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# An Analysis of Two Trials of a Portable Shear-Type Residue Processing System

by

P. Oakley*

and

G.H. Manning**

* Philip Oakley and Associates
Vancouver, B.C.

** Pacific Forest Research Centre
Canadian Forestry Service
Victoria, B.C.

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# Foreword

ENFOR is the acronym for the Canadian Government's ENergy from the FORest (ENergie de la FORêt) 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 dependence on petroleum and other non-renewable energy sources.

The Canadian Forestry Service (CFS) administers the ENFOR Biomass Production program component which deals with such forest-oriented subjects as inventory, harvesting technology, silviculture and environmental impacts. (The other component, Biomass Conversion, deals with the technology of converting biomass to energy or fuels, and is administered by the Renewable Energy Branch of the Department of Energy, Mines and Resources). Most Biomass Production projects, although developed by CFS scientists in the light of ENFOR program objectives, are conducted by forestry consultants and research specialists under contract. Contractors are selected in accordance with science procurement tendering procedures of the Department of Supply and Services. For further information on the ENFOR Biomass Production program, contact...

ENFOR Secretariat
Canadian Forestry Service
Department of the Environment
Ottawa, Ontario
K1A 1G5

This report is based on ENFOR project P-291 which was performed under contract (DSS File No. 04SB.KH603-3-0404) by Philip Oakley and Associates, Vancouver, B.C., and summarizes ENFOR projects P-183 and P-184, carried out respectively by Forestal International Ltd., Vancouver, B.C. (DSS File No. 05SB.KL017-0-1037) and the B.C. Ministry of Forests, Victoria, B.C. (DSS File No. 05SB.KL017-0-1036)

# Abstract

Cost efficient systems for collecting, processing and transporting logging residues must be developed in order to promote and encourage the utilization of the wood fibre and energy potentially available in this material.

Logging residues were inventoried and collected on sites representing the typical topographic and stand conditions of the West Coast and Interior wet belt of British Columbia. A crawler tractor with a brush blade and rubber-tired skidders aided by front-end loaders were used to pile residues on flat and moderately-sloped sites after primary logging had been completed. A mobile highlead tower was used to yard residues on a steeply sloped site.

A mobile shear-type processor was designed and built to overcome some of the problems and limitations of using mobile chippers to process logging residue at field sites. The processor was used to shear residues into bolts of uniform length. Some of this material was transported to mills for reprocessing into hogged fuel and chips.

Productivity, cost and fuel consumption were determined for each phase of the operation at the various field sites. In addition, this information was interpolated to obtain productivity and cost estimates for operating the shear processor in a sortyard or millyard. The shear processor was also compared with mobile chippers operating at similar sites. The study includes material analysis, energy values, energy balance and cost-benefit analysis.

Results indicate that a shear-type processing system is a technically feasible alternative to mobile chippers. The system is economically feasible as a fuel processor at current oil prices if used in a sortyard located within medium distance (60 km) of a coastal conversion plant with an existing under-utilized hogging system.



# Résumé

Il faut rentabiliser la collecte, le faconnage et le transport des déchets de coupe si l'on veut encourager l'utilisation de la matière ligneuse et de l'énergie qu'elle recèle.

On a inventorié et ramassé les déchets de coupe dans des endroits réunissant les conditions topographiques et stationnelles typiques de la zone humide de la côte et de l'intérieur de la Colombie-Britannique. Un tracteur sur chenilles, doté d'une lame frontale, et des débusqueuses à roues, assistées par des chargeuses forestières, ont servi à empiler les déchets sur un terrain plat ou en pente douce, après le faconnage. Le débusquage sur pente abrupte s'est fait par téléphérage relevé, à pylone mobile.

Une ébrancheuse-tronconneuse mobile à cisaille a été concue et construite pour surmonter certaines difficultés et limitations des déchiqueteuses mobiles utilisées sur place. Elle a servi à tronconner les résidus en billons de longueur uniforme, dont une partie a été transportée dans des usines pour faconnage secondaire en copeaux et combustible de bois déchiqueté.

La productivité, les coûts et la consommation de carburant ont été déterminés à chaque étape des travaux, sur les divers chantiers. De plus, on a estimé par interpolation la productivité et les coûts de l'utilisation d'une ébrancheuse-tronconneuse à cisaille dans une aire de triage ou la cour d'une scierie. On a aussi comparé cette ébrancheuse-tronconneuse à des déchiqueteuses mobiles fonctionnant dans des chantiers semblables. L'étude comprend une analyse des engins, un état du rendement énergétique, un bilan de l'énergie et une analyse de rentabilité.

Les résultats montrent qu'il est techniquement faisable de remblacer la déchiqueteuse mobile par l'ébrancheuse-tronconneuse à cisaille. Économiquement, compte tenu des prix actuels de pétrole, c'est une solution possible pour la production de combustible, si elle est utilisée sur une aire de triage située à distance moyenne (60 km) d'une usine côtière de transformation dont le système de déchiquetage du bois en combustible est sous-utilisé.

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# Introduction

This report summarizes projects undertaken by Forestal International and the British Columbia Ministry of Forests to test equipment and systems for transforming forest residue waste into an economic product, and provide a cost-benefit evaluation of the systems.

The first project originated with an unsolicited proposal submitted by Forestal International Limited (Forestal) in June 1980. In March 1981, Forestal was awarded a two-year contract (ENFOR Project No. P-183) to conduct harvesting trials on Vancouver Island and complete the design and construction of a mobile shear processor. Data from all phases of the project were compiled and analysed and a final project report was prepared.

The second project was undertaken by the British Columbia Ministry of Forests under an agreement with the Canadian Forestry Service (ENFOR Project No. P-184). Logging residue was collected on sites in the Interior wet belt near Lumby B.C. The shear processor as developed by Forestal was used to process material collected on one of these Interior locations.

Logging residues comprise a wide range of materials including non-merchantable whole trees as well as tops, limbs, splintered and rotten logs, bark and stump-root systems. This material is scattered over logged areas and represents both a significant fire hazard and an impediment to reforestation.

In British Columbia, where most of the economically accessible forest resource is fully committed, logging residues represent a vast potential source of additional wood fibre and energy. In particular, overmature cedar hemlock stands of the British Columbia Interior wet belt have a large logging residue component which must be considered in providing acceptable forest management. However, most studies to date have shown that the cost of producing pulp or fuel chips from logging residues exceeds the market price of these products. This is largely due to the high cost of collecting, processing and transporting these residues with conventional harvesting and processing equipment, and to the current lack of demand for fuel and pulp chips.

Cost-efficient systems for collecting, processing and transport of logging residues must therefore be developed in order to promote and encourage the utilization of the wood fibre and energy potentially available in this material. The objective of the projects on which this report is based was to develop and field test alternative methods of harvesting, processing and transporting logging residues.

# Equipment Development

## Initial Investigations

A literature review was carried out to identify methods and equipment which have been used to process forest biomass. Equipment manufacturers were consulted regarding methods which might be used to reduce logging residues to a more uniform piece size with a higher bulk density than that of unprocessed logging residues.

To date, most attempts to utilize logging residues have involved the use of mobile chippers to reduce residues of varying size and condition. Some of the problems encountered were the following:

1. Residue chips are usually used only for fuel because they contain quantities of bark, rotten fibre and foliage which make them unacceptable for the manufacture of wood pulp. There is no generally accepted process for separating the useful chips from the unacceptable chips once they are mixed together during the chipping process.

2. The size and shape of chips produced by mobile chippers are not optimum for energy conversion purposes. The ragged and fractured particles common to hogged fuel are more suited for combustion than are the smooth-sided chips, which tend to compact.

3. Most mobile chippers cannot process logs larger than 50 cm in diameter. To chip larger logs, chipper power units must be capable of developing more than 370 kw (500 hp). An engine of this size, coupled with a correspondingly heavy drive train, is difficult to incorporate into a compact mobile unit and is very expensive to build and operate.

4. Considerable wear of the chipper knife occurs in processing logging residues because the material is dirty and is often dry, and thus hard. Machine down time is high due to frequent knife maintenance and because proper knife sharpening equipment is not normally available on logging operations.

5. The capital cost of mobile chipping equipment is high (approximately $750,000) in relation to the level of output. This contributes to the unacceptably high unit production costs often associated with mobile chipping of logging residues.

6. Mobile chippers are complex machines to operate. They require a skilled operator and crew as well as frequent maintenance. These are not always available at remote woods operations.

7. Chippers are designed to operate on large, solid pieces such as logs. Small, dirty misshapen residue pieces result in low productivity and high costs.

The objective in developing alternative concepts for processing logging residues was to overcome many of the limitations of mobile chippers while retaining some of their more useful features.

A contract was therefore awarded by ENFOR, through Forestal, to Nicholson Murdie Machines Limited (Nicholson) for the manufacture of a prototype of a mobile logging residue processor. Nicholson was selected for this work because of their extensive experience in manufacturing mobile chipping equipment for west coast conditions, and because of their initial work with FERIC in developing a shear to process sortyard waste into a more uniform product.

## Design of the Shear Processor

The shear concept was further developed by discussion and field trips to the proposed test sites with Nicholson representatives. It was felt that the shear would overcome many of the problems associated with the use of mobile chippers, while continuing to meet the objective of reducing logging residues into a more uniform and compact form for transportation to an energy conversion facility.

The basic concept was to develop a mobile unit which would be capable of operating at remote forest sites or sortyards and which would not require a high degree of maintenance, specialized equipment or highly skilled operating personnel. The cost of the unit would be less than that of mobile chippers and the machine would be capable of handling most material sizes found in logging residues. Logging residues of all diameters and lengths would be sheared into short, uniform lengths which could be further processed into either hog fuel or pulp chips.

A number of design parameters were identified and submitted to the Nicholson team in order to ensure that the processor would be suited to the residue material and site conditions normally encountered on both Coast and Interior logging operations. The design parameters included specifications for such items as: overall size and mobility of the processor; infeed conveyor size and speed; shear size, shape and cycle time; and outfeed conveyor height, angles and speed.

One of the most important features of the shear-type processor is the size of material which it can accommodate. Initially, a 100-cm opening was considered appropriate. However, analysis of the size distribution of logging residues on the test sites revealed that a 75-cm opening would handle most of the material. It was decided that a 75-cm model would be sufficient to test the concept and that, if in the future a larger model was required, the design could be modified to increase the capacity of the machine.

The mobile processor consists of a 7-m-long infeed conveyor, a vertically mounted shear with a 75-by-75-cm opening and a 12-m-long outfeed conveyor which carries the processed material to a height of up to 5.5 m.

The infeed conveyor, shear unit, fuel and hydraulic tanks and diesel engine are mounted on a 11-m-long high-bay trailer. The outfeed conveyor is mounted on a separate trailer. All components are driven by hydraulic motors which are powered by a GM 6-71 diesel engine.

The system was designed to process 80 to 100 tonnes of logging residue per operating day. This rate of production is based on average loading of 25 percent of the shear opening capacity, a shear cycle time of 8 to 10 seconds, an average sheared bolt length of 75 cm, and an average of 5 hours of actual processing time per day (62.5 percent utilization).

Drawings of the Nicholson shear processor are shown in Figures 1 to 4.

### Estimated Capital and Operating Costs

The estimated capital cost and operating costs for the shear processor are shown in Table 1. The capital costs are estimates made by Nicholson for a production model based on the existing prototype with some improvements and modifications. The operating costs are normal standard costs for equipment of this type. Total standard costs with operator range from $60.00 per hour on the basis of 200 shifts per year to $56.00 per hour on the basis of 240 shifts per year.

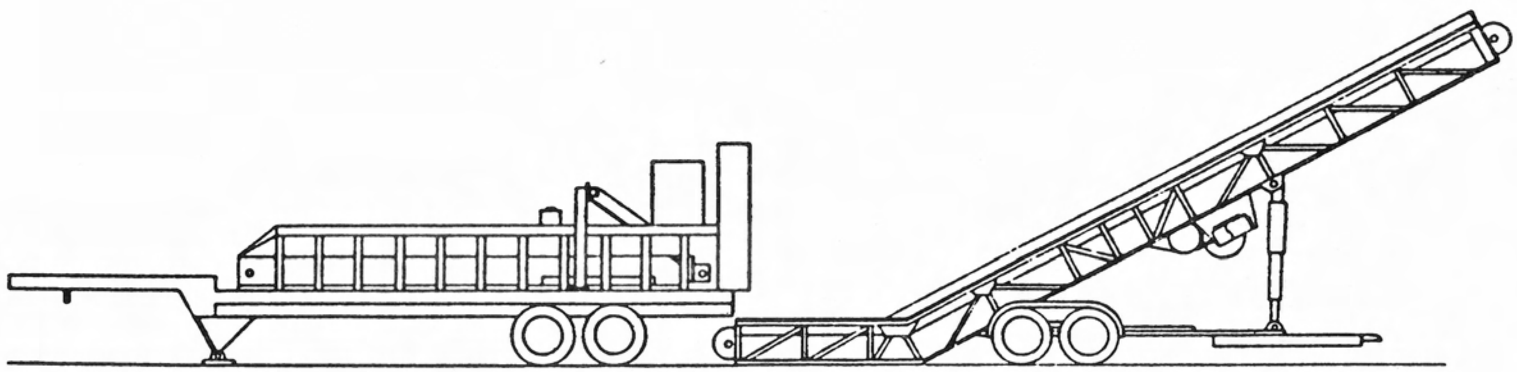
## Residue Collection Trials

### Test Site Selection

Sites on Vancouver Island, were selected by Forestal at the Greater Victoria Water District (GVWD) Tree Farm near Victoria (Fig. 5). The current logging operations of GVWD are concentrated in areas of overmature timber which have been affected by root rot (*Phellinus weirii*). Consequently, logging residue accumulations are moderate to heavy on most recently logged areas. The policy of GVWD is to pile and burn logging residues in order to maintain water quality and to facilitate their reforestation program.

These Coast sites were selected to represent the range of topographic conditions commonly found in west coast logging sites. The species composition of Douglas-fir, hemlock and western cedar is typical of the southeast portion of Vancouver Island. Two test sites were selected, one on steep, broken terrain; the other on moderately-sloped terrain. The steep-site residues were gathered in a second pass with a highlead cable system. Those from the moderately sloped area were gathered with a crawler tractor and brush blade.

In the Interior wet belt of British Columbia two sites were selected in the Lumby area (Fig. 5) by Ministry of Forests personnel. These sites were chosen to ensure that typical ground conditions and slash concentrations found in this area would be represented in the trials. A site designated Railroad Creek represented moderately-sloped



Side view

Figure 1. Schematic diagram of Nicholson hydraulic shear with outfeed conveyor.

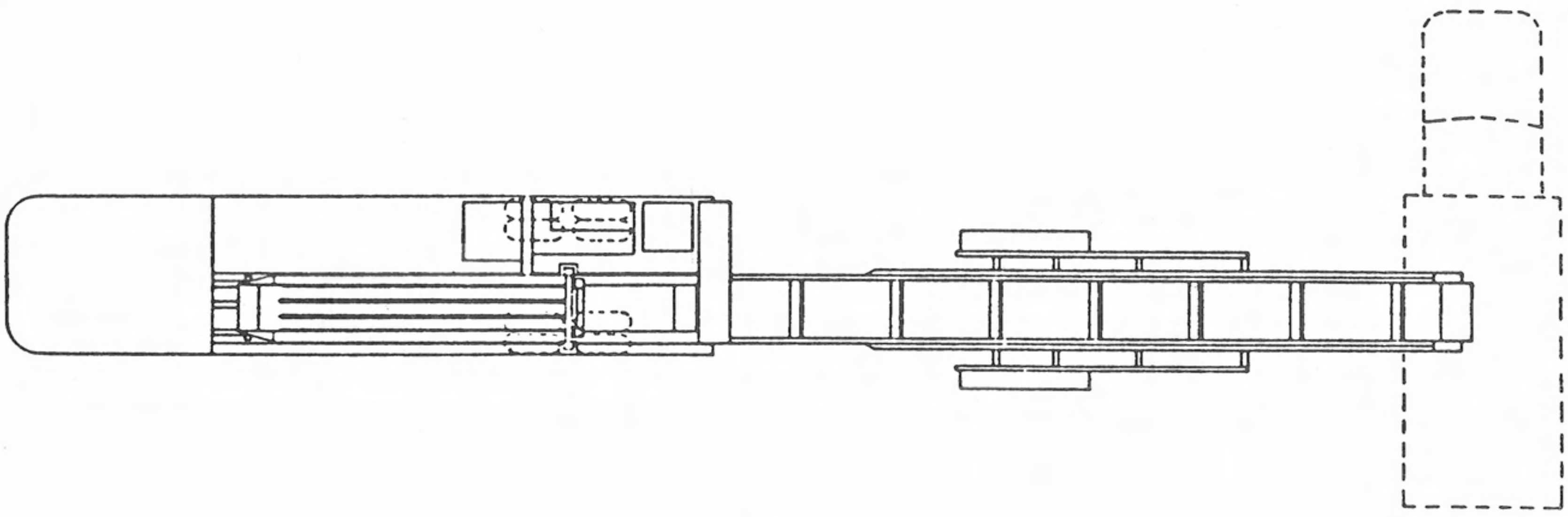



Figure 2. Schematic diagram of Nicholson hydraulic shear with outfeed conveyor.

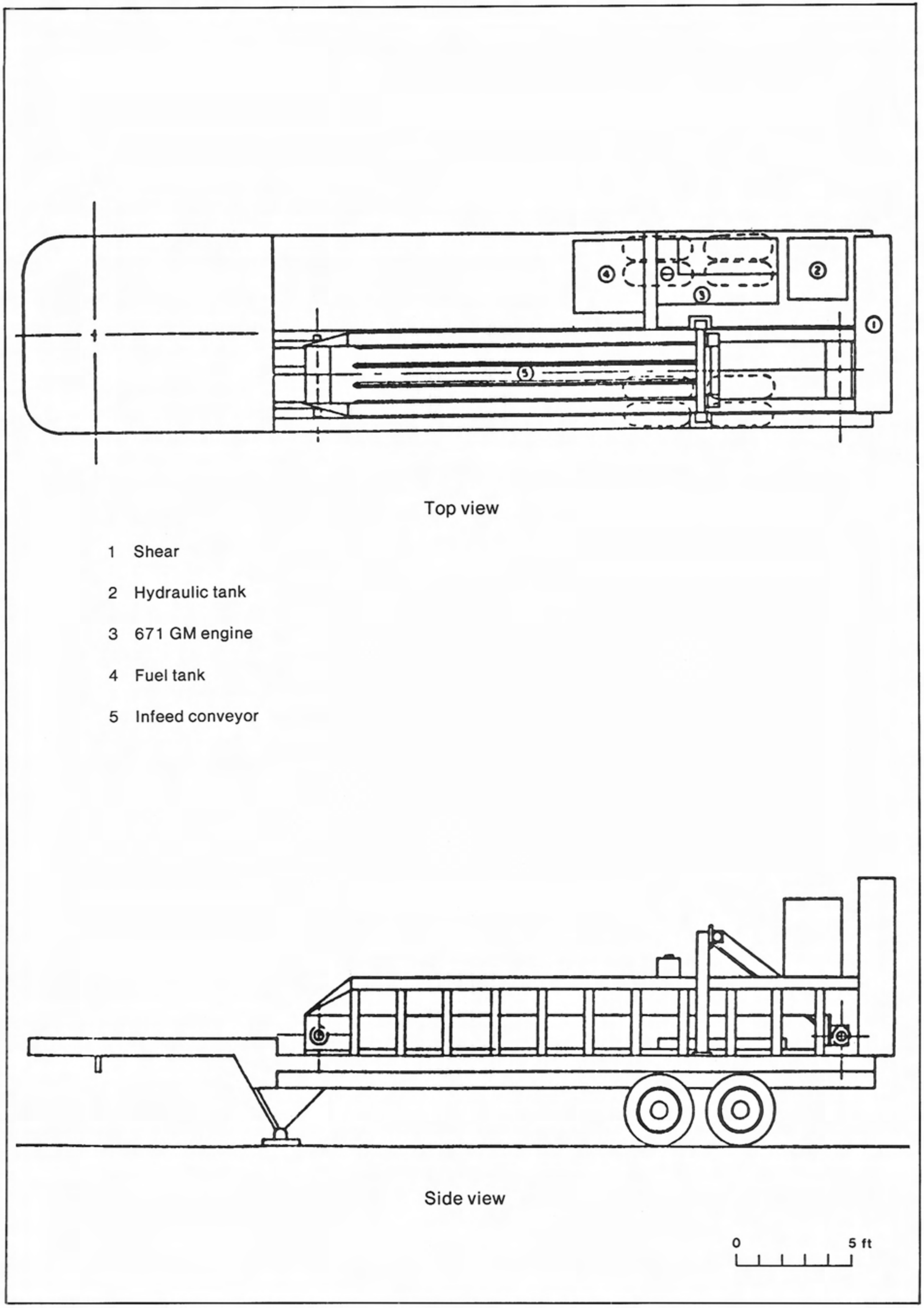



Figure 3. Diagram of Nicholson hydraulic shear.

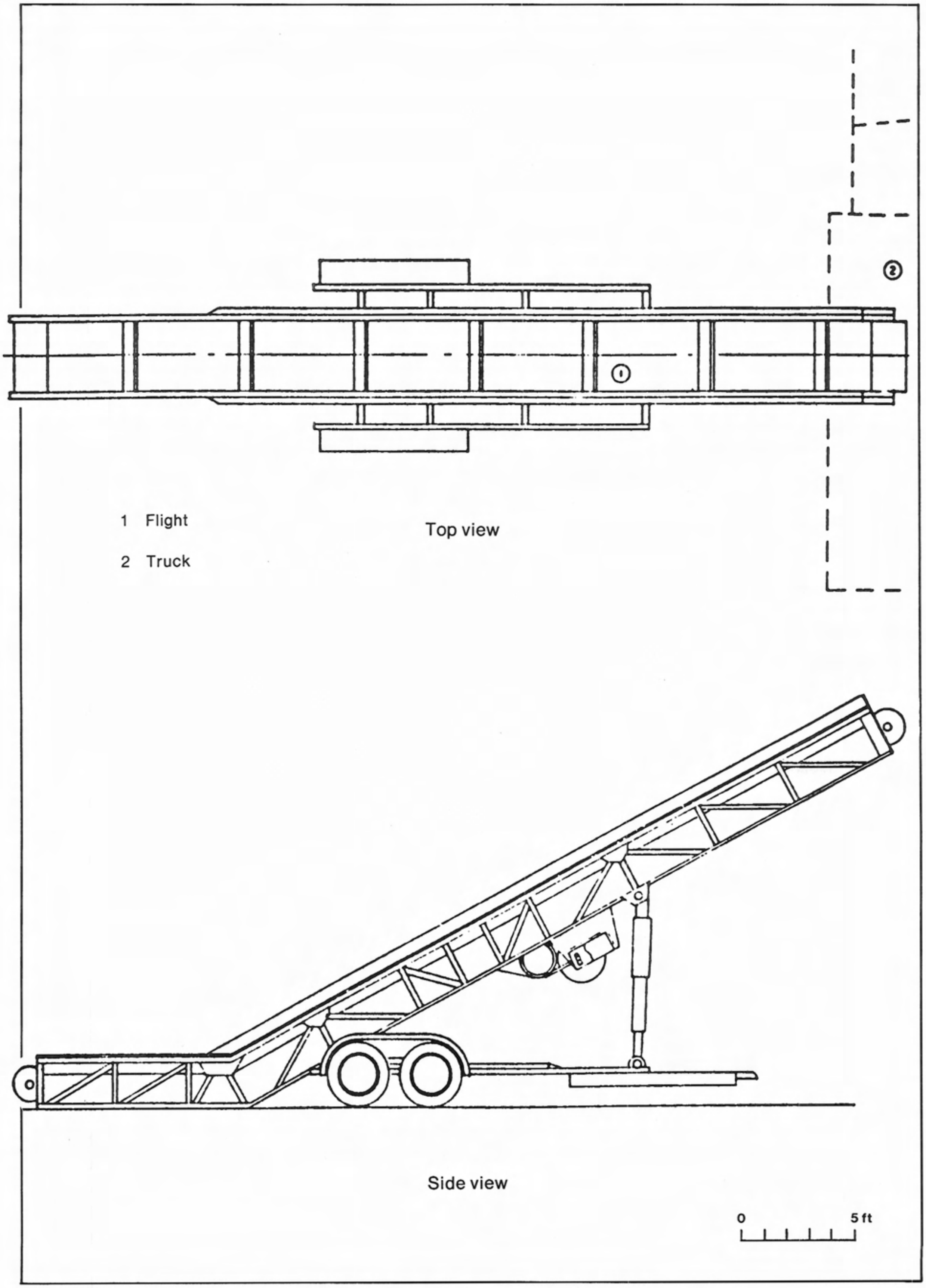



Figure 4. Diagram of Nicholson outfeed conveyor.


Figure 5. Location of test sites.

areas with sideslopes between 20 and 50 percent. The second site, Kathy Lake, was relatively flat with minor sideslopes of 5 to 10 percent and had areas of wet, swampy ground. The logging residues at both sites were gathered with rubber-tired skidders and piled with front-end loaders.

## Logging Residue Inventory

Logging residues were inventoried before and after the collection trials to obtain information on the quantity, condition and piece size distribution of material collected, and material remaining on the test sites. The modified line-intersect sampling technique with inventory plot centers located on a predetermined systematic grid was used to measure the quantity of logging residues on all test sites.

The pre-collection residue volumes are shown in Table 2. The average total volume ranged from 179 $m^3$/ha on the Interior wet belt flat site to 674 $m^3$/ha on the Interior wet belt moderate slope site. It is interesting to note that on this latter site the sawlog volumes logged prior to the residue study amounted to only 25 percent of the gross volume whereas the merchantable volumes removed from the former site was in excess of 65 percent of the gross volume. The Coast sites have residue volumes per hectare which were between the extremes found in the Interior, and range from 270 $m^3$/ha on the moderately sloped site to 497 $m^3$/ha on the steep site. The steep site's greater volume was probably caused by breakage during the falling and yarding phases of prime logging.

Table 3 shows the residue volume by diameter class. In general on the Coast the volume of material was distributed relatively evenly through the diameter classes except that a greater percentage of volume was found in the 65+ cm class on the steep-sloped area than on the moderately-sloped area. The mean piece size was approximately 35 cm in diameter. As a rule the percentage of rotten material was greatest in the larger diameter classes and least in the smaller diameter classes. At the mean piece size of 35 cm, the percentage of sound and rotten material was approximately equal.

In the Interior wet belt the distribution of logging residue by diameter class was markedly different between the moderately-sloped site at Railroad Creek and the flat site at Kathy Lake. The moderately-sloped site was similar to the Coast Site except that most of the volume was concentrated in the middle diameter classes and the piece average of 25 cm was smaller than at the Coast. The flat site had a diameter distribution which was heavily skewed to the small diameter classes with 82 percent by volume of the pieces having a diameter of less than 35 cm.

## Collection Methods

a) Coast

On the moderately sloped area a 104 kW (140 hp) crawler tractor (International Harvester TD 15-C) with a brush blade was used to pile logging residues at or near roadside processing points. On the steeply sloped area a mobile tower yarder (Madill 071) was used to yard residues to a roadside landing.

A brief trial involving residue collection on moderate slopes using a skidder equipped with a special flexible toothed brush blade (Eden Piling Rake) was not successful. The skidder could not carry sufficient quantities of material or clear the site sufficiently to meet the requirements of the project. Due to topographic factors and variability of residue concentration on the steep site, not all of the original area selected for collection trials was cleared. In certain areas where the terrain was excessively steep and rocky or where residue concentrations were minimal, collection of residues was not considered to be practical or necessary.

It was noted that a number of rotten pieces were destroyed or lost during the collection operation with both the crawler tractor and highlead yarder collection methods. Many of these pieces were very rotten and fell apart while being moved to the collection points.

The crawler tractor was able to carry large accumulations of residues over relatively long distances. In general this method proved to be an efficient and an inexpensive method of collecting logging residues. However, the method is restricted to flat or moderate terrain and has limited scope on the steep, rough terrain typical of B.C. Coastal logging operations.

The small mobile tower yarder (15-m high) used for collecting residues was the only practical way of recovering material from steep, rough slopes. The tower was equipped with light lines and a high speed winch which made it ideally suited for yarding residues. However, problems encountered in individually handling a large number of small and rotten pieces resulted in lower production and higher collection costs than those incurred using the crawler tractor on the flat site. It was difficult to achieve a reasonable size of payload per turn or cycle of the machine. The small or rotten pieces which typify logging residues would fall off or break apart during yarding resulting in low volumes per cycle.

b) Interior Wet Belt

The same equipment type and methods were used on both sites in the Interior rubber-tired skidders in the 71 to 93 kW (95 to 125 hp) range using conventional slider-bell chokers were used to skid the residue material to a central landing at roadside. At the landing a rubber-tired front-end loader decked the material so that it was readily accessible for processing. Large branches and root pans were removed using a power saw. The root pans were not retained for future processing.

The average skidding distance was approximately 200 m; the longest distances were 350 m on the flat site (Kathy Lake) and 500 m on the moderately-sloped site (Railroad Creek). These long distances contributed to the relatively high collection costs but were necessary due to the road spacing in these areas.

Rubber-tired skidders are used for approximately 80 percent of the logging in the Interior wet belt. Because of the general availability of these machines this method was used for harvesting the test material. However, this method was not found to be efficient for collecting small 7-15 cm diameter material as many pieces would slide out of the chokers. As well, the piece volume was minimal.

Both sites were winter logged for the merchantable logs due to the predominantly wet ground conditions. The collection of residual material occurred during the summer of 1981, a period of unseasonably high rainfall. Both sites were excessively wet, which resulted in poor traction and heavily rutted trails for the skidders. This also contributed to higher-than-expected collection costs.

## Productivity and Cost of Collection

The Ministry of Forests (MoF) in the Interior wet belt and Forestal on the Coast used similar methods to determine the actual areas cleared and the volume removed. The volumes collected were determined by subtracting the post-collection inventory volume from the pre-collection inventory volume, adjusted for material lost or destroyed during collection.

The area cleared and the volume collected for the four test areas are summarized in Table 4. The test areas were much larger in the Interior and the total volumes were also larger. There was a significant difference between the percentage collected of original volume on the Coast with that of the Interior wet belt. The Interior trials collected between 92 and 93 percent of the available material whereas accumulations at the Coast varied from 67 percent to 75 percent of the available material. The harvesting of residual material of small size in the Interior would cause higher collecting costs even if all other factors were equal.

The productivity and cost results for the collection trials are shown in Table 5. The unit costs per cubic metres were converted to green tonnes (Gt) of unspecific moisture content by sampling the material collected from the various sites to determine their respective green densities (Appendix 2).

The extremely high unit costs incurred on the Interior wet belt flat site were caused by i) collecting the logging residue from wet sites in extremely rainy weather, ii) the relatively low volumes per hectare, iii) the extremely close utilization standards, and iv) the small piece size. For these reasons the unit costs from this location are not used in other calculations or estimates. Of the three remaining sites the unit costs were lowest on the moderately-sloped Coast site, highest on the steep-sloped Coast site, and medium high on the moderately-sloped Interior site. The main reasons for this are as follows:

- The hourly cost of the highlead system was higher than that of the crawler tractor system due to the larger crew required and higher fixed costs. The highlead system required a four-man crew compared to the one man needed on the crawler tractor.

- Similarly, the Interior wet belt moderate slope used a rubber-tired skidder and front-end loader and had a two-man crew compared with a crawler tractor and one man on the Coast moderate slope.

- The collection productivity of the highlead system is much less than that of the crawler tractor. The average volume collected per machine hour was only 8.9 $m^3$ for the highlead system versus 23.2 $m^3$ for the crawler tractor system.

- The combined productivity for the rubber-tired skidder and front-end loader at 6.2 $m^3$ per machine hour is also much lower than the crawler tractor. This is caused in part by longer average yarding distance, smaller log diameter (25 cm versus 35 cm) and the wet conditions in the Interior.

Residue collection with the crawler tractor, although substantially more cost efficient is only practical on level or moderately-sloped areas, which limits its usefulness on the Coast. This method would not be practical for moving residues uphill, nor for moving material over distances greater than 100 to 200 m.

With the highlead system, some gains in productivity could possibly be achieved by using pre-set chokers and by increasing the number of chokers used from two to three. These improvements would decrease costs by no more than ten percent.

# Field Processing Trials

## General Description

During the winter and spring of 1982, the mobile processor was assembled at Nicholson Murdie Machines Limited in Victoria, B.C. After a short period of factory tests in May, 1982, the processor was moved to the GVWD Tree Farm, 30 km northwest of Victoria.

Two large piles of logging residues had been assembled at the steeply sloped site during collection trials of the mobile tower yarder the previous summer. Since no useful information would have been provided by conducting additional processing trials at the moderately-sloped site where the residue material was of a similar type, the field trials were only carried out at the steep site.

Processed material was transported 6 km from the GVWD test site to a yard area located outside the Tree Farm. Each load was weighed on portable axle scales to determine the weight and bulk density of the processed material. This also provided an estimate of the solid wood equivalent (SWE) volume processed by the system. All phases of the trials were timed to determine the availability and utilization of the processor and to obtain productivity data on a productive machine-hour basis. These trials were completed in June, 1982.

After the residue processing trials at the GVWD, the processor was moved to the Interior wet belt of B.C, where trials were carried out by the B.C. Ministry of Forests, to assess the suitability of this system for processing logging residues in the decadent cedar-hemlock forests of that region.

In the Interior the shear processor operated for 26 days on residual material from the moderately-sloped site (Railroad Creek). Green cedar and hemlock from adjacent stands were also processed to determine if there was productivity differences between processing air-dried and freshly-cut green material.

The processed material was transported by truck container-type bins of from 19 $m^3$ to 30 $m^3$ capacity to a site 0.25 km from the processor. Each container of material was weighed using a set of portable scales to determine the weight and the bulk density of the material. Also, samples of the sheared material were analyzed to determine size distribution by weight.

## Processing Equipment and Labor

The processing equipment used and the operating labor required was similar for the Coastal and Interior tests. In addition to the operating personnel there were personnel from Forestal or FERIC monitoring the system and Nicholson representatives modifying and adjusting the prototype processor.

The equipment used included the following:

- Barko 450 hydraulic grapple loader (crawler mounted on the coast, rubber-tired in the interior)
- Nicholson mobile shear-type processor
- Container Trucks (2) - Interior
- Dump Trucks (2) - Coast
- Power saw
- Other equipment on an as needed basis:
  crawler tractor
  rubber tired skidder - Coast
  low-bed tractor unit - Coast

Operating labour consisted of:

- Loader operator
- Processor operator
- Landing man
- Truck drivers (two on the coast, one in the interior)

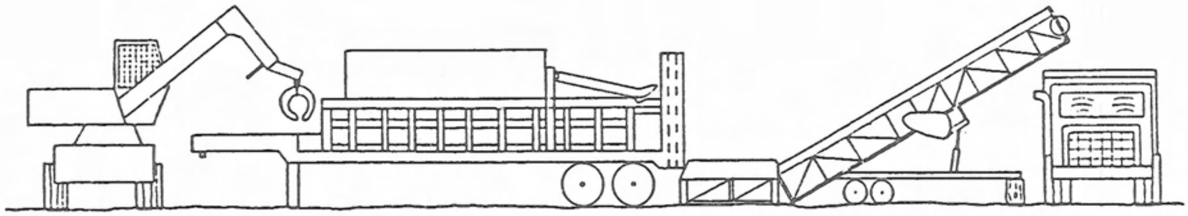



Figure 6. Position of processing equipment in landing.

## Processing Methods

The equipment was positioned in the loading as shown in Figure 6. The grapple loader was placed so that it could reach a maximum of residue material from the piles and at the same time load this material onto the infeed conveyor of the processor. On the Coast, due to the limited width of the landings, the loader was placed behind, rather than beside the processor's infeed conveyor. The processor unit was placed longitudinally on the roadway with the outfeed conveyor placed in line with or at a slight angle to the shear unit. Trucks were positioned under the end of the outfeed conveyor either in line with or on an angle to the conveyor axis.

The total length of the processing system, including loader and truck, was approximately 30 m. Prior to the field trials, there had been concern that it would be difficult to find 30 m of flat, straight roadway to set up the system. However, experience gained during trials showed that it is possible to set up the system on roads which are not entirely straight by arranging the different components of the system at angles to each other. The equipment units also functioned acceptably when operating on undulating roadways as well as on steep road gradients. In one case, the processor was set up and operated without difficulty on a 15 percent grade.

The loader was used to select and sort material from piles. Oversized pieces (greater than 75 cm in diameter) were rejected. Mis-shapen pieces or pieces with large limbs or roots were set aside for bucking or delimbing with a powersaw. The loader was also used to move and position the processor in the landing. Short moves along a residue pile were accomplished by lifting the processor at the infeed conveyor end using the loader's grapple and then pulling or pushing the processor into position using the loader's travel, rotation or boom movement.

Initially, it had been planned to use a front-end loader for feeding residue material to the processor. However, due to the height, position (off road) and interwoven nature of the piles collected by the highlead system, it was decided that a grapple loader would be more suitable for sorting and loading residue material onto the processor.

The grapple loader proved to be the ideal machine for use with the mobile processor. In order to utilize the full capacity of the shear unit, and thereby achieve maximum production, the loader operator attempted to keep the infeed conveyor as full as possible. The operator's position, above and to the right of the infeed conveyor, enabled him to observe material feeding into the shear. He was often able to avoid delays due to blockages by using the grapple to assist the flow of material along the infeed conveyor. Because of this, it was seldom necessary to reverse the conveyor in order to reject or rearrange occupied in sorting material from the piles and loading the processor's infeed conveyor.

Material was advanced through the shear opening in increments equal to the length of material desired. At the end of each advance, the shear was lowered, cutting the material protruding through the shear opening. Sheared material dropped onto the outfeed conveyor and was carried to the top of the conveyor from where it fell into a truck or container. During the field trials, material was cut into lengths of 60 to 160 cm. The timing of the advance ranged from three to eight seconds depending on the lengths being cut and the degree of loading of the conveyor. The shear cycle-time varied between six and ten seconds depending on the species, dryness and diameter of pieces being cut. The average total cycle-time, including the advance of the infeed conveyor, was 16.5 seconds.

On the Coast, the operator's position beside the infeed conveyor and shear did not provide sufficient visibility of either of these components. It was also a hazardous position. The operator was in danger of being struck by material being loaded or conveyed forward by the infeed conveyor and by the hydraulic hoses or fluid should a hydraulic coupling or hose break. In the Interior the processor had a remote operator console from which all components of the processor could be controlled.

Moving time between landings required one to two hours depending on the length of the move. Short moves within a landing required 15 to 30 minutes. The addition of hydraulic jacks to raise and lower the processor's support legs would reduce this time.

In general, the processor performed very well considering that it was a prototype model working under operational field conditions.

## Productivity and Cost

A summary of the residue and green timber processing productivity which occurred over 39 operating days is shown in Table 6. The machine availability improved from 81.6 percent on the Coast to the 92 percent range in the Interior. This may reflect improvements made to the processor on the Coast by Nicholson.

The utilization of the machine ranged from approximately 54 percent on the Coast to 64 percent when processing logging residue in the Interior. This improvement was caused by the processor having more room, requiring fewer moves, and waiting less time for trucks at the Interior processing site. An inherent problem with processing material in field situations are work delays caused by moving, limited site area, limited material available and transportation delays which cause low machine utilization. The average production per productive machine hour ranged from 12.8 Gt on the Coast to 15.2 Gt for Interior logging residue and 21.5 Gt for green timber.

Residue processing costs (Table 7) are based on standard costs for the equipment and personnel used rather than actual costs which varied between geographic areas, contractual arrangements and availability of equipment.

The total hourly cost of the equipment based on 200 shifts per year ranges from $176.00 to $183.00. This does not include collecting the logging residue and transporting the processed material. Based on the operating days, volumes processed and productivities shown in Table 6 the costs range from $22 to $27 per Gt for processing logging residue.

## Transportation of Processed Residuals

On the Coast, some processed logging residue was transported 90 km to Crofton pulpmill using 3-axle container trucks. The trucks had self-tilting steel containers with a volume capacity of 30 $m^3$ (Appendix 4). The payload of the containers was 8.6 Gt. In the Interior wet belt the material was moved only a few hundred metres from the processor trial site using similar equipment.

The capacity of the trucks used in the trial was relatively small compared with trucks used to transport pulp chips. This resulted in high transportation costs ($20.00/Gt for a 90-km haul). Larger truck units should reduce the cost of transportation.

In determining a better truck configuration for transporting processed material the following key factors were considered:

— The sheared residual bolts have a bulk density greater than pulp chips.

- The individual bolts are dropped from a conveyor into the container which will cause damage unless the equipment is heavy duty, all steel construction.

- Size and weight requirements for commercial vehicles travelling on B.C. highways.

- The limitations of loading and unloading sites.

- The limitations of typical logging road systems.

In Table 8, the configurations and capacities are shown for five truck units and compared with the capacity of a 5-axle highway logging truck. The 3-axle container truck and 6-axle dump truck and trailer (A-train) are representative of heavy duty equipment available at this time. The three larger units are based on the latest truck technology as used for hauling pulp chips, but modified for the heavy duty requirements of loading and transporting sheared logging residue. The table indicates the container truck and dump truck and trailer are limited by volume, whereas the three larger units are approximately at the break-even point between being limited by volume and limited by weight. These large units have capacities close to or in excess of the conventional 5-axle highway logging truck.

The budget capital cost of the tractor and tri-axle semi-trailer, 7-axle B train, and 8-axle B train are \$143,000, \$161,000 and \$170,000 respectively, based on new equipment. The hourly costs shown are total standard costs based on operating 2400 hours per year.

Using the capacities and hourly costs for the various truck configurations transportation costs for coast sheared residuals per green tonne were calculated for various haul distances. The results are shown graphically in Figure 7. The cost for the 7-axle B train is not shown but the costs are between those of the truck and tri-axle semi-trailer and the 8-axle B train. This graph is indicative of the cost relationship between the various units and does not allow for long loading delays nor the cost of unloading. The three larger units would require at least a semi-portable trailer tipper which would cost approximately \$100,000.

The graph indicates transportation costs may be reduced by the use of larger trucks provided there are:

- Medium to long hauls.
- Sufficient volume.
- Adequate loading area (large landings).
- Good logging roads (no adverse grade).

It is doubtful if all these conditions will be found at field processing sites.

# Estimated Costs for Sortyard and Millyard Processing

The productivity of the shear processor when operating in the landing or at field sites was limited by frequent moves and lack of room for the transportation units removing the processed material. Yarding, loading and hauling costs associated with removal of logging residue may be lower if done in conjunction with the prime logging using the same equipment but congestion will increase in the landing, and may adversely affect yarder productivity. Smaller piece size will also affect yarder productivity. On the other hand, sortyards and millyards produce large volumes of debris as a byproduct of remanufacturing and sorting logs. Disposal of this debris is difficult and costly. For these reasons, estimates have been made of the equipment and personnel required and the associated costs of operating the shear system in a yard.

## Processing Method

The shear processor should be located in an unused paved portion of the yard and logging residue or sortyard debris brought to the machine by mobile equipment used in the yard. A small hydraulic loader would be located adjacent to the processor at the infeed conveyor and would feed the processor from the pile of delivered material. The loader could be a smaller model than used on site because the material would be closer and easier to lift onto the infeed conveyor. After the material is processed it would go up the outfeed conveyor and drop into a truck-container and

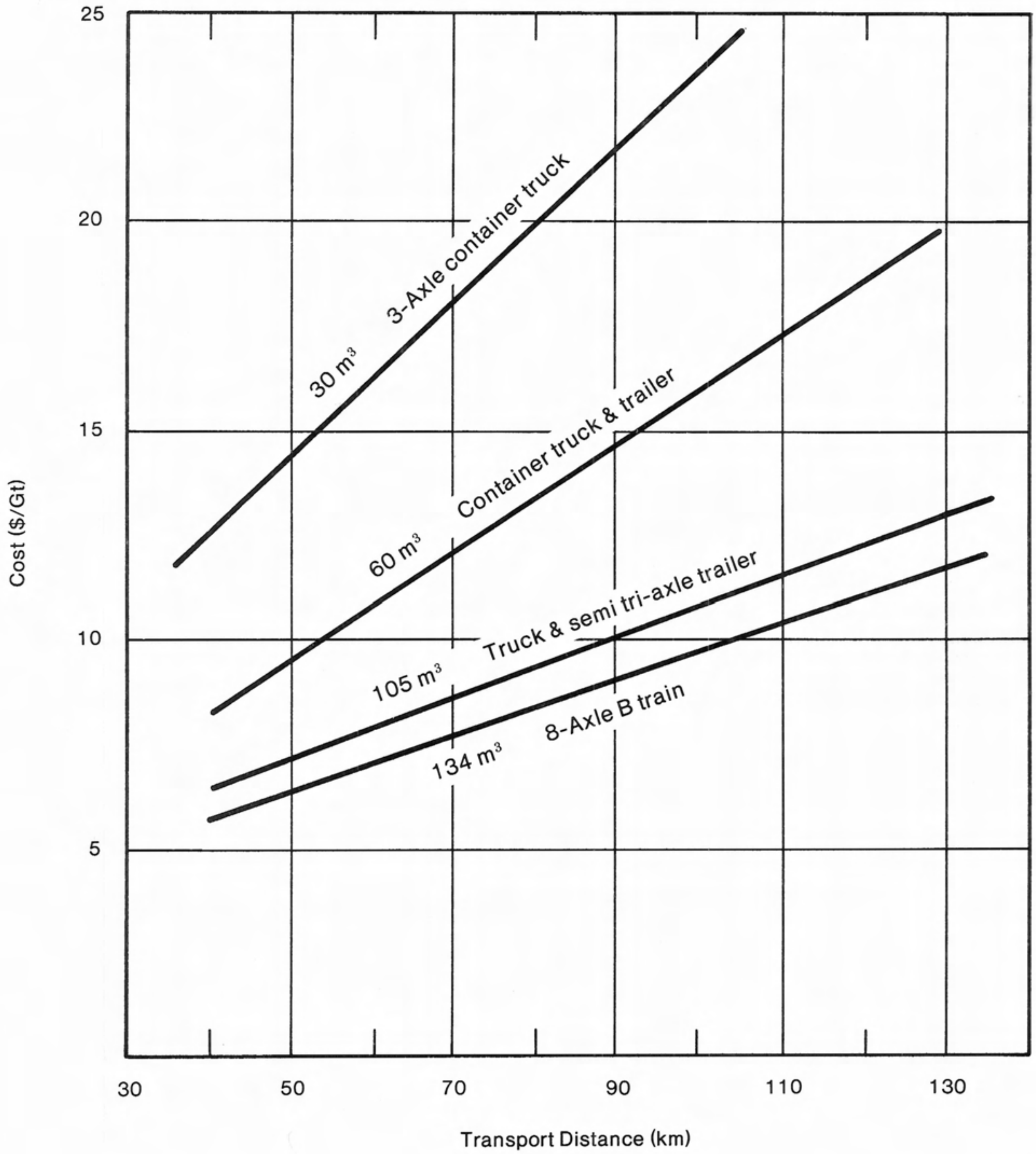



Figure 7. Transportation costs sheared material.

then be transported to the mill.

There would be adequate space for loaded and empty trucks or containers so that the processor could operate without long delays. In the case of a millyard the processor could be located adjacent to the mill hogging system with the processor outfeed linking the two systems.

The system would require a maximum of three operating personnel, a loader operator, a processor operator and a groundman. If the processor were automated it is possible the groundman could tend the processor as well as perform his other tasks.

### Estimated Productivity and Cost

The estimated productivity and costs are shown in Table 9. They are based on working with three operating personnel, a productivity of 16.0 Gt per productive hour and machine utilization of 85 percent. The productivity is based on the actual productivity obtained in the Interior wet belt processing logging residue and is believed to be conservative when operating in a yard. The machine utilization factor is normal for equipment working within a yard.

The costs per unit are estimated to be $\$5.33/m^3$ or \$9.70/Gt. These estimates are less than half the costs incurred during the trials and yet are based on the same productivities and costs. This variance is caused by much improved machine utilization and no need for other support equipment. There is a strong possibility that the shear processor operator would not be required, which could reduce the operating costs by approximately 10 percent.

## Energy Values of Residuals

To determine the energy value of processed logging residues a comparison is made of this material with other energy producing substances. Bunker 'C' oil, which many industrial boilers use for fuel, is used as a yardstick. This oil has an energy value of 6640 megajoules per barrel (MJ/Bbl) and a current price of \$25 per barrel.

The energy values of residues for Coast and Interior wet belt sites are shown in Table 10. These values were calculated using the following criteria:

**The average gross calorific or fuel value of the residue (MJ/ODt)**

— Less

heat loss due to heating the water formed from the combustion of hydrogen.

— Less

heat loss due to heating the water present as moisture

— Less

heat loss due to heating dirt in debris

— Equals

**the net or as-fired heating value of the logging residue**

The oil replacement value (Barrels/Gt) is determined by the ratio of the as-fired heating value of logging residue times the boiler efficiency of a wood fired boiler divided by the energy content of bunker 'C' oil times the boiler efficiency of an oil fired boiler. The detailed calculations are shown in Appendix 2.

The Coast logging residue has an oil replacement value of 1.816 barrels per green tonne (Bbl/Gt) *versus* 1.415 Bbl/Gt for the Interior wet belt. This is caused by a slightly higher average fuel value and a lower moisture content of the residual materials. The moisture content is an important factor in determining net energy values of logging residues. It is not known if the samples taken from the Coast and Interior wet belt should normally have such a variation in moisture content between them or within Interior and Coast sample, or if it was caused by exceptional weather conditions.

With bunker 'C' oil at a cost of \$25 per barrel the oil replacement value is \$45.41/Gt for Coast residues and \$35.37/Gt for Interior wet belt material. Thus, the Coast has a better opportunity to utilize logging residues. Also, there are numerous converting plants using oil or hogged fuel on the Coast whereas most Interior plants use natural gas; although gas prices are a fixed percentage of oil price.

# Energy Balance

During the field trials, fuel consumption of all equipment was monitored in order to determine the total energy expended on each phase of the work. The energy value of diesel fuel consumed was assumed to be 40 MJ/ℓ. The net or as-fired heating value per green tonne of processed logging residues previously calculated was used as the total energy produced.

As illustrated in Table 11, the total energy value of fuels consumed in collecting, processing, transporting and hogging logging residues varied from 805 MJ/Gt on the Coast sites to 1007 MJ/Gt on the Interior wet belt sites. The ratio of energy consumed to energy produced was 1:16.5 on coastal sites and 1:10.75 on the Interior sites.

# Collection, Processing and Transportation Cost/Benefit Summary

In order to evaluate the shear processing system the information generated in previous sections is summarized and compared with the chipping system for processing logging residue at field sites or in a central location.

## Comparison of Processing Methods and Locations

To develop cost/benefit relationships, the chipping system and shear system are compared by: on-site processing at both moderate and steep sloped locations; sortyard processing; and, millyard processing for the shear system. To standardize the analysis, the following assumptions and sources of information are used:

- The field site is 20 km from the sortyard and 80 km from the mill.
- The sortyard is 20 km from the field site and 60 km from the mill.
- On-site harvesting or collection costs are from this study. Harvesting costs for sortyard processing assume the material is gathered in the primary logging phase using the highlead system. The costs at $14/m^3$ compare with normal highlead yarding costs of $7 to $11/m^3$. Small logging residue is not collected.
- Processing and loading costs for the shear system are from this study and the chipping system costs are based on ENFOR Project P-36.
- Load and unload costs are for unloading only when the material is processed on site.
- Transport to yard costs are based on moving the material on 5-axle logging trucks on gravel logging roads. The residue material is mixed with normal logs which form most of the load.
- Process in sortyard costs for the shear system are based on the study results with an 85 percent machine utilization factor. The costs of chipping are based on ENFOR Project P-36 and FERIC TN-65.
- Transport to mill costs for on site processing are based on using a 3-axle 30-$m^3$ capacity van because of limited room at roadside and the assumed condition of the logging access road. Transportation costs for sortyard processing are based on using a 60-$m^3$ capacity truck and trailer unit because the space around the processor is not limited and the road to the mill is likely of higher class than the logging road.
- Process in millyard is only possible in cases where this is the direct destination of the logs from the same area as the logging residue.
- Hogging at mill cost is an average based on information from several industry sources. Costs vary considerably depending on the age of the plant, utilization and relationship to an existing converting plant.

The projected costs for these processing systems are shown in Table 12. The estimated total costs vary from $101/Gt to $49/Gt with the lowest costs associated with processing in a sortyard or millyard. This is caused by the best combination of harvesting and transportation costs for sheared material together with the lowest processing costs which can be attained by using the processor in a yard where the machine utilization factor is higher and approaching the machine availability factor.

The lowest projected cost of $49 to $50/Gt exceeds the oil replacement value of $45/Gt on the Coast and $35/Gt in the Interior wet belt based on bunker 'C' oil at $25/barrel.

## Opportunity for Commercial Use of the Shear System

Processing logging residue in a sortyard on the Coast using the same type of material collected on southeastern Vancouver Island results in a cost*/benefit** relationship of $51/$45 (1.13) or a net loss of $5/Gt. There are numerous sortyards on the Coast located within 60 km of mills which have existing hogging plants. These yards produce sortyard debris (30 to 110 Gt per day) which must be disposed of by burning or placing in land fills. Disposal costs range up to $10/Gt or about $0.15/m³ of logs sorted. There is an opportunity to furnish a shear processor with a mixture of logging residue and sortyard debris thus solving a problem associated with sortyards and providing a mix of materials which when processed will have a positive cost/benefit relationship.

Table 13 shows the estimated costs for processing sortyard debris and logging residue. A cost allowance of about 20 percent is made on processing debris to allow for its smaller size in comparison to logging residue. The cost of transportation to the mill and hogging costs are estimated to be equal for both types of material. The average cost of debris disposal is shown as a credit of $6/Gt.

As indicated, sortyard debris is processed at a total cost of some $23/Gt compared to $50/Gt for logging residue.

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* Total cost/Gt (see Table 12).
** Energy value of material.

# Conclusions and Recommendations

1. Nicholson Murdie Machines Limited of Victoria, B.C. with direction from Forestal and FERIC, have successfully designed and constructed a prototype shear processor which is capable of reducing logging residue of varied size into pieces or bolts of uniform length. The shear processor complete with infeed and outfeed conveyor has an estimated capital cost of $250,000 and operating cost including an operator of $56.00 to $60.00 per hour.

2. Collection trials using a 15-m high mobile tower yarder on a Coast steep site, ($11.18/m$^3$) a crawler tractor with brush blade on a Coast moderately-sloped site (2.59/m$^3$), and rubber-tired skidders yarding material that was piled by front-end loaders on Interior sites ($8.13/m$^3$), indicate the following:

   — On flat or moderately-sloped sites with stable soils and short yarding distances a crawler tractor with a brush blade is the least cost option.

   — Logging residue should not be collected from sites with low volumes per hectare or small piece size because of high cost.

   — On steep slopes consideration should be given to logging the larger residue pieces at the same time as prime logging to reduce collection costs.

3. The on-site processing trials proved the shear processor had an acceptable machine availability factor of from 82 percent in the initial trial on the Coast to 92 percent for the later trial in the Interior. The average productivity per productive machine hour was satisfactory at 15.2 green tonnes in the later trial. Machine utilization reached 63.8 percent when processing logging residue, which probably was as high as can be expected when using the processor at on-site locations. Delays caused by equipment movement and inadequate space are inherent in the system when only part of the original stand (on moderate or steeply sloped areas) is processed at roadside. On-site processing works well where there are large volumes, often the complete timber stand, being processed on relatively flat locations.

4. Transportation is over 35 percent of the total cost of collecting, processing and delivering forest residuals to the mill. The following comparisons and relationships will assist in determining the most efficient transportation system.

   — The shear processed residual bolts have a bulk density over 15 percent greater than similar chipped material and therefore more can usually be carried in a container of a given size.

   — Trucks transporting chips or sheared logging residue may be limited by volume rather than by weight.

   — The bulk density of logging residuals in log form is greater than processed residual bolts and a highway logging truck can transport more material than a container truck with a similar axle configuration.

   — A B-train container truck and trailer loaded with processed residual bolts has a similar payload to a highway logging truck.

   — On longer hauls, large container trucks and trailers have lower transportation costs than smaller units provided there is sufficient room to load and the road is of good quality.

5. Combining the costs of collection, processing and transportation for various logging residue processing systems showed the sortyard or millyard processing system was superior to field processing systems. Summarized below are all costs from residue collection to

final processing at a mill 80 km from the collection site.

| On-site Processing | Total Cost/Green tonne |
|---|---|
| Moderate Sites | |
| Chipper | $ 86 |
| Shear | 54 |
| Steep Site | |
| Chipper | 102 |
| Shear | 70 |
| Sortyard Processing | |
| Chipper | 55 |
| Shear | 50 |
| Millyard Processing | |
| Shear | $ 49 |

6. Collection, loading and transportation costs of logging residue to a sortyard or millyard could probably be reduced on moderate and steep sloped sites by:

   – Changing the bucking specifications so that logging residuals, whenever possible, are left attached to the adjoining merchantable log.

   – Yarding, loading and transporting logging residue and merchantable logs at the same time.

   – Having sortyards with the capability to separate logging residue from merchantable logs, and other minor forest products such as cedar shake and shingle bolts.

7. Analysis of the logging residue indicates the oil replacement value is $45 per green tonne for mixed species on the Coast and $35 per green tonne for hemlock-cedar in the Interior wet belt. This shows costs exceeding benefits by $5 per green tonne on the Coast and $15 in the Interior.

8. Estimates suggest the shear processor, if used in sortyards within 60 km of a Coast mill with a hogging system, can provide a source of feed stock for boilers at below the current cost of bunker 'C' oil when processing sortyard debris.

   These initial estimates should be proved and refined by trials with the processor in a sortyard or millyard, and additional transportation trials and simulations for various truck sizes and configurations.

# Bibliography


Blakeney, K.J. 1980. Development and Testing of a Field Treatment System for Logging Residues. Forestal International Limited, ENFOR P-36, Canadian Forest Service, Report BC-X-212, 70 p.

Bowater, Newfoundland Ltd. 1983. Forest Biomass as an Alternative Fuel at Bowater Newfoundland Limited, ENFOR Project No. 10Sc KL001-1-002, 123 p.

Brown, L.F. et al. 1981. Green Mountain Timber Sale - Wood Residue Utilization Study, Oregon Wood Residue Utilization Committee & USDA Forest Service.

Brown, J.K. 1974. Handbook for Inventorying Downed Wood Material. Intermountain Forest and Range Experiment Station, USDA Forest Service, Technical Report INT 16, 24 p.

Dobie, J. and Wright, D.M. 1979. Metric Conversion Factors for Forest Products in Western Canada. Forintek Canada Corp., Western Forest Products Laboratory, Technical Report No. 1, 59 p.

FAO. 1973. Production Handling and Transport of Wood Chips, 86 p.

FAO. 1976. Wood Chips - Production Handling Transport, 136 p.

Hatton, J.V. 1979. Chip Quality Monograph No. 5, Pulp and Paper Technology Series. TAPPI, CPPA, 323 p.

Johnston, B.D. 1981. Hog Fuel Production from Sortyard Debris. FERIC, Technical Note No. TN-48, 24 p.

Johnston, B.D. 1982. Trial of System for Debarking and Chipping British Columbia Logging Residues. FERIC, Technical Note No. TN-65, 31 p.

McDaniels, T.L. 1982. Forest Biomass Energy in British Columbia Opportunities, Impacts and Constraints. McDaniels Research Ltd., ENFOR P-135, Canadian Forest Service, Report BC-X-226, 154 p.

Nagle, G.S. 1980. Analysis of Salvage Yarding Systems and Costs in Pacific Coast Forests. Nawitka Renewable Resource Consultants Ltd., ENFOR P-162, Canadian Forest Service, Report BC-X-214, 36 p.

Plummer, G. et al. 1980. The Forester's Wood Energy Handbook. American Pulpwood Association, Southern Division Office, 33 p.

Pottie, M.A. 1981. A Way to Make Pulp Chips from Logging Debris Using a Small Drum Debarker. FERIC, Technical Note No. TN-49, 18 p.

Powell, L.H. 1982. Mobile Chipper Study: Processing Logging Residues for Energy Biomass. FERIC, Technical Note No. TN-61, 22 p.

Sinclair, A.W.J. 1981. Utilization of Coastal B.C. Log Sortyard Debris. FERIC, Technical Report No. TR-46, 68 p.

Sinclair, A.W.J. 1982. Trial of Separator and Shear System for Processing Sortyard Debris for Hogged Fuel and Pulp Chips. FERIC, Technical Report. No. TR-51, 43 p.

Withycombe, Richard P. 1982. Estimating Costs of Collecting and Transporting Forest Residues in the Northern Rocky Mountain Region. USDA Forest Service, Technical Report INT-81, 12 p.

**Table 1. Capital and Operating Cost Estimates of Nicholson Shear**

| | Cost Per Year | |
|---|---|---|
| Capital cost of shear & outfeed conveyor | $250 000 | |
| | 200 Days | 240 Days |
| Interest on investment @ 15% | $ 18 750 | $ 18 750 |
| Depreciation 10 yr life no residual value | 25 000 | 25 000 |
| Insurance @ 1% of capital cost | 2 500 | 2 500 |
| Repairs & maintenance | 24 000 | 28 800 |
| Fuel 13.65 litres/hour @ $.41/litre | 8 960 | 10 750 |
| Operator $25.00/hour (including fringes) | 40 000 | 48 000 |
| Total Cost per Year | $119 210 | $133 800 |
| Total Cost per Hour | $ 59.60 | $ 55.75 |
| or | $ 60.00 | $ 56.00 |

**Table 2. Pre-collection Residue Volume per Hectare**

| Location | Sound | Decayed | Total |
|---|---|---|---|
| | cubic metres per hectare (percent) | | |
| Coast Steep Slope | 286.6 | 210.1 | 496.7 |
| | (58) | (42) | (100.0) |
| Coast Moderate Slope | 123.4 | 146.6 | 270.0 |
| | (46) | (54) | (100.0) |
| Interior Wet Belt | 551.6 | 122.1 | 673.7 |
| | (82) | (18) | (100.0) |
| Interior Wet Belt | 164.9 | 14.5 | 179.4 |
| | (92) | (8) | (100.0) |

**Table 3. Residue Volume by Diameter Class**

| Location | Diameter Class cm 5-20 | 20-35 | 35-50 | 50-65 | 65+ |
|---|---|---|---|---|---|
| | Percent by Volume | | | | |
| Coast Steep Slope | 19 | 18 | 22 | 20 | 21 |
| Coast Moderate Slope | 26 | 33 | 23 | 14 | 4 |
| Interior Wet Belt Moderate Slope (Railroad Cr.) | 10 | 26 | 34 | 23 | 7 |
| Interior Wet Belt Flat (Kathy Lake) | 38 | 44 | 12 | 4 | 2 |

**Table 4. Results of Collection Trials: Area and Volume**

| Location | Collection Method | Test Area (ha) | Original Volume ($m^3$/ha) | Post Collection Volume ($m^3$/ha) | Volume Collected into Piles ($m^3$/ha) | ($m^3$) | Percent of Original Volume (%) |
|---|---|---|---|---|---|---|---|
| Coast Moderate Slope | Piling with Crawler Tractor | 3.4 | 270 | 53 | 181 | 615 | 67 |
| Coast Steep Slope | Yarding with Highlead Tower | 3.5 | 497 | 73 | 372 | 1302 | 75 |
| Interior Wet Belt Moderate Slope | Yard-Rubber-tired Skidder Deck with Front-end Loader | 7.1 | 674 | 51 | 623 | 4423 | 92 |
| Interior Wet Belt Flat | Yard-Rubber tired Skidder Deck with Front-end Loader | 10.7 | 177 | 13 | 164 | 1806 | 93 |

**Table 5. Results of Collection Trials: Productivity and Cost**

| Location | Collection Method | Area Cleared (ha) | Volume Collected ($m^3$) | Machine Hours Required (hr) | Equipment and Labour Cost ($/hr) | Equipment and Labour Cost ($Total) | Productivity Cost (hr/ha) | Productivity Cost ($m^3$/hr) | Productivity Cost ($/ha) | Productivity Cost ($/$m^3$) | Productivity Cost ($/Gt) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coast Moderate Slope | Piling with Crawler Tractor | 3.4 | 615 | 26.5 | 60 | 1 590 | 7.8 | 23.2 | 468 | 2.59 | 4.73 |
| Coast Steep Slope | Yarding with High-lead Tower | 3.5 | 1 302 | 145.5 | 100 | 14 550 | 41.6 | 8.9 | 4 157 | 11.18 | 20.40 |
| Interior Wet Belt Moderate Slope | Yard-Skidder | 7.1 | 4 424 | 503.5 | 50 | 24 943 | 70.9 | 8.8 | 3 513 | 5.64 | |
| | Buck & Deck | | | 210.0 | 52 | 11 029 | 29.6 | 21.1 | 1 553 | 2.49 | |
| Total | | 7.1 | 4 424 | 713.5 | 50 | 35 972 | 100.5 | 6.2 | 5 066 | 8.13 | 16.87 |
| Interior Wet Belt | Yard Skidder | 10.7 | 1 806 | 457.0 | 90 | 41 311 | 42.7 | 4.0 | 3 861 | 22.87 | |
| | | | | 172.0 | 55 | 9 496 | 16.1 | 10.5 | 887 | 5.26 | |
| Total | | 10.7 | 1 806 | 629.0 | 81 | 50 807 | 58.8 | 2.9 | 4 748 | 28.13 | 58.37 |

**Table 6. Residue Processing Productivity**

| | Coast | Interior | |
|---|---|---|---|
| | | Logging Residue | Green Timber |
| Total Production Gt | 713 | 1411 | 455 |
| Number of Operating Days | 13 | 21 | 5 |
| Machine Availability % | 81.6 | 91.9 | 92.6 |
| Machine Utilization % | 53.9 | 63.8 | 68.5 |
| Average Productivity Productive Machine Hour (Gt) | 12.8 | 15.2 | 21.5 |
| Average Hourly Production (Gt) | 6.9 | 8.4 | 11.4 |

**Table 7. Residue Processing Costs**

| | Coast | Interior | |
|---|---|---|---|
| | Logging Residue | Logging Residue | Green Timber |
| **Hourly Owning & Operating Cost** | | | |
| Nicholson Shear c/w Operator | $ 60.00 | $ 60.00 | $ 60.00 |
| Barko 450 Loader c/w Operator | | | |
| Crawler mounted | 85.00 | | |
| Truck mounted | | 70.00 | 70.00 |
| Other Equipment as required | 10.00 | 32.00 | 32.00 |
| Landing Man c/w Chainsaw | 21.00 | 21.00 | 21.00 |
| **Total Hourly Cost** | $ 176.00 | $ 183.00 | $ 183.00 |
| **Daily Cost** | $1 408.00 | $1 464.00 | $1 464.00 |
| **Daily Production** | | | |
| Estimated Solid fibre ($m^3$) | 96.0 | 139.4 | — |
| Green tonnes (Gt) | 52.6 | 67.2 | 91.0 |
| **Cost** | | | |
| Solid fibre ($m^3$) | $ 14.67 | $ 10.50 | $ — |
| Green tonnes (Gt) | 26.77 | 21.79 | 16.09 |

**Table 8. Transportation Methods and Capacities**

| Configuration | Container Capacity (m³) | Load (Gt) Sheared Material Int. | Load (Gt) Sheared Material Coast | Load (Gt) Chips Int. | Load (Gt) Chips Coast | Max Load (t) | Estimated Cost/Hour ($) |
|---|---|---|---|---|---|---|---|
| Container Truck (used) 3-Axle | 30 | 7.6 | 8.6 | 5.2 | 5.9 | 15.0 | 55 |
| During Truck & Trailer (A-train) 6-Axle | 60 | 15.2 | 17.2 | 10.4 | 11.8 | 30.0 | 65 |
| Tractor & Tri-Axle* Semi-Trailer | 105 | 26.5 | 28.3 | 18.1 | 20.6 | 29.8 | 65 |
| 7-Axle B-train* | 134 | 34.0 | 36.3 | 23.3 | 26.5 | 32.5 | 70 |
| 8-Axle B-train* | 134 | 34.0 | 36.3 | 23.3 | 26.5 | 37.9 | 73 |
| Highway Logging Truck 5-Axle | — | — | — | — | — | 31.5 | 60 |

* Configuration, Volume Capacity and Maximum Load provided by A. Copes of Columbia Trailer Co. Ltd., Burnaby, B.C.

**Table 9. Estimated Production Costs Of Shear System in Sortyard or Millyard**

| | | |
|---|---|---|
| **Productivity** | | |
| Average Productivity/Productive Hour | | 16.0 Gt |
| Machine Utilization | | 85.0% |
| Daily Production | | 108.8 Gt |
| **Hourly Owning & Operating Cost** (240 Operating Days/Year) | | |
| Nicholson Shear c/w Operator | | $ 56.00 |
| Small Hydraulic Loader c/w Operator | | 45.00 |
| Other Equipment as Required | | 10.00 |
| Groundman | | 21.00 |
| **Total Hourly Cost** | | $ 132.00 |
| **Daily Cost** | | $1156.00 |
| **Cost per Unit** | | |
| $m^3$ (SWE) | $ 5.33 | |
| Green tonne (Gt) | $ 9.70 | |

**Table 10. Energy Values of Residues**

| | Coast | Interior |
|---|---|---|
| Average Gross Fuel Value MJ/ODt | | |
| Mixed-Fir, Cedar, Hemlock | 21 000 | |
| 50/50 Hemlock, Cedar | | 19 985 |
| Moisture Content (wet basis %) | 28.6 | 37.0 |
| Net or As-Fired Heating Value | 13 347 | 10 830 |
| Oil Replacement Value | | |
| Bunker 'C' Equivalent (Barrels/Gt) | 1.816 | 1.415 |
| Bunker 'C' @ $25/Barrel ($/Gt) | 45.41 | 35.37 |

**Table 11. Energy Consumed versus Energy Produced**

| Phase | Equipment | Energy Value of Fuel Consumed (MJ/Gt) Coast | Interior |
|---|---|---|---|
| Residue Collection | Crawler Tractor with Brush Blade | 73 | |
| | Mobile Highlead Yarder | 75 | |
| | Skidders (4) | | 217 |
| Residue Processing | Nicholson Shear Barko 450 Loader | 203 | |
| | Nicholson Shear Barko 450 Loader Tractor | | 336 |
| Transportation | 30 $m^3$ Container Truck (80 km) | 399 | |
| | 60 $m^3$ Container Truck (80 km) | | 324 |
| Hogging Plant | (Estimate) | 130 | 130 |
| **Total Energy Consumed** | | **805-807** | **1007** |
| Total Energy Produced* | | 13347 | 10830 |
| Ratio of Energy Consumed to Energy Produced | | 1:16.5 | 1:10.75 |

* Table 10.

**Table 12. Projected Costs for Various Processing Systems**
**($ per Green tonne)**

| | On Site Processing | | | | Sortyard Processing | | Millyard Processing |
|---|---|---|---|---|---|---|---|
| | Moderate | | Steep | | | | |
| | Chipper | Shear | Chipper | Shear | Chipper | Shear | Shear |
| Harvesting & Decking | 4.80 | 4.80 | 20.40 | 20.40 | 14.00 | 14.00 | 14.00 |
| Processing & Loading | 52.00 | 20.20 | 52.70 | 20.20 | – | – | – |
| Load & Unload | 2.30 | 2.30 | 2.30 | 2.30 | 4.60 | 4.60 | 4.60 |
| Transport to Yard | – | – | – | – | 4.20 | 4.20 | – |
| Process to Sortyard | – | – | – | – | 17.50 | 9.70 | – |
| Transport to Mill | 26.00 | 18.00 | 26.00 | 18.00 | 14.00 | 9.50 | 12.60 |
| Process to Millyard | – | – | – | – | – | – | 9.70 |
| Hogging at Mill | – | 8.00 | – | 8.00 | – | 8.00 | 8.00 |
| Total Cost/Gt | 85.10 | 53.30 | 101.40 | 68.90 | 54.30 | 50.00 | 48.90 |

**Table 13. Projected Costs for Shearing Sortyard Debris and Logging Residue ($ per Green tonne)**

| | Sortyard Debris | Logging Residue |
|---|---|---|
| Harvesting & Decking | – | 14.00 |
| Load & Unload | – | 4.60 |
| Transport to Yard | – | 4.20 |
| Process in Sortyard | 11.64 | 9.70 |
| Transport to Mill | 9.50 | 9.50 |
| Hogging at Mill | 8.00 | 8.00 |
| Debris Disposal | (6.00) | |
| **Total Cost/Gt** | **$23.14** | **$50.00** |

# APPENDIX 1

## ABBREVIATIONS, DEFINITIONS AND FACTORS

### Abbreviations

| | |
|---|---|
| Bbl | barrel |
| BCFP | British Columbia Forest Products |
| cm | centimetres |
| ENFOR | **EN**ergy from the **FOR**est |
| FERIC | Forest Engineering Research Institute of Canada |
| Forintek | Forintek Canada Corporation, Western Forest Products Laboratory |
| Gt | green tonnes (of unspecified moisture content) |
| GVWD | Greater Victoria Water District |
| ha | hectares |
| hp | horsepower |
| hr | hour |
| kg | kilograms |
| $kg/m^3$ | kilograms per cubic metre |
| kW | kilowatt |
| l | litres |
| m | metres |
| $m^3$ | cubic metres |
| $m^3/h$ | cubic metres per hectare |
| MJ | megajoules |
| MJ/BBL | megajoules per barrel |
| MJ/L | megajoules per litre |
| MJ/ODT | megajoules per oven-dried tonne |
| Nicholson | Nicholson Murdie Machines Limited |
| ODt | oven-dry tonnes |
| PFRC | Pacific Forest Research Centre |
| t | tonnes |

**Definitions**

| | |
|---|---|
| Brush Blade | An attachment for a crawler-tractor to accumulate loose woody material into piles. |
| Bulk Density | The density of loosely packed materials determined by dividing the total weight by the volume of solid and space occupied by the material. |
| Bunker C | Number 6 fuel oil; lowest grade oil, residual product of petroleum refining industry. |
| Clean Pulp Chips | Pulp chips produced from clean wood only; free of bark, rot twigs or foliage. |
| Conveyor Flight | A right angle conveyor component which carries the sheared material along the outfeed conveyor and prevents the material from rolling back toward the shear. |
| Decadent | Term used to describe over-mature forest stands which have a high incidence of rotten or decayed trees. |
| Energy Balance | The relationship between the energy value of the wood fuel produced and the energy value of the fuels consumed in producing and transporting these fuels to the energy conversion facility. |
| Energy Value | The theoretical heating value of the fuel expressed in Joules. |
| Equipment Availability | The scheduled machine hours less mechanical delays divided by the scheduled machine hours, expressed as a percentage. |
| Equipment Utilization | The scheduled machine hours less mechanical and non-mechanical delays, divided by the scheduled machine hours, expressed as a percentage. |
| Green Density | Density in $kn/m^3$ of wood in an air-dried or "as-received" condition, i.e., unspecified moisture content. |
| High Lead | A logging system using mobile tower yarder and aerial cables to accumulate logs from steep slopes to the roadside. |
| Hog Fuel | Wood waste processed by hogging equipment which tears, crushes or breaks wood rather than cutting it. |
| Incurred Costs | Actual costs incurred on the project. |
| Logging Residues | Loose woody material remaining on the ground after logging operations; commonly referred to as "slash". |
| Margin | Difference between production costs and the value (real or calculated) of the material produced. |
| Mechanical Delays | Productive machine time lost due to maintenance, repairs, warm-up, fueling, inspections, etc. |

| | |
|---|---|
| Mobile Tower Yarder | A piece of equipment used on steep slopes to accumulate logs at the roadside. Consists of a steel tower, cable drum winches and wheeled or tracked undercarriage. |
| Moisture Content (Dry Basis) | Green weight less dry weight, divided by dry weight and expressed as a percentage. |
| Moisture Content (Wet Basis) | Green weight less dry weight, divided by green weight and expressed as a percentage. |
| Non-mechanical Delays | Productive machine time lost due to weather, moving, conferences, waiting for other equipment, etc. |
| Opportunity Cost | The cost of a particular activity or enterprise expressed in terms of the value of an alternative activity or enterprise which had to be postponed or cancelled in order to accomplish the first activity. |
| Oven-dry Density | Density in $kn/m^3$ of wood in a moisture-free or oven-dry state. |
| Processed Material | Material which has been sheared by the Nicholson shear-type processor. |
| Productive machine hours | Scheduled machine hours less mechanical and non-mechanical delay time. |
| Projected Costs | Estimated costs under operational conditions assuming optimum utilization of equipment and productivity levels which could be expected from a well-trained, motivated and experienced crew. |
| Re-processed Material | Material which has been hogged or chipped for fuel or fibre. |
| Replacement Value | The unit value of one fuel in terms of the value of the quantity of an alternative fuel which it can replace. |
| Residue Chips | Chips produced from forest residues, normally similar to whole tree chips but only suitable for fuel because they contain quantities of bark, rotten fibre, foliage or other non-woody material. |
| Solid Wood Equivalent (SWE) | The proportion of the loosely packed material volume that is occupied by solid material; usually expressed as a decimal fraction or percentage of the total volume of solid and space. |
| Whole Tree Chips | Chips obtained from chipping whole tree sections including bark, branches and foliage. |

## Factors

### Densities (in $kg/m^3$)

| | Average Green Density | | Average Oven-Dry Density |
|---|---|---|---|
| Cedar | 532 | | 329 |
| Douglas-fir coast | 652 | | 450 |
| interior | 643 | | |
| Hemlock | 782 | | 423 |
| Coast | | | |
| Logging Residue Study (Mixed F H C) | | 548 | 427 |
| Interior | | | |
| Logging Residue Study (50/50 Hemlock Cedar | | 482 | 376 |
| Sheared Material (in Container Trucks) | | | |
| Coast | | | |
| Logging Residue | | 270 | |
| Interior | | | |
| Logging Residue | | 253 | |
| Green Hemlock | | 320 | |
| Green Cedar | | 203 | |
| Pulp Chips (normal Compaction) | | | |
| Coast-Logging Residue | | 197 | |
| Interior-Logging Residue | | 173 | |

### Volumes

1 Unit (volumetric) = 200 $ft^3$ = 5.663 $m^3$
1 Bone Dry Unit (BDU) = 2400 OD lb = 1088 OD kg
1 Unit = 0.78 BDU (plus or minus)
1 $m^3$ of logs = .4904 Units of chips
Coast Logging Residue
1 Unit = 5.663 $m^3$ = 1.53 Gt

Interior Logging Residue
1 Unit = 5.663 $m^3$ = 1.43 Gt

### Power

1 Horsepower (hp) = 0.7457 Kilowatts (kW)

# APPENDIX 2

## ENERGY VALUES OF LOGGING RESIDUES

Using the following formula from FERIC Technical Report No. TR. 51 the net heating value can be calculated.

1. **Net or As-Fired Heating Value**

The equation used to determine the net or as-fired heating value of a kilogram of debris is:

Q = (E - W - T - S) (1 - A)

Where:

Q = as-fired or net heating value (kilojoules per kilogram of wet debris)

E = bone dry heating value (kilojoules per kilogram of dry debris)

W = heat loss due to heating the water formed from the combustion of hydrogren in the debris (kilojoules per kilogram of dry debris)

W = 0.54 kg of water x 2442 kilojoules per kilogram

0.54 = 0.54 kilograms of water is formed from hygrogen in the debris for every bone dry kilogram of debris burned

2442 = heat required to evaporate a kilogram of water (kilojoules per kilogram)

T = heat loss due to heating the water present as moisture in the debris (kilojoules per kilogram of dry debris)

T = B (2442)

B = moisture content (dry basis) per kilogram of debris

S = heat loss due to heating the dirt in the debris (kilojoules per kilogram of dry debris)

S = 0.84 x D x (t1 - t2)

0.84 = specific heat of sant (kj/kg°C)

D = kilograms ash per kilograms of dry debris

t1 = temperature at which ash leaves the furnace of the boiler (°C)

t1 = 204°C

t2 = ambient temperature (°C)

t2 = 15.6°C

A = moisture content (wet basis) per kilogram of debris

2. **Oil Replacement Value - Bunker "C" Equivalent**

$$\text{Bunker C Equivalent (Barrels/Gt)} = \frac{Q \times BeW}{\text{Energy content Bunker C} \times BeO}$$

Where:

BeW = Boiler efficiency of wood fired boiler

BeO = Boiler efficiency of oil fired boiler

Energy content per barrel of bunker C = 6640 megajoules

3. **Oil Replacement Value Calculation**

**a) Coast Logging Residue (Mixed Fir-Cedar-Hemlock)**

Given:

| | |
|---|---|
| Average Fuel Value | 21 000 Mj/ODt |
| Moisture Content | |
| Dry Basis | 40.0% |
| Wet Basis | 28.6% |
| Ash Content | 7.0% |
| Efficiency of wood fired boiler | 75.0% |
| Efficiency of oil fired boiler | 83.0% |

$$Q = [(21\ 000) - (0.54 \times 2442) - (0.40 \times 2442) - (0.84 \times 0.07)(204.0 - 15.9)](1 - 0.286)$$

$$= 13\ 347 \text{ Mj/Gt}$$

$$\text{Bunker C Equivalent} = \frac{13\ 347 \times 0.75}{6\ 640 \times 0.83}$$

$$= 1.816 \text{ Barrels/Gt}$$

**b) Interior Logging Residue (50/50 Cedar-Hemlock)**

Given:

| | |
|---|---|
| Average Fuel Value | 19 985 MJ/Odt |
| Moisture Content | |
| Dry Basis | 60.0% |
| Wet Basis | 37.0% |
| Ash Content | 6.38% |
| Efficiency of wood fired boiler | 72.0% |
| Efficiency of oil fired boiler | 83.0% |

$$Q = [(19\ 985) - (0.54 \times 2442) - (0.60 \times 2442) - (0.84 \times 0.638)\ (204.0 = 15.6)]\ (1 - 0.37)$$

$$= 10\ 830 \text{ Mj/Gt}$$

$$\text{Bunker C Equivalent} = \frac{10\ 830 \times 0.72}{6\ 640 \times 0.83}$$

$$= 1.415 \text{ Barrels/Gt}$$