Energy ENFOR from the Forest

ANALYSIS OF SALVAGE YARDING SYSTEMS AND COSTS IN PACIFIC COAST FORESTS

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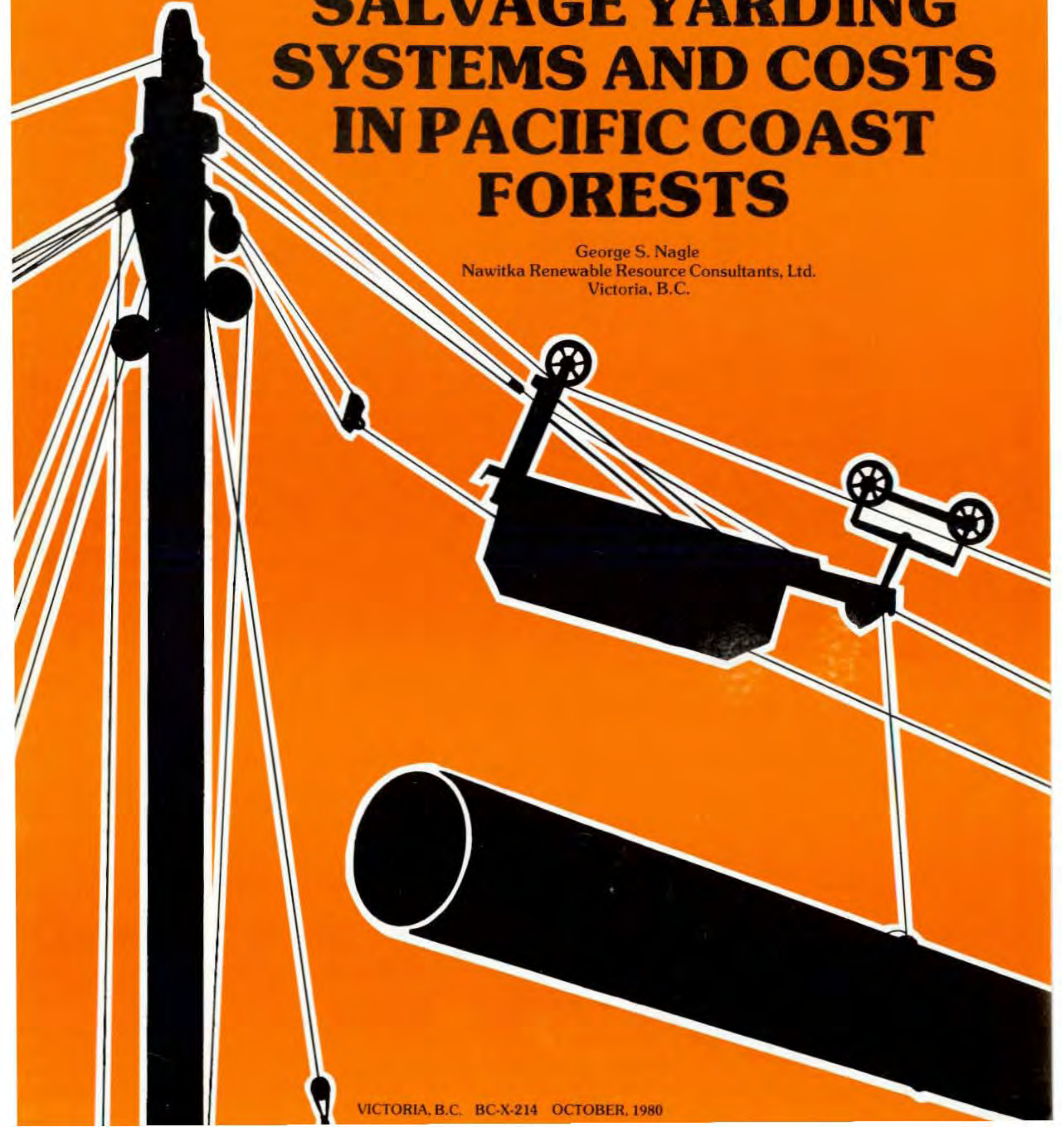

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FOREWORD

ENFOR is the bilingual acronym for the Canadian Forestry Service's ENergy from the FORest (ENergie de la FORet) program of research and development aimed at securing the knowledge and technical competence to facilitate, in the medium to long term, a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger Federal Government initiative to promote the development and use of renewable energy as a means of reducing our dependence on petroleum and other non-renewable energy sources.

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ABSTRACT

The objective of this study was to review and analyze existing cost estimates for harvesting forest residuals to guide development of new equipment and systems. Major problem areas identified were piece size and accessibility. Thirteen separate studies were reviewed in detail, providing a range of yarding costs from $5 - 70 per bone dry tonne, depending on utilization standards and accessibility. On the basis of the analysis done for this report, about 2-million bone dry tonnes per year are estimated to be available in British Columbia at a cost not exceeding $30/tonne at roadside. This represents about 50% of available material. New technology will be required to harvest the remainder.

RESUME

Le but de la présente étude était de revoir et d'analyser les évaluations disponibles des coûts de récupération des résidus forestiers pour aiguiller la mise au point de nouveaux équipements et systèmes. La dimension et l'accessibilité des rémanents ont été les principaux secteurs problèmes identifiés. Treize études indépendantes ont été passées en revue de façon détaillée, fournissant un éventail de coûts de débusquage allant de $5 à $70 par tonne anhydre, selon les normes d'utilisation et l'accessibilité. En se fondant sur l'analyse effectuée en vue de ce rapport, l'auteur estime qu'environ 2 millions de tonnes anhydres par année seraient disponibles en Colombie-Britannique à un coût n'excédant pas $30 la tonne, rendu au bord de la route. Ceci représente environ 50% du matériel disponible. Il faudrait de nouvelles techniques pour récolter le reste.

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INTRODUCTION

The world crisis in petroleum resources has stimulated public and private interest in alternate energy sources, including forest-based fuels. To better define the fuel resource base in Canada's forests, and to develop a new generation of wood combustion equipment, Energy, Mines and Resources Department of Canada (EMR) has instituted the ENFOR and FIRE programmes.

This project has been undertaken as a part of the ENFOR (Energy from the Forest) programme. The project is a segment of an integrated effort to define the economic energy potential of Pacific Coast forests.

Pacific Coast forests contain a significant mass of wood, bark and foliage material which is not harvested from the land in current operations. A further mass, mostly bark and misshapen material is currently extracted to various transit and processing points and then abandoned as uneconomic. This uneconomic material is disposed of at some cost, depending on its characteristics and the relevant pollution control regulations.

A general stiffening of regulations on open burning, and on dumping of these materials has raised disposal costs at almost all points. In combination with rising petroleum prices, the impact of these costs has been to increase the proportion of "delivered" wood wastes which is being used as a commercial fuel at processing centers.[1]

At present, trials and studies are underway in all regions of Canada and the United States with the common objective of increasing the proportion of the logged stand which is delivered to a processing point (e.g., roadside, landing, log yard or pond, mill site). Differing timber types, terrain, and product markets dictate a wide range of technology and systems for this purpose.

In mature or overmature Pacific Coast forests, with large timber on steep and broken terrain, a particularly difficult and specialized set of problems exist. However, since the volume of woody material left after logging in these types can exceed the total logged volume from stands in other regions, the physical resource opportunity is substantial.

Many individual trials of residual logging have been conducted, over the years, on the B.C. Coast, with a fibre extraction objective. ENFOR projects since 1977 have attempted to improve the definition of the residual biomass after logging (Jones 1979) and have conducted trials of particular equipment under particular conditions (Blakeney 1980). It is clear that the extraction of forest residuals - yarding, loading, hauling, present key difficulties.

To guide future development efforts in the logging of residuals, this project was initiated in early 1980, with the following objectives:

- to review available materials and industry experience on the extraction of coast forest residuals, with particular emphasis on the yarding or skidding phase, and with regard to productivity of equipment under different conditions.
- to analyze this experience by updating cost estimates where possible, reviewing its relevance to the new energy harvesting possibilities, and outlining emergent needs for new equipment and systems for bringing forest residuals to roadside.

The report has three main sections, titled: Problem Definition, Cost Analysis, and Future Development Prospects. The first section is particularly important, if not very new. Many inter-relations exist between the various stages of extraction **and processing,** and a gradual process of increased residue utilization is underway at all points. A total view of current and prospective extraction and primary processing systems must be maintained under these conditions.

[1]This represents a return to earlier patterns when west coast mills generated some or all of their own steam and power by burning wood wastes.

PROBLEM DEFINITION

The Resource Opportunity

Unutilized woody materials, suitable for burning, are left over at each stage of forestry sector operations. Figure 1 provides a rough picture of the present proportion of residual materials left in the forest, handled in mill yards (including debarking), and generated by manufacturing processes on the B.C. Coast.

If the logged material is equated to 1978 Coast log scale of 32.3 million m^3 or roughly 25.9 million green tonnes, the estimated total of non-pulp residual materials was about 7.2 million bone dry tonnes of burnable material in that year.

The proportions shown in Fig. 1 are not static. A crude production hierarchy of wood products first (lumber, plywood), then clean wood particles for pulp, then woody fuel, then disposal has evolved in B.C. over several decades, with varying proportions to each activity at different times.

Wood product and pulp mills will probably expand their use of current "waste" or burnable material at all stages, as technology and markets change. The current residuals from manufacturing, made up mainly of sawdust and cedar materials, will likely shrink and be absorbed into fibre plants. The residues from mill yards, including bark, will likely increase rapidly, and utilization in fibre plants will continue to be problematical unless new separation/

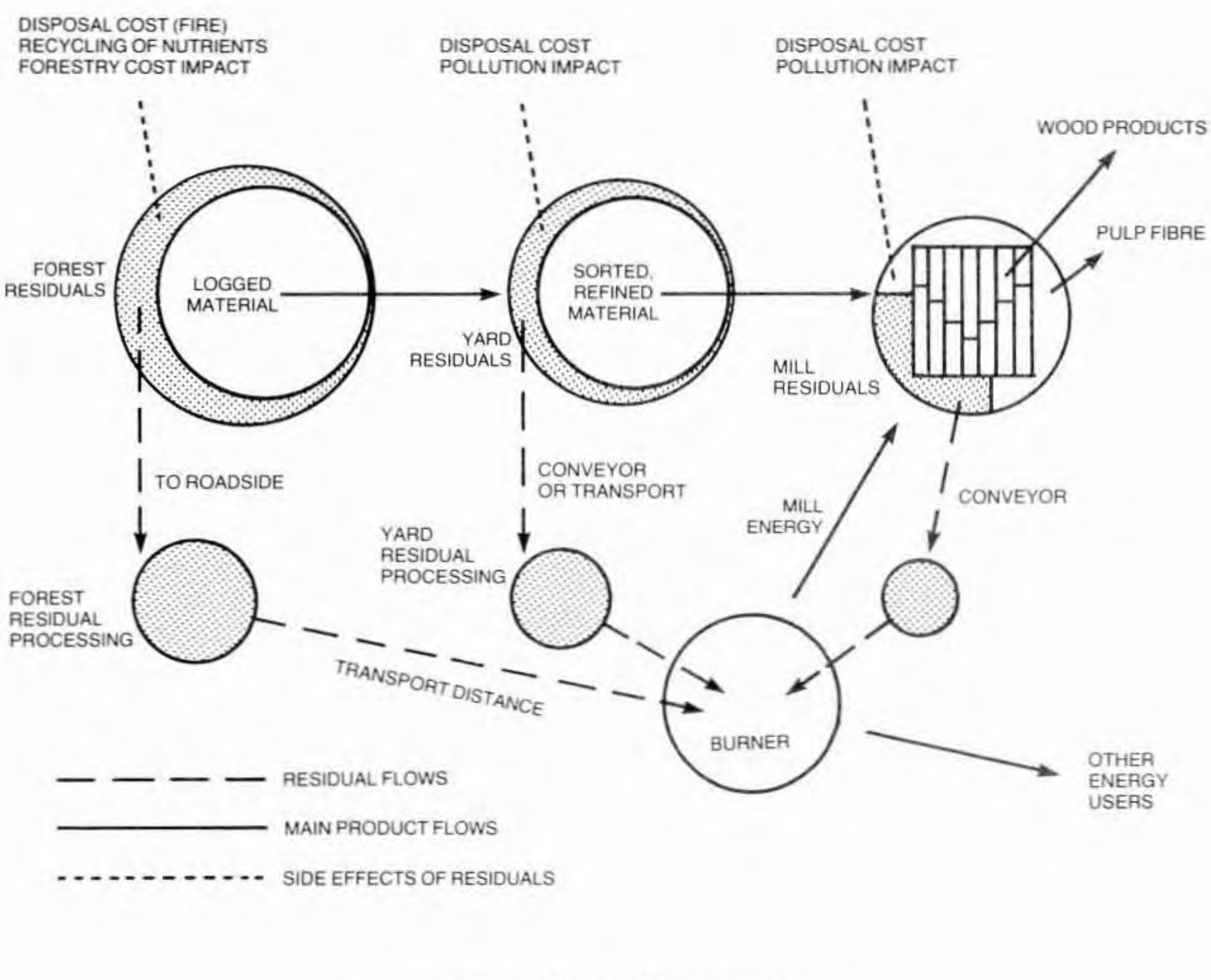


Figure 1 Potential Residual Flows on B.C. Coast
(area of circles proportional to volume of material)

processing technology is developed. These residues present a growing fuel opportunity, and entail significant disposal costs, in waste-burners or land-fills. Delivery costs to any user can be readily defined.

The largest volume of unutilized materials is that still left in the forest after logging. This group of residues is also the most variable, in physical and economic terms.

The quantity and nature of the residual material after economic logging is a function of a complex set of factors:

- present and forecast states of final product markets
- industry structure in the log-shed
- economic location of the setting
- terrain of the setting
- volume, species and condition of the stand

Most of these factors operate in a fairly straightforward and predictable manner, but there are many details and interactions that require attention. For example, steep and broken terrain not only increases cost of extraction but also will increase the volume of residuals per unit area due to breakage of commercial timber. Some species differentials are significant. Normal logging of overmature cedar trees will likely leave a high proportion of material which is very durable, may be of high value in special products (e.g., shakes) but will normally create problems for a fibre plant. Logging in overmature hemlock stands will leave large volumes of material with various degrees of rot, often in very large residual pieces. Equipment suitable for the main stand may be inappropriate for extraction of residuals.

Thus the problem of defining residue supply potentials in economic terms is not easy, and there are important links between all of the extraction and processing stages which will affect the economic cost of utilizing residues for fuel.

The first step will be to define, more closely, the physical parameters of logging residuals.

The Physical Dimensions of Logging Residues

The problems of accurate measurement of even existing logging residues are formidable on the B.C. Coast. Large and small logs, branches, foliage, slabs and splinters lie jumbled on steep and broken terrain. No historic body of data exists on volume or weight of these materials.

Since whole-tree data including tops and stumps are scarce, the subtraction approach (total - removals = residuals) is not well defined. Improved definition of residuals and of whole tree weights is currently receiving attention in the region. Several studies offer preliminary data which will be useful in attempting to define the residue extraction problem as closely as possible.

Volume Per Unit Area

The volume of residuals found by Jones (1979) on Vancouver Island is (probably) typical of the B.C. Coast.

The distinction between the drier forest types of Eastern Vancouver Island, dominated by Douglas-fir, and the wet hemlock-balsam of the North and West is clear. The data fall within the range of the residues found in Pacific forests of the U.S. (Howard

TABLE 1
VOLUME OF LOGGED TIMBER AND RESIDUALS
PER UNIT AREA ON VANCOUVER ISLAND

	Average Roundwood Removals 1977[1]	Estimated Sound Logging Residues 3" + (7.62 cm +)[2]	
	Ccf/Ac (m^3/ha)		
North and West V.I.[3]	97 (679)	37 (259)	
	.72	.28	proportions
Eastern V.I.[4]	120 (840)	23 (161)	
	.84	.16	proportions

[1]BCFS data
[2]Jones 1979
[3]Sayward, Port McNeill, Port Hardy, Gold River, Tofino, Port Alberni Ranger Districts
[4]Langford, Duncan, Lake Cowichan, Parksville, Campbell River Ranger Districts.

TABLE 2
LOGGING RESIDUES BY STAND AGE
PNW-US 1970[1]

Age of Harvested Stand	Total Residual Volume	Rotten Wood	Utility (Chip) Logs[2]	Net Residual Volume
		cunits/ac	(m^3/ha)	
101	12.4 (86.8)	1.5 (10.5)	1.0 (7.0)	9.9 (69.3)
101-200	19.5 (136.5)	3.5 (24.5)	6.0 (42.0)	10.0 (70.0)
201-300	39.2 (274.4)	10.2 (71.4)	15.0 (105.0)	14.0 (98.0)
301+	58.1 (406.7)	18.0 (126.0)	18.0 (126.0)	22.1 (154.7)

[1]Howard 1973; to 4" x 4' piece size
[2]Estimates: would be expected to be chipped in periods of tight pulpwood supply

TABLE 3
RESIDUE VOLUMES IN U.S.

	Ccf/ac	m^3/ha	Notes	
West coast				
Ore. Wash.	15.0 - 45.0	105 - 315	4"+	(includes high proportion of broken material in old growth from steep ground)
N. Rocky Mts	14.0 - 26.0	98 - 182	3"+	Larch-Douglas-fir types
S. Rocky Mts	9.30 - 17.30	65 - 121	3"+	Pines
South West				
Ponderosa Pine	10.0	70	3"+	Ponderosa types
East	7.0	49	Tops,	limbs and non-util. spp/trees, heavy to hardwoods

(Source: Henley & Clarke 1976)

1973).

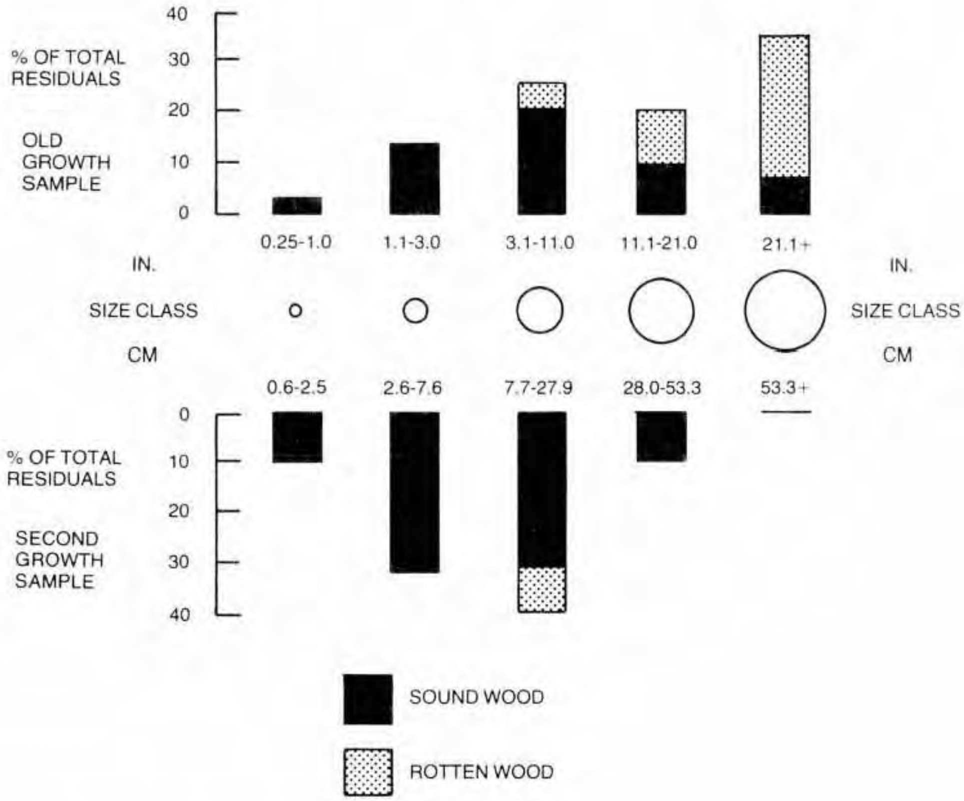
Much of the extra volume of unutilized material in wet Pacific forests is a function of over-mature stands, with larger tops and a higher proportion of rotten wood. The impact of stand age is shown clearly in Table 2, drawn from National Forest Data in Washington and Oregon.

The lower volumes of residuals in younger stands have significant import for the future, but most B.C. Coast harvesting will take place in stands over 200 years old for the next two to three decades.

A general comparison with other regions is made possible by Table 3. Logging methods and costs will be significantly different for some of these zones, and the areas with the highest volumes per unit area will not necessarily have the most economic forest residue supplies.

Size and Shape of Residue Pieces

A crucial question in designing residue extraction systems is the size of material to be handled. The variability in size within each area is even more important. In general, older Pacific Coast forests present the maximum average piece size and the



[1] Blakeney 1980

[2] The amount of rotten material in the sample stand was no doubt high due to the Phellinus weirii infection area which was being cleared

Figure 2 Distribution of Green Weight of Residues by Size Class[1]

maximum variability. Second growth forests in the region are much more uniform, and will resemble many other forest types across the continent.

Detailed data are gradually being developed in B.C. and elsewhere. Figure 2 shows the distribution of green weight of residues found by Blakeney in the second ENFOR study on Vancouver Island (1979). In the old growth sample, over half the residue is in pieces 11 inches (28 cm) and greater, and over 30% is 21 inches (53 cm) or greater. In the second growth sample, less than 10% is over 11 inches.

The condition and form of the pieces is also critical to extraction and processing. The high proportion of rotten wood, and misshapen large pieces from large tree tops present problems in handling old growth residues.

Table 4 provides another estimate of the weight of residue in Pacific forests, to different minimum piece sizes.

The equivalent factor in the residue sampled by Jones (1979) would be 0.43 bone dry tonnes per cunit of logs harvested in the North and West of Vancouver Island, and 0.22 bone dry tonnes/cunit on the East side. Since this sample included material to 3 inch diameters, a tentative conclusion could be drawn that utilization is by now closer on Vancouver Island than in the sample period in the PNW (1969).

Another approach to defining expected logging residuals is through detailed study of the whole tree. Major efforts are underway in this field in B.C. and in the Pacific Northwest, but most estimates are still based on very small samples.

Adamovich (1979) provides a profile of Douglas-fir and western hemlock trees which is useful, although

TABLE 4
RELATIONSHIP OF RESIDUE QUANTITY TO LOG VOLUME HARVESTED ON NATIONAL FOREST CLEARCUTS OF THE DOUGLAS-FIR REGION OF OREGON AND WASHINGTON IN 1969[1]
(In dry tonnes of residue per cunit of logs harvested)

Minimum piece diameter (inches)	Minimum piece length: 8 feet	12 feet	20 feet
		Gross weight of residue	
4	0.52	0.42	0.24
8	.49	.40	.23
12	.43	.35	.21
		Net weight of residue suitable for chips	
4	.35	.28	.16
8	.33	.27	.15
12	.27	.22	.12

[1]Derived from Howard (1973), in Grantham et al. 1974, p. 4

TABLE 5
GREEN WEIGHT OF RESIDUALS IN PROPORTION TO COMMERCIAL BOLE
B.C. INTERIOR

Whole Bole to 10 cm (4 in) including bark		Whole tree including bark and branches: 30 cm (12 in)	60 cm (24 in)
100	Western Hemlock	122	112
100	Wet Belt Douglas-fir	116	114
100	Dry Belt Douglas-fir	125	120

(Source: Adamovich 1979)

based in the interior wet belt. Figure 3 shows the importance of the bole, in all segments of these trees.

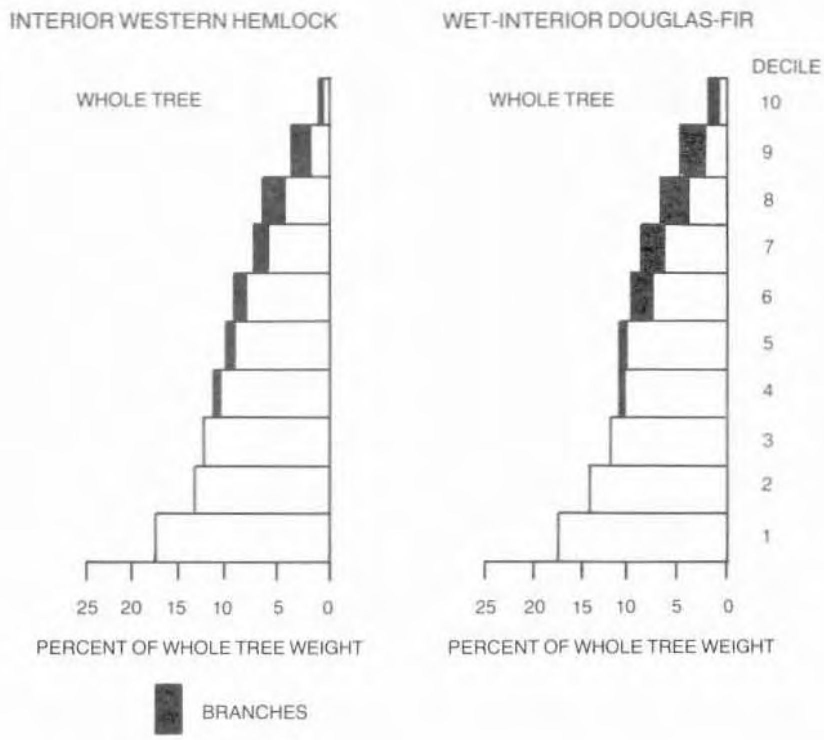
The upper bole (above 10 cm) and branches together represent 16-25% of the commercial bole weight in 30 cm (12 in) trees, and 12-20% in 60 cm trees (Table 5).

These general proportions are supported by the estimates provided by Howlett (1977), and illustrated in Fig. 4.

In this case, the bole above 10 cm, and branches, represent about 21% of the weight of the bole below 10 cm.

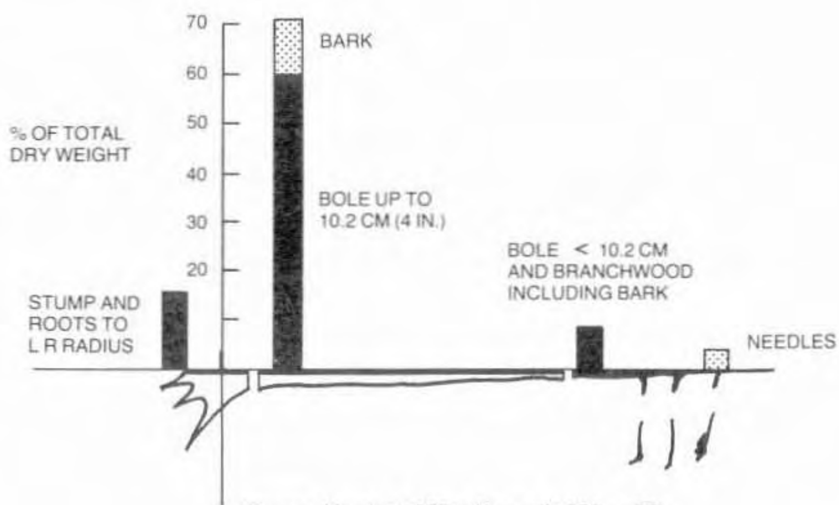
From these imperfect estimates of residue volume per unit area, and of tree characteristics, several conclusions can be drawn which will be important in economic extraction of forest residues in the next two to three decades on the B.C. Coast:

- 20-40 cunits, or 18-36 bone dry tonnes of woody-materials 3 in (7.6 cm) and larger is currently left on each acre logged in coastal B.C.
- a large fraction of these residuals is bole material (probably 80% or more)
- a significant volume of branchwood remains undetected in these residue estimates, but may be 20-25% of the total bole volume



(Adamovich 1979)

Figure 3 Green-Weight Distribution for Deciles of Tree Height



(Source: Howlett 1977 in Bergvall 1978, p. 57)

Figure 4 Weight Distribution of Components of Mature Softwood Trees

Resource Institutions

The amount and type of material left on each setting after logging is dependent on logging and forest management practices, as well as on physical facts and economic pressures. The prevalence of public forest in the resources of B.C. and in the PNW U.S. will be an important factor in the long run supply of residual materials.

Both the BCFS and the USFS have to be concerned with public responses to forest residues at current levels. The Close Utilization policies of the BCFS have attempted to reduce the volume left after logging on the Coast for two decades. The degree of success has probably been greater in the more uniform forests of the Interior regions, but regulation and economics have combined to gradually reduce, as well, the volume left behind on the Coast.

The only available data by land ownership for the PNW U.S. (Grantham et al. 1974) seems to show closer utilization on private lands than on public lands. This study found an average 15-20 cunits/acre left on private lands, and 30-35 cunits/acre on public lands. The difference seems likely to be due more to differences in timber types (Douglas-fir and much second growth on private lands, old growth hemlock and firs on public lands) than to land ownership or forest management practices.

However, increasing regulation of utilization levels, of residue disposal practices at all stages, and intensification of forest management practices will continue to affect the economics of residue extraction and utilization.

The Economic Opportunity

As petroleum prices rise, it is possible to envisage a gradually tightening "net" being cast over logging residuals, according to their extraction and processing cost. Unfortunately for the easiest versions of such gradualism, there are significant scale problems (or lumps) in energy supply functions. Even minor thermal stations require complete commitment of some fixed proportion of residues within a log shed, all at once. Alternative power sources, such as hydro or nuclear stations, enter the market in even larger "chunks" and affect the market for forest-based fuels for decades at a time.

The rising capital and environmental costs of these alternatives may appear to favor forest-based energy, but if the expected delivery cost of forest residuals cannot be better defined than at present, no sensible planning is possible for energy from this source.

The economic opportunity to utilize forest-based materials for energy is therefore wholly dependent on the development of cost data for existing technologies, and cost estimates for feasible new technologies of extraction and processing. The B.C. Coast waterways provide a better opportunity for a gradual, economic approach to supply than most inland timber sheds, but careful assessment of alternative wood sources remains essential.

The cost of collecting coast forest residues to roadside has generally been accepted to be the major uncertainty of economic supply of this material for any purpose. Therefore, this review will attempt to clarify the knowns, and provide a framework for some speculations about this activity.

The Economic Location of Coast Residues

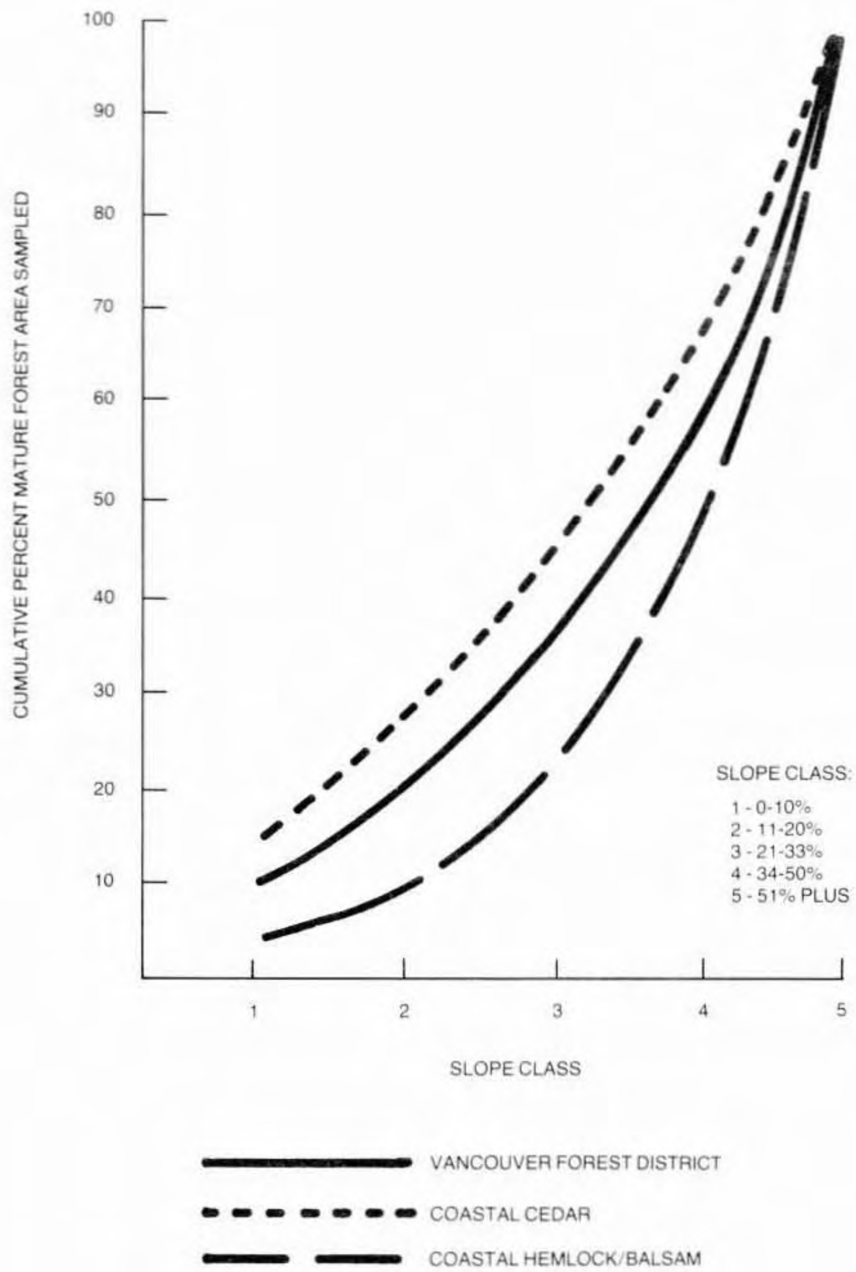
The bulk of the old growth logging remaining on the B.C. Coast will be in the wetter hemlock-balsam types, and on steep ground. Figure 5 illustrates the problem (Hedin 1978). In the Vancouver Forest District, only about one-third of the mature forest area is on slopes less than 30%, and nearly one-half is on slopes greater than 50%.

The largest fraction of mature coastal forest is on the North Coast, in the Prince Rupert Region, where average slopes are steeper and timber defect (therefore variability of residue size and volume) is higher.

Heavy cable systems will be required for 75% or more of principal logging activity. This equipment is badly suited to handle small pieces. Present large log loading, truck hauling and water transport systems are also unable to handle small pieces effectively in their present configuration. The whole delivery system has been designed to handle the largest pieces of the largest forests on the continent. Productivity and wage rates are high, based on capital intensive logging methods.

Most of these parameters of economic location work against easy solutions to residue delivery on the B.C. Coast. Nonetheless there are good prospects for gradual increments to utilization with present equipment at several points. At some threshold level, probably set up by the size of material to be handled, a whole new generation of equipment and/or a complete second pass at the setting (relogging or prelogging) becomes essential.

The economic approach of regarding marginal cost of additional supplies as the appropriate decision variable can help define the engineering impera-



(Source: Hedin 1978)

Figure 5 Distribution of Slope Class
B.C. Coast

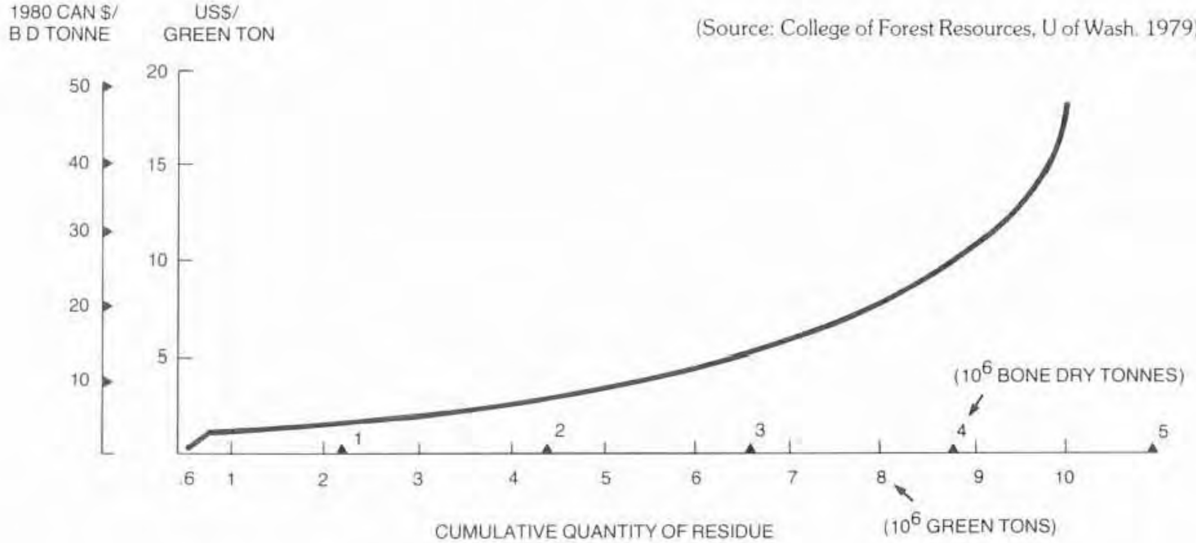


Figure 6 Yarding Cost vs. Cumulative Residue Volume
Douglas-Fir Region - PNW US
To a Minimum Piece Size of 4" × 4'

tives. A recent view of forest-based energy costs by the College of Forest Resources, University of Washington (1979) provides a good example of the approach, if not the final details.

Figure 6 shows an estimated supply response based entirely on the extra cost of obtaining smaller and smaller pieces with cable systems. A similar function can be imagined for the B.C. Coast, with a similar scale and shape. Further details of yarding cost experience and other cost variables need consideration, and some of these details can be clarified with existing information.

COST ANALYSIS: EXTRACTION OF FOREST RESIDUALS

A Costing Framework

In this review of cost experience in B.C. and the PNW US, the well-known problem of definition of the assumptions and conditions relevant to a particular unit cost was a serious concern. Some of the **physical variables** have been mentioned — terrain, distance, piece size. Weather, soil type and others could be added.

The elements that could be termed **decision variables,** or system design and supervision variables, can be equally important to a particular local cost estimate. These include equipment selection, utilization rate, crew motivation, and integration of phases of the operation. The economic assumption usually is maintained that the system will have been designed and operated to minimize cost and, in general, this is likely the case. However, the assumption needs to be kept in mind.

An even more serious problem in surveying cost estimates is the variability encountered in the accounting format used by various analysts. The treatment of overheads, profit and risk (ROI), taxes, depreciation, productive time and other factors is highly variable. The recent performance of U.S. and Canadian currencies has introduced a further complication, in comparisons over time.

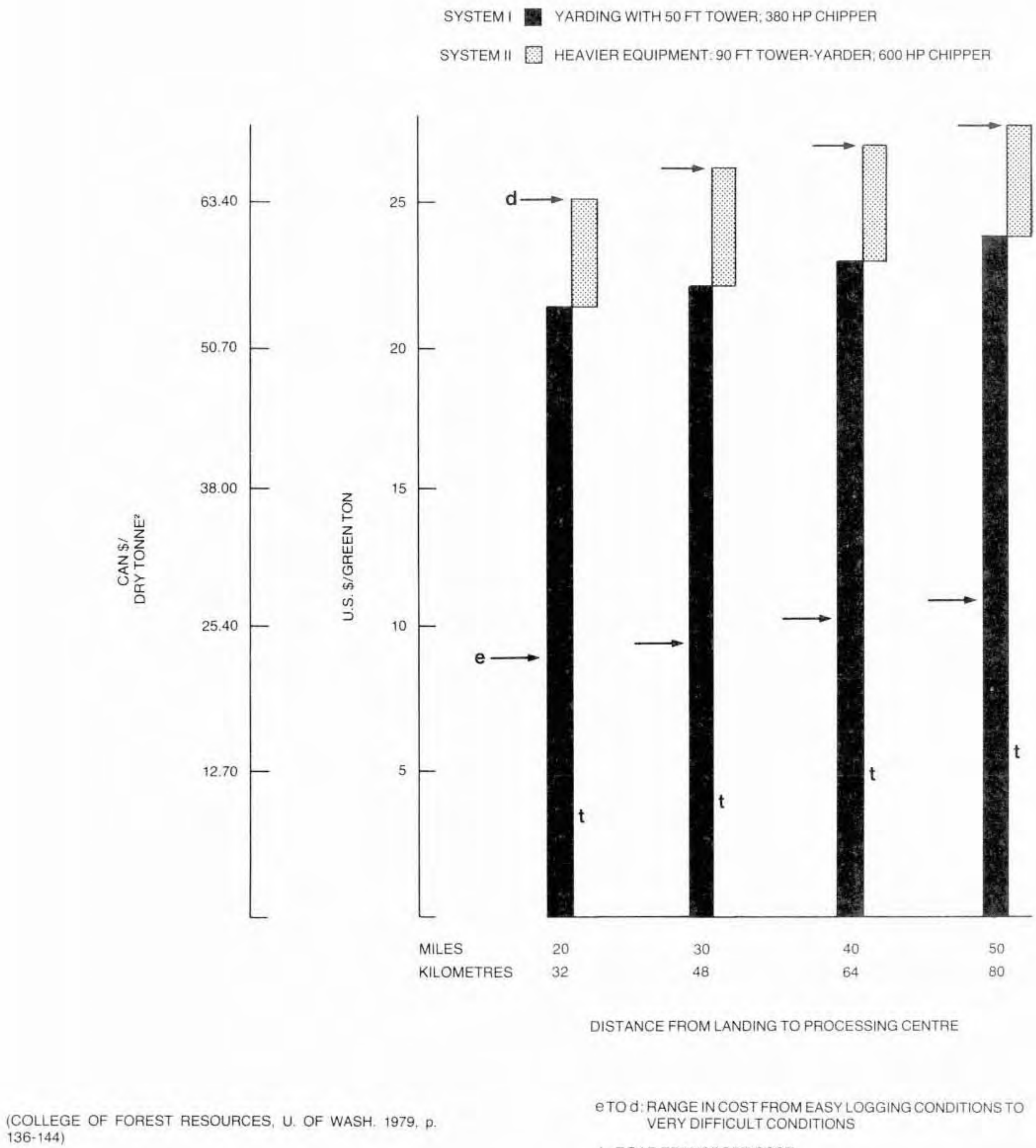


Figure 7 — Total Delivered Cost[1]
of Logging Residuals West Coast U.S.

[1] Roading cost excluded; stumpage assumed zero; ROI in equipment 15% after tax

[2] 1 green ton = 0.5 dry tons; 1 ton × 0.907 metric tonnes; Can $ = 0.85 U.S. $

TABLE 6
LOGGING EQUIPMENT FUNCTION, PRODUCTION AND COST

Equipment	Task Performed	Production Per hr (ft^3)	—1977 U.S. \$— Cost Per hr[1]	Hourly Cost Per cunit	1980 Can \$ Per b.d. tonne
Warner-Swassey Log All	felling, skidding	200	\$ 27.16	\$ 13.60	\$ 16.60
Drott LC-40 Feller-Buncher	felling, bunching	1,500	28.06	1.90	2.30
Volvo SM-880	limbing, lopping, bunching	2,000	45.36	2.30	2.80
Logma T-310	limbing, lopping, bunching	900	32.37	3.60	4.40
RTS Grapple Timberjack 2300	skidding	600	18.28	3.00	3.65
Skagit FT-3 (cable)	yarding	400	98.24	24.60	30.05
Harvester Timberjack RW-30	felling, limbing, bunching	500	29.96	6.00	7.35

[1]Updated to 1977; includes operating costs, depreciation and wages, including benefits (Source: Gardner, Schaffer and Erickson 1978, in Bergvall 1978, p. 110)

TABLE 7
PRODUCTION AND COST ESTIMATES FOR GROUND- AND CABLE-LOGGING SYSTEMS

	Small Tractor		Rubber-Tired Skidder		FMC Bunk Grapple		3-Drum Cable Yarder	
Slope - %	40-50				flat		55	
Cunits/acre (m^3/hectare)	45 (315)				not available		60 (413)	
Species	pine				not available		larch, D.fir	
Daily Costs - 1979 (\$)								
Machine & crew	274.00		246.00		497.76		688.20	
Transportation & overhead	62.28		62.28		62.28		62.28	
Total: daily skidding cost	336.28		308.28		560.04		750.48	
Production/8-hr scheduled day - cunits (m^3)	20 (56.6)		19 (53.8)		29 (82)		15.3 (43.2)	
	Can \$/ cunit	1980 Can \$/ bd tonne	Can \$/ cunit	1980 Can \$/ bd tonne	Can \$/ cunit	1980 Can \$/ bd tonne	Can \$/ cunit	1980 Can \$/ bd tonne
Skidding cost/unit volume	16.81	14.88	16.23	14.36	19.31	17.09	49.05	43.41
Additional costs								
Felling, bucking, limbing	5.21	4.61	5.49	4.86	8.21	7.27	9.90	8.76
Trails	.80	.71	2.63	2.33	Nil	Nil	Nil	Nil
Swamper tractor on landing for tops, snags & chunks	Nil	Nil	.75	.66	Nil	Nil	Nil	Nil
Cost of decked logs	22.82	20.20	25.10	22.21	27.52	24.36	58.95	52.17

(McMorland 1980, p. 39)

One of the most serious problems, in attempting to distinguish the extra costs of extra wood removals from each setting, is a tendency to average the cost of all removals in commercial and research-development data unless a separate (relogging) operation is involved.

The cost estimates provided have at least tried to distinguish the important physical and decision variables or assumptions involved in each, but many details can only be pursued in the original documents.

The General Logging Chance

Terrain and timber size (including variability) are the major factors in the general logging chance on the B.C. Coast. The area with slopes less than 30% and the areas with uniform (usually second growth) timber will yield residues at much lower cost than the steeper, over-mature types.

A good view of the spread in costs from easy to difficult conditions in general, and of the importance of extraction cost in the total delivery cost of residuals is provided in Fig. 7. These estimates were developed as part of the previously mentioned review by the College of Forest Resources, University of Washington (1979).

Tables 6 and 7 provide a limited view of machine

TABLE 8
CABLE YARDING COST
$ PER CUNIT

Average Piece Size ft^3	Yarding Cost $/cunit
.5	769
1.0	390
1.5	261
2.0	197
3.0	133
4.0	101
5.0	82
10.0	43.2
15.0	30.8
20.0	24.8
25.0	21.8
30.0	19.3
40.0	17.2
50.0	16.0
60.0	14.0
70.0	12.4
80.0	11.1
90.0	10.1
100.0	9.3

(Withycombe 1979)

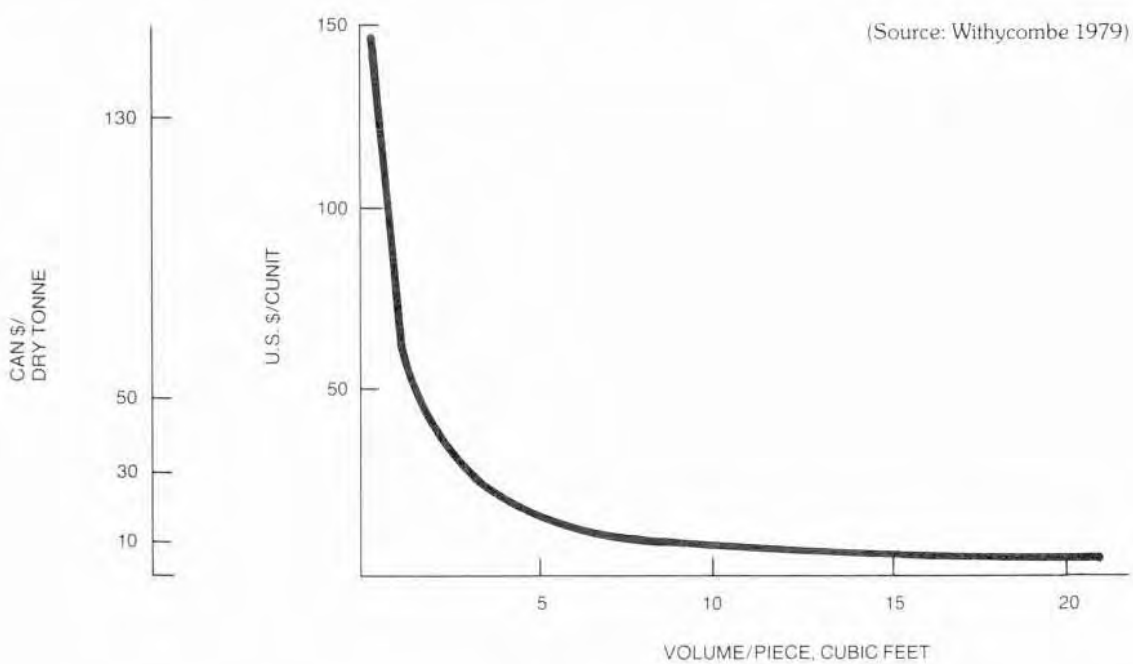
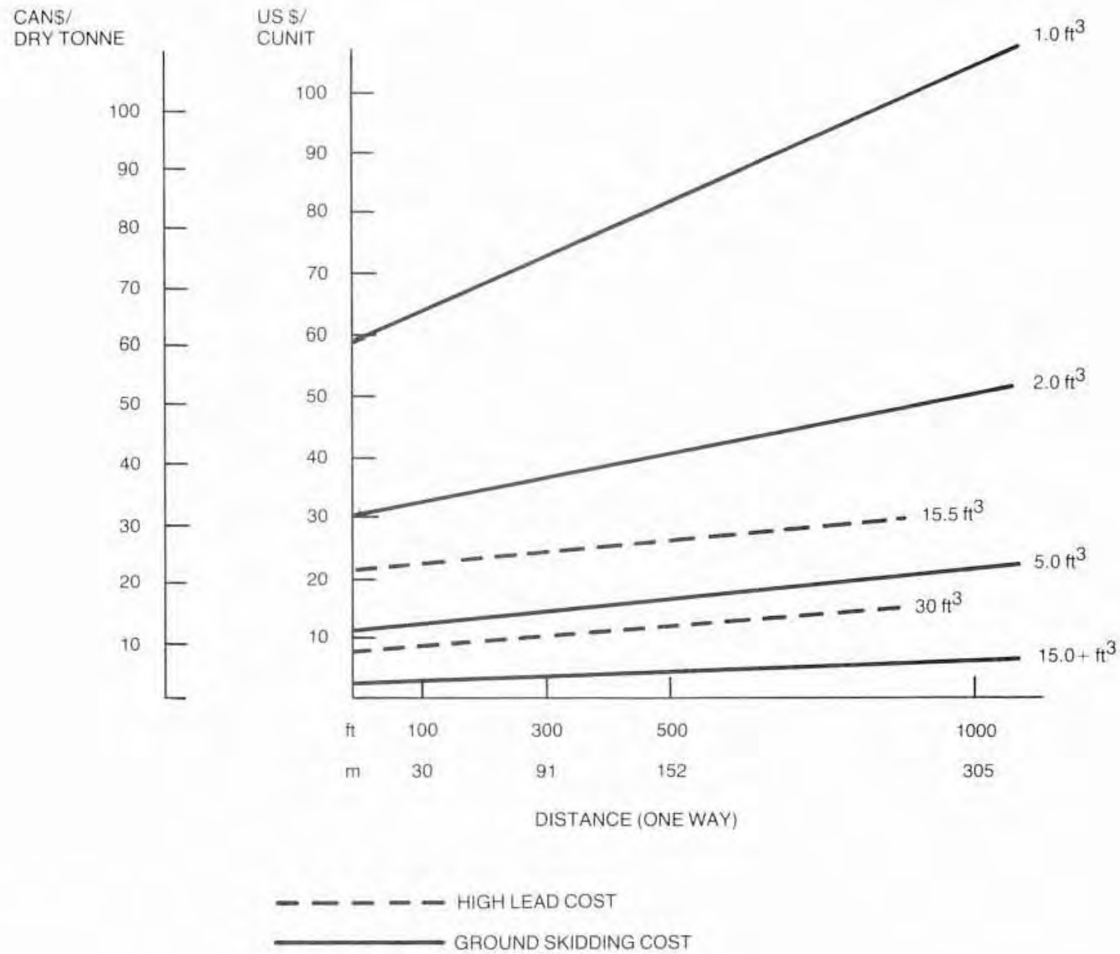


Figure 8
Ground Skidding Cost
300 feet, one way



(Withycombe 1979 & United States, Bureau of Land Management 1977a & 1977b)

Figure 9 High Lead and Ground Skidding Cost by Piece Size and Distance

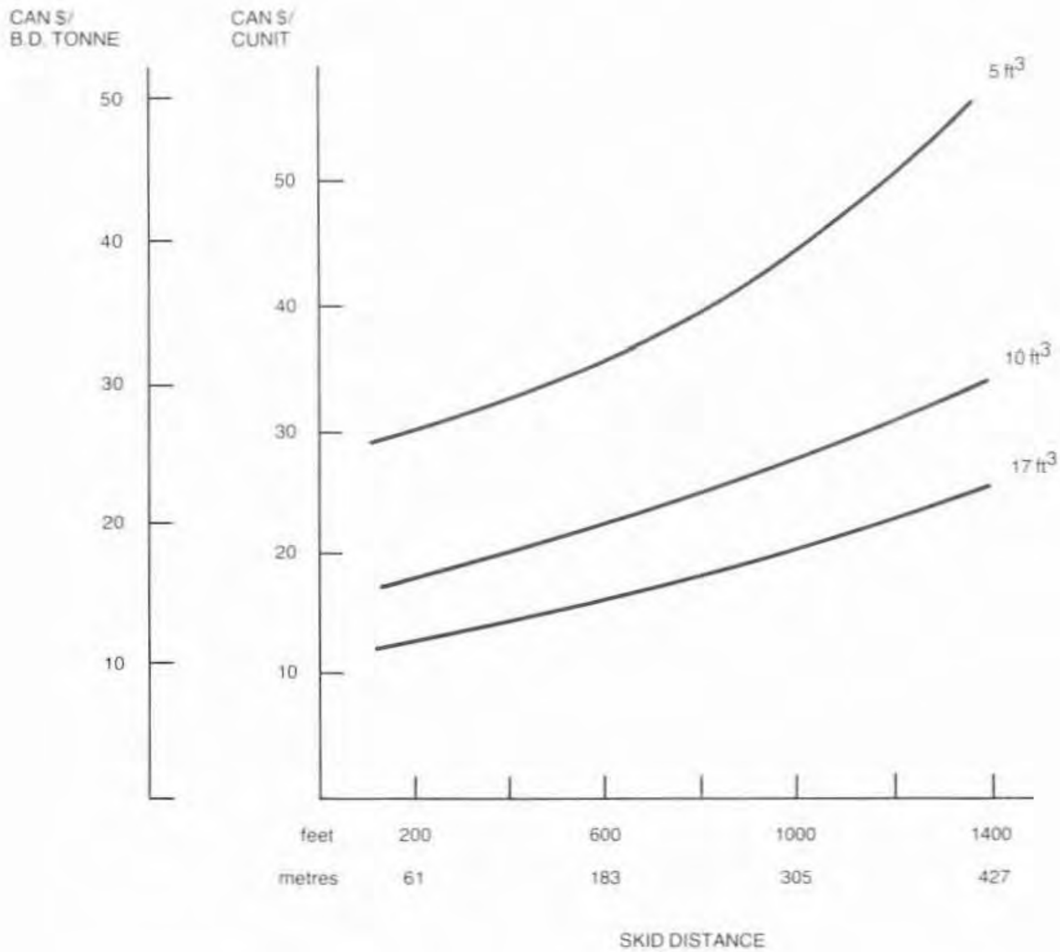
costs, productivity under certain conditions, and average cost per bone dry tonne to deliver relatively small forest materials (though commercial boles) to roadside. From highly mechanized smallwood felling/skidding on flat terrain ($2.30-4.40/b.d. tonne) to cable yarding of small timber on steep terrain ($30-60/b.d. tonne), the difference is obviously critical under any foreseeable energy supply/demand conditions.

Further refinements to the general logging chance can be outlined from existing data in terms of the impact of piece size and skidding distance.

Figure 8 and Table 8 isolate the impact of piece size on yarding productivity and cost for ground skidding and cable yarding. Although somewhat theoretical at the smallest sizes, these relationships must be kept to the front of all system design work. Present systems do not handle small pieces economically.

The only way to avoid this heavy cost impact, with current systems, is to leave small pieces attached to larger ones when bucking in the woods. Most of the total bole volume could probably be extracted in this manner under some conditions. The whole tree logging systems used on flat terrain with smaller timber typify this approach, but application in Coastal B.C. will be more difficult.

The impact of yarding distance is relatively linear for all piece sizes, as illustrated in Fig. 9 for large crawler tractor skidding and high lead yarding, from PNW-US experience. Figure 10 shows the same general



(McMorland 1980)

Figure 10 Small Crawler Tractor Skidding Cost by Piece Size and Distance

relationships for small tractor skidding, on relatively steep ground in the Kootenays.

A sharp upturn in cost/unit with distance will be experienced whenever the design capability of the system is being exceeded (e.g., long roads in high lead settings).

Residuals from normal logging usually accumulate to some degree in landings on the B.C. Coast, and this material is clearly in a more economic location than the residuals remaining in place elsewhere in each setting. It also will be of the largest sizes. However, the volumes found by Jones (1979) of 26 cunits per landing, and those reported for a BCFS survey of 18 cunits per landing, would not provide a significant supply, nor a solution to the main residue problems.

Relogging vs. Clean Logging

The relative merits and costs of clean logging in one pass, compared to relogging (or prelogging) with special, lighter equipment, have had considerable attention in the PNW-U.S. and in B.C. Unfortunately, many of the real economic and engineering issues have been clouded by institutional issues and by confusion over average and marginal costs of the extra material extracted.

On the institutional side, the volume of residuals allowable has often been specified by public and private forest agencies. This inevitably affects the cost of a second pass per unit volume. The first pass may also entail higher costs, due to the handling of small pieces with large equipment.

Both this issue and the average vs. marginal cost

TABLE 9
UNIT COST OF RESIDUAL EXTRACTION

	1961 U.S. $/Mbm			
	Relogging	One-Stage Clean Logging		Ratio
Yarding	17.36	15.08		1.15 : 1
Loading	10.70	8.40		1.25 : 1
On Truck Total (Source: Adams 1965)	28.06	23.48		1.2 : 1
	1980 Can $[1]			
	per Ccf	b.d. tonne	per Ccf	b.d. tonne
Yarding	33.85	29.85	29.40	25.95
Loading	20.85	18.40	16.40	14.45
On Truck	54.70	48.25	45.80	40.40

[1] Estimated logging Cost Inflation
1961-64 - 2%/ann.
1965-73 - 6%
1973-79 - 8.5%

TABLE 10
VANCOUVER ISLAND
ESTIMATED RESIDUE EXTRACTION COSTS

	Residues taken with normal high lead logging		Second Pass for residues	
	1978 Can $/cunit			
Yarding	21.60	(20.65)	58.10	(55.60)
Loading	16.50		5.60	
Supervision and admin.	5.00		2.10	
Profit & Risk 20%	8.62		13.16	
Total	51.72		78.96	
(1980 Can $/b.d. tonne)		(49.50)		(75.55)

(Jones 1979, with profit and risk added)

problem are illustrated in the early work of Adams (1965). Table 9 shows the original marginal costs of residues extracted in one and two pass logging and a crude attempt at updating the currencies.

By comparing the average cost of the total one-stage clean logging operation to the average cost of the two-stage operation, several subsegment analysts (e.g., College of Forest Resources, U. of Wash. 1979) have derived cost ratios of 2.8: 1 for relogging: clean-logging operations. This ignores the extra costs entailed by every commercial cunit on the clean-logging setting to extract the extra material.

Jones (1979) provides a similar comparison, with a ratio of 2.7: 1 between average cost of yarding a whole setting including some residuals and the average cost of relogging. The higher cost impact on the "normal" yarding cannot be ignored if economic engineering improvements are to be achieved in this field.

At least two system variants in cable logging have been tried to overcome the negative impact of small pieces on overall productivity. These are:

a) long logs (with bole-top attached)
b) special small chokers flown with normal butt-

TABLE 11
RUNNING SKYLINE - MOBILE YARDING CRANE

Yarding Distance	Avg piece size	Productivity Cunits per 8 hr shift (m^3) 70 (2)		40 (1.1)[1]	
200		205.8	(582.4)	156.8	(443.7)
600		161.7	(457.6)	123.2	(348.7)
1,000		133.1	(376.7)	101.4	(287.0)
1,400		113.2	(320.4)	86.2	(243.9)

[1]Assuming 4 chokers - average 160 ch/turn (70:70:15:5), 1 light choker added

RUNNING SKYLINE - MOBILE YARDING CRANE

Yarding Distance d	Avg Yarding Cost/Cunit[1] (Can $1980)		Incremental Cost/extra Unit Residues	
Pc. size:	70 (2)	40 (1.1)	Cunit	b.d. tonne
200	$ 8.70	$11.40	$39.75	$35.05
600	11.05	14.50	50.70	44.70
1,000	13.40	17.60	61.70	54.40
1,400	15.80	20.70	72.15	63.65

[1]Machine Cost - 1977 Can $: $1517/8 hr shift
1980 Can $: $1786/8 hr shift

(Sauder and Nagy 1977)

rigging to pick up the smaller pieces with minimum loss of productivity

Long top logs offer some promise for this part of the current residual volume. Breakage in yarding is a drawback, together with the necessity for private haul-roads, to permit the expected overhang of long pieces. Extra bucking in the landing and some extra loading cost can mitigate the latter effect, at some cost.

Experience with extra small chokers is not well documented to date in heavy timber settings. Table 11 provides an estimate of likely average and marginal costs, based on the yarding study of Sauder and Nagy (1977).

The marginal cost of smaller material remains high in these estimates. No doubt further operational trials would be desirable in B.C. for long-top and extra light choker variants of cable logging. Extra limbing costs will no doubt be incurred to get out the upper bole segments in either case.

Institutional/Regulatory Extraction of Residuals

Over the past 15 years, several public land agencies in western North America have specified a certain degree of clean-up beyond "economic" logging to meet various environmental or conservation objectives. For example, a reduction in slash is expected to:

- reduce the area needing fire treatment
- reduce air pollution from necessary slash burning
- reduce damage to forest soils from slash burning
- reduce damage to stream channels caused by wayward logging debris
- reduce reforestation costs
- improve management forest aesthetics and recreation opportunities

Additional raw material suitable for chipping or for minor forest products (e.g., cedar shakes, posts) is often recovered, giving a higher yield from each acre logged and, potentially, a higher allowable annual cut.

In total, probably a greater volume of logging residuals has been collected for elimination purposes than has been collected for utilization. One would expect that the data on the costs of these clean-up operations might contribute significantly to planning for forest fuel extraction from these same residual materials.

The main stumbling block to a ready transfer of such data is the focus of the operations on area cleared, rather than volume collected. All cost data are maintained on an area basis (e.g., $/ha) and usually some assumption or transference of volume from other study areas is necessary to get cost on a unit volume or weight basis ($/tonne).

Nonetheless at least two cases are worthy of a closer look. In the National Forests of the PNW states, managed by the USFS, probably the largest volumes of logging residuals in the Pacific forest types are currently being collected into piles and to roadside to meet environmental objectives. The second case is local to Vancouver Island, where the Greater Victoria Water District has been extracting logging residuals for disposal for many years.

U.S. Forest Service - National Forests, Region 6

In the mid-1970s, the USFS estimated (Clarke 1976) that about 31 million green tonnes of logging residues were generated each year on the National Forests of Region 6. About 8 million tonnes were in pieces at least 10 cm (4 in) in diameter and 1.2 m (4 ft) long, and over 5 million tonnes were in pieces 20 cm diameter by 2.4 m long (8 in x 8 ft). Roughly 80% of this latter material was deemed suitable for chipping and fibre utilization. Although the material was generally uneconomic to extract and utilize, the environmental and public relations costs were high and rising.

A graduated 5-year program of research and development, centered on new residue regulations, was initiated to reduce environmental costs and attempt to foster increased utilization. A new type of timber sale was instituted, where the estimated costs of yarding unutilized material (YUM) became deductible from stumpage.

The basic pre-sale appraisal is made using the gross scale from the USFS timber cruise, adjusted for defect only. The cost of yarding this volume is estimated as an average (per Mbm) in the appraisal. Final payments are made on scaled commercial logs, at the bid price per Mbm. The cost of reducing the expected normal slash load by collecting all material down to a particular size, is estimated separately on a per acre basis. This cost is deducted from the stumpage paid for the sale, as part of a brush disposal (BD) plan.

The current YUM standard calls for removal of all pieces 20 cm diameter o.b. by 3 m length (8 in x 10 ft) and larger. Trial sales have been conducted with residue removal down to 6 in x 6 ft (15 cm x 1.8 m) pieces, and even smaller in some forest types.

The cost allowance for yarding unutilized material is varied according to timber type and topography in each sale, and ranges from U.S. $200 to $800 per acre (Can. $580 - $2,325/ha). The USFS is currently reviewing the body of data from YUM sales, but this analysis is not complete. Officials estimate that the median allowance would be in the $400 - $450/ac range (Can $1,160 - $1,310/ha), based on experience to date.

If the mean volume of residuals yarded and piled on these typical sales is in the order of 30-35 cunits (Howard 1973; Grantham **et al.** 1974), the implied cost per cunit would be about U.S. $13.00, or Can. $13.50 per b.d. tonne.

These averages can only be regarded as indicative of the general magnitude of YUM yarding costs, without more detailed analysis of individual sales or of the whole data set.

USFS officers report that the operators have periodically complained that the cost allowance did not fully cover their extra costs. This would not be unexpected, but no doubt the buoyant markets of 1976-79 have had some effect in "covering" extra costs. The impact of slower markets in 1980 on YUM yarding practices and policies may be of interest in deducing the actual cost of these practices.

Significant problems of accounting practice are encountered by each side. The USFS feels that most equipment and capital costs (fixed costs) should be applied to the commercial volumes only, with residuals bearing only fuel, labor and other variable costs. The industry sees machine hours as being of equal total cost on any part of the logged volume.

YUM yarding practices have varied widely, according to the timber and terrain. In most types, the engineering controversy over one-pass clean logging vs. a separate, re-logging or pre-logging operation has still not been settled (Adams 1965). One pass logging is the prevalent approach, with as many "long top" logs as possible, to "piggyback" the smaller top material with the commercial log immediately below.

Neither the technical nor the insitutional methods are regarded with satisfaction in the YUM program. It is known that the cost of second-pass logging is inversely related to the volume of residuals left. There have been indications (e.g., Adams 1965) that a divided small-log/large-log set of operations could produce lower average total cost. However, the ownership and pricing of various resources on each pass have remained an institutional problem. (For example, if a large log extractor wishes to subcontract a second pass, both he and the USFS must evaluate a complex interaction between costs and returns in each separate operation, and in total, depending on what is taken in each pass. The scaling problems are increased for all concerned.

The USFS attempted a trial sale in a hemlock stand which specified what could be left in terms of a minimum and maximum number of tons per acre. This initial trial resulted in excessive costs in the first pass, due to the effort necessary to distinguish what should be left to meet the specification. No doubt the main problem was inexperience, but a longer run training problem can be envisaged for all rigging crews.

In 1979, a further trial was attempted in Region 6, where "twin" sales were logged using one- and two-pass methods. The results were not acceptable to USFS operations researchers, mainly due to inadequate controls. A further trial, more closely matched and controlled, is scheduled for 1980.

In conclusion, the massive volumes of residual material moved into piles or to roadside in the PNW US in recent years offers some general guidelines of experience for planning in B.C.:

- general size specifications, coupled with cost incentives, have resulted in very large movements of material into an accessible position for disposal or utilization[2]
- the cost has averaged Can $1,160 - 1,310/hectare which may translate roughly to Can $13.50/b.d. tonne for yarding and piling
- the benefit/cost relationships of this activity have not been analyzed in detail

In another experimental system of timber sales, the USFS offered smaller pieces in each setting at a lower price than the larger, more commercial logs. All logs below a given net volume (80 fbm) were sold on a lump sum per acre basis, based on cruise volume. Cull peelers or utility grade logs of any size were also included in the per acre pricing. Commercial logs were sold on a scale basis. The result was a blended price for various materials, which was supposed to eliminate the direct stumpage charge for low grade material, since it had already been paid for in the fixed cost per acre. These per acre material or PAM sales did not show a significant reduction in the quantity of residues after logging (Hamilton **et al.** 1975).

Greater Victoria Water District

The GVWD has been removing a high proportion of the woody material from each logged acre for many years. The objectives of keeping stream channels of all sizes free of debris, of minimizing fire hazard and of maintaining a generally tidy watershed operation with prompt reforestation have provided a strong impetus toward clean logging.

Equipment and methods have been varied with the terrain and size of residue material. In the 1960s, a shop-made 55-foot truck mounted tower was used, with various sizes of rigging, including very light rigging for second pass extraction of residuals only. Some very steep slopes and gullies were cleaned. Since the mid 1970s a truck-mounted 49 ft steel tower (Madill 071) has been used, which has skyline/slackline capability as well as the normal high-lead configuration. On easier terrain, residue material has been piled or wind-rowed using crawler tractors with brush blade.

Unfortunately for present purposes, the GVWD had no reason to record volumes or unit costs of extracting this non-commercial material, other than on an area basis (e.g., $ per acre cleaned and burned). The costs have varied from $200 per acre with tractors on easy ground, to $1,500 per acre for tightlining

[2]Utilization so far has been limited. Piles have been burned, and a large volume is currently "stored" in piles throughout the Douglas-fir and pine forests of the PNW. Within a 50 miles radius of Portland, a significant proportion of the YUM piles is removed by urban fuelwood users, under Free Use Permits issued by Ranger Offices. Some further volume has recently been removed from YUM piles to provide pulpwood to certain mills which are encountering shortages of chips due to sawmill closures.

TABLE 12
COST OF YARDING RESIDUALS TO ROADSIDE
LARGE TREES, STEEP GROUND

Cable Extraction Cost 1980 Can. $/b.d. tonne		Ref (notes)
7.50 - 8.25		Bergvall **et al.** 1978, Johnson 1977 (cost as part of sawlog operation)
9.75		Sauder and Nagy 1977 (average cost running skyline 70 cf average piece size, 600' dist.)
12.80		Sauder and Nagy 1977 (as above with 40 cf average size including residuals, average cost)
44.70		Sauder and Nagy 1977 (as above, marginal cost of extra residual volume)
11.65 - 12.85		Bergvall **et al.** 1978; Johnson **et al.** 1977 (integrated whole tree operation, average cost with smaller residuals taken)
20.30		Greater Victoria Water Dist. (cable removal of residuals - estimate)
20.10 - 22.20		Bergvall **et al.** 1978; Johnson **et al.** 1977 (relogging on average Region 6 terrain)
21.70		Grantham 1974 in Bergvall 1978 (residuals relogged to 8 in (20 cm) min diameter)
22.00		Withycombe 1979 (one pass, same piece size as Jones 1979)
24.80		Jones 1979 (one pass, average cost)
24.90		United States, Bureau of Land Management 1977a (highlead 15 cf piece size and 1977b 300' average distance)
25.85		Adams 1965 (high lead one pass clean logging; marginal cost of residuals extracted, updated est.
11.15		Adams 1965 (as above, average cost)
29.85		Adams 1965 (high lead relogging cost; updated est.)
Marginal	Average	
42.75	24.15	Grantham **et al.** 1974 4 in x 4 ft min (0.4 ft^3)
25.54	18.20	8 in x 8 ft min (3.5 ft^3)
	16.20	12 in x 8 ft min (7.4 ft^3)
44.10		Bare **et al.** 1976 (simulated residue extraction mixed 80:20 cable: ground skidding PNW)
66.70		Jones 1979 (relogging)

residues out of steep draws with the cable tower ($495 - 3,700/ha). Although no average costs have been calculated, GVWD experience suggests in the order of $250/acre on easy ground with track-mounted tractors, to $500/acre for an average high lead setting. Jones' (1979) volume of residuals for Eastern Vancouver Island of 23 cunits/acre (161 m^3/ha) would yield a yarding cost estimate of $11-$23 per cunit or $9.70 to $20.30 per b.d. tonne for moving logging residues into piles or to roadside.

A Survey of Yarding Costs

A broad distinction of logging chance can be made between the following:

- large trees on steep ground
- large trees on easy ground (say 30% slope)
- smaller and more uniform trees on steep ground
- smaller and more uniform trees on easy ground

TABLE 13
EXTRACTION OF LOGGING RESIDUALS TO ROADSIDE
PACIFIC OLD GROWTH FOREST ON EASY TERRAIN

Cost 1980 Can. $/b.d. tonne	Ref (notes)
9.95	Bonneville Power Admin/USFS 1979, using BLM Appraisal handbook. (Large track-mount machines Region 6 PWN, D. fir)
12.10	Bonneville Power Admin/USFS 1979 (as above, smaller residuals)
9.70	Greater Victoria Water Dist. (clearing operations in easy terrain, track mount large machines)
18.20	Blakeney (Forestal) 1979 (small track mount machines HFC - 185 tonnes/ha 3.3 cunits)

TABLE 14
COST OF EXTRACTION OF RESIDUALS TO ROADSIDE
SMALL TREES, STEEP GROUND
(P1 Rocky Mts; Second Growth Pacific

Cost 1980 Can $/b.d. tonne Cable	Ref (Notes)	Ground Skid
	McMorland 1980 (P1, Kootenays 40-50% slopes, small tractors, 17 cf avg piece)	14.90
	Withycombe 1979 (P1, Northern Rocky Mt. Average of residuals)	16.30
21.75	Bergvall **et al.** 1978 (whole tree, smaller timber)	
	McMorland 1980 (P1, Kootenays, 10 cf pieces marginal cost est.)	23.00
	(as above, 5 cf pieces)	38.00
	Withycombe 1979 (marginal cost of 2 cf pieces 7 in x 8 ft)	38.20
43.40	McMorland 1980 (Larch, D. fir, 55% slope)	

TABLE 15
EXTRACTION OF LOGGING RESIDUALS TO ROADSIDE
SMALL TREES, FLAT GROUND
E. Canada, S.U.S., Second Growth PNW/BC

Cost Can. $/b.d. tonne	Ref (notes)
11.80	Blakeney (Forestal) 1979 (2nd Growth D. fir on flat)
17.09	McMorland 1980 (FMC bunk grapple, flat ground)
21.10	J.P.R. & Assoc. 1976 in Bergvall **et al.** 1978 p. 76. (Michigan, easy terrain, whole tree operation loaded on truck)

Tables 12 to 15 provide a summary of the yarding cost estimates for forest residues which were found to be most relevant to B.C. Coast conditions for these broad logging chances.

This sample of experience in conditions similar to various parts of the B.C. Coast can be summarized follows:

TABLE 16
SUMMARY OF YARDING COST SURVEY

Condition	EXPECTED MARGINAL COST 1980 Can \$/b.d. tonne
STEEP TERRAIN	
OLD GROWTH	
first stage residuals[1]	\$ 20-30
second stage residuals[2]	30-70
SECOND GROWTH	
second stage residuals	15-40
EASY TERRAIN	
OLD GROWTH	
first stage residuals	10-20
second stage residuals	20-40
SECOND GROWTH	
second stage residuals	5-15

[1]to roughly 0.1 m^3 piece size
[2]smaller pieces, to roughly 0.02 m^3

FUTURE DEVELOPMENT PROSPECTS

Supply/Demand Prospects for Coast Forest Residuals

To draw conclusions regarding equipment development needs and opportunities, it will be essential to review the supply prospects with existing systems. The foregoing review of conditions and costs can be used to derive a generalized supply function for B.C. Coast forest residues.

Assuming 70% of the remaining old growth harvest on the B.C. Coast will resemble the Northwest type of Jones (1979) and 30% will resemble the Southeast type, we can derive an expected factor of 0.37 bone dry tonnes of residuals per cunit harvested. If coast harvest remains roughly at 1978 levels, the expected annual residual volume would be **4.2 million** b.d. tonnes/ann. This can be considered the maximum residual volume obtainable from mature logging for the next 20 years.

The major variables considered in the expected cost of supply will be piece size and slope of setting.

Table 17 provides a rough breakdown of these expected forest residuals by piece size, based on PNW-U.S. and B.C. estimates cited above.

Table 18 provides a summary of mature forest terrain conditions from Fig. 5.

By using these rough proportions in combination with the costs experienced under similar conditions, Table 19 has been developed to show the likely limits of harvestable volume, within specified ranges of cost. For each slope class, a harvestable proportion is defined, largely in terms of piece size.

TABLE 17

Piece size	to 8" (20 cm)	to 3" (7.6 cm)	Remainder
Proportion of total dry weight	0.50	0.27	0.20

TABLE 18
PROPORTION OF MATURE FOREST
REMAINING ON SLOPE CLASSES
B.C. COAST

Slope Classes %	0-30%	30-50%	50%+
	0.30	0.27	0.43

TABLE 19
ECONOMIC SUPPLY OF RESIDUALS

Marginal Cost Class $/b.d. tonne	Slope Class Weight: Harvestable proportion of total residuals by slope of setting	0-30 .30	30-50 .27	50+ .43	Proportion of total Residuals Harvestable by Marginal Cost	Annual Q 000 b.d. tonnes
10-20		.65	.20		.25	1,050
20-30		.20	.30	.20	.23	966
30-70		—	.15	.20	.13	546
Total availability to $70/b.d. tonne		.85	.65	.40	.61	2,562

Assuming that independent suppliers would provide extra wood from each setting according to the extra costs of extraction entailed, a crude supply function can be derived as in Fig. 11.

These cost estimates are to roadside only, and costs of hauling and processing must be added to arrive at wood energy supply costs.

However, the figure can provide some insights to guide logging research and development activities:

- new technology will be required to extract about 50% of available residuals at any likely economic price
- nearly 2 million b.d. tonnes is likely available at up to $30/b.d. tonne at roadside with minor modification to present systems

Two broad lines of R & D should be distinguished:

- totally new all-terrain systems, such as airborne platforms or very large cranes
- marginal changes to existing yarding, processing and hauling systems

The latter line of marginal change in present systems will be lower in cost and less risky. The volume it could provide (together with yard and mill residues) exceeds likely wood energy needs on the B.C. Coast for the next decade.

Possible expansions of current systems include:

- long top logging to extract most of the residual bole

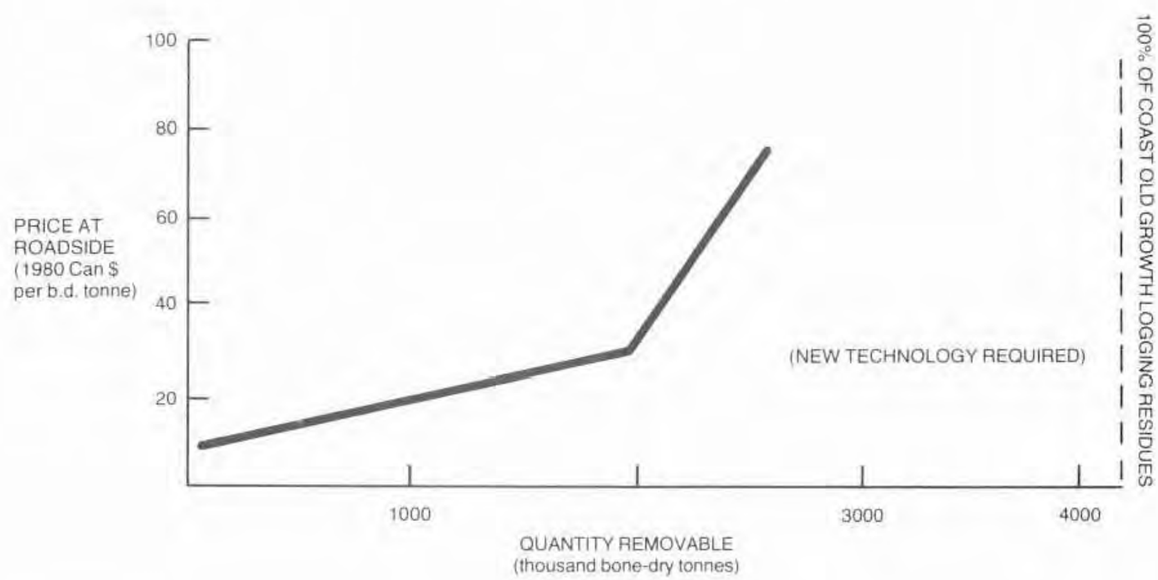


Figure 11 Current Supply Function

- extra small chokers with existing rigging systems for high lead and ground skidding
- relogging with lighter equipment, with variable leftover volumes, and on a range of forest and terrain conditions
- new approaches to processing/hauling

Although beyond the scope of this study, the latter approaches have often been mentioned in contacts made during the study. There is significant interaction between activities in the landing (especially on steep ground) and the cost of yarding. The ultimate impact can be crucial to the final delivered cost and the quality of wood fuel or fibre products.

For example, the processing cost for residuals (chipped) into vans in the ENFOR/Forestal trials (Blakeney 1979) are high[3] in relation to PNW trials (e.g., College of Forest Resources, U. of Wash. 1979). The main reasons can be found in the smaller material, and in the low degree of machine utilization in rough landings. Figure 12 shows the impact of this factor on processing cost.

Together with the disposal problems already encountered in log-sort and mill yards (Table 20), this factor provides a powerful incentive for joint processing of both sets of residues. More sophisticated cleaning and sorting could reduce processing cost and upgrade the total value of output from the combined residues.

The main problem with this approach remains in the cost of loading and hauling the physically variable, misshapen cargo (raw forest residuals). Figure 13 shows the range of loading/hauling cost by piece size for well-formed pieces.

One approach offering some promise[4] is the slashing or snipping of forest residues into small blocks (e.g., 0.5 m long) in the landing, followed by belt-loading into vans for hauling. Sorting/processing would be at fairly large facilities in log or mill yard.

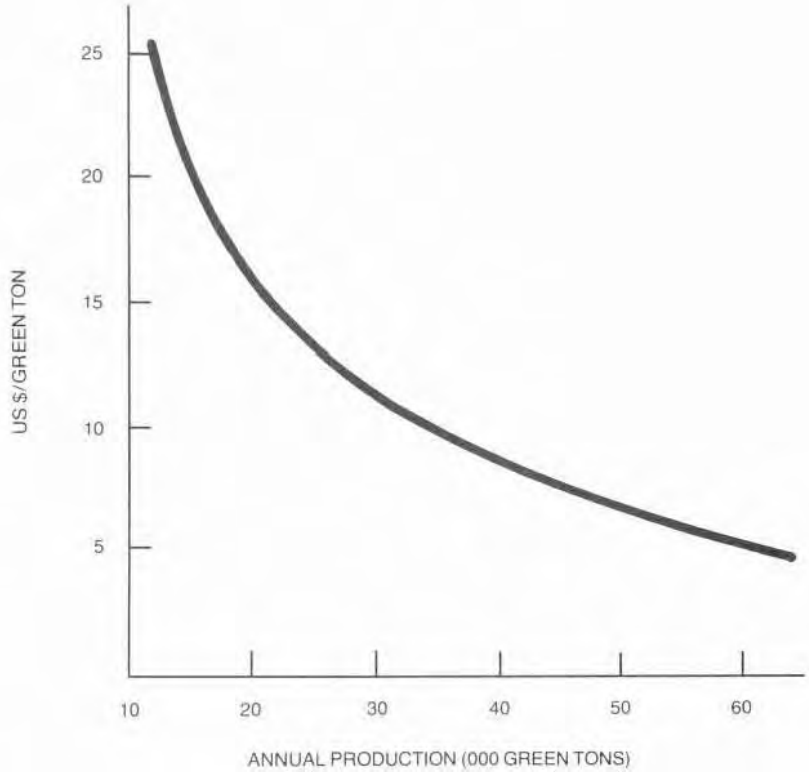
This approach could have the additional value of offering wood to the growing household market. In total, it seems to offer substantial potential for improving cost and product, in using the "first half" of forest residuals.

The marginal approach to forest residual extraction in the short run should not preclude at least computer design stages for a new generation of coast harvesting equipment. The needs for such equipment include environment protection, silvic thinning/spacing, and reaching difficult settings, as well as improving the utilization rate on all settings.

Logging in second growth stands will generate residuals which are more consistent in size and generally easier to handle in yarding and in the landing.

[3]$70/green tonne, estimated to be reducible to about $35.00 with better utilization; PNW estimates are $5-15/green tonne.

[4]FERIC engineers, personal communication.



(College of Forest Resources, U. of W. 1979)

Figure 12 Whole Tree Chipping:
Break-Even Cost of Production at
Different Levels of Machine Utilization

Together with the impact of easier terrain in these stands in the next decade or two, the result should be generally lower unit costs from this source, at least in clear cuts. The possible conjunction of silvicultural activities (thinning/spacing) with wood supply for energy merits further study.

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TABLE 20
A SAMPLE OF DEBRIS
FROM VANCOUVER ISLAND LOG YARDS[1]
BY SIZE

Piece Size:	5.1 cm (2")	5.1-30.5 cm (2-12")	30.5 cm + (12" +)	Total
Eastern V.I.	40	42	18	100%
Northern V.I.	53	23	25	100%
	46	32	22	100%

COMPONENTS OF
LARGER DEBRIS
(30.5 cm +)

	Tops & Butts	Branches	Cull Wood	Broken Wood	Bark	Rock	Total
Eastern V.I.	2	21	1	34	42	0	100%
Northern V.I.	11	8	22	53	4	2	100%

[1]Smith, D.G. 1977 (FERIC)

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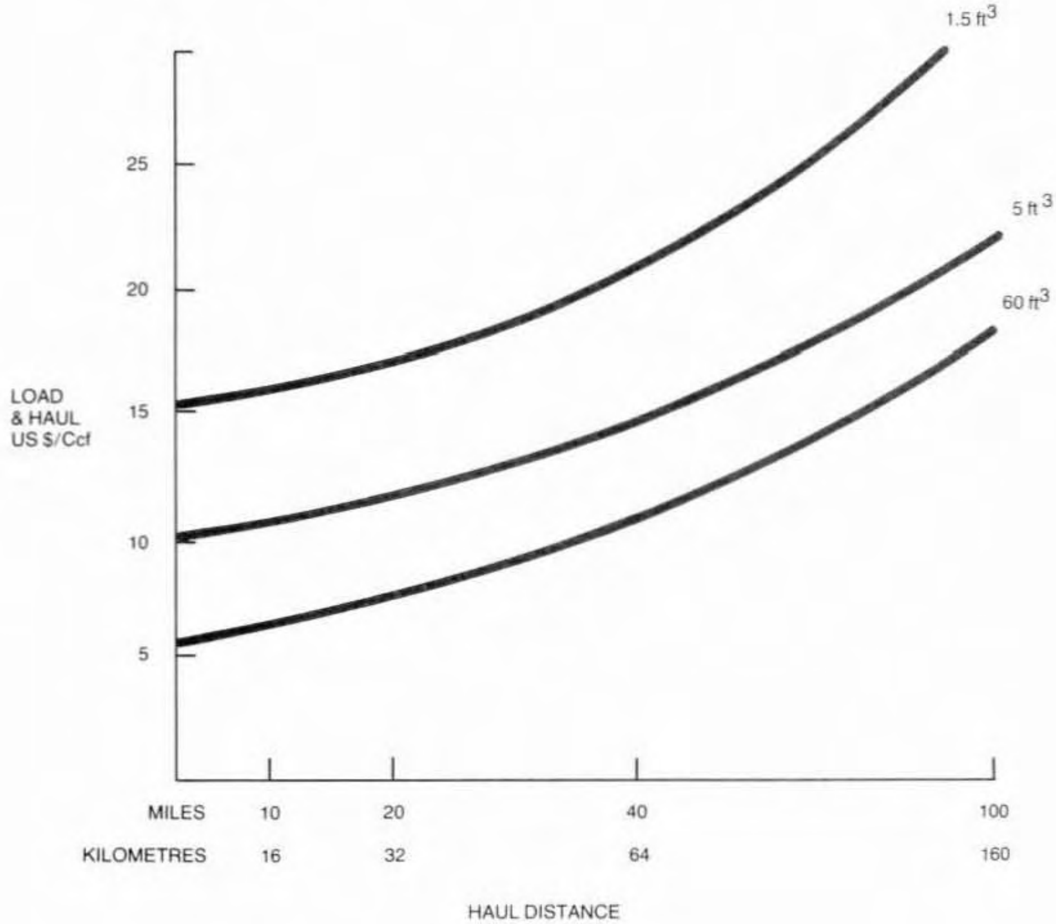

(Withycombe 1979)

Figure 13 Northern Rocky Mountains
Loading and Hauling Costs
by Piece Size

Appendix

TABLE A-1
SMALL CRAWLER TRACTOR SKIDDING
(40-50% slope, Lodgepole Pine)

AVERAGE PIECE SIZE (ft^3)		SKID DISTANCE		
	ft	400	800	1,200
	m	122	244	366
			CUNITS/SHIFT	
17[1]		22.6	18.7	14.8
10[2]		16.8	13.9	11.0
5[3]		10.3	8.5	6.7
			COST/CUNIT	
17[1]		$14.90	$18.00	$22.70
10[2]		20.00	24.15	30.55
5[3]		32.60	39.50	50.15

[1]From McMorland 1980. 80% machine utilization rate; 60% of productive time is in hook/unhook and pile activities; 7.1 pieces per turn, machine and manpower cost $336/shift

[2]10 pieces per turn; hook/unhook and pile time increased by 25% over McMorland 1980 study average

[3]14 pieces per turn; hook/unhook and pile time increased by 60%

TABLE A-2
TOTAL COST OF FOREST RESIDUE DELIVERY 1978

	Large residue 8" x 10' and larger	Small residue 3-8" x 6' and longer	
	YUM yarded[1]	Unyarded[2]	
	U.S. dollars/oven-dry	ton	1980 Can $/ b.d tonne
A. High lead (cable) yarding areas			
Yarding	—	**17.58**	**24.75**
Loading	**3.53**	**7.06**	**9.95**
Hauling, average 45 miles	**8.99**	**10.79**	**15.20**
Fuel processing:			
By chip mill	**12.14**	—	
By mobile chipper	—	**18.21**	**25.60**
	24.66	**53.64**	**75.50**
B. Tractor yarding areas			
Yarding	—	12.12	17.05
Loading	3.53	7.06	9.95
Hauling, average 45 miles	8.99	10.79	15.20
Fuel processing:			
By chip mill	12.14	—	
By mobile chipper	—	18.21	25.60
	24.66	48.18	67.80

[1]YUM yarded = with yarding of unutilized material previously accomplished

[2]For small residue, yarding and loading costs are estimated at 2.0 x cost for large residue; hauling cost is estimated at 1.2 x cost for large residue

(Bonneville Power Admin/USFS 1979)

TABLE A-3
REGION 6 PNW
RESIDUE REMOVAL COSTS[1]

	U.S. $/Ccf	U.S. $ per green ton[2]	1980 Can $ per bone dry tonne
Tactor yarding	4.22	1.69	4.38
Depreciation	.88	.35	.91
Logging overhead, etc.	3.62	1.45	3.76
	8.72	3.49	9.05
Loading	4.35	1.94	5.03
Hauling, average 45 miles	12.35	4.94	12.82
	25.42	10.37	26.90

[1]Yarding costs developed from U.S. Forest Service, Region 6 Timber Appraisal Handbook; loading and hauling costs from experience estimates
[2]At 10,000 lbs per M board feet, or 5 green tons per M board feet

(Bonneville Power Admin/USFS 1979)

TABLE A-4
NORTHERN ROCKY MOUNTAINS
COST OF YARDING RESIDUAL PIECES
BY AVERAGE SIZE

Percentage of Residue	Piece Size ft^3	Cost to Skid 300
30 percent	2 ft^3	$36.80
50 percent	10 ft^3	7.40
20 percent	50 ft^3	4.90
Weighted average	15.6 ft^3	15.72/cunit

(Withycombe 1979)

TABLE A-5
DELIVERED COST OF FOREST RESIDUALS
LAKE STATES, U.S.

	U.S. $/green ton	1980 Can $/ bone dry tonne
Relogging	16.50 - 20.30	42.80 - 52.66
Thinning	10.00 - 13.80	25.94 - 35.80
Integrated Chip/Sawlog	9.75 - 12.33	25.29 - 31.98

(College of Forest Resources, U of Wash. 1979, from USFS-NCES 1978)

TABLE A-6
ESTIMATED COST OF WOOD DELIVERY AND PROCESSING, US. PNW

Cost Item	Estimated Cost Per Bone Dry Ton Merchantable Logs	Utility Logs	Other Residue	Other Residue 1980 Can $ Per b.d. tonne
	U.S. $ 1977			
Stumpage	Full charge	Nominal Charge	No charge	No charge
Road construction and maintenance	$ 7.91	$ 1.36	$ 1.36	$ 2.08
Fall and buck	3.27	2.73	0.68	1.04
Yard	4.91	10.23	14.32	21.91
Load	1.64	1.64	2.05	3.14
General expenses	4.37	4.37	4.37	6.69
Subtotal	22.10	20.33	22.78	34.86
Haul, 40 miles[1]	4.10	4.10	4.10	6.27
Chip	—	4.78	9.55	14.61
Subtotal	4.10	8.88	13.65	20.88
TOTAL (excluding stumpage)	26.20	29.21	36.43	55.74

[1]Washington Utilities and Transportation Commission rates, 1978

(Source: Grantham 1974 in Bergvall **et al.** 1978)

TABLE A-7
COSTS PER DRY TON TO DELIVER WOOD RESIDUE
TO A PROCESSING PLANT

Cost Item	1977 U.S. $ Per dry ton	1980 Can $ Per bone dry tonne
Deliver to Landing		
Complete relogging	$ 14.50	$ 22.19
As part of sawlog operation	5.40	8.26
Complete whole tree operation	8.40	12.85
Preprocess (chip)	4.50	6.89
Transportation, 40 miles	5.26	8.05
Profit (20 percent)	3.03 - 4.85	4.62 - 7.43
TOTAL	18.19 - 29.11	27.84 - 44.56

(Bergvall **et al.** 1978)

TABLE A-8
ESTIMATED COSTS FOR LOGGING TO AN 8-INCH MINIMUM DIAMETER

Cost Item	1977 U.S. $ Per dry ton	1980 Can $ Per bone dry tonne
Yarding	$ 14.21	$ 21.74
Loading	2.20	3.37
Transportation, 40 miles	5.26	8.05
Subtotal	21.67	33.16
Profit and Risk (20%)	4.33	6.63
TOTAL	26.00	39.79

(Bergvall **et al**, 1978)

TABLE A-9
WESTERN OREGON
FALLING AND BUCKING COSTS[1]
BY BOLE SIZE

Merch Bole Length	U.S. $/Ccf (Gross Vol)
16 ft	7.57
48	4.92
80	3.64
112	2.26
144	1.90

[1] Assumes 15% breakage loss (United States, Bureau of Land Management 1977b)

TABLE A-10
EXTRACTION COSTS PER DRY TON

	1977 U.S.-PNW $/ dry ton	1980 Can $/dry tonne
Deliver to Landing:		
Complete Relogging	14.50	20.10
As part of sawlog operation	5.40	7.50
Complete Whole Tree Harvest	8.40	11.65
Preprocess (chip):	4.50	6.25
Haul:		
at 25 miles	4.25	5.90
40 miles	6.80	9.40
50 miles	8.50	11.75
60 miles	10.20	14.15
75 miles	12.75	17.65
Profit:	6.70	9.30

(Johnson **et al.** 1977)

TABLE A-11
HIGHLEAD PRODUCTIVITY MATRIX[1]
Cunits per 8-hr shift (m^3)

Landing Quality	Yarding Distance 300	300-700	700+
GOOD	99.7 (282.2)	81.8 (231.5)	58.8 (166.4)
FAIR	95.0 (268.9)	77.6 (219.6)	56.0 (158.5)
POOR	85.5 (242.0)	73.4 (207.7)	50.3 (142.3)

[1]Productivity varies with deflection, etc., as well
Average piece size 70 ft^3
(Sauder and Nagy 1977)

TABLE A-12
HIGH LEAD YARDING
COST PER CUNIT
(1977 U.S. $)

		—YARDING DISTANCE—				
LOG VOL	m	30	91	152	213	274
FT^3	ft	100	300	500	700	900
15.5		23.30	24.90	26.50	28.10	29.70
30		9.20	11.10	12.90	14.80	16.60
55		6.80	8.80	10.70	12.70	14.60

(United States, Bureau of Land Management 1977b)

TABLE A-13
SIMULATED COST OF RESIDUE EXTRACTION
TO ROADSIDE - U.S. PNW 1976

	U.S. $ 1976/cunit	1980 Can $/cunit	b.d. tonne
Cable yarder	36.25	53.20	46.90
FWD Skidder	24.65	36.20	31.95
Balanced System[1]	33.95	49.80	44.10

[1]80 : 20 high lead : skidder volume
(Bare, Jayne and Anholt 1976)

TABLE A-14
ESTIMATED YARDING COSTS OF LOGGING RESIDUE
TO VARIOUS MINIMUM SIZES

Yarding Cost		Min Size A[1]	Min Size B[2]	Min Size C[3]
1974 U.S. $ per cunit		$ 16.61	$ 12.50	$ 11.11
1980 Can $ per cunit (m^3)		27.40 (9.65)	20.60 (7.25)	18.35 (6.50)
Can $ per b.d. tonne	average	24.17	18.17	16.18
	marginal	42.75	25.54	

[1] 4 in (10 cm) minimum diameter, 4 ft min length (0.4 ft^3)
33.6 dry tonnes of residues removed per acre
20 dry tonnes suitable for fibre chips

[2] 8 in (20.3 cm) min diameter, 8 ft min length (3.5 ft^3)
25.4 dry tonnes of residues removed per acre
14.5 dry tonnes suitable for fibre chips

[3] 12 in (30.5 cm) min diameter, 8 ft min length (7.4 ft^3)
20 dry tonnes removed; 10 tonnes suitable for fibre chips

(Grantham **et al**, 1974)

TABLE A-15
COSTS OF NONBURNING AND BURNING TECHNIQUES OF LOGGING
RESIDUE DISPOSAL IN THE PACIFIC NORTHWEST

NONBURNING TECHNIQUES		COST
	Masticate	11 - 239/acre
	Chip	150 - 2,800/acre
	Pile	65 - 800/acre
	Scarify	12 - 264/acre
	Bury	74 - 1,800/acre
BURNING		
	Ignition techniques	20 - 23/acre
	Burning techniques	
	broadcast	25 - 225/acre
	pretreatment	50 - 560/acre
	pile	
	PUM	50 - 500/acre
	YUM	300 - 1,000/acre

(Source: GEOMET 1978)

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Environment Canada Environnement Canada
Forestry Service Service des Forêts

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