Advantage

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Contents

Recovery of pulp chips and hog fuel from harvesting and sawmilling residues

Abstract

The Forest Engineering Research Institute of Canada (FERIC), in cooperation with Tembec Industries Inc., performed two case studies in southwestern British Columbia. The first case study examined the feasibility of converting harvesting residues into chunks for producing hog fuel, and collecting and hauling roadside residues for producing pulp chips and hog fuel. The second case study evaluated the feasibility of recovering sawmilling residues for pulp chip and hog fuel production. In each study, FERIC determined system productivities and costs, and assessed the quality of the furnish produced.

Keywords

Fibre recovery, Logging residues, Sawmilling residues, Pulp chips, Boiler fuel, Hog fuel, Productivity, Costs, British Columbia.

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Introduction

The recovery and utilization of wood residues are subjects of growing interest to forest companies as environmental constraints and energy prices increase. Past studies by FERIC have shown that wood residues can be economically converted into wood chips for pulp mill consumption and hog fuel for energy production, given favourable market conditions (Araki 1999; Desrochers et al. 1995; Forrester 1996, 1998, 1999, 2000, and 2003; Hunt 1994). However, the feasibility of these operations has not been tested in some regions and timber types. FERIC, with funding support from Natural Resources Canada and cooperation from Tembec Industries Inc., initiated two case studies in 2003 to determine the economics and feasibility of recovering and processing both harvesting and sawmilling wood residues into pulp chips and boiler hog fuel in southwestern British Columbia. This report summarizes the results of the two case studies and presents recommendations for implementation.[1]

Case study 1: Recovery of hog fuel from harvesting residues

Harvesting residues consist of limbs, tops, and non-merchantable logs and portions of stems. These can amount to 5 to 10% of the volume recovered from a harvest site, depending on utilization standards and stand decadence. Traditionally, these materials have been burned to reduce potential fire hazard and to increase plantable area. Public concerns over the particulate matter in wood smoke as well as visual impacts and greenhouse gas emissions have resulted in restrictions being placed on when burning can occur. Large backlogs of areas requiring burning can result, presenting an ongoing wildfire hazard.

FERIC and Tembec initiated two studies to investigate the economic potential for

[1] See Forrester (2004a, b) for more detail on the two studies.

recovering logging slash for hog fuel and/or pulp chips. The first study (chunking study) evaluated the feasibility of converting harvesting residues into wood chunks during normal production. These chunks were later hogged at Tembec's Skookumchuck pulp mill. The second study (residue recovery study) investigated the feasibility of collecting and hauling roadside residues to the Elko sawmill where they were accumulated as a potential source for pulp chips and hog fuel furnish.

Figure 1. Link-Belt 2800 excavator with Waratah HTH626 danglehead processor.

Figure 2. Bin truck dumping processed chunks onto hog infeed ramp.

Objectives

Chunking study

The objectives of the chunking study were to determine the productivity and cost of producing short wood chunks using a log processor, assess the feasibility of transporting residue chunks from a landing to the pulp mill using roll-on roll-off containers, and evaluate the quality of the hog fuel produced.

Residue recovery study

The objectives of the residue recovery study were to determine the productivity and costs associated with the loading and hauling of roadside slash using an excavator and a tractor pulling a demolition-bin trailer; quantify the productivity and cost of processing the residue through a portable cradle debarker and chipper; and assess the quality of pulp chips and hog fuel furnish produced.

Equipment and methods

Chunking study

A cutblock, accessible to a demolition bin, was selected approximately 1.5 hauling hours from the Skookumchuck pulp mill. A Tembec employee collected data while a Link-Belt 2800 excavator with a Waratah HTH626 danglehead log processor (Figure 1) cut chunks of approximately 25 cm length, and dropped them into a demolition bin. The operator tried two methods to produce chunks. In the first, he processed the stem into logs, and then swung the processing head, which was still grasping the top, over the bin and cut the top into chunks. Because the operator found this method interfered with log production, he accumulated the tops and snags into a pile and chunked

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the residues in batches at a later time. When the bin was judged to be full, it was hauled to the pulp mill and weighed. The chunks were dumped into the receiving hopper (Figure 2) and conveyed to the hog mill. Samples of hog fuel were collected and sent to a commercial laboratory to determine moisture content, ash content, and calorific value, while particle size classification was done in FERIC's laboratory.

Residue recovery study

Residues were collected from two landings in a selective logging cutblock approximately 4 km from the Elko sawmill. The study was completed over three days. A Samsung 210 excavator with a bucket and rake attachment pulled the slash piles apart (Figure 3) and loaded the material into a demolition bin (approximately 45 m^3 gross volume). The trailer was then hauled to the sawmill, weighed, and off-loaded for processing at a later date. All operations were timed in detail by an on-site FERIC researcher.

The roadside residues hauled to the Elko sawmill were debarked in a Beaver Wood Waste Systems Inc. B-230 cradle-type debarker (Figure 4). A conveyor fed the debarked material to a six knife Forano SX-301 chipper (Figure 5). From there, the chips were fed into a Millworks Inc. Beaver chip screen plant with a rechipper (Figure 6). The latter had its own 55-kW generator for power while the rest of the system was powered by a 725-kW generator. All of this equipment was mounted on trailers. A Caterpillar 966F front-end loader with log forks forwarded residues to a Hitachi EX200LC which charged the debarker. The front-end loader also pushed bark from the debarker and fines from the chip screen into piles. Chips were loaded directly into 8-axle B-train chip vans for transport to Tembec's pulp mill at Skookumchuck.

Data for production information were obtained by on-site researchers who monitored activities on a shift-level basis. Production was calculated on a scheduled machine hour (SMH)[2] and a productive machine hour (PMH)[3] basis. For the chunk processing and

Figure 3. Samsung 210 loading logging residues into demolition bin.

Figure 4. Beaver Wood Waste Systems Inc. B-230 cradle-type debarker.

Figure 5. Forano SX-301 chipper.

Figure 6. Millworks Inc. Beaver portable chip screen plant with rechipper.

[2] A scheduled machine hour is the time the quipment is scheduled to operate, and includes all delays.

[3] A productive machine hour is the time the equipment is undertaking work related to its primary operating function, and is calculated by subtracting the delay time incurred from the scheduled machine hours.

residue recovery phases, all operations were detail-timed. During the debarking-chipping phase, only the front-end loader was detail-timed using a hand-held datalogger.

Chip samples were collected from the chip vans for size and thickness analyses using a BM&M vibratory chip screen and a Domtar chip thickness analyzer. Chip moisture was also determined on a wet chip basis[4] for each sample taken. The samples were sent to FERIC's laboratory in Vancouver for the analyses.

Random samples of potential hog fuel from the debarker outfeed were collected to be characterized for moisture content, ash content, and calorific value at a commercial laboratory. The rock and white wood contents were determined at the FERIC laboratory

Equipment costs were determined using FERIC's standard costing template (Appendices I and II). These costs do not include supervision, profit, and overhead, and they may differ from the actual costs incurred by the contractors. The productivities were applied to the costing information to determine the unit cost of the hog fuel and chips produced.

Results

Chunking study

The two methods of producing wood chunks from harvesting residues—producing chunks concurrent with manufacturing logs, and producing chunks from grapple loads of accumulated residue—were monitored. Chunking concurrent with log manufacture resulted in 746 chunks per hour being produced, compared to 731 chunks per hour when chunks were produced from residue accumulations. In total, 7.47 green tonnes of chunks were hauled to the mill. Samples of hog fuel were analyzed and the results indicated an overall moisture content (wet basis) of 30.9%, ash content of 0.96%, and an as-delivered calorific value of 5736 BTU/lb.

The estimated costs to chunk and transport harvesting residues to the mill were $91.90/BDt and $39.32/BDt, respectively, for a delivered cost of $131.22/BDt. The costs for hogging were not included because the hog at the mill was under-utilized and could handle additional material without any further costs to the system.

Table 1. Debarking-chipping shift-level study summary (harvesting residues)

	Total	
	(h)	(%)
Productive time	8.9	70
Delay time		
Maintenance	1.5	12
Mechanical	1.9	15
Non-mechanical	0.4	3
Total study time	12.7	100
Utilization	-	70
Availability	-	88

Residue recovery study

The results of the shift-level study of the debarking-chipping of the harvesting residues are shown in Table 1. The 286 green tonnes of harvesting residues were processed through the system in 12.7 hours and produced 100 green tonnes of pulp chips (35% recovery), with the remainder of the material going to hog fuel furnish. Converting this to bone-dry tonnes (BDT) at 34.4% moisture content results in productivities of 5.1 BDt/SMH or 7.4 BDt/PMH at a system utilization level of 70%.

The costs to load, haul, and dump harvesting residues collected at the cutblock and delivered to the Elko sawmill are shown in Table 2. Overall, 20 loads totalling approximately 286 tonnes (green weight) or about 890 m^3 (based on trailer-box dimensions) were moved to the millyard in 20 hours. This time includes set-up and clean-up activities.

Maintenance delays associated with the warm-up and shutdown of the equipment and waiting for chip vans represented about

[4] Wet chip basis is calculated as *[(weight of wet chips - weight of dry chips) × 100/weight of wet chips].*

Table 2. Costs for loading, hauling, and processing harvesting residues [a]

	System cost ($/SMH)	Time (SMH)	Total cost ($)
Cost to produce chips and hog furnish ($/h)			
Residue recovery	119.89	20.0	2 397.80
Processing	436.37	12.7	5 541.89
Hauling chips [b]	78.08	10.0	780.80
Total			8 720.50
Revenue from production of 65.58 BDt @ $65/BDt [c]			4 262.70
Net profit (loss)			(4 457.80)
Net profit (loss) ($/BDt)			(67.98)

[a] From Appendix I.
[b] For scheduling purposes drivers planned on a 4-h return trip; trucks hauled 2.5 loads.
[c] Wayne Mercer, Tembec, personal communication.

15% of the study time. Mechanical delays associated with unplugging the debarker residue outfeed conveyor and repairing the chip screen belt also represented 15% of the study time, but were probably high because of the short duration of this study.

Combining costs for all phases of the trial (Table 2) and offsetting them with the revenues for the chips resulted in a net loss (based on SMH) of $67.98/BDt. Revenue is not included for hog fuel furnish because the material was not acceptable due to its high mineral content and proportion of pieces longer than 30 cm (27%).

Detailed-timing results for the Caterpillar 966F front-end loader illustrate its utility in this trial. With a utilization of 92%, 56% of its working time was spent directly moving material to the excavator for loading into the debarker. The remainder of its time was spent moving accumulations of fines and hog fuel furnish from the outfeed conveyor and fines blower, about 30 and 10 m, respectively; levelling the loads in the chip vans prior to covering with tarps; and parked while the operator assisted the chipping equipment during breakdowns.

Laboratory sampling (Table 3) showed that, overall, 66% of the chip samples analyzed (by weight) were of acceptable quality with a range of 53–74%. Overthick and oversized chips were 29% and bark content was 4%. One of the 2.5 loads of chips hauled was rejected at the pulp mill for having a high bark content. Chip moisture content was 34.5% (wet weight basis); this value was used to derive the bone-dry tonne chip production.

Analysis of the hog fuel furnish showed 53% bark, 42% wood, and 5% mineral. The fact that 27% of the wood was greater than 30 cm in length is a concern because longer material could clog the conveyor system to the hog at the pulp mill. Moisture content averaged 34% with a range of 27–37%, and ash content averaged 26% with a range of 18–31%. Calorific values ranged from 3350 to 4900 BTU/lb. and averaged 4100 BTU/lb.

Discussion

Chunking study

Though productivity differences between the two chunk processing methods (concurrent and batch) were slight, the concurrent method required less handling of the tops and snags, and enabled the processor operator to add defect trims while manufacturing logs. A combination of the two methods may be the best solution. The increased utilization of the processor's bucking saw motor, due to the increased cutting requirements, resulted

Table 3. Summary of chip characteristics produced from harvesting residues

Sample no.	Acceptable [a]		Unacceptable [b]		Pin chips [c]		Fines [d]		Bark [e]		Total	Moisture content
	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)
1	2 226	53	1 728	41	31	1	8	0	173	4	4 166	33.4
2	2 673	63	1 330	31	74	2	9	0	148	3	4 234	25.3
3	3 202	71	1 120	25	42	1	6	0	127	3	4 497	29.1
4	3 464	69	1 329	26	32	1	4	0	202	4	5 031	34.4
5	2 752	62	1 581	35	51	1	11	0	63	1	4 458	32.4
6	2 972	64	1 280	28	54	1	14	0	295	6	4 615	36.6
7	3 254	74	896	20	38	1	10	0	220	5	4 418	36.9
8	3 135	65	1 400	29	92	2	13	0	204	4	4 844	40.0
9	3 278	63	1 738	34	55	1	5	0	111	2	5 187	40.3
10	3 481	73	1 062	22	59	1	9	0	161	3	4 772	34.8
Total	30 437	66	13 464	29	528	1	89	0	1 704	4	46 222	34.5 [f]

[a] Acceptable chips were between 13 and 45 mm long and between 2 and 10 mm thick.
[b] Oversized chips were >45 mm diameter and over-thick chips were >10 mm thick.
[c] Pin chips were 2 mm to 13 mm long.
[d] Fines were <2 mm long.
[e] Bark was unattached or attached to the chips. The latter was cut away from the chips.
[f] Weighted average.

in the motor heating above normal operating levels. Either method would also result in increased saw bar and chain wear, thus increasing overall maintenance costs.

The truck hauling the chunks was not equipped with load scales so the driver could not determine if the legal payload of 9 500 kg was achieved at the loading site. When the load was weighed at the pulp mill, the actual payload weight of 7 470 kg showed more chunks could have been added. The unit cost to transport a full load would then be reduced.

To assess the effect of other processing and hauling strategies on delivered costs, Table 4 compares the costs of three alternatives: haul full bins only; increase chunk length from 25 cm to 1 m; and haul two bins with the 1-m chunks. Economies of scale reduced the delivered cost from $131.22 to $45.72 per BDt. This result is consistent with those reported for delivered hog fuel in Alberta, at $41 and $46 per BDt (Forrester 2003). At these costs, hog fuel could be delivered competitively at natural gas equivalents of $2.43 and $2.79 per GJ. Currently, natural gas is around $6/GJ which suggests an economical advantage for hog fuel use (Figure 7).

Residue recovery study

The second study focussed on the potential to recover a higher-value product (pulp chips) from residues. It was hoped that the pulp chip value would help offset the cost of producing and hauling the hog fuel. A low productivity of 5.14 BDt/SMH coupled with a poor recovery of 35%, attributable in part to the breakage of small-diameter tops and branches in the debarker, resulted in a net loss of $67.98/BDt of chips. Compounding this was the rejection of one of the 2.5 loads of chips for a high bark content. FERIC's laboratory tests showed an overall bark content of 4% for all loads.

The potential hog fuel material had an unacceptable average rock content of 5% and an unacceptable average ash content of 26%. Contamination by rocks and gravel can be avoided at the source by taking extra care when piling the residues at the harvest site. However, this was not done because the material collected was to be burned in place. The installation of a disc-type screen nominally spaced at 15 cm ahead of the debarker could remove most of the small rocks with any oversized material being ejected by the chipper operator.

Table 4. Estimated costs for alternative scenarios for producing chunkwood

	Study results	Alternative scenarios		
		Full bin	1-m chunks	Haul 2 bins
Processing				
Chunks made (no.)	2 983	3 794	948 [a]	1 896
Time required (min.)	244	310	78	155
Productivity (no./h)	734	12	12	12
Weight produced (t)	7.47	9.5 [b]	9.5	19.0
Moisture content (%)	30.9	30.9	30.9	30.9
Production (BDt)	5.16	6.6	6.6	13.1
Processor rate ($/SMH)	116.61	116.61	116.61	116.61
Cost to produce chunks ($/BDt)	91.90	91.29	22.97	23.00
Hauling				
Weight hauled (t)	7.47	9.5	9.5	19.0
Truck rate ($/SMH)	67.66	67.66	67.66	74.41
Round trip travel time (h)	3.0	3.0	3.0	4.0
Hauling cost ($/BDt)	39.32	30.75	30.75	22.72
Total delivered cost ($/BDt)	131.22	122.04	53.72	45.72

[a] 1-m chunks are 4 times longer than chunks produced in this study (25 cm), therefore, only need 1/4 of the chunks for the same weight.
[b] Estimated gross payload of full bin.

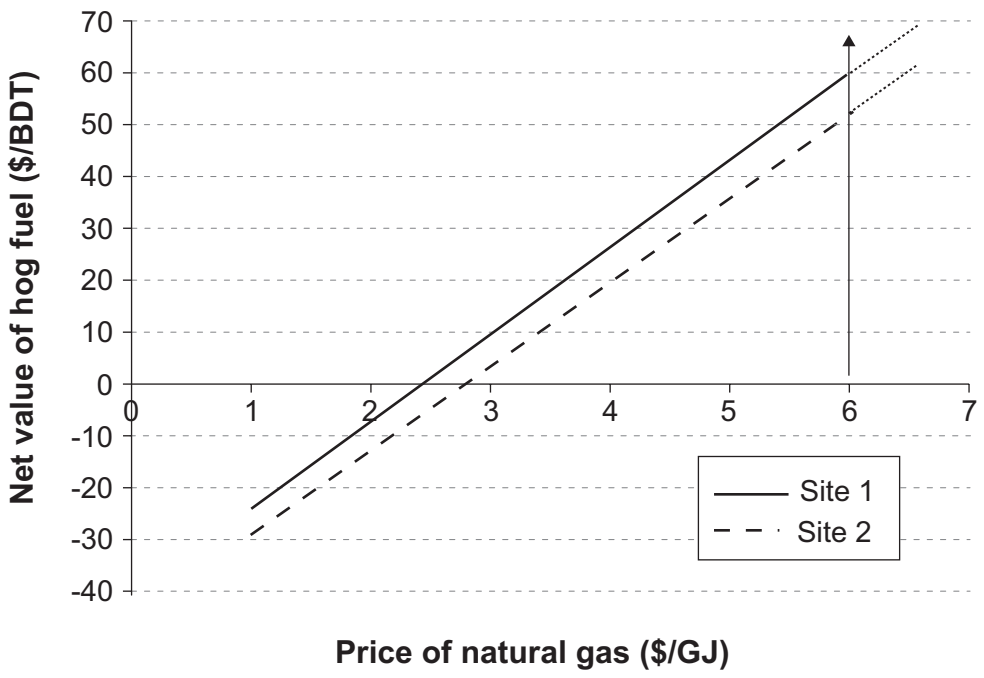

Figure 7. Net hog value versus natural gas price for two sites studied in Forrester 2003.

Another potential tool for delivering clean harvesting residues to a processing site is the Timberjack Slash Bundler (Figure 8). When working at roadside, this machine could be selective in extracting residues, thus avoiding most contaminants.

Case study 2: Recovery of pulp chips and hog fuel from sawmilling residues

Historically, sawmilling residues have been burned in stationary burners, open burned, or buried in landfills. As sawmilling equipment has evolved, the installation of debarkers and chip'n'saw systems has meant much of the residue has been converted into bark-free pulp chips as part of the milling process. Over time, pulp chips have become an important revenue source for sawmills. In addition, most jurisdictions in Canada now have regulations restricting the burning and burying of residues so mills must find disposal alternatives. As a result, most sawmills are converting all their wood waste into either hog fuel or pulp chips.

Undebarked trim ends from the merchandiser deck are processed into hog fuel, and planer shavings and sawdust are occasionally mixed in. Hog fuel commonly has low market value because its supply greatly exceeds demand. Depending on a mill's location, planer shavings and sawdust may have greater economic opportunity being sold to pellet mills, particleboard plants, or the animal husbandry industry. To offset costs and maximize potential revenue, pulp chips are the preferred product because they have a higher value than hog fuel.

Tembec's Elko sawmill has installed scalping screens to recover larger-sized residual material from its merchandiser decks. Normally, this material would flow with the smaller residues and be processed into hog fuel. In Tembec's system, the material recovered from the scalping screens is stored until the accumulated volume (Figure 9) becomes economic to debark and chip with a portable debarker-chipper system for pulp chips (Figure 10). This case study was initiated to determine the economics of

Figure 8. Timberjack Slash Bundler.

Figure 9. Accumulation of mill ends and logyard residues at Tembec's Elko logyard. Note the boulder underneath the hardhat that was placed there.

Figure 10. From the left: excavator with debarker, chipper (trailer behind has generator set and shop), and chip screen plant with rechipper.

producing both pulp quality chips and hog fuel from this type of wood waste.

Objectives

The objectives of this study were to determine system productivity and develop production costs for the recovery of sawmilling residues as pulp chips and hog fuel; assess the quality of pulp chips and hog fuel produced; and identify either alternative methods of producing these products, or modifications to the system that could improve production or product quality.

Equipment and methods

A Caterpillar 966F front-end loader with log forks forwarded mill residues 10–100 m to a Hitachi EX200LC excavator equipped with a bucket and rake. The excavator then charged the debarker. The front-end loader also pushed residues from the debarker and the chip screen plant into piles where they were stored prior to transport to the pulp mill.

The residues were debarked in a cradle-type Beaver Wood Waste Systems Inc. B-230 debarker with two rotors (Figure 4). A vibrating conveyor fed the debarked material to a six-knife Forano SX-301 chipper using disposable knives (Figure 5). At the conveyor, the chipper operator removed rocks or tramp metal before the material entered the chipper. The chips were conveyed to a Millworks Inc. Beaver portable chip screen plant with a rechipper (Figure 6), where fines were removed and oversized chips were reprocessed before they were conveyed to the chip van. The system was operated by a four-person crew.

Chips were loaded directly into 8-axle B-train trailers for transport to Tembec's Skookumchuck pulp mill. The residues from the debarker were piled for later hauling to Skookumchuk for hogging.

On-site researchers monitored activities on a shift-level basis and gathered detailed-timing data for the front-end loader using a handheld datalogger. Work sample data were also collected on the whole system, excluding the front-end loader. Chip samples, collected from the chip vans, were analyzed for size and thickness using a BM&M vibratory chip screen and a Domtar chip thickness analyzer. Bark content was obtained manually by separating the bark from the wood to quantify bark proportion by weight. Chip moisture content was determined on a wet basis for each sample taken. Potential hog fuel from the debarker outfeed was also tested for moisture content (wet basis), ash content, and calorific value at a commercial laboratory. Rock content, whitewood/bark content, and size class were conducted at FERIC's laboratory.

Results

The shift-level study over approximately eight days resulted in a system availability of 87% and a utilization of 76% (Table 5). This utilization resulted in a productivity of 9.7 BDt/SMH. Mechanical problems comprised 55% of total delay time or 15% of total time. Almost 90% of mechanical delay time was associated with a clogged debarker conveyor belt that ran off its drive spools.

Work sampling over 6.8 hours indicated that the chipper utilization at 64% was considerably lower than that implied by the overall system utilization of 76%. The chipper was waiting for the debarker 26% of the time, which caused downstream waiting time at the screen-rechipper unit.

Detailed timing totalling almost 18 hours was carried out on the front-end loader at irregular intervals throughout the study.

Table 5. Shift-level study summary (sawmilling residues)

	Total	
	(h)	(%)
Productive time	65.7	76
Delay time		
Maintenance	7.7	9
Mechanical	11.3	13
Non-mechanical	1.6	2
Total study time	86.3	100
Utilization	-	76
Availability	-	87

Seventy-three percent of this time was spent directly servicing the system by feeding the excavator, and piling or moving hog fuel and fines. The front-end loader operator spent 17% of the time assisting with repairs to other equipment, helping clear plug ups, and sharpening chipper knives. The remainder of the time was spent on miscellaneous non-mechanical delays.

Table 6. Costing summary (sawmilling residues)

	Total
Costs to produce chips and hog fuel furnish ($/h)	
Debarker [a]	30.33
Chipper[a]	107.62
Screen and rechipper [a]	55.70
Generator [a]	58.18
Excavator [a]	75.16
Front-end loader [a]	109.40
Total system cost ($/h)	436.39
Scheduled machine hours (h)	86.3
Estimated costs to debark and chip ($)	37 660
Hauling costs [b]	
Loads of chips hauled (no.)	38.5
Haul time (h/load)	4.0
Haul cost ($/h)	78.08
Estimated costs to haul chips ($)	12 024
Total cost to produce chips and hog fuel furnish ($)	49 684
Revenues derived [c]	
Pulp chips	
Amount delivered (BDt)	837.41
Value of chips ($/BDt)	65
Pulp chip value ($)	54 432
Hog fuel furnish	
Amount delivered (BDt) [d]	558.27
Value of hog ($/BDt)	0
Hauling cost ($)	8 120
Net loss ($)	(8 120)
Net revenue - chips only ($)	4 748
Net loss - chips and hog fuel furnish ($)	(3 372)

[a] From Appendix II
[b] No allowance has been made for tractors and trailers being loaded.
[c] Because the wood was a residue from the sawmill, it arrived at the chipping site with no costs attached.
[d] Based on a chip recovery of 60%.

Because the tractors and chip vans did not always return to the site due to alternative scheduling, only seven round-trip times were obtained. Although the time averaged 3.12 hours for the run from Elko to Skookumchuck, including unloading, the truck drivers budgeted four hours because of potential queuing at the pulp mill.

Table 6 provides the costing details based on equipment component. Debarking and chipping cost per hour amounted to $436.39 for a total cost of $37 660, while hauling added a further $12 024. At $65/BDt, the gross revenue derived was $54 432, giving a net return of $4 748. Deriving a value for the residue was problematic as it has generally no value but incurs a haulage cost. In this case, the hauling cost was $8 120, which resulted in an overall net loss of $3 372.

Acceptable chips comprised 77% of those sampled, with oversized and overthick chips making up 19% of the furnish (Table 7). Bark content was less than 1%.

The hog fuel furnish produced from the debarker had 21% oversized woody pieces (>30 cm) and an 8% rock component when sorted by hand. Samples tested at the commercial laboratory showed ash contents ranging from 29 to 39%, calorific values ranging from 1725–3270 BTU/lb. (as received), and an average moisture content of 37%. The overall makeup of the material was 60% bark, 32% wood, and 8% rock, as analyzed at the FERIC laboratory.

Discussion

Mechanical delays totalling 15% of all recorded shift-level time had an impact on production. Of this mechanical delay time, 48% was accrued by the debarker conveyors. This impacted the chipper as illustrated in the work sampling utilization of 64%. Although not shown by the data, chipper production was also affected to a lesser degree by the operator having to remove large rocks and tramp metal from the chipper infeed conveyor. The excavator operator removed as much rock as possible prior to

Table 7. Summary of chip characteristics produced from sawmilling residues

Sample no.	Acceptable [a]		Unacceptable [b]		Pin chips [c]		Fines [d]		Bark [e]		Total	Moisture content
	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)
1	2 884	79	631	17	88	2	30	1	33	1	3 666	21
2	3 054	78	671	17	130	3	50	1	34	1	3 939	23
3	2 954	78	671	18	113	3	23	1	28	1	3 789	32
4	2 919	82	487	14	103	3	29	1	13	0	3 551	22
5	2 756	72	929	24	105	3	20	1	19	0	3 829	35
6	2 897	76	715	19	126	3	33	1	45	1	3 816	29
7	3 073	78	683	17	106	3	31	1	47	1	3 940	30
8	2 917	73	957	24	85	2	19	0	8	0	3 986	31
9	3 043	74	928	22	78	2	23	1	62	1	4 134	30
10	3 251	82	575	14	84	2	23	1	49	1	3 982	33
11	2 887	78	487	13	247	7	68	2	31	1	3 720	22
12	3 363	78	838	19	76	2	18	0	25	1	4 320	33
13	2 904	76	758	20	96	2	40	1	45	1	3 843	30
14	2 717	72	992	26	50	1	14	0	27	1	3 800	32
Total	41 619	77	10 322	19	1 487	3	421	1	466	1	54 315	29 [f]

[a] Acceptable chips were between 13 and 45 mm long and between 2 and 10 mm thick.
[b] Oversized chips were >45 mm diameter and over-thick chips were >10 mm thick.
[c] Pin chips were 2 mm to 13 mm long.
[d] Fines were <2 mm long.
[e] Bark was unattached or attached to the chips. The latter was cut away from the chips.
[f] Weighted average.

charging the debarker but could not find it all while keeping the debarker productive. When accumulating residues, care must be taken to avoid these contaminants.

The hog fuel produced by the debarker had an 8% rock component by weight. This contributed to the high ash content and the consequent low calorific values. Based on the average moisture content of 37%, the calorific value should be between 3 715 and 4 455 BTU/lb. of wet wood (Nielson et al. 1985). The rock content had an effect on the hog fuel furnish quality and this situation could be remedied in two ways: stockpile more carefully to avoid rock and dirt contamination, and install a disc screen ahead of the debarker, sized to 15 cm, to aid in the removal of small rocks and dirt. This second option could be combined with a short picking belt from which someone would remove large rock and metal prior to the larger wood being introduced to the debarker. These modifications would ensure cleaner hog fuel furnish, reduce wear and tear on the debarker, and provide a smoother flow of wood to the chipper, thereby improving chip production while lowering unit costs.

Conclusions

The costs associated with processing chunks and delivering them in bins to the millyard are competitive with the cost of natural gas, provided that load weights are maximized. However, the additional costs associated with accelerated wear and tear on the processor's bucking saw motor, chains, and bars should be evaluated as well as the impact on normal production rates.

Loading residues directly into demolition bins, hauling the residues to an accumulation yard, and recovering chips and hog fuel furnish, as undertaken in the study, were feasible. Chip production suffered from low debarker-chipper productivity, partly because of the low 35% chip recovery factor. The hog fuel furnish produced was contaminated and oversized, and did not meet mill specifications. More selectivity when loading residues for delivery and screening prior to debarking

should alleviate the productivity and quality problems.

To maximize revenues, it is critical that chip and hog quality meet mill specifications and that conversion of sawmilling residues and the hauling of the products is efficient. Based on the observed equipment productivity and the calculated equipment costs, net revenues of $4 748 were obtained from the chips, while the hog fuel furnish was unacceptable due to oversized pieces and rock content. The addition of a disc screen at the head end of the system could aid in cleaning the hog fuel furnish.

Implementation

The cost of transporting harvesting debris can be prohibitive. Therefore, it is important to maximize load weight, e.g., by using load scales. As well, increasing chunk length to one metre and using two demolition bins rather than one can reduce hauling cost.

The quality of both hog fuel and chips can be compromised by high rock and mineral contents. Careful piling of residues both at roadside and at the millyard can help residues from being contaminated. At roadside, an alternative strategy is to use a debris baler to accumulate the residues into easily handled bundles. At the sawmill, care should be taken to avoid contaminants while stock piling the residue material. As well, a disc screen installed before the debarker would remove some of the mineral material, thus improving productivity and reducing wear on equipment.

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Appendix I

Equipment costs: case study 1[a]

	Chunk production and residue collection					Debarking-chipping harvesting and sawmilling residues							
	Waratah HTH626 processor[b]	Western Star truck with demolition bin			Samsung 210 loader	Caterpillar 966F front-end loader	Hitachi EX200LC loader	Forano SX-301L chipper	Beaver B-230 debarker	Caterpillar V12 725-kW generator	Beaver screen w/ rechipper	8-axle B-train	
		tractor[c]	tractor[d]	trailer								tractor	chip van
OWNERSHIP COSTS													
Total purchase price (P) $	480 000	39 500	39 500	20 000	160 000	395 000	200 000	300 000	300 000	200 000	226 850	105 000	140 000
Expected life (Y) y	6	5	5	5	5	8	8	10	10	10	10	4	10
Expected life (H) h	15 000	10 000	10 000	10 000	10 000	20 000	20 000	25 000	25 000	25 000	25 000	19 600	49 000
Scheduled hours/year (h)=(H/Y) h	2 500	2 000	2 000	2 000	2 000	2 500	2 500	2 500	2 500	2 500	2 500	4 900	4 900
Salvage value as % of P (s) %	30	20	20	20	20	30	30	30	30	30	30	16	2
Licensing (Lr) $/y	-	990	990	-	-	-	-	-	-	-	-	2 625	40
Interest rate (Int) %	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Insurance costs (Ins) $/y	-	-	-	-	-	-	-	-	-	-	-	4 200	5 600
Insurance rate (Ins) %	2.5	4.0	4.0	4.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	-	-
Salvage value (S)=((P*s/100) $	144 000	7 900	7 900	4 000	32 000	118 500	60 000	90 000	90 000	60 000	68 055	16 800	2 800
Average investment (AVI)=((P+S)/2) $	312 000	23 700	23 700	12 000	96 000	256 750	130 000	195 000	195 000	130 000	147 453	60 900	71 400
Loss in resale value ((P-S)/H) $/h	22.40	3.16	3.16	1.60	12.80	13.82	7.00	8.40	8.40	5.60	6.35	4.50	2.80
License (Lr/y) $/h	-	0.49	0.49	-	-	-	-	-	-	-	-	0.54	0.01
Interest ((Int•AVI)/h) $/h	7.49	0.71	0.71	0.36	2.88	6.16	3.12	4.68	4.68	3.12	3.54	0.75	0.87
Insurance ((Ins•AVI)/h) $/h	3.12	0.47	0.47	0.24	1.20	2.57	1.30	1.95	1.95	1.30	1.47	0.86	1.14
Total ownership costs (OW) $/h	33.01	4.83	4.83	2.2	16.88	22.55	11.42	15.03	15.03	10.02	11.36	6.65	4.82
OPERATING COSTS													
Fuel consumption (F) L/h	15.0	27.0	27.0	-	15.0	40.0	24.5	-	-	63.0	4.0	36.0	-
Fuel (fc) $/L	0.55	0.55	0.55	-	0.55	0.55	0.55	-	-	0.55	0.55	0.55	-
Lube & oil as % of fuel (fp) %	15	15	15	-	15	15	15	-	-	15	50	15	-
Annual tire consumption (t) no.	-	10.0	10.0	12.0	-	1.0	-	-	-	2.0	-	13.0	27.0
Tire replacement cost (tc) $	-	500	500	300	-	6 875	-	-	-	390	-	390	390
Track & undercarriage overhaul (Tc) $	25 000	-	-	-	18 000	-	30 000	-	-	-	-	-	-
Track & undercarriage life (Th) h	10 000	-	-	-	10 000	-	16 000	-	-	-	-	-	-
Annual repair & maintenance (Rp) $	75 833	17 000	17 000	5 500	28 400	45 938	21 250	30 000	30 000	20 000	11 685	25 100	10 800
Annual operating supplies (Oc) $	-	-	-	-	-	-	-	100 454	-	-	400	1 800	1 450
Shift length (sl) h	10	12	12	12	11	11	11	11	11	-	11	12	12
Operator wages (W) $/h	26.81	20.00	-	-	23.80	25.40	23.80	25.40	-	-	22.76	0.00	20.00
Wage benefit loading (WBL) %	40	40	-	-	40	40	40	40	-	-	40	40	-
Fuel (F•fc) $/h	8.25	14.85	14.85	-	8.25	22.00	13.48	-	-	34.65	2.20	19.80	-
Lube & oil ((fp/100)•(F•fc)) $/h	1.24	2.23	2.23	-	1.24	3.30	2.02	-	3.30	5.20	1.10	2.97	-
Tire or track cost (t•tc/h) or (Tc/Th) $/h	2.50	2.50	2.50	1.80	1.80	2.75	1.88	-	-	0.31	-	1.03	2.15
Repair & maintenance (Rp/h) $/h	30.33	8.50	8.50	2.75	14.20	18.38	8.50	12.00	12.00	8.00	4.67	5.12	2.20
Operating supplies (Oc/h) $/h	-	-	-	-	-			40.18	-	-	0.16	0.37	0.30
Wages & benefits (W•(1+WBL/100)) $/h	37.53	28.00	-	-	33.32	35.55	33.32	5.56	-	-	1.86	28.00	-
Prorated overtime (((1.5•W-W)• (sl-8)•+B2(1+WBL/100))/sl) $/h	3.75	-	-	-	4.54	4.85	4.54	4.85	-	-	4.35	4.67	-
Total operating costs (OP) $/SMH	83.60	56.08	28.08	4.55	3.35	86.83	63.74	92.59	15.30	48.16	44.34	61.96	4.65
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/SMH	116.61	60.91	32.91	6.75	80.23	109.38	75.16	107.62	30.33	58.18	55.70	68.61	9.47

[a] These costs are estimate using FERIC's standard costing methodology for determing machine ownership and operating costs for new machines. The costs shown here do not include supervision, profit and overhead, and are not the actual costs for the contractor or the company studied. [b] Based on a Link-Belt 210LX carrier. [c] Used in the chunking study. [d] Used in the residue recovery study. No operator costs were incurred because the truck driver operated the Samsung 210 loader.

Appendix II

Equipment costs: case study 2[a]

	Sawmilling residues recovery							
	Cat 966F front-end loader	Hitachi EX200LC loader	Forano SX-301L chipper	Beaver B-230 debarker	Caterpillar V12 725-kW generator	Beaver screen with rechipper	8-axle B-train tractor	8-axle B-train chip van
Ownership Costs								
Total purchase price (P) $	395 000	200 000	300 000	300 000	200 000	226 850	105 000	140 000
Expected life (Y) y	8	8	10	10	10	10	4	10
Expected life (H) h	20 000	20 000	25 000	25 000	25 000	25 000	19 600	49 000
Scheduled hours/year (h)=(H/Y) h	2 500	2 500	2 500	2 500	2 500	2 500	4 900	4 900
Salvage value as % of P (s) %	30	30	30	30	30	30	16	2
Licensing (Lr) $/y	-	-	-	-	-	-	2 625	40
Interest rate (Int) %	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Insurance costs (Ins) $/y	-	-	-	-	-	-	4 200	5 600
Insurance rate (Ins) %	2.5	2.5	2.5	2.5	2.5	2.5	-	-
Salvage value (S)=((P•s/100) $	118 500	60 000	90 000	90 000	60 000	68 055	16 800	2 800
Average investment (AVI)=((P+S)/2) $	256 750	130 000	195 000	195 000	130 000	147 453	60 900	71 400
Loss in resale value ((P-S)/H) $/h	13.83	7.00	8.40	8.40	5.60	6.35	4.50	2.80
License (Lr/y) $/h	-	-	-	-	-	-	0.54	0.01
Interest ((Int•AVI)/h) $/h	6.16	3.12	4.68	4.68	3.12	3.54	0.75	0.87
Insurance ((Ins•AVI)/h) $/h	2.57	1.3	1.95	1.95	1.3	1.47	0.86	1.14
Total ownership costs (OW) $/h	22.56	11.42	15.03	15.03	10.02	11.36	6.65	4.82
Operating Costs								
Fuel consumption (F) L/h	40.0	24.5	-	-	63.0	4.0	36.0	-
Fuel (fc) $/L	0.55	0.55	-	-	0.55	0.55	0.55	-
Lube & oil as % of fuel (fp) %	15	15	-	-	15	50	15	-
Annual tire consumption (t) no.	1.0	-	-	-	2.0	-	13.0	27.0
Tire replacement cost (tc) $	6,875	-	-	-	390	-	390	390
Track & undercarriage overhaul (Tc) $	-	30 000	-	-	-	-	-	-
Track & undercarriage life (Th) h	-	16 000	-	-	-	-	-	-
Annual repair & maintenance (Rp) $	45 938	21 250	30 000	30 000	20 000	11 685	25 100	10 800
Annual operating supplies (Oc) $	-	-	100 454	-	-	400	1 800	1 450
Shift length (sl) h	11	11	11	-	-	11	12	12
Operator wage (W) 4/h	25.40	23.80	25.40	-	-	22.76	20.00	-
Wage benefit loading (WBL) %	40	40	40	-	-	40	40	-
Fuel (F•fc) $/h	22.00	13.48	-	-	34.65	2.20	19.80	-
Lube & oil ((fp/100)•(F•fc)) $/h	3.30	2.02	-	3.30	5.20	1.10	2.97	-
Tire or track cost (t•tc/h) or (Tc/Th) $/h	2.75	1.88	-	-	0.31	-	1.03	2.15
Repair & maintenance (Rp/h) $/h	18.38	8.50	12.00	12.00	8.00	4.67	5.12	2.20
Operating supplies (Oc/h) $/h	-	-	40.18	-	-	0.16	0.37	0.30
Wages & benefits (W•(1+WBL/100)) $/h	35.56	33.32	35.56	-	-	31.86	28.00	-
Prorated overtime (((1.5•W-W)•(sl-8) +(1+WBL/100))/sl) $/h	4.85	4.54	4.85	-	-	4.35	4.67	-
Total operating costs (OP) $/SMH	86.84	63.74	92.59	15.30	48.16	44.34	57.29	4.65
Total Ownership and Operating Costs (OW+OP) $/SMH	109.40	75.16	107.62	30.33	58.18	55.70	68.61	9.47

[a] These costs are estimated using FERIC's standard costing methodology for determining machine ownership and operating costs for new machines. The costs shown here do not include supervision, profit and overhead, and are not the actual costs for the contractor or the company studied.