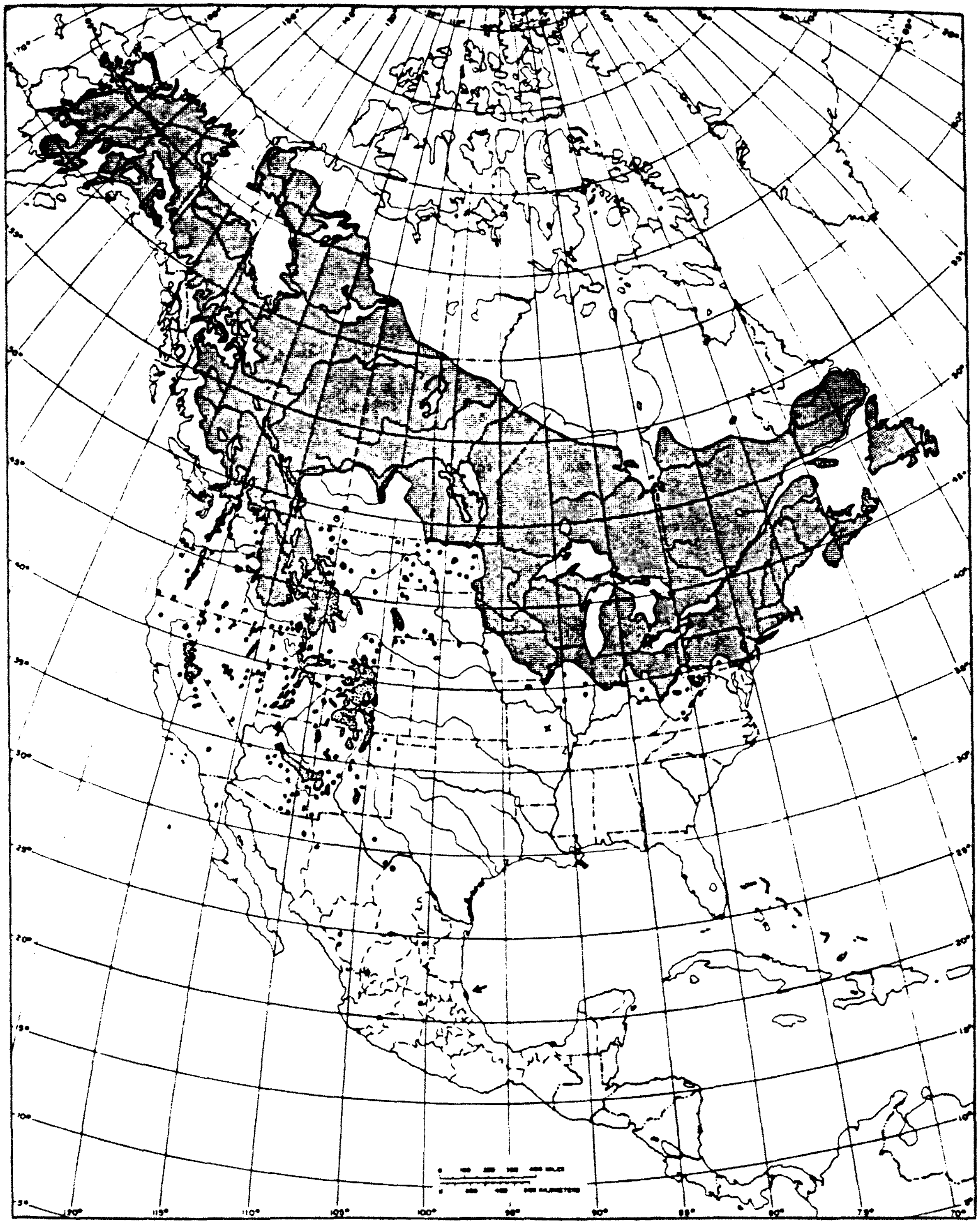

Figure 1. Distribution of aspen (Populus tremuloides) in North America. Source: Little (1971)

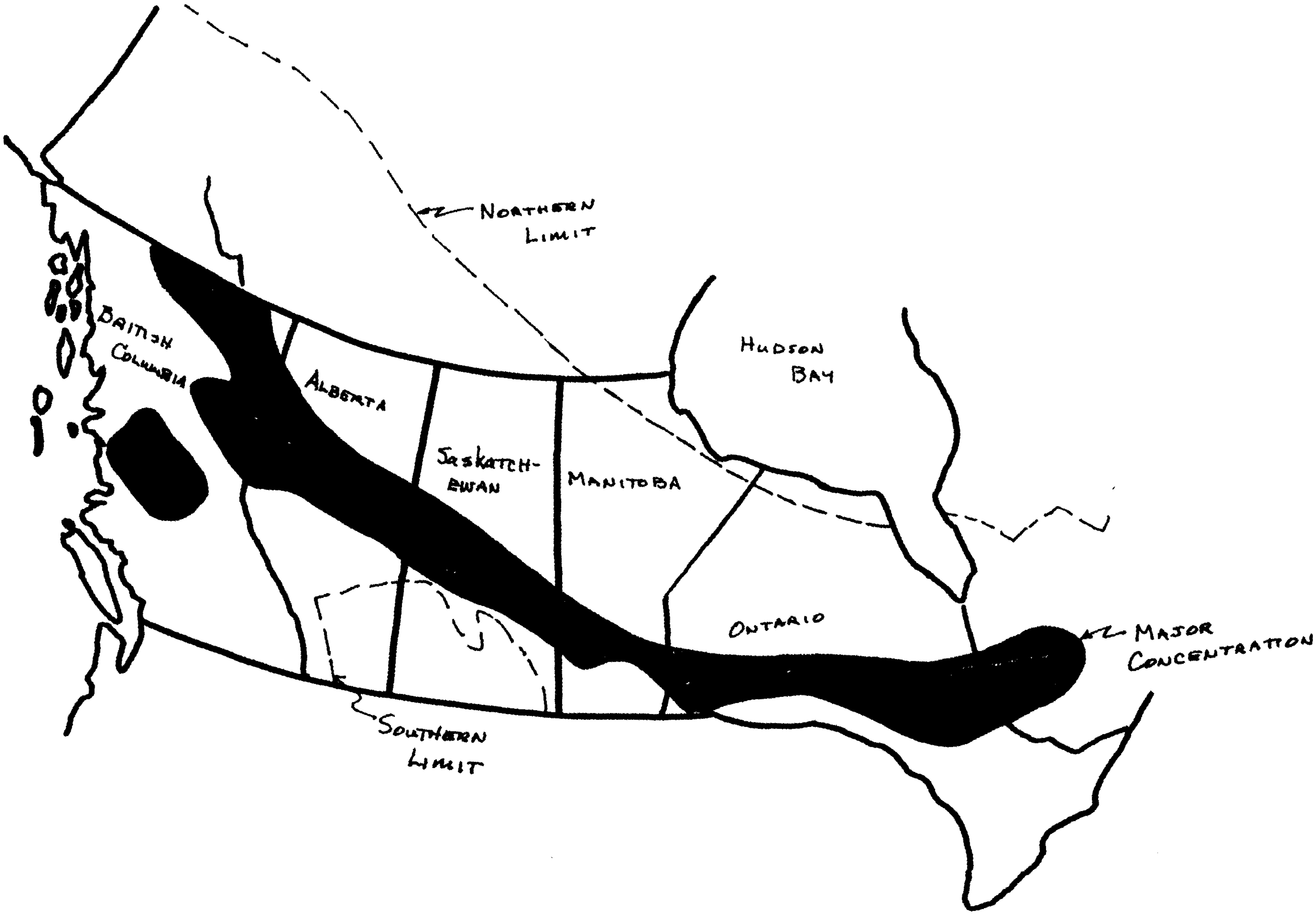

Figure 2. Distribution of aspen through Canada.

The following aspects of aspen management are significant to its utilization in wood products:

1. For maximum fiber and/or lumber returns from aspen, it must be harvested at maturity, not after (Davidson, et al. 1959, Thomas 1968, Hinds and Wengert 1977).

2. Aspen should not be cut in multiple entry or selective cut prescription, as the residual trees will be significantly damaged and infected with wood destroying fungi and will lose any future value for wood utilization. Regeneration with multiple cuts also suffers appreciably (Brinkman and Roe, 1975).

3. Thinning aspen at any early age (15 ft [4.6 m] high) may increase the growth of the residual and produce larger sawtimber trees at maturing (Schlaegel and Ringold 1971, Brinkman and Roe 1975).

4. Left to itself, a mature aspen forest will frequently convert to a conifer forest, if the conifer seed source and other conditions are suitable. This conversion occurs when the present aspen forest matures, usually in one generation. Aspen on a low quality site may not convert to conifers but may instead convert to sagebrush or range. Some sites may continue in aspen, generation after generation. A natural succession prediction model has been developed (Schier 1975, Bartos 1973).

5. Conifer sites adjacent to aspen that are opened up sufficiently will sometimes convert to aspen (Gottfried and Jones 1975).

6. Domestic livestock grazing during the 3 years following logging can suppress regeneration of new aspen trees (Baker 1925, Jones 1975).

CHAPTER II. CHARACTERISTICS OF ASPEN TREES, LOGS, AND WOOD THAT AFFECT UTILIZATION[2]

Tree Size

The typical dominant aspen tree at maturity in the Rockies is between 9 to 21 inches (24 to 54 cm) dbh (diameter at breast height) and 44 to 83 feet (13 to 25 m) high (Baker 1925). A mature stand may also have a significant number of trees smaller in diameter and somewhat shorter (Table 2). In contrast with the Lake states, Rocky Mountain aspen at maturity is twice as old, several inches larger, and 20 feet (3 m) or so higher.

Tree size and age have been classified into four site classes (Table 3). The purpose of such classification is to provide guidance for the assessment of present and future utilization potential of aspen on these sites. Aspen on Site classes 3 and 4, specifically, because of the small average tree size, has little commercial potential (although such sites may need management) under present utilization standards. New site index curves for aspen have been developed (Edminster et al. 1985).

Decay in the Living Tree

Trees past maturity are subject to rapid decay, mortality, and volume loss. One of the significant problems in assessing the potential of an aspen forest for utilization is estimating the extent of decay in a stand. Unlike many other tree species, the frequency and distribution of unsound knots in aspen shows no relationship to the decay volume (Alemdag and Honer 1972). The extent of loss of volume in the central Rocky Mountains as a function of age and Baker's site classification is presented in terms of cubic volume (Figure 3) and board foot volume (Figure 4). The cubic foot losses are approximately 10 percent at 90 years age on site 3, at 110 years on site 2, and at 140 years on site 1. These losses do not seem too significant, although as a rough approximation, a 10 percent decay loss would increase logging and hauling costs about 10 percent for the remaining usable fiber.

However, the board foot (log scale) losses, using the same data as for the cubic volume losses, indicate more clearly the influence of decay on utilization potential. After 70 years of age, trees on all three site classifications have at least a 10 percent board foot loss. A 10 percent loss to decay effectively eliminates the log from being used for the profitable production (sawing) of lumber. In other words, these data in Figure 5 can be used by land managers to establish the potential harvesting age for a young stand that will be used for saw logs in the future. Further, the data establish the maximum age of a stand today that has potential for consideration for saw log harvest. The number of trees that have measurable cull as a function of age is also shown (Figure 5). Half of the trees will have measurable cull (and therefore poor potential for use as a saw log) at 125 years of age.

---

2 (Information in this Chapter is based on Colorado data when Alberta data are not available)

Table 2. Characteristics of Even-Aged Aspen at Probable Pathological Rotation Age (Baker, 1925)

	SITE CLASS 1	2	3	4
Age (years)	120	110	100	80
Average DBH (inches)	11.2	8.9	7.1	5.3
(cm)	28	23	18	13
Dominant DBH (inches)	21	18	16	9
(cm)	53	46	41	23
Average Height (feet)	73	59	45	35
(m)	25	23	19	13
Dominant Height (feet)	83	74	63	44
(m)	25	23	19	13
Volume (cu. ft./acre)	5350	4300	3300	1600
(m^3/ha)	374	300	230	110

NOTE: Data based on average of all trees 4" (10 cm) DBH and greater

Table 3. Criteria of Aspen Site Classes (Baker 1925).

Age	Height of dominant trees Site 1	Site 2	Site 3	Site 4
	- - - - -	Feet	- - - - -	
10 years	13	11	8	6
20 years	25	19	15	13
30 years	37	29	23	19
40 years	47	38	30	24
50 years	57	48	37	30
60 years	66	55	44	35
70 years	73	62	50	40
80 years	77	67	55	44
90 years	80	71	60	47
100 years	81	74	63	49
110 years	82	75	66	----
120 years	83	76	----	----
130 years	83	----	----	----
140 years	83	----	----	----
150 years	83	----	----	----

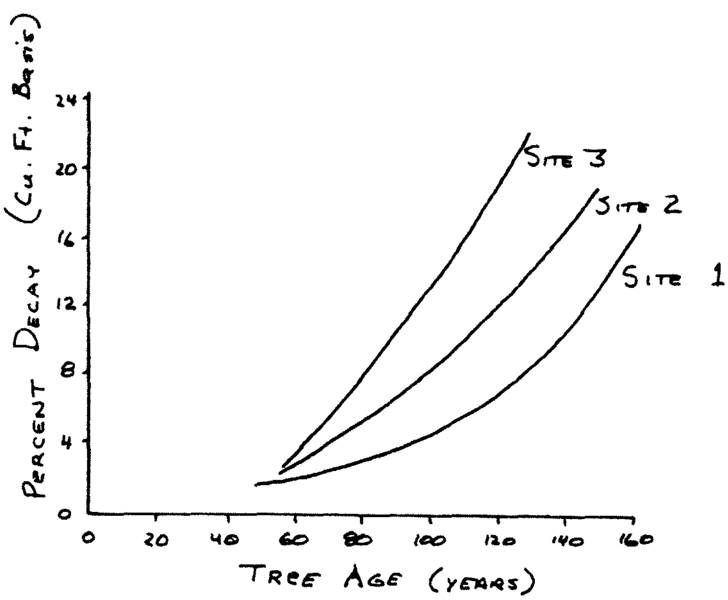

Figure 3. The volume loss (cubic foot basis) in Rocky Mountain aspen from decay as a function of age and Baker's site class. (Davidson _et al_. 1959)

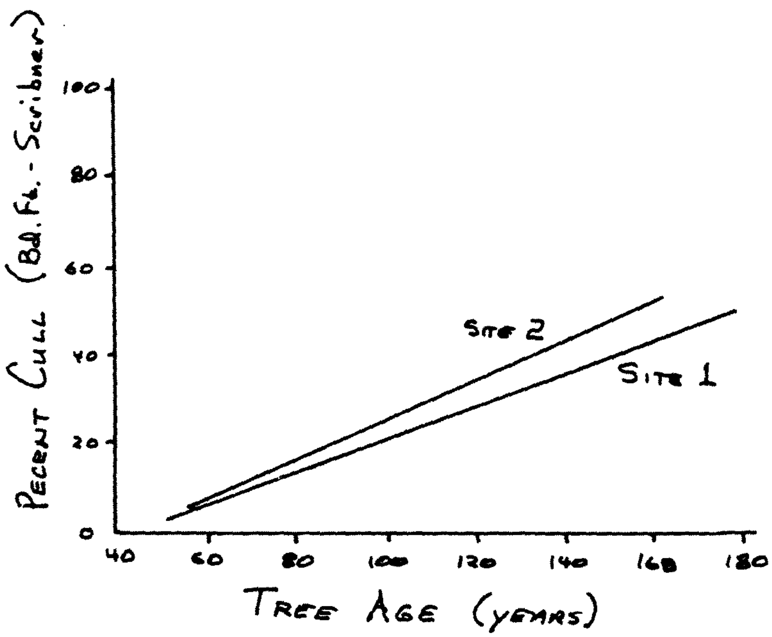

Figure 4. The cull loss (board foot Scribner) of Rocky Mountaine aspen from decay as a function of age and Baker's site class. (Hinds and Wengert 1977)

Figure 5. Percent of trees with measurable cull.
(Hinds and Wengert 1977)

In short, these data illustrate the need for prompt harvesting of mature aspen. These data are so critical for management and utilization of aspen that they should be verified for their applicability to Alberta. Thomas (1968) reported that 50 year old aspen in Alberat averages 6.5 and 7.5 inches (17 and 19 cm) in diameter (for dry sites and wet sites respectively) with approximately 15% cull. At 100 years, average small end diameter of the first 8-foot (2.4 m) is 10 inches 925 cm) with cull being 75 to 85%. If these dat are confirmed for the entire range of aspen in Alberta, the potential for producing acceptable quality sawlogs or veneer logs is remote. In the Lake States, decay losses come at an earlier age, but loss are not so severe as those reported by Thomas.

Decay in Rocky Mountain aspen is attributed to over 20 different fungi, but the major decay fungus affecting utilization potential is Phellinus tremulae (= Fomes igniarius) (Davidson et al. 1959). One of the major causes of aspen tree mortality is Cenangium singulare (Hinds and Krebill 1975).

Taper and Form

The following form factors for aspen were published by Baker (1925):

Tree Height feet	Form Factor
50	.43
60	.44
70	.46
80	.52

The average taper for a sample merchantable Rocky Mountain aspen bole is 0.114 in per ft (0.95 cm/m) of length (Wengert 1978a).

Volumes

The most broadly based volume tables for Rocky Mountain aspen are based on over 1000 trees from Colorado (Tables 4 and 5) (Peterson 1961). The functional basis for Peterson's data is:

$$\text{Vol.} = \frac{[\text{dbh}-4]^{0.0827 + B}\ [\text{total ht.}-4.5]^{0.4045}}{2.9655} + .3$$

where $B = .6593 \log_{20} (\text{total ht.}-4.5)$

where volume is board feet, dbh is inches, and height is feet.

More recently, relationships between gross merchantable volume of the tree, diameter and height were established in Colorado by Edminister et al. (1982):

Table 4. Scribner Board-foot Volume to a 6-inch Top Diameter Inside Bark for Western Aspen.

Diameter breast height outside bark (inches)	Merchantable heights in 16-foot logs										
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
	Board-feet (Scribner)										
6	9	18	27	35							
7	9	20	30	40	49						
8	9	22	34	45	56	67	78				
9	9	24	38	51	65	78	90	103			
10	9	26	43	58	74	89	104	119	133		
11		29	48	66	84	102	119	136	153		
12		32	54	75	95	116	136	155	175		
13		36	60	84	108	131	154	176	199	221	
14			67	95	121	148	174	200	225	250	
15			75	106	136	166	195	224	253	282	
16				118	152	185	219	251	284	316	
17				131	169	206	243	280	316	352	
18				145	187	229	270	311	352	392	432
19					207	253	299	344	389	434	478
20					228	279	329	379	429	478	527
21						306	361	416	471	525	579
22						334	395	456	516	575	634
23						364	431	497	562	628	692
24							469	541	612	683	754
25							509	587	664	741	818

Source: Peterson (1961)

Table 5. Cubic-foot Volume to a 4-inch Top Diameter Inside Bark for Western Aspen

Diameter breast height outside bark	Total height in feet									
	20	30	40	50	60	70	80	90	100	110
Inches	Cubic feet									
4	0.66	0.67	0.68	0.68	0.69					
5	1.50	1.80	2.05	2.26	2.44	2.61				
6	2.24	2.93	3.53	4.06	4.55	5.00	5.43			
7	2.94	4.08	5.09	6.03	6.91	7.74	8.54			
8		5.21	6.69	8.08	9.41	10.7	11.9			
9		6.37	8.35	10.2	12.1	13.9	15.6			
10		7.51	10.0	12.4	14.8	17.2	19.5	21.8		
11		8.67	11.7	14.8	17.7	20.7	23.6	26.5		
12		9.81	13.5	17.1	20.7	24.3	27.9	31.4		
13			15.2	19.5	23.8	28.0	32.3	36.6	40.9	
14			17.0	21.9	26.9	31.9	37.0	42.0	47.1	52.2
15			18.8	24.4	30.1	35.9	41.7	47.6	53.5	59.5
16			20.6	26.9	33.4	40.0	46.6	53.4	60.2	67.0
17			22.4	29.5	36.7	44.1	51.6	59.2	67.0	74.8
18				32.1	40.1	48.4	56.8	65.3	74.0	82.8
19					43.6	52.7	62.0	71.5	81.2	91.1
20					47.1	57.1	67.4	77.9	88.7	99.6
21					50.6	61.6	72.8	84.4	96.2	108
22					54.2	66.1	78.5	91.1	104	117
23							84.1	97.8	112	126
24							89.9	105	120	136
25							97.5	112	128	145

Source: Peterson (1961)

$V = 8$ (for $D^2H < 2500$)
$V = 0.011389\ D^2H - 20.5$ (for $2500 < D^2H < 8850$)
$V = 0.010344\ D^2H - 11.3$ (for $D^2H > 8850$)

where V = gross volume, board feet, Scribner Rule for top diameter 6-inches (21 cm) inside bark, D = diameter at breast height outside bark, (in), and H = total tree height (ft).

or

$V = 0.002195\ D^2H - 0.91$ (for $D^2H < 11,800$)
$V = 0.001837\ D^2H + 3.31$ (for $D^2H > 11,800$)

where V = gross volume, cubic feet, for top diameter 4-inches (10 cm) inside bark.

Volume equations developed by Kemp (1958) are

$V = 0.343 + 224\ D^2/H$ for ($D < 21$ inches dbh.)

where V = volume in cubic feet, D = diameter at breast height (inches), and H = total tree height (feet)

$V = -9.547 + 1309\ D^2/H$ for $D < 21$ inches dbh.

where V = volume in board feet (Int. 1/4-inch rule)

$V = -18.544 + 1197\ D^2/H$ for $D < 20.9$ inches dbh.

where V = volume in board feet (Scribner rule)

In a stand of 55-year old aspen in Alberta, the volume of aspen was 259,000 lb/acre (Peterson _et al_. 1970). (Note: These equations above are presented to show the data that have been generated in the Rockies to encourage utilization and management of the resource. Although they would not be directly applicable to Alberta, they do show the type of data that can be obtained.)

Bark

The percentage of bark on the merchantable boles from Colorado averages 17 percent of the total volume (Wengert 1978a). Bark percentage in the Lake States about 12 percent (Marden _et al_. 1975). The percentage was not significantly affected by diameter or age in either study.

A linear regression analysis between double bark thickness (DBT) at various heights and the corresponding diameter, outside bark (DOB) and inside bark (DIB) for Rocky Mountain aspen resulted in the following equation which accounts for 2/3 of the variation.

$DBT = -0.081 + 0.103\ (DOB) = -0.086 + 0.0854\ (DIB)$

where all measurements are in inches, or

DBT = -0.206 + 0.103 (DOB) = -0.218 + 0.0854 (DIB)

where all measurements are in centimeters.

A study of Canadian aspen (Smith and Kozak 1967) resulted in a regression equation of

DBT = 0.103 + 0.065 (DOB) for measurements in inches, or

DBT = 0.262 + 0.065 (DOB) for measurements in centimeters.

In the spring, the bark-cambium interface is extremely slippery, making debarking quite easy. The adhesion is much tighter throughout the remainder of the year.

Defect

Two seemingly inherent characteristics of aspen are crook and sweep. In a study of over 300 merchantable logs from Colorado, New Mexico, and Utah, 12% of the gross volume was deducted in scaling (Scribner) for crook and sweep (Wengert (1978a). Of course, proper bucking procedures can reduce the effect of these defects, but such procedures are time consuming, and with aspen's low stumpage value, may not be economically beneficial. (Defect caused by fungal infections was discussed earlier.)

Weight

Over the past several years, sufficient data (Wengert 1978a) have been collected to produce estimates of weight for different sizes of aspen logs in the Rocky Mountains (Tables 6 and 7). Such data are useful in calculating skyline design limits, determining skidding capacities, and estimating truck payloads, for example. The assumptions used to prepare these logs weight tables are presented in Table 8.

Therefore, the typical log weights are 46.12 pounds per cubic foot (738.8 kg/m^3) with the bark on, and 44.30 pounds per cubic foot (709.6 kg/m^3) without bark.

The typical weight of 1000 board feet (MFBM) of 1.00-inch (2.54 cm) thick lumber is estimated, using an average green density (at 30 percent moisture content) of 30.84 pound per cu. ft. (494.0 kg/m^3) 83.3 feet MFBM to be 2570 pounds for each 1 percent moisture content loss the weight of this MFBM will decrease by 19.8 pounds. Other thicknesses are in proportion to the 1-inch data. The weight per MFBM will change as the MC at which the MFBM is measured. Other weights are provided in Table 9.

One cord of aspen pulpwood with bark on weighs approximately 4075 pounds (1850 kg) green. A cord contains approximately 60 (27 kg) pounds of green bark at 95 percent moisture content. Other weight data are given in Table 10.

Table 6. Estimated Average Log Weights, Pounds (kg), for Aspen for Known Large End Diameters

Large End Diameter		Log Length, feet [meters] 8.25 [2.5]		16.5 [5.0]		24.75 [7.5]		33.0 [10]	
inches	[cm]	- - - -	- - -	pounds	[kg]	- - -	- - -		
6	[15]	64	[29]	107	[49]	135	[61]	151	[68]
7	18	89	40	154	70	199	90	227	103
8	20	118	54	208	44	274	124	321	146
9	23	151	68	271	123	363	105	431	195
10	25	189	86	342	155	464	210	557	253
11	28	230	104	421	191	577	262	700	318
12	30	276	125	509	231	702	318	860	390
13	33	326	148	605	274	840	381	1036	470
14	36	380	112	709	322	991	450	1229	557
15	38	438	149	822	373	1154	523	1439	653
16	41	501	227	943	428	1330	603	1665	755
17	43	567	257	1072	486	1517	688	1908	865
18	46	638	289	1209	548	1718	729	2167	983
19	48	713	323	1355	615	1931	876	2443	1108
20	51	792	359	1509	684	2156	978	2736	1241

Note: Large end diameter would not include butt swell.

Table 7. Estimated Average Log Weights, Pounds, for Aspen for Known Small End Diameter

Small End Diameter	Log Length, feet [meters] 8.25 [2.5]		16.5 [5.0]		24.75 [7.5]		33.0 [10]	
inches	- - - - - -		pounds [kg]		- - - - - -			
4	42	[19]	103	[47]	186	[84]	297	[135]
5	62	28	148	67	260	118	403	183
6	87	39	201	91	346	157	525	238
7	116	53	263	119	445	202	665	302
8	149	68	333	151	556	252	820	372
9	186	84	411	186	679	308	993	450
10	228	103	498	226	815	370	1182	536
11	273	124	593	269	963	437	1387	629
12	323	147	696	316	1124	510	1610	730
13	377	171	808	367	1297	588	1848	838
14	435	197	928	421	1483	673	2104	954
15	497	225	1056	479	1681	762	2376	1078
16	563	255	1193	541	1892	858	2664	1208
17	634	288	1337	606	2115	959	2970	1347
18	708	321	1491	676	2350	1066	3291	1493
19	787	357	1652	749	2598	1178	3630	1647
20	870	395	1822	826	2859	1297	3984	1807

Table 8. Basica Assumptions for Preparation of Log Weight Tables.

Item	Value
Taper:	0.114 inches per foot (0.95 cm/m)
Moisture contents[1]:	bark, 96% (oven-dry basis)
	sapwood, 91% (oven-dry basis)
	heartwood, 74% (oven-dry basis)
Specific gravity[2]:	bark, 0.45 (green volume, oven-dry weight-basis)
	wood, 0.38 (green volume, oven-dry weight-basis)
Volume:	bark 17%
	sapwood 62%
	heartwood 21%

[1]From time to time, average moisture contents in aspen wood may be as high as 130%. In such cases, the values in the tables must be increased by 18 percent. A decided variation in moisture content with season has also been noted (Yerkes 1967).

[2]See following section for additional information on specific gravity.

Table 9. Estimated Average Weight of Lumber, Pounds Per nominal MFBM (kg per nominal MFBM)

Moisture Content %	Actual Thickness 3/4-inch (1.9 cm)	1-inch (2.5 cm)	1-1/8 inch (2.9 cm)
		lb/MFBM*[1]	
30	1928	2570	2891
	875	1160	1311
25	1884	2512	2826
	855	1139	1282
20	1841	2454	2761
	835	1113	1252
15	1797	2396	2696
	815	1087	1223
10	1754	2338	2630
	796	1060	1193
5	1710	2280	2565
	776	1034	1163

[1]For 3/8-inch lumber, 1 MFBM is 12" x 12" x 3/4"; for 1-inch lumber, 1 MFBM is 12" x 12" x 1"; for 1-1/8 inch lumber, 1 MFBM is 12" x 12" x 1-1/8". Volume is measured at indicated MC. To calculate the weight at one MC (MC) when the volume is measured at a different MC (MC), divide the estimate weight at MC_1 by (100 + MC) and multiply by (100 + MC_2).

Table 10. Estimated Basic Properties and Weight for Rocky Mountain Aspen. (Only slight variations are expected for Alberta aspen, as the SG in both locations is similar.)

	English	SI
Specific gravity (based on green volume, OD[1] weight) of wood	0.38	0.38
Specific gravity (based on green volume, OD weight) of bark	0.45	0.45
OD weight of wood per unit of green volume	24 lb/ft^3	0.38 g/cm^3
OD weight of bark per unit of green volume	28 lb/ft^3	0.45 g/cm^3
Average green moisture content of sapwood	91 pct	91 pct
Average green moisture content of heartwood	74 pct	74 pct
Average green moisture content of bark	96 pct	96 pct
Bark volume per rough log	16.5 pct	16.5 pct
Green wood volume per bolt[2]	4.9 ft^3	0.14 m^3
Green bark volume per bolt[2]	0.79 ft^3	0.022 m^3
OD weight of wood per bolt[2]	117 lb	53 kg
OD weight of bark per +olt[2]	22 lb	10 kg
Green bark weight per bolt[2]	15.9 pct	15.9 pct
Green sapwood weight per green volume	45 lb/ft^3	0.73 g/cm^3
Green heartwood[3] weight per green volume	41 lb/ft^3	0.66 g/cm^3
Green bark weight per green volume	55 lb/ft^3	0.88 g/cm^3
Green bark weight per bolt[2]	44 lb	20 kg
Green wood per green, rough cord[4]	79 ft^3	2.2 m^3
Green wood per green, peeled cord[5]	95 ft^3	2.7 m^3
Green wood + bark per green, rough cord[4]	4400 lb.	2000 kg
Green wood + bark per green, rough cord[4] with 33% bark loss in skidding	4100 lb.	1900 kg

TABLE 10. CONTINUED.

12% MC wood weight per 12% MC volume	27 lb/ft^3	0.45 g/cm^3
12% MC lumber (25/32-inch [1.98 cm]) weight per MFBM	1800 lb	800 kg
20% MC lumber (1-1/8-inch [2.9 cm] weight per MFBM	2800 lb.	1300 kg

[1]OD = oven-dry at 215°F (102° C)
[2]Based on a bolt 100" (2.5 m) long and 10" (25 cm) d.i.b. at small end
[3]Bacterial wetwood may increase this value by 10% or more
[4]Based on 16 rough bolts per cord
[5]Based on 19 peeled bolts per cord

Structure (Kennedy 1968)

Because aspen belongs to the hardwood[3], or broad-leafed, class of trees, the wood has numerous pores (vessels) scattered among the fibers. The pores are very small however, being barely visible with the unaided eye. The pores are fairly uniform in size through the annual ring, although they become slightly smaller toward the end of the growing season. As a result, the annual rings are distinctly but not conspicuously defined. (Rings can be made more conspicuous [Brace 1966, Maini and Coupland 1964, Svoboda and Gullion 1972, and Trujillo 1975].) The rays are extremely low and narrow. The fibers, the most abundant cell, are more shorter (0.05 inches [1.3 mm] long) than softwood fibers (0.14 inches [3.5 mm] long). The result of these characteristics is that aspen is very uniform in textures, structure, and appearance.

Aspen has many loose knots that may break or fall out during processing. Aspen also has tension wood scattered throughout the stem which causes some processing problems.

Heartwood/Sapwood

In contrast with Lake States aspen trees, which according to Dr. Alex Shigo of the U.S. Forest Service Northeast Forest Experiment Station have little if any heartwood, there is a great deal of heartwood in Rocky Mountain aspen. In a small sample of trees from New Mexico, 1/4 to 1/3 of the cross-sectional area at stump height was heartwood.

Aspen heartwood, compared with sapwood, is characterized by a very slight darkening in color, a lower moisture content, and a greatly reduced permeability. The heartwood wood vessels are usually heavily occluded. Characteristically, the heartwood will frequently appear "dry-looking" shortly after exposing the freshly cut end of a log to the air. A method has been developed for distinguishing heartwood and sapwood (Wengert 1976) based on permeability differences. Alcohol is brushed on freshly sanded end grain of aspen. In minutes the alcohol has evaporated from the heartwood, while the sapwood still appears wet.

Occasionally, anaerobic bacteria will infect areas of heartwood and sapwood (Sachs et al., 1974, Ward 1976), although the process is not completely understood. These infected areas, called wetwood, wet streak, or wet pockets are hard to dry, are lower in pH, are impermeable, have a high moisture content (up to 160%), and have a fatty acid (rancid) odor. (Wengert 1983).

Color, Odor and Texture

Aspen wood is practically tasteless and odorless when dry. When wet, aspen wood, especially bacterial wetwood, has a distinctive and sometimes slightly unpleasant odor. Aspen is a soft, virtually splinterless wood.

---

[3] The hardwoods are not necessarily harder than the softwoods.

Specific Gravity

The specific gravity (SG) of aspen logs depends on site conditions, geographic locations, and growth rate (Kennedy 1968 and Wilde and Paul 1959). Since many wood strengths and physical properties are related to SG the determination of this value is of considerable interest. Measured values for the SG of aspen have been reported (Table 11).

Although an extensive survey has not been made in the Rocky Mountains, limited sampling (Wengert 1978a) indicates the specific gravity of aspen wood and bark from Baker's site classes 1 and 2 in the Rocky Mountains is given in Table 12. The values for wood appear to be related to site class probably being lower on site classes 3 and 4. These values are in close agreement with density surveys from the Lake States (Table 11).

The historic United States value of specific gravity for aspen wood given by the U. S. Forest Service is 0.35 (see Table 11), which is based on 5 samples from Wisconsin (0.36) and 6 from New Mexico (0.34) (Markwardt and Wilson 1935). The New Mexico trees had a growth of 7.3 rings per inch, almost 3 times the average growth rate seen in the West, and therefore, these trees do not represent the typical Western aspen. Subsequent Lake States density surveyors have indicated the shortcomings of the 5 tree samples from Wisconsin, as well. The historic lower SG values have been widely distributed in the United States and would account for the weaker mechanical strengths for U. S. aspen compared to Canadian. The lower U.S. v+lues have probably affected the utilization potential when strength is important.

Green Moisture Content and Density

The green moisture content of aspen varies somewhat (82% to 102% MC) with the season of the year (Figure 6) and also year to year (Yerkes 1967, Marden _et al_. 1975, Jensen and Davis 1953). Typical average moisture content based on unpublished values for the Rockies are:

Heartwood	74% M.C. (oven-dry basis)
Sapwood	91% M.C. (oven-dry basis)
Wetwood	up to 160% MC
Bark	96% M.C. (oven-dry basis)

Basic densities can be calculated from the above average moisture contents and previously given specific gravities (Table 13).

Storage of aspen logs in the woods results in very little decrease in moisture content if the bark is left intact (Yerkes 1967). Some end drying could be expected for logs stored in open locations and exposed to sunlight and wind.

Trees that are felled, but the crown is not immediately removed will lose substantial moisture through the leaves (Garrett 1985).

Table 11. Specific Gravity of Aspen.

Specific Gravity (Green vol.; O.D. wt.)	Source	Reference
	Aspen Wood	
0.360	Wisconsin	USDA (1974)
0.344	New Mexico	USDA (1974)
0.35	Average of WI and NM (above)[1]	
0.383	Wisconsin	Paul (1956)
0.375 (range 0.325-0.421)	Wisconsin	Wilde and Paul (1959)
0.389 (range 0.310-0.470)	Wisconsin	Buijtenen *et al*. (1959)
0.408 (range 0.380-0.456)	Wisconsin	Pronin (1971)
0.367 (range 0.343-0.407)	Michigan	Erickson (1972)
0.374 (standard deviation ± 0.024)	Western Canada	Kennedy (1974)
	Aspen Bark	
0.505 (range of 0.446-0.602)	Michigan	Erickson (1972)
0.452 (range 0.37-0.52)	Minnesota	Lamb and Marden (1966)
	Aspen Wetwood	
0.357 to 0.329	Minnesota	Haygreen and Wong (1966)

[1] Historic value in the U.S.

Table 12. Specific Gravity of Rocky Mountain Aspen from Limited Samples.

Material	Specific Gravity (Green Volume and oven-dry weight)	Specific Gravity (Oven-dry volume and weight)
Sapwood	0.38	0.43
Heartwood	0.39	0.43
Bark	0.45	---
Wetwood	0.36	0.40

Table 13. Basic Density for Aspen Wood and Bark.

	Density-Green	Density-Oven-Dry
	lb/cu ft [kg/m^3]	lb/cu ft [kg/m^3]
Heartwood	41.28 [661.2]	26.84 [429.9]
Sapwood	45.31 [725.8]	26.84 [429.9]
Bark	55.06 [882.0]	24.97 [400.0]

Measuring Moisture Content Under 30% MC

Moisture content is a critical property for many uses of aspen.When moisture content is measured with an electric resistance, pin type moisture meter (probably the most common moisture measurement technique), the corrections provided in Table 14 should be added to the meter readings.

Shrinkage

Aspen has a fairly low shrinkage-3.6 percent radial (green to oven-dry), 6.6 percent tangential, and 11.8 percent volumetric (Kennedy 1968). The published U.S. values are 3.5, 6.7, and 11.5 percent (FPL 1974). The large tangential-to-radial shrinkage ratio of 1.8 means aspen will be subject to cupping and diamonding when moisture content changes occur in drying (unless restrained).

Longitudinal shrinkage is usually ignored for most species of wood. However, for aspen, which has an abnormal amount of tension wood, longitudinal shrinkage can be significant-0.16 to 0.72 percent, green to oven-dry (Kennedy 1968). This longitudinal shrinkage means aspen lumber will be subjected to both bowing (warping like a ski) and crooking (side bend) in drying, and veneer will be subject to buckling when moisture content changes occur in drying and in use.

Strength and Stiffness

Clear wood strength values for aspen, measured in the United States (Markwardt and Wilson 1935, Haygreen and Wang 1966) and in Canada (Kennedy 1965) are summarized in Table 15. As mentioned previously, the 1935 U.S. data are based on 11 trees whose specific gravity was 10 percent or more lower than the recent survey data and whose growth rate was up to 3 times faster than average. These U.S. strength data are therefore subject to question. Because of the significant effect these strength values have on subsequent marketing of lumber (for example, see the section on studs), the clear wood strength of U.S. aspen should be reevaluated.

Design values based on these 1935 strength values and used throughout North America (published by WWPA (1983) and by other grading agencies) are given in Table 16.

Nail Holding Power

The average holding power of a seven penny, cement-coated nail driven 1-1/4 inches (3.2 cm) into the side grain of dry or green aspen is about 194 pounds (863 N). The same nail driven into green aspen, but tested after the wood has thoroughly dried, is only about 20 pounds (89 N) (Johnson 1947). This large loss after drying is typical for all species.

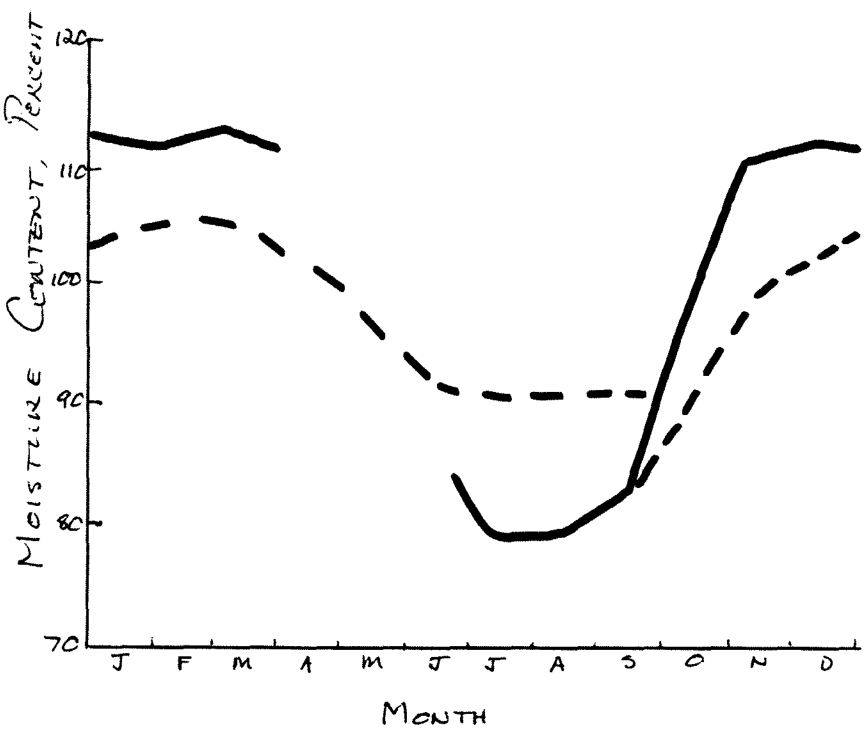

Figure 6. Seasonal variation of moisture content in aspen trees in South Dakota (dashed line) (yerkes 1967) and in Minnesota (solid line) (Marden *et al*. 1975)

Table 14. Corrections for the Electrical Resistance, Pin Type Moisture Meter (Pfaff 1974).

Meter Reading	Add to Reading
%	%
7	0.9
8	1.2
9	1.5
10	1.8
11	2.1
12	2.4
13	2.7
14	3.0
15	3.3
16	3.6
17	3.9
18	4.2
19	4.5
20	4.8
21	5.1

Table 15. Mechanical Properties of Aspen (<u>P. tremuloides</u>).

	Specific gravity	Moisture Content at test	Static bending			Work (in. lb./cu. in.)		
	Green vol.	Percent	Stress at P.L. (psi)	Modulus or rupt. (psi)	Modulus of elas. (psi)	To P.L.	To max. load	Total
Normal SG	0.37	green	2900	5500	1,310,000	0.37	6.9	20.2
Low SG	.35	green	--	5100	860,000	--	6.4	--
Normal SG	.37	12	5200	9800	1,630,000	.99	10.3	21.0
Low SG	[1].37	12	--	8400	1,180,000	--	7.6	--
Wetwood	[2].329 [3].357	green	2666	4973	612,000	--	--	--

	Compression parallel to grain			Compression perpendicular to grain	Hardness (lb.)		Shear parallel to grain	Clevage	Tension perpen. to grain	Toughness (5/8 in. sq. sample)
	Stress at P.L. (psi)	Max. crushing (psi)	Modulus of elas. (psi)	Stress at P. L. (psi)	Side	End	Max. stress (psi)	(lb./in.)	Max. stress (psi)	(in.-lbs.)
Normal SG, green	1510	2350	1,250,000	200	320	340	720	180	440	[4]165
Low SG, green	--	2140	2,140,000	180	300	--	660	--	230	
Normal SG, 12%	3280	5270	5,270,000	510	480	630	980	260	610	4115
Low SG, 12%	__	4250	--	370	350	--	850	--	260	
Wetwood, green	1428	1878	525,000	--	--	--	--	--	--	

[1]Specific gravity 0.38 at 12% moisture content.
[2]Com. II
[3]Bending
[4]Specific gravity = 0.39
Sources: Low specific gravity-Markwardt and Wilson (1935): Normal Sg--Kennedy (1965). wetwood--Haygreen and Wong (1966)

Table 16. Recommended Design Values (PSI)[1] for WWPA Graded Lumber (WWPA 1974).

Grade	Extreme fiber stress in bending "Fb"		Tension parallel to grain "Ft"	Horizontal shear "Fv"	Compression		Modulus of elasticity "E"
	Single	Repetitive			Perpendicular "Fc_1"	Parallel to grain "Fc"	
Light framing and studs - 2" to 4" thick, 2" to 4" wide							
Construction	650	750	400	60	185	625	900,000
Standard	375	425	225	60	185	500	900,000
Utility	175	200	100	60	185	325	900,000
Studs	500	575	300	60	185	325	900,000
Light framing - 2" and less in thickness, 2" wide							
Construction	600	700	325	60	185	625	900,000
Standard	275	325	150	60	185	500	900,000
Utility	75	100	50	60	185	200	900,000
Light framing - 3" and less in thickness, 3" wide							
Construction	550	625	300	60	185	625	900,000
Standard	350	400	200	60	185	500	900,000
Utility	100	125	50	60	185	250	900,000
Structural light framing and appearance - 2" to 4" thick, 2" to 4" wide							
Select structural	1300	1500	775	60	185	850	1,100,000
No. 1/appearance	1100	1300	650	60	185	675/825	1,100,000
No. 2	925	1050	525	60	185	550	1,100,000
No. 3	500	575	300	60	185	325	900,000
Structural joists and plants and appearance - 2" to 4" thick, 6" and wider							
Select structural	1150	1300	750	60	185	750	1,100,000
No. 1/appearance	950	1100	650	60	185	675/825	1,100,000
No. 2	775	900	525	60	185	575	1,100,000
No. 3	450	525	300	60	185	375	900,000

[1] These design values apply to lumber when used at a maximum moisture content of 19% such as in most covered structures.
[2] Fb, F5, and Fc recommended design values apply only to 4" widths of these grades.

Ease of Gluing

Laboratory tests and experience have shown that aspen is one of the easiest species of wood to glue (FPL 1974). However, aspen is quite absorptive of liquids, so rapid assembly after spreading the glue is required to avoid a starved weak joint. In some cases, extra water can be added to the wood surface just before glue spreading to prevent premature drying of the adhesive.

Finishing

Aspen is one of the best hardwoods for paint holding ability (Zasada 1947). Of course, knots must be carefully primed. Aspen also takes stain very well, but uneven absorption may cause a "blotchy" or rustic appearance. A wash coat or sealer application prior to staining will alleviate this uneven adsorption problem. Aspen also accepts printing ink very well.

Durability and Preservation

Aspen has low natural durability and will decay rapidly under favorable conditions (MC > 22%, RH > 95%, and warm temperatures >. Therefore, aspen should be used only in conditions where it will remain dry or is exposed to liquid moisture infrequently and for relatively short periods.

Because of the low permeability of heartwood, wetwood, and some discolored areas, irregular penetration of preservative, even under pressure, can be expected (Cooper 1976) with the resulting poor protection with pressure treating. Sapwood treats very well; retentions can be quite high.

Machining and Related Properties

Machining is a broad term that includes sawing, planing, shaping, sanding, boring, and the like. Aspen machines easily, in that power consumption is low and tools are not dulled rapidly. However, it is difficult to obtain a good smooth surface on aspen, unless special care is taken. Aspen's fibers sever less cleanly than most other woods, due in part to tension wood, which tends to leave a fine fuzz on the surface. However, excellent turnings, borings, and sanded surfaces can be obtained if the following conditions (Table 17) are maintained, as appropriate.

Drying

The drying properties of aspen are important considerations in many utilization schemes. Aspen sapwood can be dried easily, but heartwood and wetwood are difficult to dry. Further information is provided in the discussions on lumber production.

Table 17. Machining Requirements for Premium Surfaces (Davis 1947 and 1962, Stewart 1973, and Wengert 1973).

(1) Moisture content, 6% or less.

(2) Knife angle, 25^{o} to 30^{o}.

(3) Feed rate or lathe speed is slow (8.7 cuts/cm [22 cuts per inch] in planing).

(4) Cutter head should have a high peripheral speed--above 25 m/s [5000 feet per minute.

(5) In the lathe, revolve the work against the knife direction; in planing, feed lumber so cutter head moves with the grain.

(6) Use a shallow, 0.8 mm [1/32-inch] final cutting depth.

(7) Plane lumber across the grain, if possible.

(8) Boring should be done using a slow feed speed.

(9) Avoid sanding with very fine grit, because it will increase fuzz.

(10) Always sand with fresh sandpaper; it's sharper and will not tend to fuzz the wood as much as old, dull sandpaper. The fuzziness common to aspen can also be removed by using special sanding procedures; that is, by using special abrasives, by using an anti-fuzz sealer, or by using a wash coat before final sanding.

Note: Based on a small number of tests, it appears that wetwood aspen does not machine as well as normal aspen.

CHAPTER III. OUTLETS FOR THE RESOURCE

Although many small specialized markets exist for the aspen resource (e.g., mink bedding, wood flour, rustic furniture, and so on), the most significant and those with the greatest potential in Alberta (excluding pulp and particleboard) are:

1. Veneer and plywood
2. Fuel wood
3. Lumber and timbers
4. Pallet shook
5. Furniture blanks and parts

In the following sections, these product areas are examined for both present and future manufacturing and marketing potential. Also included is a section examining the potential for residue utilization.

Veneer and Plywood

Demand

National use patterns for all types plywood in the United States have been published (Table 18). A general expanding market trend was seen for structural plywood which makes up 2/3 of the plywood use. Raw material restrictions (cost and availability of large logs) and substitution of other board products such as waferboard and OSB have reduced the outlook for expansion. When aspen is sold as structural plywood under P.S. 1-74, aspen is included in Group IV--which requires panels to be 6 mm [1/4-inch] thicker than Douglas-fir plywood over equivalent floor spans. Therefore, the potential of aspen for structural plywood is poor.

The U.S. Forest Service has also published data showing the uses of aspen veneer by U.S. manufacturing industries (Table 19). The market for wooden matches has declined. However, there is an increasing market for decorative plywood (although aspen plywood is very rustic with many knots and discolorations). In the aspen region, there have also been several operations that have manufactured matches, tongue depressors, chopsticks, and other items stamped from veneer sheets.

Marketing Considerations

There is likely an abundant supply of veneer grade conifers in most of the areas where aspen grows. Aspen veneer volumes are, on the other hand, limited. Veneer yields are higher, production per day is higher, quality is better, and processing costs are lower for these softwoods than for aspen. For underlayment, softwood plywood is believed to have a better economic potential than aspen.

Table 18. National Plywood Consumption (USDA 1973)

End Use	Volume 1970	Volume 1980	Increase in volume 1970 to 1980
	Million sq ft--3/8-inch basis [Million m^2-0.95 cm basis]		Pct
New housing	6,330 [588	10,150 943]	60
Residential upkeep and improvements	2,510 [233	3,100 288]	24
Nonresidential construction	1,700 [158	2,680 249]	58
Manufacturing[1]	1,656 [154	2,400 223]	45
All other uses	5,626 [523	8,470 787]	51
Total	17,822 [1,656	26,800 2,490]	50

[1]Primarily boxes, crates, and furniture; furniture uses are not expected to increase much by 1980.

Table 19. National Aspen Veneer Consumption (Gill and Phelps 1969).

Industry	Volume used 1960	1965
	Thousand sq ft - surface measure [Sq. meters - surface measure]	
Matches	99,222 [9218]	128,000 [11,900]
Millwork	-	4,748 [441]
Veneer and plywood	-	3,818 [355]
Nailed boxes	-	1,100 [102]
Furniture	14 [1]	-

NOTE: A dash indicates zero or unknown. Two different survey techniques were used in 1960 and 1965.

Aspen plywood, as prefinished paneling, potentially has a higher rate of return than for underlayment and can compete at the lower price range of paneling. A lumber retailer in Pittsburgh suburbs indicated that 25 percent of the paneling sales were inexpensive 4 x 8 foot (1.2 x 2.4 m) sheets; the remainder of the paneling sales were either more expensive plywood or was solid wood paneling. It is implied that these sales are primarily to do-it-yourselfers (from an unnumbered report of the USFS Northeast Experiment Station). The name "aspen" has recently become closely associated with skiing, and, as a result, may have considerable market appeal. (A large resort in Vail, Colorado includes in their advertisements that they have rooms paneled with aspen.) It appears that home remodeling and recreation developments, a market for paneling that has been twice as large as the new home market, has the greatest potential for aspen plywood.

The selling and advertising costs for a new paneling product could be very high. The potential therefore is greatest for a company with an established sales force, distribution system, and reputation for a quality product. But again, one serious drawback is the limited supply of veneer quality aspen in the Rocky Mountains.

General Characteristics

Aspen has many characteristics that make it desirable for veneer and plywood production (Fitzpatrick and Stewart 1968). Aspen:

1. cuts easily;
2. glues easily;
3. is light weight;
4. shrinks and swells very little; and
5. is odorless

On the other hand, aspen has some important drawbacks (Feihl 1968, Fitzpatrick and Stewart 1968, Lutz 1972, Wells 1974). Aspen:

1. has a small average log diameter;
2. has low yields;
3. has low grade recovery, mostly due to knots;
4. may fuzz when cut;
5. may buckle during drying;
6. may check and collapse in wetwood areas during drying;
7. has poor screw holding ability;
8. must be cut thicker than conifers to allow for compression and shrinkage;

9. weighs more green than some conifers;

10. must be thawed, but be below $20^{o}C$ [$70^{o}F$], to cut well;

11. requires more drying time than most conifers;

12. requires more glue than conifers;

13. waste is high in overmature logs;

14. volume per acre of veneer quality logs is usually small; and

15. has low strength when compared to most other veneer species.

In spite of these disadvantages, however, aspen was being used to some extent for veneer and plywood in both Canadian and U.S. mills. The success with aspen is due in part to low stumpage prices, which compensate for increased processing costs, and to good markets for residues. Successful processing methods that have been used to overcome aspen's disadvantages include using a fine grade birch face or making a thicker panel when strength is required, using confer cores when higher screw holding is required, and manufacturing a low grade, rustic, knotty paneling. In almost all cases, factors contributing to the mill's success are an outlet for mill waste (both trim and cores), equipment that can handle small diameter material and can peel to a small core diameter, and outlets for all grades of veneer produced.

Yield and Processing Data

A study of veneer grade yields, measured for veneer grade northern Minnesota aspen logs (Lutz 1972) developed the following percentages:

1. 37 percent of veneer sheets was free of all defects,

2. 20 percent had small, tight knots and other minor defects, and

3. 43 percent was of poor quality. This is quite high and not encouraging for structural plywood or fine decorative plywood.

Volume yields of all grades for aspen have also been measured in the Lake States (Table 20).

In an exploratory study conducted by private industry with 50 8-foot (2.4 m) logs, similar recovery yields were obtained for Rocky Mountain aspen. (The actual data cannot be released.) In Canada, yields from 12 inch diameter (30 cm), 4-foot (0.12 m) bolts were 70% of the bolt volume in one small test.

Satisfactory operating parameters for veneer lathes and dryer have been determined (Feihl 1958, Lutz 1972).

In short, there seems to be few, if any, unsolved technical problems preventing aspen veneer and plywood manufacture.

Table 20. Veneer Yields (Bulgrin *et al.* 1966).

Bolt diameter		Veneer yield	Volume recovery factor[1]
inches	cm	sq ft--3/8-inch basis	
8	20	25.0	2.5
9	23	32.4	1.6
10	25	41.6	1.4
11	28	56.1	1.9
12	30	76.0	1.9
13	33	95.9	1.9
14	36	108.3	1.8
15	38	108.0	1.5
16	41	118.8	1.5

[1] 3/8-inch basis (9.5 mm) *vs.* Scribner Decimal C

Manufacturing Costs

Manufacturing costs for aspen plywood were determined in a Canadian study (Table 21).

Estimated rate of return as a function of log diameter is presented in Figure 7 although taxes and general selling expenses are not included in the data (Noreen and Hughes 1968). These data indicate that the smaller logs, which are common in aspen, make a 4-foot (1.2-m) lathe a necessity. Further, the necessity for a residue market is clear. Finally, these data show that aspen is not well suited for a low value product (i.e., low market selling price) such as underlayment.

Summary of Plywood Potential

The constraints to aspen structural plywood manufacturing are largely economic, related basically to the poor yield and small diameter of logs and to the relatively low value of softwood plywood.

The constraint to aspen prefinished decorative paneling manufacture appears only to be in marketing, and that constraint may be negligible for established firms. Residue utilization is necessary to improve manufacturing economics. A brighter picture results if a small 1.2 m [4 ft] lathe is used on the smaller logs.

Chopsticks from Veneer

Aspen veneer can be cut or punched into various products, such as tongue depressors, ice cream sticks, matches, and chopsticks. These items are typically sold for under $0.01 each (matches are 50x less). Considering chopsticks, there is a demand for chopsticks exceeding 130 million pairs per day. Two U.S. plants (Colorado and Minnesota) anticipate each producing 5 million pairs per day (Sutter 1988). The market for chopsticks is expected to grow. However, as profit margins are very low and as labor is a high percentage of the total operating cost, the economics are not exceptional. In fact, there have been many plants that have considered this opportunity and several in Canada have attempted to profitably produce chopsticks but have failed. The U.S. plants are too new to accurately assess their economic potential, but certainly the recent fall of the U.S. dollar will help their outlook.

The processing system is to begin with 4 foot long logs, with no visible decay in the center. The logs are then peeled into veneer, the veneer thickness being the thickness of the finished chopstick plus shrinkage. The sticks are then punched out of the veneer, dried, sorted, and then finally packaged. Only white color is permitted in the stick, so there is some veneer loss. Yields are typically 50,000 to 60,000 chopsticks per cord.

Table 21. Estimated Manufacturing Costs for Plywood, Capacity of 150 MM sq ft Annually (Vajda 1974, adjusted for 6% inflation, approximately).

Item	Cost
	$/1000 sq ft (3/8 in basis)
Labor	$35.00
Chemical	9.00
Power & fuel	5.00
Supplies	6.50
Admin. & Overhead	4.50
Ins. & taxes	2.50
Depreciation	12.00
TOTAL conversion cost	74.50
Raw material, veneer logs	58.00
TOTAL costs	132.50

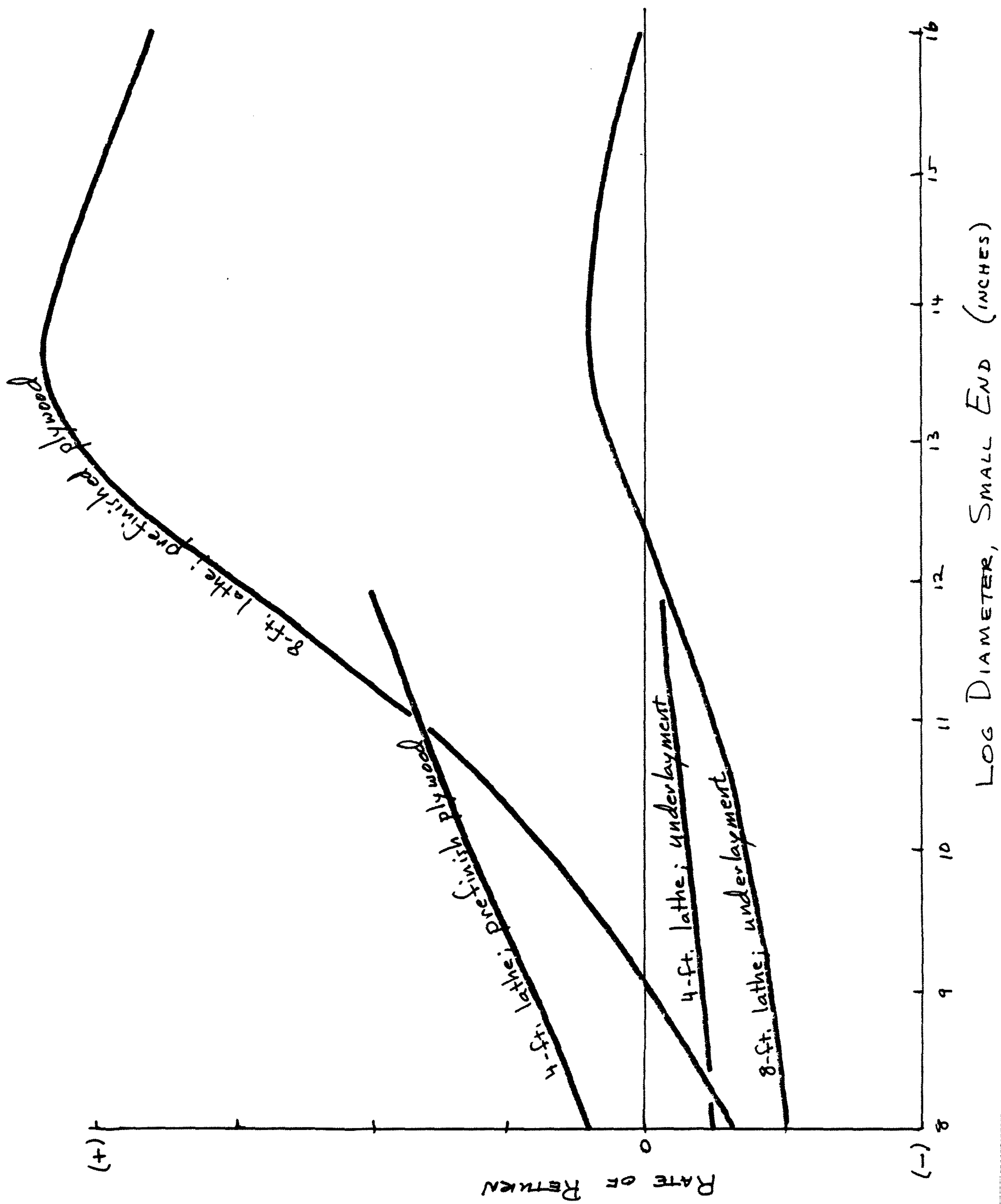

Figure 7. Estimated rate of return for aspen underlayment and aspen prefinished paneling as a function of log diameter and Lathe size, based in part on data of Noreen and Hughes (1968).

Fuel

The use of aspen for fuel can be important in the overall utilization scheme because fuel:

1. can be from short length and partially decayed logs, and from trees of poor form (which comprise a large amount of the resource);

2. requires little processing (i.e., low capital);

3. can be economically harvested by small operators in locations too remote for typical sawtimber harvesting; and

4. can be obtained from mill residues.

There are two use categories for fuel: home heating and cooking (including home fireplace) and industrial (steam power). In either case, fuel wood's low value means that transportation distances from the resource should be less than 100 km [60 miles].

The use of roundwood and residue in industrial plants for fuel is limited only by economics-primarily the capital cost of the required equipment necessary to meet clean-air standards and necessary to handle most fuels. If petroleum fuels increase in price, wood residues may find increasing use as fuels. The fuel value of aspen wood and bark has been determined (Table 22).

Industrial Use

A wood burning boiler for steam generation costs 4 times as much as an oil fired boiler-$115,000 vs. $28,000, in the example used by Dost (1968). Other costs (taxes, insurance, maintenance, excluding fuel), are also about 4 times more for wood burning.

The fuel requirements of 34 billion Btu's/year (36 x 10^{12}J/yr) for a large size mill would cost over $150,000[1] for gas, based on $4.50 per thousand cubic feet ($160/thousand m^3) for gas, or require approximately 2150 units of wood (bark fuel values are not included). Therefore, using Dost's analysis, the fuel value of aspen wood compared with gas is $70 per unit. The only constraints are the value of wood or wood residues for other uses and the high capital expenditure for the boiler. In the Rockies, therefore, the use of aspen residues for industrial fuel has potential; the use of roundwood is marginal based on the economics.

The present market for aspen as an industrial fuel in existing mills is small. Further, the more available conifers can provide a source of fuel that is as good as aspen.

Home Heating and Cooking

Aspen has a low heat value per cord. Aspen also burns rapidly, especially when dry. It is therefore not considered a prime home fuel.

Table 22. Fuel Value of Aspen Wood and Bark.

Moisture content	Condition	Heat available[1] from moist wood		Fuel value per unit[2]
%		Btu/lb.	MJ/kg	$
		ASPEN WOOD		
0	Oven-dry	7098	16.51	57.92
10	Kiln-dry	6341	14.75	56.92
20	Air-dry	5710	13.28	55.92
40	Air-dry partially	4718	10.97	53.90
100	Green wood	2934	6.82	47.88
150	Green wetwood	2101[3]	4.89	42.86
		ASPEN BARK		
0	Oven-dry	7298	16.98	19.92
10	Kiln-dry	6541	15.21	17.84
20	Air-dry	5910	13.75	16.12
45	Green	4700	10.93	12.82

[1] Allowance is made for heating of water in the wood, heat losses through chimney, etc.

[2] Based on \$3.40/million Btu's [\$1.60/10^9J]. Does not include fuel value of bark which is 8 to 15 percent of wood's value. A unit is 2400 O.D. pounds (1089 kg) of wood.

[3] Based on values 200 Btu/lb higher than aspen wood values. Assumes 800 lbs (363 kg) bark per 2400 pound unit.

Sawn Products -- A. 4/4 through 6/4 lumber

In the overall utilization of aspen for lumber, attention must be given to the utilization of residues, for as estimated in Figure 8, only 30 to 50 percent of the log volume is converted into lumber (Noreen and Hughes 1968, Wengert and Donnelly 1980). These data are based on straight, decay free logs, so the lumber recovery from "woods run" logs would probably be less. Further, it is axiomatic in the Lake States and Canada aspen based lumber industry that to be successful an aspen lumber operation must not be based on only one lumber product, but must produce several products and must, in addition, have a residue market (Herrick and Christensen 1967, Leach and Gillies 1972, Neilson 1974, and Noreen and Hughes 1968).

Aspen Lumber Demand

The potential demand for aspen lumber could arise from two sources:

1. As a supplement to conifer supplies both in the woods and in the market place.

2. In its own right, due to its unique properties.

In the next 10 years or so, no general shortage of softwood is expected in Canada or the U.S. For example, "Available supplies of softwood from the Rocky Mountains in the U.S. are projected to increase about 50 percent between 1970 and 2000 to nearly 1.3 billion cubic feet [48 x 10^6 m^3]. . . . Actual timber harvests on National Forests in the Rockies in 1970 were about 27% below the estimated allowable cuts . . ." (USDA 1973, p. 74). Therefore, it appears that the need to "supplement" the available lumber supply (Item (1) above) is not imminent. However, in some local areas, conifer harvests are at or near the allowable cut so that some industries may have to utilize aspen to fulfill their production demands.

The characteristics and properties of aspen (based on Zasada (1947), Johnson (1943), FPL (1974), and the author's observations) that will affect lumber production are presented in Table 23.

The following is a list of solid wood products for which aspen is ideal because of one or more of its desirable properties[7]:

Paneling-nailability and attractiveness, wears smoothly, low weight.

Crates and boxes-good toughness and nailability, wears smoothly, low weight.

Broom handles-splinterless.

Toys (puzzles, blocks)-splinterless and embosses well.

---

[7]Uses for residues in lumber manufacture are covered in a later section.

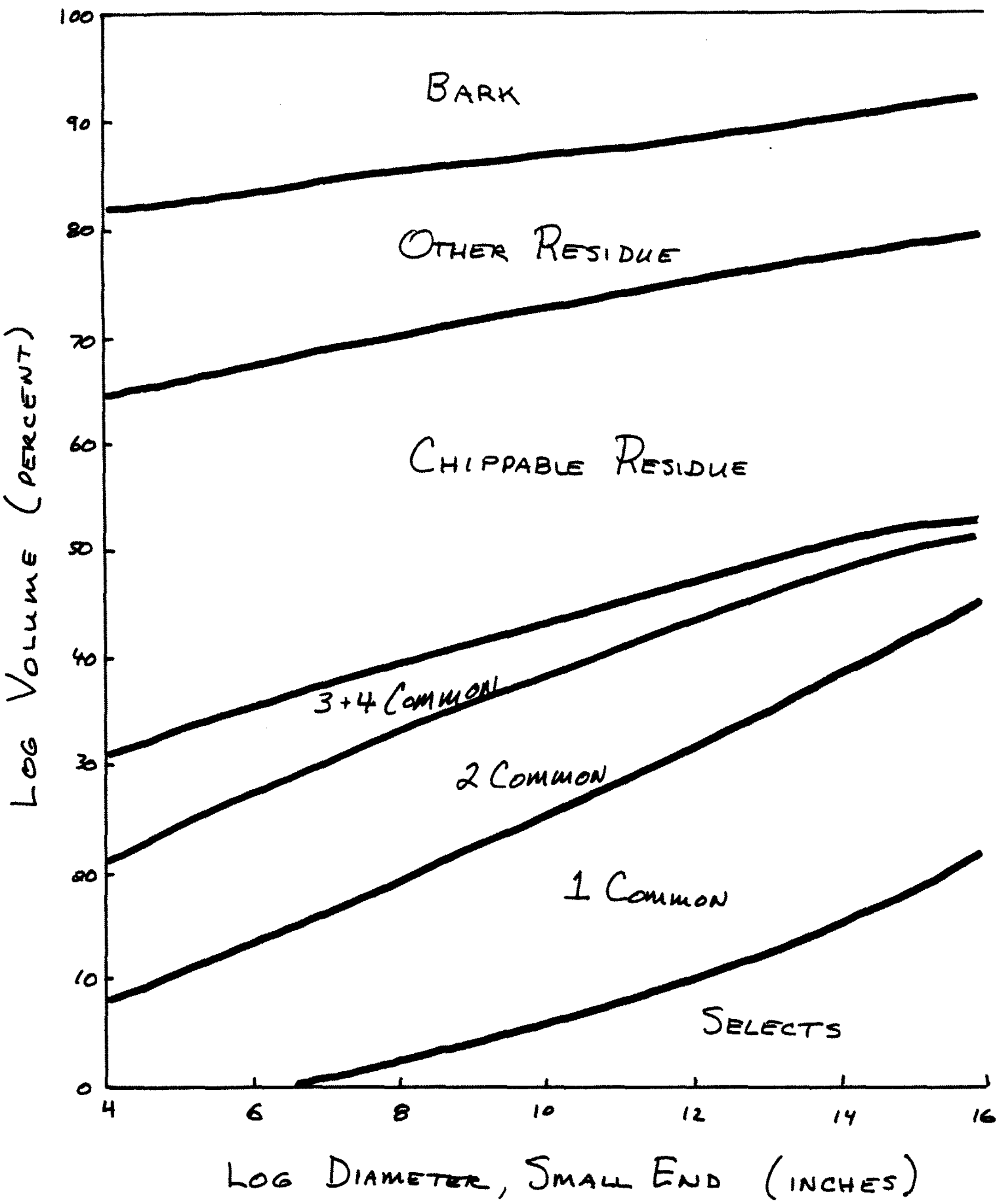

Figure 8. Estimated volume distribution of 8-foot aspen logs sawn into lumber. Estimates derived from Noreen and Hughes (1968) and Wengert and Donnelly (1980).

Table 23. Characteristics and Properties Affecting Lumber Production

Many knots-mostly tight; some loose
White color in normal wood; discoloration frequent in mature and over-mature trees
Light weight-416 kg/m^3 [26 lb/cu ft] when air-dry; green specific gravity 0.38
Odorless when dry
Shrinks very little after drying
Splinterless
Warps (cup and crook) during drying due to high tangential to radial shrinkage ratio
Decays easily
Small diameter trees--most lumber produced will be 20 cm [8 in] wide; although a few may be wider
Mature trees are typically quite defective-knots, incipient decay
Logs are frequently crooked
Indistinct grain in sapwood
Weak in bending-MOE is 8,100,000 kP [1.18 million psi] and MOR is 58,000 kP [8400 psi] at 12% moisture for clear wood
Both bark and wood digestible by ruminants (up to 55% digestible)
High in toughness (when green, equal to Douglas-fir; dry to southern yellow pine)
Weak in nail and screw holding
Nails without splitting even at the end of a board
Glues well
Paints excellently
Stains well-some blotchiness without wash coat
Inks well
Wears smoothly
Sapwood and normal heartwood dry very easily
Wetwood, when present, very difficult to dry
Machines easily; dulls knives slowly; low energy requirements.
Grain tears occasionally, especially end grain, when machining
Surface fuzzes occasionally in sawing, sanding, and machining
Very absorbent when dry
Embosses well

Seats, unfinished-splinterless.

Tongue depressors-splinterless, tasteless.

Glued up stock-glues well.

Other uses for which aspen lumber is suitable, but for which it must usually compete directly with the conifers are provided in Table 24.

Several substantial markets for aspen lumber have developed in recent years in the Lake States: Lumber for door core stock (probably #1 use); lumber for low-cost bedroom furniture; and lumber for kitchen cabinet framing. Some of these markets may be available to lumber producers in Alberta if transportation costs can be kept to a minimum. Prices for rough lumber in 1987 in the Lake States are given in Table 25.

Several potentially strong lumber markets are also developing: lumber for children's toys (splinterless safety feature) and other furniture; lumber for furring strips; and lumber for molding

A second possibility is for the Alberta mills to develop similar markets as are in the Lake States locally in Alberta. Manufacturing facilities already in operation use conifers for kitchen cabinets and molding.

For these operations aspen could compete "head-on" with the conifers at the same approximate prices (or slightly less). (For example, some sales of aspen lumber have been made to these markets in Denver and Albuquerque.)

A third market for aspen is as lumber sold through "cash-and-carry" retail outlets. The largest demand is for pine in #3 Common grade, a shelf grade board (paintable, but knotty), although some better grades are also sold. The ease of painting and gluing aspen should make it desirable in this market along with its freedom from splinters. Retail price for #3 common pine is approximately $.85 per board foot, dried and planed. For higher grade pine boards, the retail price is over $1.00 per board foot, dried and planed. For this board market, kiln- or solar-drying of lumber is a requirement, as low MC's are required.

Another significantly sized, and potentially attractive market for aspen lumber is as solid wood paneling. Tongue-and-groove end-matched paneling is popular and is gaining market acceptance throughout the Southwestern U. S. due to the efforts of a producer in southwestern Colorado. This paneling use requires the middle grade boards, as the uppers are too plain (not enough knots) and lack "character." The lumber must be kiln dried for use as paneling, however. For paneling, kiln dried lumber (No. 2 Common) is sold at about $300/MFBM to the manufacturing plant. The retail price of paneling is $700 to $1000 per 1000 square feet.

Table 24. Manufacturing Constraints for Some Products.

Use	Possible Constraint
Cut stock	
Finger joint stock	
Pattern stock	Fuzziness and tension wood
Molding	Fuzziness and tension wood
Factory and shop lumber	
Prefab housing components	
Furring strips	
Lath	Stain
Door core stock	No active industry
Kitchen cabinet material	
Furniture	Fuzziness when exposed
Paneling	Fuzziness and tension wood
Dowels	Fuzziness and tension wood
Package reinforcing	
Rulers	Tension wood
Wire spools	

Table 25. Price of 4/4 Aspen, Birch, and Oak Lumber in Wisconsin in May 1987 (Peterson 1987).

N.H.L.A. Grade	$ per MFBM Aspen	Birch	H. Maple	Red Oak
No. 1 Common	260	290	295	595
No. 2 Common	175	210	235	300
No. 3A Common	170	190	210	180
No. 3B Common	170	155	155	155
Millrun	175	240	250	490

The size of these various markets is unknown, but I estimate the annual potential for Alberta aspen could be

Lake States: 5 to 10 million board feet
Cabinets and molding: 2 to 5 million board feet
Cash and carry: 2 to 5 million board feet
Paneling: 2 to 5 million board feet

Achieving these levels would depend on adequate market development, an active economy, and a reliable (lumber available every month) aspen industry. The reliability requirement should not be underestimated.

Economics

This section examines the economics of producing 4/4 to 6/4 inch (2.5 to 3.8 cm) lumber.

Logging costs. Aspen trees are frequently free of limbs along the merchantable bole especially if minimum top diameter is 20 cm [8 in]. Felling and limbing costs are slightly less for aspen than for the same size conifers. However, due to aspen's small diameter and therefore its low volume per piece relative to the associated conifers, skidding and loading costs will tend to be higher. Historic logging costs are presented in Table 26.

Milling costs. In a study in the Rocky Mountains (Wengert and Donnelly 1980), using log grades for aspen developed by Bailey (1973) for Canadian aspen, approximately 35% of the log's volume was converted into 4/4 lumber and the yield of No.2 Common (NHLA grade) and better was 12 percent for the best log grade and under 4 percent for the lower log grades. Cost data are presented in terms of log diameter for the two mill sizes (Figure 9) and for different amounts of decay (Figure 10). These mill costs and poduction rates were obtained from two sources using typical circular saws (Leach and Gilles 1972 and Noreen and Hughes 1968). Actual costs can vary widely depending on mill type, labor requirements, overhead and so forth. A small log mill (skragg) can reduce costs by 25 to 50% over the typical circular sawmill costs used here, and thereby profitably process smaller diameter logs (Figure 11). Any mill anticipating conversion of a large amount of aspen should consider investing in a mill to process the small aspen logs. However, the crook in aspen logs can cause feeding problems in high speed headrigs that require straight logs.

Logs with decay can usually not be profitably sawn. The large drop in product value (based on hardwood grades and prices) for logs with 25 to 50 percent decay (Figure 10) is a result of the geometry of the log. With heart rot, a 25 cm [10 in] log with 25 percent decay has a center section of rot 13 cm [5 in] in diameter; with 50 percent decay, 18 cm [7 in]. The outer cylinder in both cases is solid, usable wood, but the board foot recovery per log is quite small from this thin cylinder.

Drying costs. Drying costs, as reported in the literature, vary from mill to mill. The data presented here (Table 27) include stacking and unstacking charges and a degrade loss of 3 percent. These costs are applicable to normal wood, but may be 2 to 3 times too low for wetwood.

Table 26. Estimated Stumpage and Logging Cost, F.O.B. Mill, Based on US Forest Service Data for Region 2 and Region 3 (in the mid 1970's).

	Aspen, R-2 and R-3		Av. for conifer species, R-3
	Sawtimber	Cordwood	Sawtimber
	$ / MFBM	$ / cord	$ / MFBM
Felling and bucking	8.50	5.25	7.25
Skidding and loading	13.07	7.20	9.56
Logging depreciation	1.64	1.64	3.76
General logging overhead	2.94	2.00	5.59
Truck hauling	18.00	14.00	18.00
Subtotal	44.15	30.09	44.16
Stumpage	1.00	.50	
Total	$45.15	$30.59	

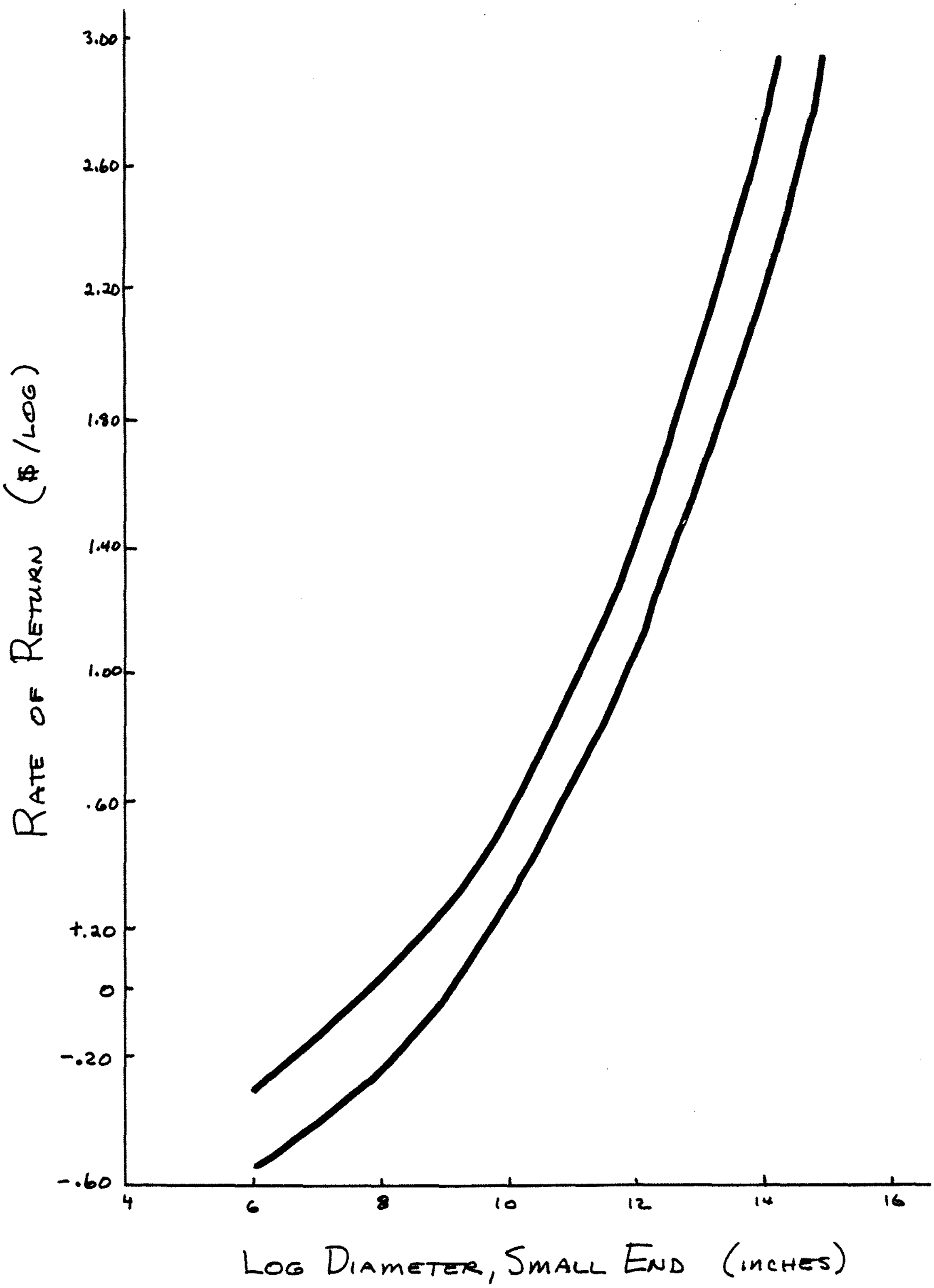

Figure 9. Estimated rate of return for aspen 8-foot (2.5 m) logs sawn on a circular headrig mill. Small log mill is upper curve. Adapted from Leach and Gillies (1972) and Noreen and Hughes (1968).

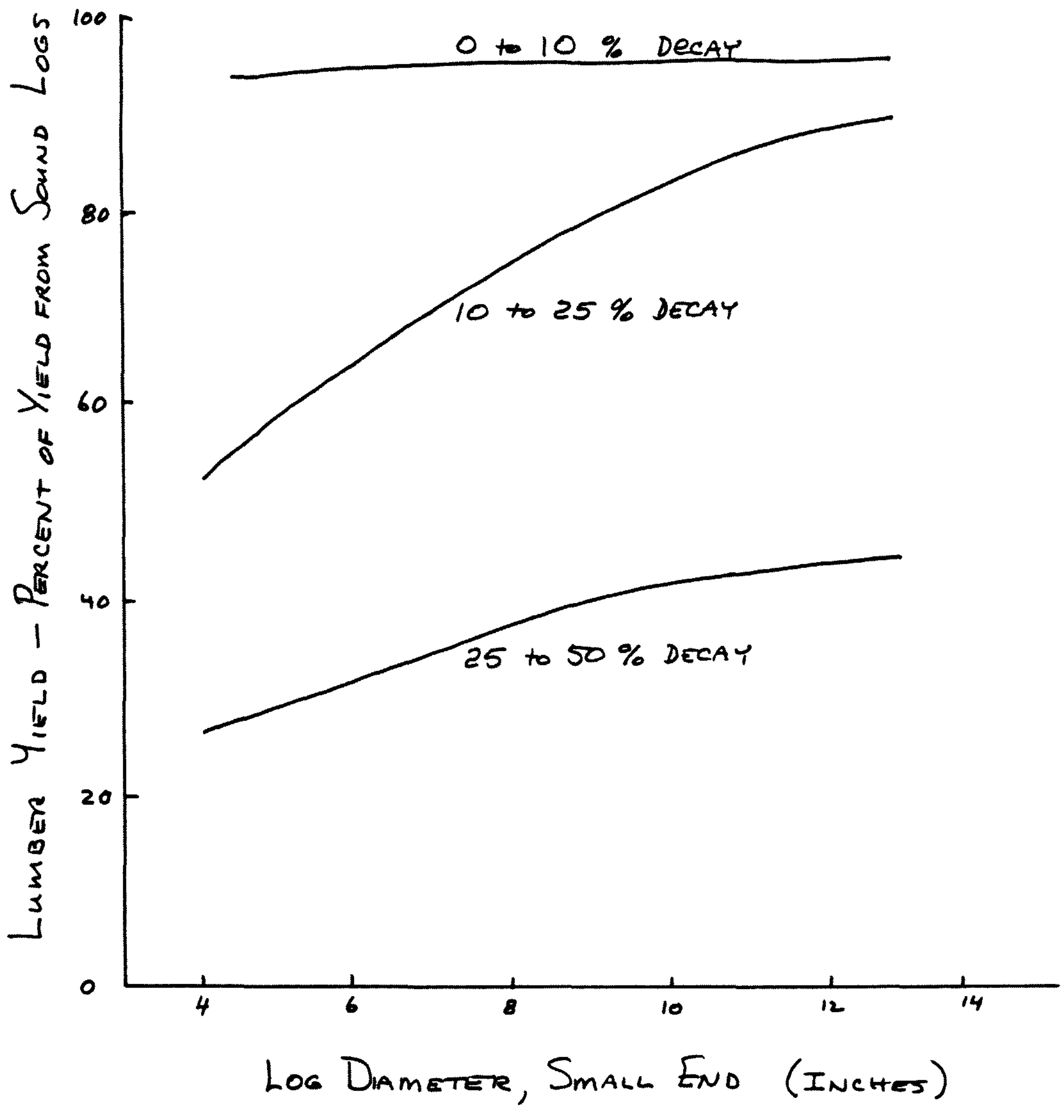

Figure 10. Effect of decay on lumber yield from 8-foot (2.5 m) aspen logs. Adapted from Leach and Gillies (1972).

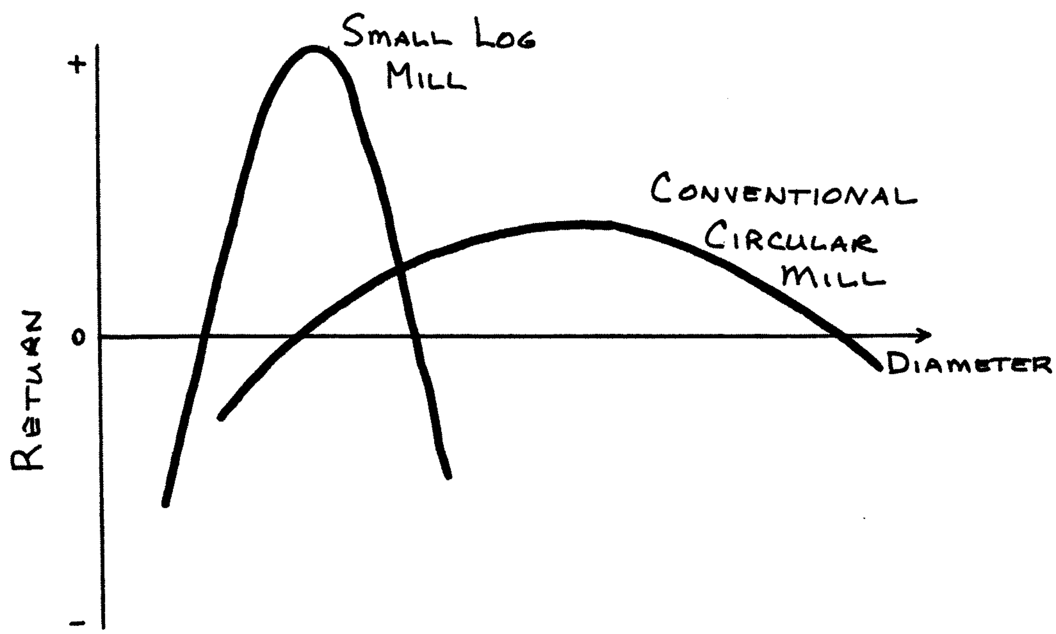

Figure 11. Effect of small log sawmills on returns. Adapted from White (1978).

Table 27. Estimated Aspen Lumber Drying Costs (7 day drying cycle), Adapted from Wengert and Lamb (1983)

Cost Item	$ per MFBM
STEAM KILN	
Equipment, amortization, land, buildings	4.55
Insurance, maintenance	4.85
Interest on inventory	.61
Supplies	1.20
Labor	6.32
Energy (steam and electricity)	8.75
TOTAL	26.28
DEHUMIDIFIER	
Equipment, amortization, land, buildings	3.25
Insurance, maintenance	6.85
Interest on inventory	.61
Supplies	1.20
Labor	6.32
Energy (electricity @ $0.04/kWh and gas)	10.73
TOTAL	28.96

Depending on the end use, wetwood degrade loss may be as high as 25 percent and drying times can be nearly three times as long. In most parts of Alberta, air drying proceeds too slowly to be a practical procedure.

Kiln drying costs using dehumidification or steam kilns are nearly equal. The difference is the size of the capital investment and whether a forest products company wants to generate power or let that job to the electric company. Quality in the two systems will also be equal, if they are properly run. Therefore, there is no inherent preference for either system. When the costs are analyzed, because of the economies of scale, it is found that for mills drying less than 2 million BF per year, the dehumidifier is preferred. A dehumidifier operation would include some sort of supplemental heat (gas, for example) to initially heat the wood and melt any snow or ice. Further, a small boiler for steaming at the end of drying to relieve drying stresses (casehardening) would be essential.

Total manufacturing costs. If the various cost items presented above are total and along with estimates for associated costs, the total manufacturing costs can be estimated (Table 28).

Processing Problems

There are three significant problems in processing aspen for lumber: wetwood, uneven drying, and machining.

1) Effect of wetwood. Wetwood is important in utilization in that:

(a) the green weight of wetwood is increased as much as 30 percent over normal wood,

(b) the drying time for wetwood can be as much as three times that for normal wood,

(c) excessive shrinkage, collapse, and honeycomb can occur in wetwood during drying, and

(d) the strength of wetwood lumber is much lower (10 percent) and much less stiff (50%) than normal wood (Haygreen and Wang 1962).

Wetwood, which is very dependent on site and perhaps the genetic characteristics of the clone, can significantly limit the use of aspen for lumber in those cases when it occurs in a large proportion of trees.

2) Drying. As indicated previously, the drying properties of aspen are important considerations in many utilization schemes. Sapwood of aspen can be dried easily, but heartwood and wetwood aspen dries with difficulty (Wengert 1973). Sapwood is usually dried as fast as possible. Temperatures as high as 116^{o}C [240^{o}F] with a drying time of 36 hours have been used successfully for sapwood. Because aspen has a high tangential to radial shrinkage ratio and a great deal of tension wood, care should be taken to use good stacking practices and low dryer humidities to minimize warp. Research by Huffman and Cech (1976) has indicated the benefits of low temperature (under 140^{o}F [60^{o}C]) for the first three days of drying for reducing warp and other degrade. Typical kiln schedules are given in

Table 28. Total Manufacturing Costs[1] for Dry (6 percent moisture content), Graded, 1 inch (2.5 cm) Aspen Lumber.

Log Scaling Diameter	Manufacturing costs	
	Small mill	Medium mill
Inches	$ / MFBM	
4	283.30	218.39
5	215.71	172.83
6	181.29	149.53
7	157.60	133.48
8	143.01	123.62
9	133.12	116.94
10	126.16	112.24
11	121.09	108.80
12	117.32	106.25
13	114.26	104.18
14	111.79	102.51
15	110.03	101.33
16	108.48	100.28

[1]Stumpage, harvesting, transportation, sawing, drying, and grading cost are all included.

Tables 29 and 30. Because machining properties are related to moisture content, aspen should be dried to below 6 percent moisture content for uses requiring good smooth surfaces. Variability in final moisture content is typically a problem (Huffman and Cech 1976), so equalization is required. Typical equalization conditions are given in Table 31. Further, to reduce the effects of tension wood and longitudinal casehardening, aspen should be conditioned at the end of the drying schedule at 180°F [82°C] dry-bulb temperature and at an equilibrium moisture content 1 percent higher than given in the Dry Kiln Operator's Manual (Rasmussen 1961). Typical conditioning conditions for aspen are given in Table 32. Conditioning time, although subject to wide variation, will be about 8 to 12 hours until stresses are relieved for 1 inch (2.5 cm) stock.

The difficulty in drying aspen wetwood and heartwood is attributed to an extreme decrease in permeability and perhaps a slight decrease in diffusivity. Wetwood, with up to twice as much water as normal wood, can require up to 5 times more time to dry than sapwood. Further, the wetwood-normal wood zones are subject to severe collapse and honeycomb during drying. This effect of wetwood is most noticeable in 2 inch (5 cm) stock; in 1 inch (2.5 cm) stock it is considerably less of a problem. Heartwood may require up to 2 times more time to dry than sapwood. Long air drying is one solution; intermediate steaming during drying is reported to be suitable for studs (Mackay 1974); rapid initial drying followed by a long equalization period is suitable when energy costs and kiln residence time are not critical. An exploratory study at the U.S. Forest Products Laboratory by this author showed that a steaming treatment of several hours duration near the end of drying will recover much of the collapse in 2 inch (5 cm) material.

<u>3) Machining</u>. Machining problems with aspen have already been covered in detail. The major problems are fuzzing and, if the MC changes after machining, warping.

Sawn Products-B. Pallets and Boxes

In marketing aspen lumber, there should be little difficulty in selling the high grades. The real difficulty is in obtaining suitable markets for lower grade boards, most of which are sawn from the center sections of a log. These lower grade boards are generally heartwood and may have wetwood. This means that kiln drying costs to produce 7 percent moisture content lumber for furniture can be as high as $90 per thousand board feet. Degrade, mostly collapse, will also be high. These costs may be prohibitive. As an alternative to manufacturing kiln dried boards for furniture from low grade lumber, the manufacture of aspen pallet and box lumber should be considered (Caeser 1974, Large and Frost 1974, and Leach and Gillies 1972). Generally, pallet and box lumber, if dried, is only air dried to approximately 20-30 percent moisture content. (Air drying is usually required to increase nail holding, decrease weight, and eliminate decay hazards.)

Aspen has been successfully used for pallets and boxes for years. Based on visits by this author through the Lake States in late 1973, I estimated that one half of the aspen lumber produced was used for pallets or containers.

Table 29. Traditional Kiln Schedule for 4/4 through 6/4 Aspen Lumber. (Rasmussen 1961, T12-E7)

Moisture Content	Dry-Bulb	Wet-Bulb	Depression	EMC	RH
%	°F	°F	°F	%	%
Above 60	160	140	20	8	59
60 to 50	160	130	30	6	44
50 to 40	160	120	40	4	32
40 to 30	160	110	50	3	22
30 to 20	170	120	50	3	24
20 to End	180	130	50	3	26

Table 30. Low to Moderate Collapse Aspen Kiln Schedule for 4/4 Through 6/4. (McMillen and Wengert 1976)

Moisture Content	Dry-Bulb	Wet-Bulb	Depression	EMC	RH
%	°F	°F	°F	%	%
Above 60	110	100	10	12	70
60 to 50	115	100	15	10	58
50 to 40	120	100	20	8	49
40 to 30	130	105	25	7	43
30 to 20	150	110	40	4	28
20 to 12	180	135	45	4	30
12 to End	180	130	50	3	26

Table 31. Traditional Wet-bulb Equalization Settings for Equalizing Aspen. (Adapted from McMillen and Wengert 1976)

	Dry-Bulb Temperature						
Final MC	140	150	160	170	180	190	200 °F
%	- - - - - - -			°F	- - - - - - -		
6	92	101	110	120	130	140	150
7	99	108	118	127	137	147	157
8	105	115	125	135	145	156	167

Note: Aspen must always be dried to a low MC and be carefully equalized to avoid wet spots.

Table 32. Traditional Wet-bulb Settings for Conditioning Aspen. (Adapted from McMillen and Wengert 1976)

Final MC	Dry-Bulb Temperature 140	150	160	170	180	190 °F
	- - - - - - °F - - - - - -					
6	126	136	147	157	168	178
7	128	138	149	159	170	180
8	130	140	151	161	172	182

Note: A 1°F higher wet-bulb is suggested for relief of longitudinal stresses. Dry-bulb temperature should always be as high as possible.

Demand for Pallets

The national demand for pallets in the U.S. has increased rapidly (Figure 12). A similar trend in Canada exists. This demand has and will continue to put a very heavy strain on Eastern U.S. and Canadian hardwoods. It is conceivable that pallet parts from Alberta aspen could serve some of this growing demand. Because assembled pallets occupy so much room, shipping pallet parts (shook) should be a more economical method (Reeves 1974). Actually, many users prefer to purchase pallet parts and have their own crews assemble them during slack periods.

Demand for Boxes

The total demand for wooden boxes in 1970 in the U.S. was 1.8 billion board feet of lumber, about 60 percent of the lumber usage for pallets (USDA 1973). Trends during the last two decades have been toward replacing wood boxes with paperboard and plastic containers and toward increased use of containerized, bulk shipments. Nationwide in the U.S., therefore, the demand for wood boxes is expected to decline slowly--1/2 to 1% a year.

There is a very active market for boxes in the eastern parts of Kansas, Oklahoma, and Texas for military ammunition. Aspen is the preferred species because it can be nailed at the end without splitting and because it is splinterless. Forty million board feet of aspen could be used annually for this purpose. One competitive species is #3 Common Canadian spruce, purchased in 1975 at $118 to $120 per thousand delivered. Lumber for boxes is typically 1 inch x 4 inches x 4 feet (2.5 cm x 10 cm x 1.2 m). There are likely to be other areas of demand for ammunition boxes, but they have not been documented in this report.

A second market that has potential for aspen is vegetable boxes for fruit growing areas of California, Oregon, and Washington. The competitive species is Douglas-fir. The advantages of aspen are that it is odorless, light weight, splinterless, and nails without splitting. The main constraint of this market is transportation costs form the mill in Alberta to the Western states.

Suitability of Aspen

Laboratory testing of aspen pallets was conducted by the U.S. Forest Products Laboratory (Heebink 1962)[4]. In order to compensate for aspen's lower strength which is less than the strength of commonly used pallet species like oak and birch, deck boards were made 33 percent thicker (1-inch [2.5 cm] instead of three-fourths inch [1.9 cm]). In addition, longer, spirally grooved nails were used to compensate for aspen's poor nail holding ability. Heebink found that aspen pallets manufactured in this manner:

---

[4]General recommendations for pallets should apply to boxes as well.

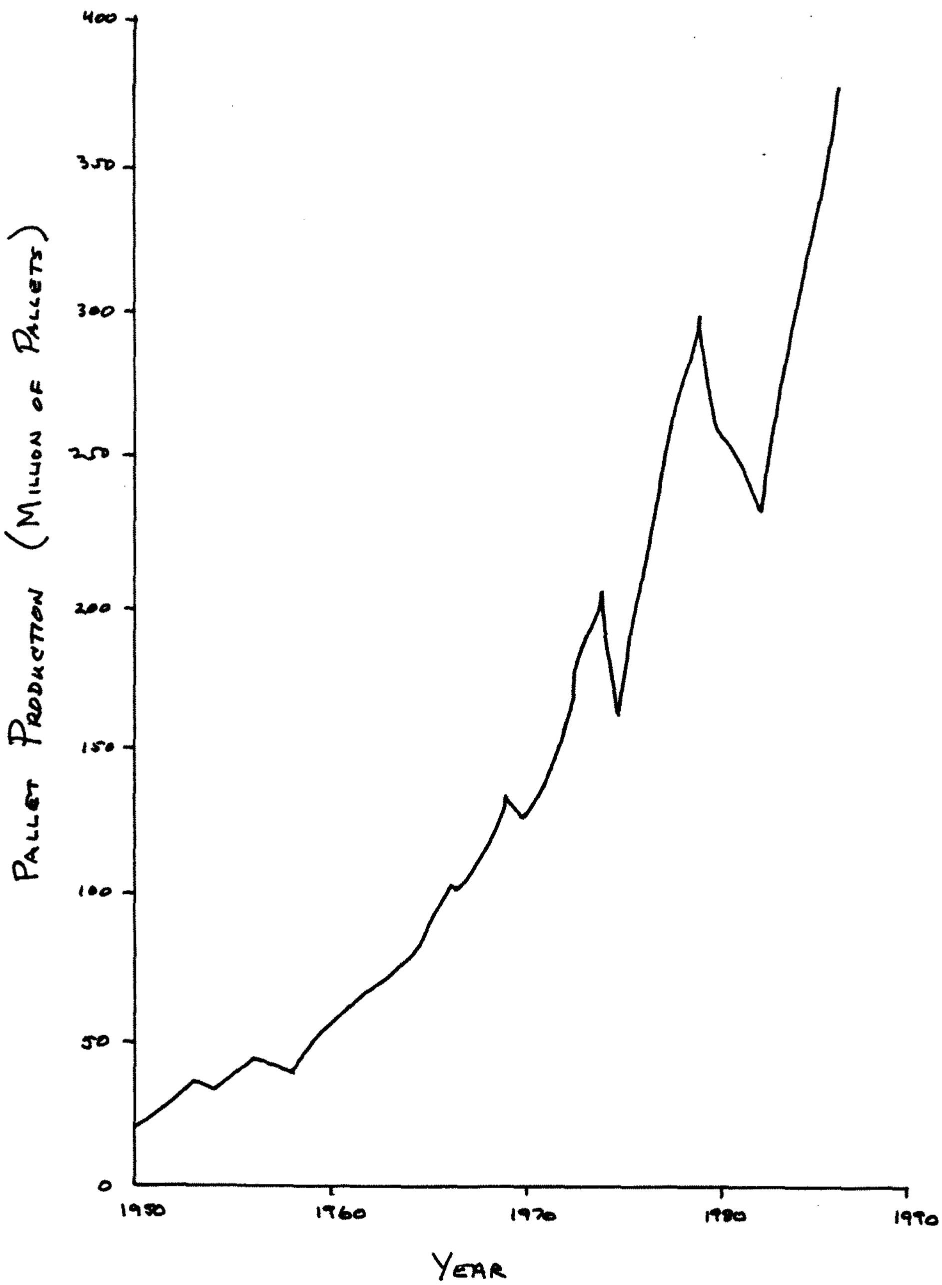

Figure 12. The national demand in the U.S. for wooden pallets. (Stern 1987).

"outperformed pallets made of commonly used hardwoods in a series of rough-handling tests at the Forest Products Laboratory. The specially designed aspen pallets survived over twice as many falls in the revolving drum during this study as standard pallets did in studies made previously at the Laboratory and by the U.S. Navy. In drop tests, the aspen pallets deformed much less from cornerwise impacts than oak pallets did in a previous Laboratory study. Toughness tests, conducted as a supplement to the performance evaluations, indicated that aspen for a lightweight species, is a very tough wood. Based on the results of this study, it is apparent that aspen pallets will perform satisfactorily."

On the other hand, the Canadian Eastern Forest Product Laboratory reports that all-aspen pallets, manufactured without the size increase noted above, have not performed as well as desired (Reeves 1974). They suggest that aspen should only be used for the deck boards, approximately 14 board feet per pallet. The stringers and leading deck boards should be a denser species.

Stern and Wallin (1975) compared aspen and oak pallets and found that aspen could provide a stiffer, more rigid, and longer service life than similar oak pallets if (a) lift trucks have and use impact panels (Stern 1973) and (b) longer and larger headed nails are used.

Advantages and Disadvantages

One of the primary advantages of an aspen pallet or box is its light weight. A nonreversible, double, flush, 4-way, notched, 3-stringer, 40 x 48 inch (1.0 x 1.2 m) pallet (Stern and Wallin 1975) would weight 70 pounds (32 kg) if made entirely of aspen by the U.S. FPL system (Heebink 1962) with 1 inch (2.5 cm) deck boards, 82 pounds (37 kg) if made of mixed aspen-oak by the Canadian system (Reeves 1974), and 102 pounds (46 kg) if made entirely of oak. This weight greatly affects the east of manual handling and the shipping costs.

Many pallets use less wood than the one described above. A 2-way nonreversible pallet may have three 2- x 4-inch (5 x 10 cm) stringers and 11 1- x 6-inch (2.5 x 15 cm) deck boards or about 26 board feet of lumber. An all aspen pallet would weight 42 pounds (19 kg); a mixed oak-aspen pallet, as assembled according to the experimental system of the Canadian Forest Products Laboratory (Reeves 1974) would weigh 55 pounds (25 kg); and an all oak pallet would weigh 70 pounds (32 kg).

Other advantages of aspen for pallets and boxes are (Sands 1947):

a. White color

b. Inks well

c. Wears smoothly

d. Little tendency to split under stress

e. Nails easily without splitting, even at the ends

f. Sliverless, splinterless

g. Lower cost than most other hardwoods

These are several disadvantages, however:

a. Low in decay resistance

b. Timber supply is seasonal in supply (due to snow or wet weather limiting logging)

c. Softness of the wood (i.e., low density)

d. Some discoloration may be confused with decay

Manufacturing Costs

The pallet industry typically has a relatively low fixed cost to variable cost ratio (about 0.2), which means that producers can make easy entry and exit from pallet manufacturing as market demand fluctuates.

Pallet manufacturing costs, based on a 1969 survey (Sendak 1973) have been updated to 1986 by author (Table 33).

Sawn Products-C. Studs[11]

Demand

The demand for studs, nominally 2 to 4 inches thick and 2 to 6 inches wide (38 to 89 mm thick and 38 to 140 mm wide) is difficult to ascertain. As a conservative estimate, it is assumed that 3200 BF of studs are used per one-or two-family housing unit, 600 BF per multifamily unit, and 800 BF per mobile home (USDA 1973). In addition, an unknown volume of studs is used in nonresidential construction and manufacturing. Assuming 20,000 new one-and two-family units and 60,000 new mobile homes manufactured annually in the Alberta region, a conservative estimate of the potential annual demand for studs is 112 million board feet. This demand is presently satisfied in part by local species-spruce, lodgepole pine, etc.-and in part by West Coast species. But the region's projected growth indicates a need for a substantial additional supply.

Certainly there is room for inclusion of small volumes of aspen in this regional market. However, aspen cannot be graded and included in "White wood" or "Western Wood" groups according to present rules; it must be stamped as "Aspen" (WWPA 1981). For the majority of buildings, the architect or builder specifies the grade and species (or species group) of

[11] This discussion applies, in general, to other dimension sizes, as well.

Table 33. Estimated Pallet Manufacturing Costs

Item	Cost Pct. of total	 $ per pallet
Lumber	50	6.16
Other material	4	.50
Labor	19	2.34
Other variable	10	1.24
Deprec. and rent	3	.36
Admin. and other fixed	9	1.10
Profit	5	.62
TOTAL		12.32

studding. Therefore, some market development would be necessary if very large volumes of aspen were to be marketed, or the species grouping would have to change to permit aspen in a group with softwoods.

Suitability of Aspen for Studs

Aspen has been used occasionally in the Lake States for studs. However, of the two recent manufacturers of aspen studs, one stopped producing within a year and the other has switched completely to softwood species. The two biggest problems are low yield, due to small log size, and expensive drying, due to wetwood and heartwood (Bailey 1973, Thompson 1972, and Wengert 1973). The frequency and severity of wetwood seems to increase as log diameter (or tree age) increases. In addition, juvenile wood around the pith which contains a large amount of tension wood and is formed for as long as the first 20 annual rings in Lake States' aspen, has contributed to warping problems especially for studs from small logs (Thompson 1972).

Yield

If aspen is to be made into studs, the most promising procedure is to saw them only from the outer portions of logs, avoiding heartwood, wetwood, and tension wood. Such a system is discussed by Thompson for aspen (1972) and by Hallock and Malcolm for red pine (1972).

Thompson's study is summarized in Figure 13 and Table 34. His data point out that a very small percentage of 2- x 4-inch (5 x 10 cm) stud grade lumber is produced. Even when all lumber and cants produced, except for the very defective pieces, are considered, the percentage of volume converted is just over one-third. It is therefore concluded from Thompson's data that waste is high. Without an economic market for the waste, steady production from aspen would appear to be an economically questionable process. Many producers have tried manufacturing aspen studs but have found if unprofitable due to poor yields.

Drying

The drying of studs is a problem due to discolored wood, heartwood, and/or wetwood (Bailey 1972). If wetwood-free logs were used, drying time could be substantially reduced. In a Canadian study (Bailey 1973), aspen studs were air dried for 8 weeks in the summer and then kiln dried 5-1/2 days. After drying, almost one-fourth of the lumber was still above 19 percent moisture content, although most of the studs without wetwood were below 19 percent. In another study by Ward at the U. S. Forest Products Laboratory (Wengert 1973, Ward 1976), green studs were kiln dried at high temperature. After 5 days, many wetwood studs were still over 50 percent moisture content. By comparison, most other species used for construction lumber and sapwood aspen can be high temperature dried in 14 to 48 hours. Three typical kiln schedules are presented in Tables 35, 36, and 37. (See also the drying discussion for 4/4 through 6/4 inch lumber.)

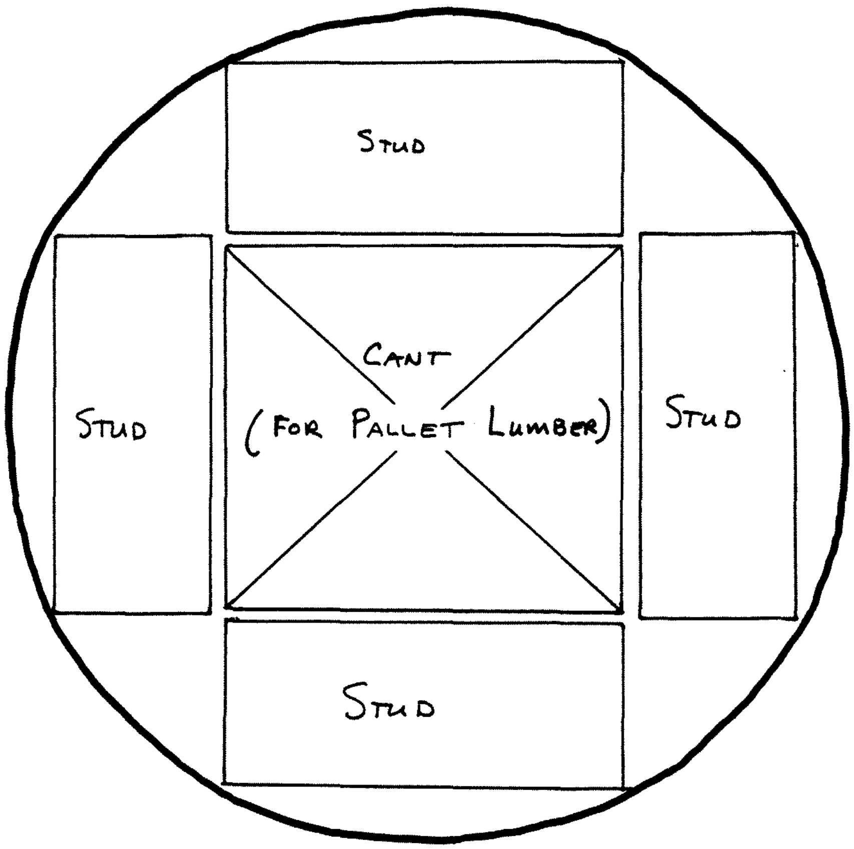

Figure 13. General sawing pattern for aspen to avoid manufacturing problems with wetwood, heartwood, and juvenile wood (Thompson 1972).

Table 34. Yield of Studs From 100-inch (2.5 m) Aspen Logs in Minnesota. (Thompson 1972)

Log dia. class	No. of 2x4 studs[1] per log	No. of 2x3 studs[1] per log	Cant size	Average log volume	Log volume Converted to 2x4 studs[1]	Log volume converted to 2x3's, 2x4's and cants[2]
Inches (cm)			Inches (cm)	Cu ft (m^3)	%	%
7-1/2 - 9 (19 - 23)	1.02	0.5	2-1/2 x 4 (6.3 x 10)	3.56 (0.101)	13	37
9 - 10-1/2 (23 - 27)	1.12	0.11	3-1/2 x 4 (8.9 x 10)	4.83 (0.137)	10	34
10-1/2 - 12 (27 - 30)	1.78	0.47	5-1/2 x 4 (14 x 10)	6.87 (10.195)	12	41

[2]Excludes rejects (e.g., shorter than 8 feet [2.4 m])

Table 35. A 96-hour Kiln Schedule for Aspen 2x4's. (Bramhall and Wellwood 1976.)

Moisture Content	Dry-Bulb	Wet-Bulb	Depression	EMC	RH
%	^{o}F	^{o}F	^{o}F	%	%
Over 40	140	133	7	14	82
40 to 30	150	130	20	8	57
30 to End	170	120	50	3	24

Table 36. The Traditional 8/4 Kiln Schedule. (Rasmussen 1961, T10-E6.)

Moisture Content	Dry-Bulb	Wet-Bulb	Depression	EMC	RH
%	°F	°F	°F	%	%
Above 60	140	125	15	10	65
60 to 50	140	120	20	8	55
50 to 40	140	110	30	6	39
40 to 30	140	90	50	3	15
30 to 25	150	100	50	3	19
25 to 20	160	110	50	3	22
20 to 15	170	120	50	3	24
15 to End	180	130	50	3	26

Table 37. Low to Moderate Collapse Aspen Kiln Schedule. (McMillen and Wengert 1976.)

Moisture Content	Dry-Bulb	Wet-Bulb	Depression	EMC	RH
%	°F	°F	°F	%	%
Above 70	140	133	7	14	82
70 to 60	140	130	10	12	75
60 to 50	140	125	15	10	64
50 to 40	140	120	20	8	54
40 to 30	140	110	30	6	38
30 to 25	150	100	50	3	18
25 to 12	170	120	50	3	24
12 to 8	180	130	50	3	26
8 to End	200	140	60	2	

Further Considerations

Aspen can be graded and used as a stud, as structural light framing, and as structural joists and plants (Tables 15 and 16). However, the design values for these uses are for normal wood. A study conducted at the University of Minnesota (and recently confirmed by the Canadian Forest Products Laboratory in unpublished research) has clearly shown that wetwood is substantially weaker than normal wood (Haygreen 1970). Reductions reported by Haygreen are:

Property	Reduction in strength of wetwood compared with normal wood
	%
Static bending:	
FS or PL	22
MOR	18
MOE	44
Compression parallel:	
FS at PL	28
MAX. crush.	20
MOE	59

Work at the Canadian Forest Products Laboratory (Littleford and Roth 1975) also indicated stained wood has a significant loss in strength when compared with unstained wood.

This reduction, especially in bending MOE, is serious enough to discourage manufacturing of studs from the center of aspen trees. Butt logs of mature or overmature trees, where wetwood tends to be more prevalent, would be particularly deficient.

On the other hand, recent work has shown that the design values for aspen may be lower than necessary (Littleford and Roth 1975). This is not too startling, as design values used in the United States are based on only 11 trees that were faster growing and of lower SG than average. (See the earlier sections on the specific gravity and strength of aspen.)

Manufacturing Costs

Due to aspen's small diameter, studs from aspen are expensive to manufacture when compared to trees of larger diameter. However, cost can be kept low with special small log equipment such as skragg or chipping canter headrigs, provided these machines can operate with crooked logs. The wetwood problem also raises costs. Kiln drying costs are usually $12 to $15 per thousand board feet; however, with wetwood, costs are two to three times as much.

To summarize, a demand for studs exists, but market development would be necessary to channel aspen into this demand in large volumes. Manufacturing costs, especially drying, are higher for aspen than for other species unless special equipment is used. There is some uncertainty about the strength of wetwood studs. It appears that the use of aspen for studs does not have a high potential at this time.

Sawn Products-D. Furniture Parts

Thorough studies of the potential for manufacturing furniture parts from aspen and for then selling these parts to furniture, cabinet and millwork shops has been conducted by Flann (1974) and by Wengert (1984, 1987). The key benefit of such an approach, compared to first manufacturing lumber and then selling the No. 1 Common and Better grades to a furniture plant that then cuts the lumber into parts, is that the typical low grade aspen log can easily be converted into high grade products, without the constraints of historical grading patterns. Flann showed that a log, which when sawn into lumber was worth $0.44 per gross cubic foot ($16 per m^3), could be sawn directly into furniture parts (mostly white in color and free of knots) producing a product value for the log of $1.19 per gross cubic foot ($42 per m^3). It is a 250% increase in product value. Wengert's data for oak showed an increase in value of 61% when manufacturing parts instead of lumber from US Forest Service F-3 logs; low grade oak lumber, however, has a good value, so the benefit is smaller when sawing parts.

The suggested manufacturing scheme (which is similar to SDR production flow) is:

1) Saw logs on a skragg or other small log sawmill, producing 4/4 and 5/4 cants. Light edging for the cants can be used, but because aspen has so little taper and butt swell, edging is probably not necessary.

2) The cants are sorted for quality, eliminating the highly defective pieces; stacked; and dried conventionally. (Note: vacuum drying is certainly attractive here, but no tests have been conducted with aspen to ascertain the feasibility.)

3) After drying, the cants are gang ripped (or single saw ripped) into strips and then the strips are crosscut into parts. (It is possible to crosscut first, but generally a rip first operation is better for highly defective wood and short cuttings.) It is

anticipated that approximately 30% of the log's volume will end up as parts (Wengert 1987 and Flann 1974).

Furniture parts, depending on the species, sell between $1000 to $1500 per MFBM of parts. With a 30% conversion rate, 280 cubic feet of logs (approximately 1700 FBM log scale, International 1/4-inch Rule) will be required to produce 1000 FBM of parts. With Lake States aspen logs selling at $40/MFBM, the process of converting logs into parts increases the value of 1700 FBM of logs from $68 to $1000. On the other hand, converting a log to lumber would only increase the value from $68 to $300.

Further practical research and development in Alberta is necessary to establish the exact operating system, economic constraints, and overall benefits. However, the potential is very large for this type of operation.

Sawn Products-E. Mine Timbers and Framing

Demand

Wood is used in underground mines primarily to support the roof. (Most metal mines are in rock stable enough so only minimal, if any, supports are required.) In drifts (tunnels) that are mined only for a brief period, an inexpensive, nondurable species (almost always used green) is sufficient. At typical underground bituminous coal mine uses 1 board foot of sawn timbers and 0.54 lineal feet of round and split timbers per tone of coal (0.18 lineal m per tonne) (Knutson, 1970). With increased demand for coal and increased pressure to reduce strip mining, a large demand for timbers for use in mines in the Eastern states could develop, perhaps as high as 100 million board feet of sawn timbers annually.

Suitability

Mine timbers are "custom" sized depending on the size of the drift, mining equipment used, and rock stability. Several common sizes are 2- x 6-inch (5 x 15 cm), 2- x 8-inch (5 x 20 cm), and 4- x 6-inch (10 x 15 cm) in 2- to 8-foot (0.6 to 2.4 m) lengths. Aspen's advantages as a mine timber species include the following: it's fairly lightweight, it saws easily, it bends easily thereby giving a visual warning of rock shifting and impending failure, and it is splinterless. On the other hand, aspen decays easily and does not treat evenly with preservatives, so would not be suitable as permanent timbering. Perhaps aspen's primary benefits are its low cost and widespread availability. Further equipment for manufacturing mine timbers requires low capital investment and only 2 or 3 person to run it. Prices for delivered mine timbers can reach as high as $150 per thousand board feet.

This market is typically developed directly between mill operator and mine operator. Therefore, very little is known about the size, activity, and prices for mine timbers.

Manufacturing Residues

Because of aspen's low value as lumber and its high residue volumes (Figure 8), profitable residue utilization is important in order to increase the potential rate of return for aspen logs. For every 1,000 bd. ft. of lumber produced, approximately 1 unit (2,400 oven dry pounds [1300 kg]) of residue results. In the Lake States, pulp mills are buying aspen residue (fines) at profitable prices, but similar opportunities may not be available in Alberta. Therefore, different residue utilization systems must be developed.

This section examines briefly various market alternatives for aspen residues-including slabs, edgings, trim, defective lumber, sawdust, and bark. This is followed by a close look at aspen for animal bedding and feed.

Potential Products

With increasing demand for wood and increasing environmental controls, burning manufacturing residues is generally no longer an acceptable procedure (unless energy is recovered and clean air requirements are satisfied). Therefore, numerous uses for manufacturing residues including bark, are being explored as indicated by many recent symposia and articles on this subject. Although many potential uses for waste wood and bark have been suggested, not all are applicable to aspen or to the Alberta market situation. Some are not yet technically feasible; others require different species; and others are not economically feasible in Alberta. However, some uses appear promising for aspen residues.

Fine Residues:

Animal bedding - primarily for feedlot cattle

Poultry litter

Fuel briquets

Animal feed

Soil amendment

Potting medium

Mulch, including highway mulch

Chemical spill absorbent

Wood flour

Lumber Residues:

Toy blocks

Toy parts

Trellis

Lath-building

Apiary supply parts

Pallets (discussed earlier)

Measuring sticks, paint stirring sticks, etc.

Some of these uses are discussed below. A general economic evaluation of fine residue handling is given by Gray and Canady (1971).

<u>Fuel Briquets</u> (see Reineke 1964)

There are two types of fuel briquets-a compressed wood form (usually without a binder) and a charcoal briquet (usually with a binder). Typically, softwoods are used for compressed wood; hardwoods for charcoal.

Dry wood or bark (<10% moisture content) is required for briquetting. Aspen wood and bark have been briquetted successfully. Briquetting machines are expensive. Because of the easy accessibility of most of the aspen area to free firewood from the Provincial forests, local demand for fuel briquets is not expected to be large. On the other hand, low economic return for a small producer generally discourages shipping such products long distances.

<u>Wood Flour</u> (see Reineke 1966)

Wood flour is a loosely defined product that includes wood in very fine particle form. Flour finds applications as

(1) an absorbent,

(2) a chemically reactive substance,

(3) a chemically inert filler,

(4) a modifier of physical properties,

(5) a mild abrasive, and

(6) a decorative material.

Aspen flour is used in products such as linoleum, explosives, plastics, adhesives, roofing, and pharmaceuticals (Reineke 1966, Shulman and Wilner 1960, Billups and Cooper 1962). Wood flour specifications-particle size, species, purity, etc.-vary depending on the use.

Aspen is a desirable wood flour species. It is clean looking, uniform in color, odorless, tasteless, virtually extractive free, resin free, absorptive, and flows easily.

Manufacturing equipment for wood flour added to a lumber mill or other existing plant would cost a minimum of $30,000 for a 40-mesh, 1 ton (0.9 tonne) per hour production rate. Electrical costs would be about $5.00 per ton ($4.50 per tonne). (Cost would more than double for 80-mesh size.) Wood must be dry and bark free.

Prices vary with quality, grade, and size of mesh and may be $50 or more per ton ($45 per tonne). This present demand for wood flour has not been quantified.

Bark Flour

Bark can also be made into a flour. However, the properties of bark flour, specifically its color and high chemical content, make it unsuitable for the same uses as wood flour. The only potential use for bark flour mentioned in the literature was as in oil absorbent (Chow 1972). It absorbs up to seven times its weight-one gallon of oil per pound of bark (8 l/kg). A brief heat treatment (costing less than $4 per ton [$3.60 per tonne]) is necessary to prevent leaching of water soluble extractives from the bark. Bark flour is desirable for treating oil spills on water, as it will absorb the oil readily but will not contribute to high biochemical oxygen demand or to toxicity to fish. However, more testing is in order to establish that the phenols and other compounds in aspen bark won't cause other environmental problems. This is a new product for bark or wood, so demands and prices are not established.

Soil Amendment (see Bollen and Glennie 1961)

The benefits from adding wood and/or bark to the soil are

1) increased moisture retention,

2) greater aeration, and

3) increased tilth through humus formation.

All of these three advantages are extremely desirable effects.

On the other hand, wood has the major disadvantage of competing with the plant for the available nitrogen, resulting in a nitrogen-deficient condition unless supplemental nitrogen is applied. (Using wood and bark as animal bedding before use as a soil amendment is one possible way to add the needed nitrogen.) Other possible disadvantages of bark as an amendment are 1) too much water retention, 2) slower soil warming, 3) decrease in pH, and 4) compaction of fines. Because of aspen's susceptibility to rapid decay, nitrogen demands would be expected to be higher than for many other species. However, aspen's low density would be desirable property. An evaluation of aspen residue as a soil amendment should be conducted especially with the bark.

The only processing at the sawmill would be hammermilling and handling and packaging for shipment (or storage, if loaded directly into cars or trucks).

At present, large scale use of aspen as a soil amendment should probably be looked at as an inexpensive disposal method for residues rather than as a profitable product.

There is one possible constraint. An exploratory study reported that aspen wetwood contained an unknown toxic chemical perhaps a volatile acid that killed tomato seedlings (Knutson 1968).

Mulch (see Bollen and Glennie 1961)

A mulch is applied to the top of soil and is not immediately mixed in with the soil, as contrasted with a soil amendment. However, in time the mulch does break down and mixes with the soil, so it becomes a soil amendment. As a result, the same advantages and disadvantages of wood and bark as a soil amendment apply to mulch, except for the differences in time scale.

The most commonly used mulch materials are peat moss, bark chunks, and straw. The local availability of aspen wood and bark give it a price advantage over other products that must be imported. All perform adequately, although bark chunks and straw are preferred where wind erosion is likely. (Note the previous comment regarding wetwood toxicity.)

Potting Medium (see Lunt and Clark 1959)

Bark provides an excellent potting medium for nursery container stock and for rooting plant cuttings.

Bark and/or wood when mixed with soil can be used for packing the roots of young trees and other nursery stock before sale and planting.

Aspen could compete with existing potting medium-chopped straw, peat, nonlocal wood and bark residue-when aspen is available locally.

Lumber Residue

It would be desirable, if not essential for a plant producing aspen lumber to look for an economic outlet for its slabs, edgings, and trim. Aspen's unique characteristics should favor such utilization. The splinterless nature of aspen would be desirable in toy parts and toy blocks. Further, aspen's softness would help in embossing designs on these items. Aspen's resistance to splitting in nailing or stapling would be an advantage for some items such as snow fence lath, garden trellis lath, and mouse trap bases. Aspen's splinterlessness, softness, and ease of printing are desirable for rulers and yardsticks. Aspen's freedom from odor and taste makes it excellent for apiary supplies. In short, many products can be made from coarse residues, and aspen has several important advantages over most other species. An educational effort is needed, however, to bring aspen's unique properties to the attention of the wood-using community.

Animal Bedding

Demand and Feasibility

Large amounts of animal bedding are used each year primarily to control runoff, reduce odor, and possibly to increase weight gains in cattle feedlots. Usage levels for New Mexico are given in Table 38. If it is assumed that usage levels are the same throughout Alberta, then the market can be estimated if the livestock and poultry numbers are known. Although straw is the most commonly used bedding material, wood is entirely suitable. In fact, wood is at least 50 percent cheaper than straw per pound and absorbs more water per unit weight (Allison and Anderson 1951). Further, manure mixed with sawdust bedding when applied to the soil gave similar growth rates for crops of corn and barley as manure mixed with straw. Many of the newer grains planted today have shorter stalks and therefore straw production per acre is decreasing, indicating a decreased availability of straw. A further advantage of aspen as bedding is that it tends to neutralize the odor from animals (Gray and Coudy 1971).

Economic Considerations

Aspen used for bedding can come from roundwood, harvesting residues, or mill residues. Costs for roundwood and mill residues used for bedding should be approximately $24 and $6 per ton (dry basis) respectively, based on the cost of similar materials used for pulp chips.

Constraints

As there is very little aspen production presently, little aspen roundwood or residue is available to establish a viable market for aspen bedding. However, the bedding market appears to be growing. Aspen could likely be a source of supplemental or replacement material. In this market, competition from the coniferous species should be minimal since there is an active pulp market for softwood residues and roundwood.

One potential constraint is that both the bark and wood of aspen begins to mold if stored for long periods, especially in warm weather. Therefore, an aspen bedding operation will have to be able to "move fast" in the summer months. A second time constraint develops because the early months of the year are the time of greatest demand for bedding. In order not to lose some of the wood bedding market, inventories would have to be increased in the fall. The wood bedding supply must be dependable throughout the year.

Dried bedding is more desirable than wet bedding as it is more absorbent.

Table 38. Estimated Bedding Use Pounds Per Year (kg per year). (Gray 1973)

Livestock	Usage	
	lb/yr/animal	kg/yr/animal
Laying Hens	10	5
Swine (Sows)	400	180
Dairy Cows	300	135
Feeder Cattle	200	90

Desirability

Because the raw material for bedding can be residue, or trees unsuitable for sawtimber (such as those from Site Classes 3 and 4), this use is important in an over-all utilization/land management scheme. Further, because low capital is required, "on-farm" production is a possibility using small pieces of wood and a corn chopper or portable hog. One major advantage aspen has over other species is that it is splinterless, an especially significant factor for poultry use. Wood residues can be baled in a hay baler for convenience in handling.

Cattle Feed

Cattle consume about 4349 pounds (1973 kg) of feed per head per year while "on feed." In a 150 day feed lot, they consume about 750 pounds (340 kg) of roughage per hand. In a wintering maintenance ratio, about 2500 pounds (1100 kg) of roughage is required per head. In past years, adequate hay has been available for feed in most regions; however, shortages have occurred in scattered areas. Many climatologists believe that the Western Plains have enjoyed a series of wet years, with the cycle now headed toward a drier period. As a result, hay supplies will be reduced. Further, with increasing food demand worldwide (and therefore an increasing export potential for agricultural food crops), hay may not be the most profitable or the wisest use of Alberta's crop land. The possibility of using aspen wood and bark (or even aspen foliage) for a portion of the feed for cattle and other ruminants, such as sheep, has potentially important consequences in the area, especially in terms of aspen forest management and utilization.

In addition to feeding cattle and sheep, aspen could be potentially used in feeding many zoo animals. It could also be used as an emergency winter range feed supplement for big game animals when natural forage is scarce.

Technical Considerations

An acceptance diet for cattle and other ruminants (and large animals) must provide roughage, minerals, energy, protein, and vitamins. Aspen wood and bark can be used in a ruminant feeding program to supply roughage and/or energy. It is especially attractive because it's splinterless and has some initial digestibility. Although untreated aspen wood cannot provide adequate energy, due to its low digestibility, an inexpensive steam treatment has been reported in laboratory tests to modify the wood to provide digestibility levels on the same order as hay (Bender 1970, Heaney and Bender 1970, Milligan 1974). Commercialization trails of steaming have not been as successful (Stake Technology Ltd.). There are also other more expensive treatments that improve digestibility (Table 39), but they are not now commercially feasible in small or medium scale plants. Aspen wood has little or no protein or vitamin value. (This is true for all wood species, not just aspen.)

On the other hand, aspen bark is fairly digestible without any treatment (Mellenberger 1972). The bark contains 3 percent crude protein and many

Table 39. Digestibility of aspen in laboratory trials. (Baker *et al*. 1975; Bender *et al*. 1970; Enzmann *et al*. 1969)

Material and Process	Digestibility (dry matter basis)
	(pct)
Aspen wood	
Electron irradiation	78
Ball milling	80*
Swelling in anhydrous liquid ammonia	50
Swelling in sodium hydroxide	50
High pressure steaming	47 (34% - 57%)
Groundwood fibers	37
Untreated	33
Steamed *in vivo*	48 (digestible energy = 2.17 kcal/gm)
Aspen bark	
Ensiled, *in vivo*	37 (digestible energy = 1.60 kcal/gm)
Untreated, *in vivo*	50-55
In vitro	66.5
Alfalfa hay (full bloom)	51 (digestible energy = 2.11 kcal/gm)

*80% is the maximum possible.

vitamins (Enzmann et. al. 1969), although it is quite bitter in taste. A strong phenolic smell (like shoe polish) is often noted. By contrast, wood and bark from coniferous species have not been very digestible in laboratory trials.

Both the bark and wood are reported to be very palatable in some tests, (but the opposite in other tests) to cattle, sheep, and goats and many zoo animals. Bark and wood are not suppose to affect meat quality when used in a balanced ration but the United States Dept. of Agriculture has not approved aspen feed. The Canadian Dept. of Agriculture is following test results.

Some undesirable side effects of aspen with sheep affecting wool production and mortality of the offspring have been noted in preliminary work at the University at Saskatoon.

Another unanswered point in feeding is the effect of different types of aspen wood and bark (e.g., heartwood, sapwood, fissured bark) on digestibility. The chemical composition of these different types of wood and bark differs from "normal" wood and bark. Some variation in feeding results might therefore be expected as the type of raw material changes.

In short, aspen appears to have a very good technical potential for feed (based on laboratory trials) as roughage in a concentrated feed and as a less expensive energy source in maintenance or fattening feeding programs. Further research is still needed to develop the full potential and address unanswered, yet critical questions.

Resource

There are three potential sources of raw material for aspen feed:

1) Whole trees, especially those as might be obtained from power line clearings, ski area maintenance, scenic or wildlife area improvements, and the like.

2) Tree tops, branches, and leaves as would result from usual logging practices when the merchantable bole is taken to the sawmill. Note: Aspen foliage (especially from sprouts) is a normal part of the diet of cattle grazing in aspen forests.

3) Manufacturing residue, using the 60 percent of the log that is not converted to lumber (both bark and wood) or using only the bark.

These three sources produce different amounts and types of wood and bark. Previous studies (cited previously) have only looked at sound aspen wood. The digestibility or other effects of decayed wood are not known. Some observations suggest that young aspen wood has higher digestibility than older wood. Foliage is reported to be very digestible.

The utilization of aspen for feed can be important in the overall aspen utilization and timber management scheme, because

1) short length logs can be utilized

2) partially decayed logs can possibly be utilized

3) logs can be from trees of poor form and small diameter

4) processing and capital investment costs are possibly low

5) small operators can harvest logs from locations too remote or too small for typical sawtimber harvesting

6) mill residues can be used

7) whole tree-chipping can be considered.

Economic Considerations

Aspen used for feed can come from three sources-whole trees, harvesting residues, and manufacturing residues. The cost of using manufacturing residues are summarized (Table 40).

One possibility for aspen feed is that ranchers may be able to harvest aspen roundwood for their own use during the winter and process it into feed. In this case, the variable costs should be low. Further, in a "shortage" or emergency feed situation, economic considerations are less constraining. At the present time, there is not a large enough aspen using industry to supply much harvesting or mill residues, although this may change. However, with hay prices of $80. per ton or higher, producing aspen feed from roundwood has potential. However, the costs of raw material must be quite low, in any case.

Constraints

The major potential constraint is economic, as the aspen must compete with hay. However, this report indicates that aspen can be manufactured for under $50 per ton ($45/tonne), a competitive price, and further, that hay shortage might be imminent. Another constraint is that the idea of feeding aspen is new so there will be a resistance to change. Finally, all the operating parameters have not yet been well defined. That is, the response of digestibility to too much steaming, to decay wood, to old fissured bark, and to storage of green wood or bark have not been studied or guidelines defined. Some questions on the healthiness of aspen to animals and to the human consumer exist. However, answers to these questions will come rapidly if the livestock industry expresses interest in aspen feeding.

Table 40. Estimated Cost of Using Aspen Sawmill Residues for Feed in a Small Processing Plant at the Sawmill

Item	Cost
	($ per ton of feed)
Raw material	0 to 20
Debarking and chipping	6
Other processing (estimate)	8 to 20
TOTAL	14 to 46

SELECTED ASPEN UTILIZATION LITERATURE
(excluding particleboard and pulp)

Alemdag, I.S.; Honer, T.G. 1972. Is decay volume strongly related to number of knots and log volume in poplar? Bimonthly Res. Notes (Canad.) 28(2+3): 18

Allison, F.E.; Anderson, M.S. 1951. The uses of sawdust mulches and soil improvement. USDA Circ. 891. 19 p.

Bach, L.; Wang, E.I.C.; Micko, M. 1983. Wood quality of Alberta aspen: mechanical strengths of clear, stained, and decayed wood. Agric and Forestry Bull (Univ of Alberta) 6(3):7-9.

Bailey, G.R. 1973. Aspen: Framing lumber yields high, but drying a problem. Canadian For. Ind. 92(12):43, 44, 47-49.

______________; Dobie, J. 1977. Alberta poplars - tree and log quality. Western Forest Products Lab Information Report VP-X-155. WFPL (Vancouver, BC) 8pp.

Baker, A.J. 1976. Aspen wood and bark in animal feeds. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. p. 75. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

______________. 1976. Recommendations on processing and storage of aspen residue. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 98-100. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

______________; Millett, M.A.; Satter, L.D. 1975. Wood and Wood-based residues in animal feeds.) In Cellulose Technology Research, edited by A. F. Turbak. Am. Chem. Soc. Symp. Series 10. pp. 75-105.

Baker, F.S. 1925. Aspen in the central Rocky Mountain region. USDA Dept. Bull. No. 1291. 45 pp.

Bartos, D.M. 1973. A dynamic model of aspen succession. In IUFRO Biomass Studies, Proc. IUFRO Conf, Vancouver, B.C.

Bas, F.J.; Ehle, F.R.; Goodrich, R.D. 1985. Evaluation of pelleted aspen foliage as a ruminant feedstuff. J Animal Science 61(5):1030-1036.

Bender, F. et. al. 1970. Potential of streamed wood as a feed for ruminants. For. Prod. J. 20(4):36-41.

Billups, N.F.; Cooper, B.F. 1962. Wood products as tablet-disintegrating agents. For. Prod. J. 12(6):280-282).

Bollen, W.B.; Glennie, D.W. 1961. Sawdust, bark, and other wood wastes for soil conditioning and mulching. For. Prod. J. 11(1):38-46.

Brinkman, K.A.; Roe, E.I. 1975. Quaking aspen: silvics and management in the Lake States. USDA For. Serv. Ag. Hdbk. No. 486. 52 pp.

Bulgrin, E.H. et al. 1966. Veneer yields from Lake States aspen. USDA For. Serv. Res. Pap. FPL 59. 8 p.

Caesar, P.W. 1974. Poplar--its past and future as a lumber product. In Poplar Util. Symp., pp. 124-135. West For. Prod. Lab Info. Rpt. VP-X-127 (Vancouver).

Chow, S. 1972. thermal reactions and industrial uses of bark. Wood and Fiber 4(3):130-138.

Cooper, P.A. 1976. Pressure preservative treatment of poplar lumber. Forest Prod. J. 26(7):28-31.

Davidson, R.W. et al. 1959. Decay of aspen in Colorado. USDA For. Serv. Rocky Mtn. For. and Range Exp. Sta. Pap. No. 45. 14 p.

Davis, E.M. 1962. Machining and related characteristics of U.S. hardwoods. USDA Tech. Bull. 1267. 68 p.

______________. 1947. Machining and related properties of aspen. USDA For. Serv. Lake states Aspen Rep. No. 8. 8 pp.

Delmhorst Instrument Co. c. 1975. Things to consider to best utilize moisture meters on wood. Technical Bulletin 5958-481. (Boonton, NJ). 4 p.

Dost, W.A. 1968. Comparative cost study made on steam production. Forest Ind. 95(2):90-93.

Edminister, C.B.; Mowrer, H.T.; Hinds, T.E. 1982. Volume tables and point-sampling factors for aspen in Colorado. USDA Forest Service Rocky Mountain forest and Range Exp. Sta. Research.

Enzmann, J.W. et al. 1969. Chemical composition and nutritive value of poplar bark. J. Ani. Sci. 29(4):653-660.

Erickson, J.R. 1972. The moisture content and specific gravity of the bark and wood of northern pulpwood species. USDA For. Serv. Res. Note NC-141. 3 pp.

Fasick, C.A. et al. 1973. Evaluation of the use of wood products in mobile home manufacture. For. Prod. J. 23(6):11-16.

Feihl, A.O. 1958. Veneer and plywood from aspen poplar. Canad. Woodworker: 30-32.

Feihl, A.O.; Godin, V. 1968. Veneer and plywood from trembling aspen. In Growth and Utilization of Poplars in Canada, Chapter XIII. Department of Forestry and Rural Development, Publ. No. 1205. Ottawa. Fitzpatrick, J. M. and Stewart, J. V. 1968. The poplar resource. In Growth and Utilization of Poplar in Canada, Chapt. XIV, pp. 214-239. Dept. For. and Rural Devel. Publ. 1205 (Ottawa).

Flann, I.B. 1974. Conversion of hardwood logs into factory lumber and furniture components. Eastern Forest Products Laboratory (now Forintek)

Fullinwider, J.A. 1976. Colorado steers and aspen bark. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 76-83. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

Gill, T.G.; Phelps, R.B. 1969. Wood used in manufacturing industries, 1965. USDA For. Serv. Stat. Bull. No. 440. 100 p.

Goff, W.H. 1976. Problems and opportunities associated with aspen logging systems. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 91-94. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

Gottfried, G.J.; Jones, J.R. 1975. Logging damage to advance regeneration on an Arizona mixed conifer watershed. USDA For. Serv. Res. Pap RM-147. 20 p.

Gray, J.R. 1973. Uses of sawdust and bark in New Mexico. New Mexico Ag. Exp. Stn. Bull. No. 608. 28 p.

______________; Canady, J.D. 1971. Feasibility of baling wood shavings and sacking sawdust in the Four Corners Economic Development Region. New Mexico Ag. Exp. Stn. Spec. Rpt. No. 10. 27.

Green, A.W.; Setzer, T.S. 1974. The Rocky Mountain timber situation, 1970. USDA For. Serv. Resource Bull. INT-10. 78 p.

Hallock, H.; Malcolm, F.B. 1972. Sawing to reduce warp in plantation red pine studs. USDA For. Serv. Res. Pap. FPL 164, 27 p.

Hanks, L.F.; Brisbin, R.L. 1978. Lumber grade yields for graded aspen (Populus tremuloides) logs and trees. USDA Forest Service Research Paper NE-423. Northeastern For. Exp. Sta. (Delaware, OH) 13pp.

Haygreen, J.G. 1970. The strength of aspen studs. Univ. of Minn. For. Notes No. 221, 4 p.

______________ and Wang, S.-S. 1966. Some mechanical properties of aspen wetwood. For. Prod. J. 16(9):118-9.

Heaney, D.P.; Bender, F. 1970. The feeding value of steamed aspen for sheep. For. Prod. J. 20(9):98-102.

Heebink, T.B. 1962. Performance of pallets form low quality aspen. USDa For. Serv. FPL Rpt. No. 2264. 14 p.

Hinds, T.E.; Krebill, R.G. 1975. Wounds and canker diseases on Western aspen. USDA For. Serv. Forest Pest Leaflet 152. 9 p.

______________; Wengert, E.M. Growth and decay losses in Colorado aspen. 1977. USDA For. Serv. Res. Pap. RM-193. 10 p.

Hiratsuka, Y.; Loman, A. A. 1984. Decay of aspen and balsam poplar in Alberta. Can. For. Serv. Information Rpt. No. NOR-X-262. (Alberta) 19pp.

Huffman, D.R. 1972. Kiln-drying aspen studs. Forest Prod. J. 22(10):21-23.

______________; Cech, M.Y. 1976. Kiln-drying 1-inch aspen. Canadian Forest Industries 96(8):27-35.

Jenson, R.A.; Davis, J.R. 1953. Seasonal moisture variations in aspen. Minnesota Forestry Notes no. 19. 2 p.

Johnson, R.P.A. 1947. Mechanical properties of aspen. USDA For. serv. Lake States Aspen Rpt. No. 7. 16 p.

Jones, J.R. 1975. Regeneration on an aspen clearcut in Arizona. USDA For. Serv. Res. Note RM-285. 8 p.

______________; Trujillo, D.P. 1975. Development of some young aspen stands in Arizona. USDA For. Serv. Res. Pap. RM-151. 11 p.

Kaufert, F.H.; Neetzel, J.R.; Hanson, W. 1978. Thirty-five years of test results on fence posts treated with pentachlorophenol. Minnesota Forestry Notes No. 270. Univ. of Minn. (St. Paul) 4pp.

Keays, J.L., et al. 1974. Present and future uses of Canadian poplars in fibre and wood products. Western For. Prod. Lab. Info. Rpt. VP-X- 120 (Vancouver). 49 p.

Kennedy, R.W. 1965. Anatomy and fundamental wood properties of poplar. In Growth and Util. of Pop. in Canada, Chap IX, pp. 149-168. Dep. For. and Rural Devel. Publ. No. 1205 (Ottawa).

Knutson, D.M. 1968. Wetwood in trembling aspen (Populus tremuloides Michx.) PhD thesis, Univ. of Minn. (University Microfilms No. 69-11417) 152 p.

Knutson, R. 1970. A look at the mine-timber market in the Appalachian bituminous coal region. USDA For. Serv. Res. Pap. NE-147. 9 p.

Koepke, M.S. 1976. Aspen market opportunities: lumber, excelsior, and residue. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 47-52. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

Krebill, R.G. 1972. Mortality of aspen on the Gros Ventre elk winter range. USDA For. Serv. Res. Pap. INT-129. 16 p.

Large, H.R.; Frost, R.E. 1974. Quality distribution of pallet parts from low-grade lumber. USDA For. serv. Res. Pap. NE-284. 9 p.

Larmore, F.D. 1959. Influence of specific gravity and resin content on properties of particleboard. For. Prod. J. 9(4):131-134.

Lawrence, J.D.; Fasik, C.A. 1973. Interregional patterns of wood use in mobile home production, 1971-1975. For. Prod. J. 23(11):16-20.

Leach, H.A.; Gillies, G.B. 1972. An economic study of the manufacture of aspen lumber for panels, dimension stock, and pallets. Dep. Ind. Trade and Comm, Wood Prod. Branch (Ottawa). Unnumbered.

Leuschner, W.A. 1972. Projecting the aspen resource in the Lake States. USDA For. Serv. Res. Pap NC-81. 32 p.

Little, E.L., Jr. 1971. Atlas of United States trees. Vol. 1. Conifers and important hardwoods. USDA For. serv. Misc. Publ. No. 1146.

Littleford, T.W.; Roth, J.W. 1975. Evaluation of structural grades of northern aspen. Western For. Prod. Lab. Info. Rpt. VP-X-148. (Vancouver) 17 p.

Lowery, D.P. 1976. Potential utilization of aspen residues in the Rocky Mountains. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 95-97. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

Lunt, O.R.; Clark, B. 1959. Horticultural applications for bark and wood fragments. For. Prod. J. 9(4):39A-42A.

Lutz, J.F. 1972. Veneer species that grow in the United States. USDA For. Serv. Res. Pap. FPL 167.

Mackay, J.F.G. 1978. Drying trembling aspen lumber in direct-fired kilns. Forest Prod. J. 28(1):21-23.

_______________. 1976. Delayed shrinkage after surfacing of high-temperature kiln dried northern aspen dimension lumber. Forest Prod. J. 26(2):33-36.

_______________. 1975. Properties of northern aspen discolored wood related to drying problems. Wood and Fiber 6(4):319-326.

_______________. 1974. High-temperature kiln-drying of northern aspen 2-by 4-inch light-framing lumber. For. Prod. J. 24(10):32-35.

_______________, E.A. Hamm and R. O. Foschi. 1977. Reducing crook in kiln-dried northern aspen studs. Forest Prod J 27(3):33-38.

Marden, R.M. et al. 1975. Wood and bark percentages and moisture contents of Minnesota pulpwood species. USDA For. Serv. Res. Pap. NC-114. 9 p.

Markwardt, L.J.; Wilson, T.R.C. 1935. Strength and related properties of woods grwon in the United States. USDA Tech. Bull. No. 479. 108 p.

McIntosh, J.A. 1977. Aspen. In Forest Utilization Symposium Proceedings. pp. 1-5. Forintek Canada Corp. Special Publication SP No. 6. (Vancouver, B.C.).

Mellenberger, R.W. et al. 1972. Digestion of aspen, alkali-treated aspen, and aspen bark by goats. J. Anim. Sci. 32(4):756-763.

Miller, R.L.; Choate, G.A. 1964. The forest resource of Colorado. USDA For. serv. Resource Bull. INT-3. 54 p.

Milligan, J.D. 1974. The use of aspen poplar in livestock diets. In Poplar Util. Symp. pp. 196-205. Western For. Prod. Lab. Info. Rpt. VP-X-127. (Vancouver)

Millikin, D.E. 1955. Determination of bark volumes and fuel properties. Pulp and Pap. Mag. of Canada 56(13):106-108.

Mullins, E.J.; McKnight, T.S. 1981. Canadian Woods: Their Properties and Uses. Univ of Toronto Press. 389pp.

Neilson, R.W. 1974. Consideration for an integrated poplar complex. In Pop. Util. Symp. pp. 233-242. Western For. Prod. Lab. Rpt. VP-X-127. (Vancouver)

Noreen, P.A.; Hughes, J.M. 1968. Some economic guides for alternative uses of aspen logs. Univ. of Minn. Agric. Exp. Stn. Tech. Bull. 260. Forest Serv. 3. 19 p.

Panshin, A.J. et al. 1950. Forest products, their sources, production, and utilization. McGraw-Hill Book Comp., Inc. (New York). 549 p.

Peterson, G. 1961. Volume tables for aspen in Colorado. USDA For. Serv. Res. Note RM-63. 4 p.

Petersen, H.D. 1975. Wisconsin forest products price review, lumber edition. University of Wisconsin-Extension (Madison). 4 p.

Pfaff, F. 1974. Electric moisture meter correction factors for eastern Canadian species. Eastern Forest Products Laboratory (now Forintek) Report OPX 89E.

Pronin, D. 1971. Estimating tree specific gravity of major pulpwood species of Wisconsin. USDA For. Serv. Res. Pap. FPL 161. 16 p.

Rasmussen, E.F. 1961. Dry Kiln Operators Manual. USDA Ag. Hdbk No. 188. (Wash. D. C.) 197 p.

Reade, A.E.; McQueen, R.E. 1983. Investigation of white rot fungi for the conversion of poplar into a potential feedstuff for ruminants. Can. J Microbiology 29(4):457-463.

Reeves, J.D. 1974. The potential of poplar for pallets. In Poplar Util. Symp., pp. 136-152. West. For. Prod. Lab. Info. Rpt. VP-X-127 (Vancouver)

Reineke, L.H. 1966. Wood flour. USDA For. Serv. Res. Note FPL-0113. 13 p.

______________. 1964. Briquets from wood residues. USDA For. serv. Res. Note FPL-075. 7 p.

Reynolds, H.G. 1969. Aspen grove use by deer, elk, and cattle in Southwestern coniferous forests. USDA For. Serv. 4 p.

Runyon, G.K. 1976. Lumber markets for Rocky Mountain aspen. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 46. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

Sachs, I.B. et al. 1974. Scanning electron microscopy of bacterial wetwood and normal heartwood in poplar trees. In Proc. Workshop Scan. Elec. Micros. and Plant Sci. pp. 453-460. IIT Inst. Tech. (Chicago).

Sampson, G.R.; Ruppert, F.A. 1983. Potential for economical recovery of fuel from land clearing residue in interior Alaska. USDA Forest Service Research Papaer PNW-308. Pacific Northwest For. and Range Exp. Sta. (Fairbanks) 11pp.

Sands, W. 1947. Aspen for containers. USDA For. serv. Lake States Rpt. No. 10, 12 p.

Schier, G.A. 1975. Deterioration of aspen clones in the middle Rocky Mountains. USDA For. serv. Res. pap. INT-170. 14 p.

Schlaegel, B.E.; Ringold, S.B. 1971. Thinning pole-sized aspen has no effect on number of veneer trees or total yield. USDA For. Serv. Res. Note NC-121. 11 p.

Sendak, P.E. 1973. Wood pallet manufacturing costs in Pennsylvania. FPJ 23(9):110-113.

Shulman, J.; Wilner, B.L. 1960. New uses for wood flour in rigid polyurethane foams. For. Prod. J. 10(10):487-490.

Singh, T. 1984. Variation in the ovendry wood density of ten prairie tree species. Forestry Chron 60(4):217-221.

Smith, J.H.G.; Kozak, A. 1967. Thickness and percentage of bark of the commercial trees of British Columbia (Unnumbered). Univ. of B. C. (Vancouver). 33 p.

Stayton, C.L. et al. 1971. Aspen and paper birch mixtures as raw material for particleboard. For. Prod. J. 21(12):29-30.

Steiner, P.R.; Anderson, A.W. 1982. Effects of veneer preheating temperature, press and assembly time on aspen LVL. Forest Prod J 32(10):39-44.

Stern, E.G.; Wallin, W.B. 1975. Design of aspen pallet deckboard-stringer joints. For. Prod. J. 25(2):51-54.

Stern, R.K. 1973. Increasing serviceability of wood pallets. USDA For. Serv. Res. Pap. FPL 215. 12 p.

Stewart, H.A. 1973. Cross-grain knife planing improves surface quality and utilization of aspen. USDA For. Serv. Res. Note NC-127. 4 p.

Sutter, C.A. 1988. Aspen chop sticks become a big business. National Hardwood Magazine 61(13):38,40.

Taylor, F.A. 1977. Lumber markets. Forest Utilization Symposium Proceedings. pp. 17-19. Forintek Canada Corp. Special Publication SP No. 6. (Vancouver, BC)

Thomas, R.P. 1968. Decay as a limiting factor on poplar utilization. In Growth and Utilization of Poplars in Canada, Chapter XIII. Department of Forestry and Rural Development, Publ. No. 1205. Ottawa.

Thompson, R.D. 1972. Aspen studs produced on chipping headrig. Forest Industries: 60-62.

Troxell, H.E. 1976. Aspen veneer and plywood. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 84-86. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

U.S.D.A. 1973. The outlook for timber in the United States, USDA For. Serv. For. Res. Rpt. 20. 367 p.

__________________. 1965. Regional wood use by manufacturing industries. USDA For. Serv. Res. Note WO-7. 10 p.

Ward, J.C. 1986. The effect of wetwood on lumber drying times and rates: an exploratory evaluation with longitudinal gas permeability. Wood and Fiber Science 18(2):288-307.

Ward, J.C. 1976. Kiln drying characteristics of studs from Rocky Mountain aspen and Wisocnsin aspen. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 73-74. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

Wells, J. 1974. Operating experience with poplar plywood. In Pop. Util. Symp. pp. 206-211. Western For. Prod. lab. Rpt. VP-X-127 (Vancouver)

Wengert, E.M. 1987. Development of a grading system for short length lumber. In Proceedings Hardwood Symposium, pp.120-141. Hardwood Research Council (Memphis, TN). Wengert, E. M. 1976. Market opportunities and limitations for Rocky Moutain aspen. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. p. 53. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. Ft. Collins.

__________________. 1984. Furniture parts at half the cost. Furniture Design and Mfr. 38(12):49-50,52.

__________________. 1977. Detecting heartwood and sapwood in aspen. Wood Science.

__________________. 1976. Some properties and characteristics of aspen that affect utilization in the Rocky Mountains. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 62-67. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

__________________. 1976. Lumber yield from Rocky Mountain aspen. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. p. 69. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

__________________. 1973. Aspen workshop held by Wood Seasoning Assn. South. Lbmn. 227(2524):190-191.

__________________, and D. M. Donnelly. 1980. Lumber yield potential of aspen in the Rocky Mountains. USDA Forest Service, Rocky Mountain Forest and Range Exp. Sta. Research paper RM-227. (Ft. Collins, CO). 7 p.

__________________, D. M. Donnelly, D. C. Markstrom, and H. E. Worth. 1985. Wood utilization. In Aspen: Ecology and Management in the Western United States. pp. 169-180. USDA Forest Service. Rocky Mountain Forest and Range Exp. Sta. General Technical Report RM-119.

WWPA. 1981. Western Lumber Grading Rules. Western Wood Products Association Portland). 222p.

Yanchuk, A.D.; Dancik, B.P.; Micko, M.M. 1983. Intraclonal variation in wood density of trembling aspen in Alberta. Wood and FIber Science 15(4):387-394.

Yerkes, V.P. 1976. Processing low quality trees by the SHOLO approach. In Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Proceedings of the Symposium. pp. 70-72. USDA Forest Service Rocky Mountain Forest and range Exp. Sta. General Technical Report RM-29. (Ft. Collins, CO).

_______________. 1967. Effect of seasonal stem moisture variation and log storage on weight of black hills ponderosa pine. USDA For. Serv. Res.