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Contents

Recovering logging residues for hog fuel in northern Alberta

Abstract

The Forest Engineering Research Institute of Canada (FERIC) and Alberta-Pacific Forest Industries Inc. examined the feasibility of recovering logging slash and converting it to power boiler fuel (hog fuel). This report presents hogging productivity and costs, hog delivery costs, hog fuel quality, and cost comparisons with natural gas.

Keywords

Fibre recovery, Logging residues, Forest residues, Slash treatment, Boiler fuel, Hog fuel, Productivity, Costs, Alberta.

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Introduction

The conversion of roadside harvesting residues, or slash, to fuel suitable for power boilers has not been a priority for forest companies in western Canada. With recent increases in the cost of natural gas, using logging residues could become more cost-effective. Harvesting residues have been salvaged for pulp chips (Dyson 2002) and various other products (Sinclair 1984). Desrochers et al. (1995) reported on drum chippers recovering roadside slash for energy in eastern Canada and northeastern United States. Hunt (1994) documented chippers working in Alberta on roadside residues to reduce fire hazard and clear planting areas.

In the spring of 2001, Alberta-Pacific Forest Industries Inc. in Boyle, Alberta, initiated a study on converting recovered logging slash into hog fuel for energy in its pulp mill operation. The company asked FERIC to monitor four equipment combinations used to recover and process various types of residues. This report documents the productivity and cost results of the trial and characterizes the hog fuel produced.

Objectives

The objectives of this study were to:

- Determine system productivity, cost per delivered tonne of hog fuel, and cost per unit of energy.
- Analyze the hog fuel to determine moisture and ash contents, and calorific value.
- Identify factors affecting the productivity of the systems.

Methods

Shift-level data were collected for the hog mill and excavator on seven study blocks. Time spent by the auxiliary equipment assisting the system was also recorded on a block-by-block basis. The loading of hog fuel into vans was timed and weights of the hog fuel produced were obtained from Alberta-Pacific's weigh scale. Work sample data were collected for the hog mill and excavator to examine the working relationship between the two machines.

Samples of the delivered hog fuel were taken after the trucks were unloaded at Alberta-Pacific's pulp mill. FERIC personnel sampled for particle size and set aside a sub-sample for moisture and ash contents and heating value analysis at Alberta-Pacific's laboratory.

Sites and systems

To determine the effect of transportation distance on hog fuel cost, the study was done at two locations. Site 1 was 6 km from the pulp mill, and Site 2 was 85 km away. The study also examined how the condition of the residues (Table 1) affected the processing and characteristics of the hog fuel produced. Site 1 included three cutblocks and slash was fresh, i.e., harvested six months earlier in the winter. The slash was aligned along the access roads, and in one cutblock, perpendicular to the road in piles. At Site 2, the four cutblocks contained slash one to four years old. Coniferous and deciduous residues were processed separately at Site 1, and mixed-species residues were processed at Site 2.

Figure 1. Hitachi EX200LC-5 excavator loading infeed deck of the Peterson Pacific HC 2400 hog mill.

In all cases, a 343-kW Peterson Pacific HC 2400 portable hog mill was supported by a Hitachi EX200LC-5 excavator (Figure 1) which fed residues into the hog mill and loaded hog fuel onto trucks. At Site 1, a Komatsu WA380-3 front-end loader with a log grapple was used intermittently to forward residues to the excavator. At Site 2,

Table 1. Description of study units and equipment used

Study location	Residue condition, type, and placement [a]	Harvesting equipment
Site 1		
Block 1	Fresh, mixed species, P/B	Peterson Pacific hog mill, Hitachi excavator, with or without Komatsu front-end loader
	Fresh, coniferous, P/R	Peterson Pacific hog mill, Hitachi excavator, with or without Komatsu front-end loader
	Fresh, deciduous, P/R	Peterson Pacific hog mill, Hitachi excavator, with or without Komatsu front-end loader
Block 2	Fresh, deciduous, P/R	Peterson Pacific hog mill, Hitachi excavator Komatsu front-end loader
Block 3	Fresh, coniferous, P/R	Peterson Pacific hog mill, Hitachi excavator
	Fresh, deciduous, P/R	Peterson Pacific hog mill, Hitachi excavator
Site 2		
Block 1	1 year old, mixed species, W/R	Peterson Pacific hog mill, Hitachi excavator Caterpillar excavator, Timberjack forwarder
Block 2	2 years old, mixed species, W/R	Peterson Pacific hog mill, Hitachi excavator Caterpillar excavator, Timberjack forwarder
Block 3	3 years old, mixed species, W/R	Peterson Pacific hog mill, Hitachi excavator Komatsu crawler tractor
Block 4	4 years old, mixed species, W/R	Peterson Pacific hog mill, Hitachi excavator Komatsu crawler tractor

[a] P/B: piles within block, P/R: piles at roadside, W/R: windrows at roadside.

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a Timberjack 230A forwarder was loaded by a Caterpillar 225 excavator (Figure 2) in the two cutblocks containing one- and two-year-old residues, and forwarded material to the primary machines. At the remaining two cutblocks at Site 2, a Komatsu D65E crawler tractor (Figure 3) constructed piles from the settled windrows.

The Peterson Pacific hog mill's rotor had been modified by adding ten used feller-buncher saw teeth to complement the standard set of 24 cutters (Figure 4). To facilitate moving the hog mill at the site, a jeep latched onto the fifth wheel pin of the hog mill to allow the excavator to tow it from pile to pile (Figure 5).

A Kenworth tractor and a 103 m^3 trailer van with a walking floor hauled the hog fuel to Alberta-Pacific's mill site, where it was unloaded and mixed with hog fuel from other sources. One trailer was hot loaded initially but this process was deemed to be inefficient. Subsequently, the hogged material was stockpiled and loaded out at irregular intervals or at the end of processing in the area.

Figure 2. Caterpillar 225 excavator loading Timberjack 230A forwarder with 2-year-old residues.

Figure 3. Komatsu D65E crawler tractor piling 3-year-old residues for processing.

Figure 4. Detail of Peterson Pacific hog mill rotor. Used feller-buncher saw teeth were added.

Figure 5. Hitachi EX200LC-5 excavator moving the hog mill using a jeep.

Results

Shift-level studies

The results of the shift-level study are summarized in Table 2. In the first cutblock at Site 1, the front-end loader did not contribute appreciably to the system's productivity. Where mixed-species residues were in piles perpendicular to the road and within the cutblock, productivity was 4.6 bone dry tonnes (BDt) per productive machine hour (PMH) when the front-end loader was used, compared to 4.9 BDt/PMH without the front-end loader. Productivity was better when coniferous residues piled at roadside were processed using the front-end loader, at 10.1 compared to 4.7 BDt/PMH without the loader. Productivity in deciduous piles was 7.3 and 9.0 BDt/PMH with and without the front end loader, respectively.

In the second cutblock, which contained fresh deciduous piles at roadside, productivity improved to 12.6 BDt/PMH. Working alone in the third cutblock, the hog mill and excavator achieved productivities of 9.6 and 9.2 BDt/PMH in the roadside coniferous and deciduous piles, respectively.

At Site 2, in the blocks with the aged residues, productivities of 10.8 and 2.0 BDt/PMH were achieved when processing the one- and two-year-old material, respectively. The forwarder and excavator assisted by stockpiling the residues for the primary equipment. When processing in the three- and four-year-old slash piled by the crawler tractor, the system realized product-ivities of 5.5 and 14.8 BDt/PMH, respectively.

Moving the hog mill between piles affected productivity. At Site 1, moving represented 11–23% of productive time without the front-end loader's assistance and 4–12% with the machine's assistance. Because longer moves were required at Site 2 where the slash was from one to four years old, moving time ranged from 24 to 40% of productive time. No front-end loader assistance was provided at Site 2.

The duration of each machine/residue combination was short. Therefore, both mechanical and non-mechanical delay times were summed and apportioned according to the total productive machine hours for each combination. Mechanical delays represented 52% of the total delay time followed by non-mechanical delays at 37% and maintenance at 11%. The wait parts time represented 31% of total delay time. This delay was associated with a bearing repair to the infeed deck on the Peterson Pacific hog mill, which, though not shown in the data, was responsible for the loss of a complete shift. The maintenance time included fueling, warming up, greasing, and changing bits, and seems low for a generally high maintenance machine like a hog mill. With this system, the excavator was the prime machine and when it was unavailable, the hog mill could not operate. Therefore, maintenance on the hog was frequently done when the excavator was loading hog fuel on to the trucks.

Table 2. Time and productivity for the system, by treatment unit [a]

	Productive time (h)	Non-productive time (h)	Productivity (BDt)	Productivity (BDt/PMH)	System cost [b] ($/PMH)
Site 1					
Block 1					
P/B, mixed species, no FEL	11.32	15.57	55.7	4.9	196.54
P/B, mixed species, with FEL	5.81	7.86	27.0	4.6	286.17
P/R, coniferous, no FEL	3.77	5.69	17.9	4.7	196.54
P/R, coniferous, with FEL	4.80	6.90	48.3	10.1	286.17
P/R, deciduous, no FEL	17.85	25.50	161.3	9.0	196.54
P/R, deciduous, with FEL	5.76	8.44	42.0	7.3	286.17
Block 2					
P/R, deciduous, with FEL	6.32	9.03	79.4	12.6	286.17
Block 3					
P/R, coniferous, no FEL	10.62	14.73	101.5	9.6	196.54
P/R, deciduous, no FEL	2.62	3.60	24.1	9.2	196.54
Site 2					
Block 1					
W/R, 1-yr-old slash	2.85	4.39	30.8	10.8	408.42
Block 2					
W/R, 2-yr-old slash	7.78	10.36	15.8	2.0	375.02
Block 3					
W/R, 3-yr-old slash	19.40	27.45	106.8	5.5	236.05
Block 4					
W/R, 4-yr-old slash	9.15	13.28	135.0	14.8	234.10

[a] FEL: front-end loader, P/B: piles within block, P/R: piles at roadside, W/R: windrows at roadside.
[b] Costs for equipment other than the Peterson Pacific hog mill and the Hitachi excavator have been prorated based on actual hours worked.

Work sample studies

Unlike the shift-level data, the work sample observations clearly show the advantage of using the front-end loader to forward residues at Site 1. The hog mill's grinding time rose from 74 to 90% of total time (Figure 6), and the excavator's time spent loading the hog mill increased from 60 to 73% of total time (Figure 7). The front-end loader spent most of its time picking up and forwarding residues. It was idle 18% of the time due to the confined work area and low volume of residue accumulation.

At Site 2, the hog mill was productive 74% of the time, with 20% spent waiting for the excavator and 6% moving from pile to pile. The primary excavator was able to load the hog mill 82% of the time because the forwarder/excavator combination or the crawler tractor accumulated the residue. The other major time component for the excavator was moving the hog mill from pile to pile.

Hog fuel analysis

Average moisture and ash contents for the hog fuel as delivered to the mill are shown in Table 3. The company's specification of a maximum of 50% average moisture content was met in all cases. At Site 1, the average moisture content ranged from 27 to 36%. With the aged slash at Site 2, the moisture was highest in the one-year-old residue at 40% while the two- to four-year-old material ranged from 25 to 28%. Ash content in all blocks

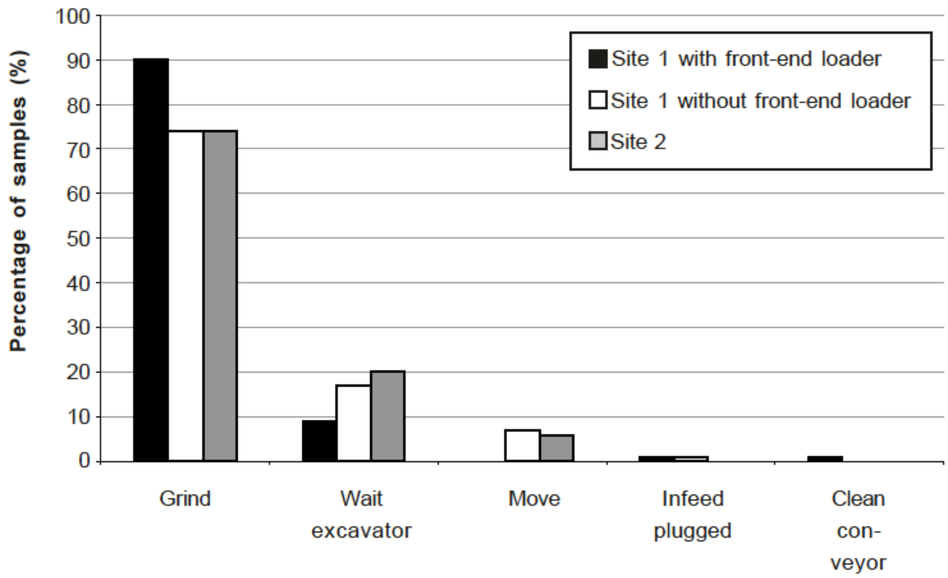


Figure 6. Work sample observations of hog mill.

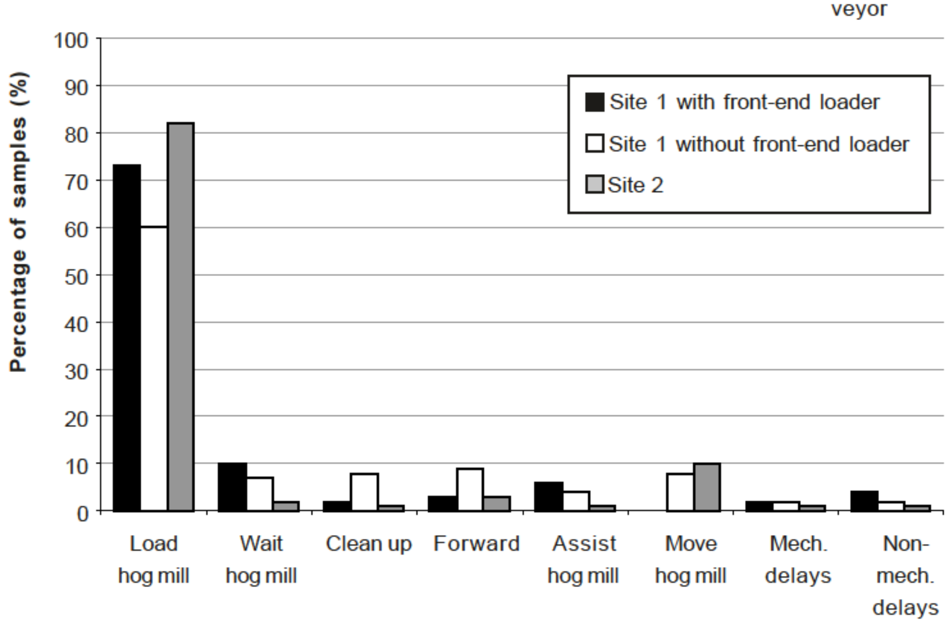


Figure 7. Work sample observations of excavator.

ranged from 1.55 to 6.12% with only 5 of the 13 residue/equipment combinations meeting the company's specification of 2.55%. Calorific values for the hog fuel ranged from 10 853 to 14 503 kJ/kg, well within Alberta-Pacific's specification of 10 050 kJ/kg at 50% moisture content.

Particle size distribution (Table 3) ranged from 19 to 37% for the oversized class, 3 to 8% for the midsized class, and 60 to 76% for the smallest size class. Alberta-Pacific's specifications were 0, 5, and 95%, respectively. The material piled within the cutblock at Site 1, without front-end loader assistance, had the poorest particle sizing for two reasons. This brushy, small-diameter material was very flexible and fed straight through the cutters. The sizing screens in the hog mill were changed to accommodate the material, and particle size was better for the rest of the study. The aged residues at Site 2 produced better particle sizes than the fresh slash at Site 1.

Costs

Hogging costs (Table 4 and Appendix I) at Site 1 ranged from $22.71 to $62.21/BDt when the front-end loader was assisting, and from $20.47 to $41.82/BDt when the hog mill/excavator system worked alone (Table 4). Total costs including truck loading (Appendix II) and hauling (Appendix III) ranged from $32.74 to $79.32/BDt.

Hogging costs at the Site 2 locations containing one- and two-year-old residues were $37.82 and $187.51/BDt, respectively, with an extra excavator and forwarder. With loading and hauling, the total delivered

Table 3. Properties of hog fuel produced [a]

Site and residue type	Moisture content (%)	Ash content (%)	Energy content (wet) [b] (kJ/kg)	Size distribution >7.62 cm (%)	3.18–7.62 cm (%)	<3.18 cm (%)
Site 1						
Block 1						
P/B, mixed species, no FEL	33.0	2.46	13 036	36.9	3.4	59.7
P/B, mixed species, with FEL	36.0	3.50	12 496	30.3	4.6	65.1
P/R, coniferous, no FEL	26.8	2.99	14 503	29.3	4.1	66.6
P/R, coniferous, with FEL	33.4	2.51	12 769	25.6	4.1	70.3
P/R, deciduous, no FEL	29.8	3.07	13 364	27.4	4.3	68.2
P/R, deciduous, with FEL	33.2	2.24	12 706	24.2	4.1	71.7
Block 2						
P/R, deciduous, with FEL	29.4	2.71	13 480	28.3	5.0	66.7
Block 3						
P/R, coniferous, no FEL	33.8	4.98	13 202	26.7	3.4	69.9
P/R, deciduous, no FEL	33.1	4.48	12 411	34.2	4.2	61.6
Site 2						
Block 1						
W/R, 1-yr-old slash	40.3	6.12	10 853	20.5	7.8	71.7
Block 2						
W/R, 2-yr-old slash	27.5	1.55	13 426	19.1	5.4	75.5
Block 3						
W/R, 3-yr-old slash	24.6	1.90	14 047	21.0	6.6	72.4
Block 4						
W/R, 4-yr-old slash	25.0	3.61	13 291	20.1	5.2	74.7
Company specifications	<50.0	2.55	10 050 [c]	0.0 (>7.5 cm)	5.0 (7.5–3.75 cm)	95 (<3.75 cm)

costs were $59.60 for processing the one-year-old residues and $304.88/BDt for processing the two-year-old residues.

With the advance piling done by the crawler tractor, hogging costs for the three- and four-year-old slash were $42.92 and $15.82, respectively. Total delivered costs including loading and hauling were $51.41 and $39.55 for the three- and four-year-old residues, respectively.

The average bone-dry-tonne costs of the hog fuel for the first three blocks close to the mill and three of the remaining four blocks (85 m away) were used to develop a comparative value scenario between hog fuel and natural gas at values of $1–6/GJ (Table 5). The blocks are separated because the haul distances were different. At an average cost to hog, load, and haul of $40.85/BDt (Table 5) and for values of natural gas of $1–6/GJ, Figure 8 shows that for Site 1, when the price of natural gas exceeds $2.43/GJ it becomes economically viable to use hog fuel. For Site 2, this point is reached when natural gas reaches $2.79/GJ and the hog fuel cost is $45.56/BDt.

Table 4. Summary of costs [a]

	Phase cost ($/BDt)			
	Hog	Load	Haul	Total
Site 1				
Block 1				
P/B, mixed species, no FEL	40.11	6.16	7.62	53.89
P/B, mixed species, with FEL	62.21	6.16	10.95	79.32
P/R, coniferous, no FEL	41.82	6.16	6.08	54.06
P/R, coniferous, with FEL	28.33	6.16	5.30	39.79
P/R, deciduous, no FEL	21.84	6.16	6.37	34.37
P/R, deciduous, with FEL	39.20	6.16	5.60	50.96
Block 2				
P/R, deciduous, with FEL	22.71	7.83	5.99	36.53
Block 3				
P/R, coniferous, no FEL	20.47	7.23	5.04	32.74
P/R, deciduous, no FEL	21.36	7.23	5.37	33.96
Site 2				
Block 1				
W/R, 1-yr-old slash	37.82	6.17	15.61	59.60
Block 2				
W/R, 2-yr-old slash [b]	187.51	56.50	60.87	304.88
Block 3				
W/R, 3-yr-old slash	42.92	2.49	6.00	51.41
Block 4				
W/R, 4-yr-old slash	15.82	8.30	15.43	39.55

[a] FEL: front-end loader, P/B: piles within block, P/R: piles at roadside, W/R: windrows at roadside.

[b] These results are out of line with the others because the weigh scale data provided may not have been complete and a long delay occurred during loading.

Table 5. Net value of hog fuel compared to price of natural gas [a]

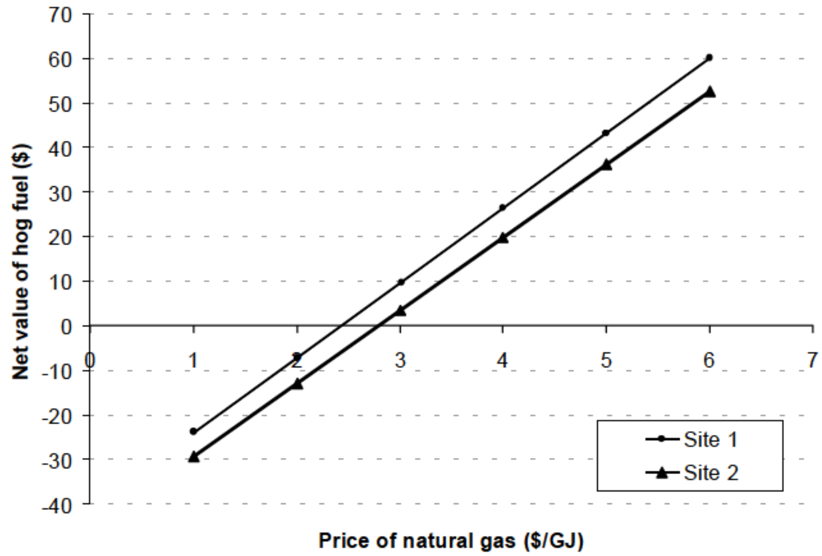
	Price of natural gas ($/GJ)	Amount of hog fuel (BDt)	Hog-fuel-specific energy (BTU/kg)	Equivalent amount of natural gas (GJ)	Energy value of natural gas ($)	Energy value of hog fuel ($/BDt)	Cost to produce hog fuel ($/BDt) [b]	Net value of hog fuel ($/BDt)
Site 1								
	1	557	18 208	6 354	6 354	11.40	40.85	(24.04)
	2	557	18 208	6 354	12 709	22.81	40.85	(7.23)
	3	557	18 208	6 354	19 063	32.41	40.85	9.58
	4	557	18 208	6 354	25 418	45.62	40.85	26.39
	5	557	18 208	6 354	31 772	57.02	40.85	43.20
	6	557	18 208	6 354	38 127	68.43	40.85	60.00
Site 2								
	1	273 [c]	17 700	3 045	3 045	11.17	45.56	(29.22)
	2	273	17 700	3 045	6 091	22.34	45.56	(12.88)
	3	273	17 700	3 045	9 136	33.51	45.56	3.46
	4	273	17 700	3 045	12 181	44.69	45.56	19.80
	5	273	17 700	3 045	15 227	55.86	45.56	36.14
	6	273	17 700	3 045	18 272	67.03	45.56	52.48

[a] Based on the following assumptions: specific energy of natural gas equals 1.06×10^{-6} GJ/BTU; and energy contained in hog fuel equals 6.023×10^{9} million BTU at Site 1 and 2.886×10^{9} million BTU at Site 2 (as delivered, with energy efficiencies of 70% for hog fuel and 80% for natural gas).

[b] Prorated average for each site.

[c] Site 2 Block 2 removed (see Table 4, Footnote b).

Figure 8. Net hog value versus natural gas price for Site 1 and Site 2.



Discussion and implementation

Across the various treatments, 4–40% of productive time was spent moving the hog mill and excavator between either windrows or piles. The slash accumulations were generally small and/or spread out, so there were frequent moves at Site 2, at 24–40% of PMH. Planning for comminution at the harvesting stage would allow for fewer and larger piles, thereby reducing moving time and the need for auxiliary equipment and its attendant costs. A comparison of productivity and costs for the hogging system alone and with assistance from a front-end loader at Site 1 shows not only a productivity increase from 7.81 to 8.67 BDt/PMH, but also a cost increase from $25.24 to $33.04/BDt with the front-end loader.

Though not verified in the data, on-site observations showed that some time and work flow were lost because the excavator operator could not see into the hog mill's infeed. This caused unnecessary waiting time and reduced production. An excavator-type loader with a hydraulically raised cab (Figure 9) could alleviate this problem while not causing the transportation difficulties that a fixed high-rise cab log loader would. The operator's visibility would be much improved while loading the hog mill, and while loading the hog fuel into trailers.

Figure 9. Liebherr log loader with a hydraulically raised cab.

If slash utilization is planned prior to initial harvesting, slash could be consolidated into large piles, thereby requiring only the portable hog mill and excavator/loader on site during hogging operations. Loading hog fuel directly into the trailer from the hog mill was tried but the outfeed conveyor from the hog mill was not long enough to reach the centre of the trailer.

The average productivity at Site 1 of 8.1 BDt/PMH (Table 2) and the average load of 14.2 BDt/cycle (Appendix III) show a potential average hot loading time of 1.75 h/cycle. The average cycle time (Appendix III) was 1.39 h, which would result in a wait time for the truck of 0.36 h. If slash accumulations were large enough, perhaps a swivelling pneumatic discharge could service two or more empty trailers. This would eliminate the trucks' wait time and release the excavator from loading duties, thus reducing on-site equipment time. Based on PMH, the excavator spent 38% of its time during the loading phase waiting for trucks at Site 1, and 33% at Site 2 (Appendix II).

The hog fuel analysis showed average moisture contents ranging from 25 to 40%. The aged slash that was 2–4 years old at Site 2 produced hog fuel with average moisture contents ranging from 25–28%, suggesting some merit in reduced moisture content over time. Ash content was generally higher than the company's specification of 2.55% (by weight), but should be mitigated by better piling of slash during harvesting to minimize dirt contamination and by mixing with normally sourced hog fuel. Particle sizing showed some improvement with smaller screens in the hog mill but still did not meet the company's specifications. The screens can only be downsized so much before the increased dwell time of the material will begin to have an impact on productivity. Mixing with conventionally sourced hog fuel should lessen the impact of the oversized fuel particles.

Conclusions

Though the conversion of harvesting residues to hog fuel has not been a priority in western Canada, rising natural gas prices could make it an attractive endeavor. This study shows that hog fuel hauled 6 and 85 km with delivered costs of $41 and $46/BDt, respectively, can replace natural gas when gas exceeds $2.43/GJ and $2.79/GJ. If slash utilization is planned prior to initial harvesting, slash could be consolidated into large piles, thereby requiring only the portable hog mill and excavator/loader on site during hogging operations. A loader with an elevated cab to improve operator visibility of the hog mill infeed deck would reduce plugging and also benefit the loading of hog fuel into the trailers. If hot loading was desirable, a swiveling pneumatic discharge would enable loading multiple trailers while full trailers are en route to the mill. Additional research and trials are required on this concept to assess the impacts of planning for slash utilization during harvesting.

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Appendix I [a]

Machine costs ($/productive machine hour (PMH))

	1998 Komatsu WA380-3 front-end loader	1996 Timberjack 230A forwarder	1979 Caterpillar 225 excavator	1970 Komatsu D65E crawler tractor	1987 Kenworth T800 tractor and tridem walking floor trailer	2001 Hitachi EX200LC-5 excavator	Peterson Pacific HC 2400 portable hog
OWNERSHIP COSTS							
Total purchase price (P) $	235 400	69 550	32 100	19 260	76 505	310 300	419 440
Expected life (Y) y	8	6	6	6	6	8	10
Expected life (H) h	16 000	12 000	12 000	12 000	12 000	16 000	20 000
Scheduled hours/year (h)=(H/Y) h	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Salvage value as % of P (s) %	20	20	20	10	10	20	20
Interest rate (Int) %	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Insurance rate (Ins) %	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Salvage value (S)=((P•s)/100) $	47 080	13 910	6 420	1 926	7 651	62 060	83 888
Average investment (AVI)=((P+S)/2) $	141 240	41 730	19 260	10 593	42 078	186 180	251 664
Loss in resale value ((P-S)/H) $/h	11.77	4.64	2.14	1.44	5.74	15.51	16.78
Interest ((Int•AVI)/h) $/h	4.24	1.25	0.58	0.32	1.26	5.59	7.55
Insurance ((Ins•AVI)/h) $/h	1.77	0.52	0.24	0.13	0.53	2.33	3.15
Total ownership costs (OW) $/PMH	17.77	6.41	2.96	1.89	7.53	23.43	27.47
OPERATING COSTS							
Fuel consumption (F) L/h	32.0	18.0	27.0	28.0	38.0	24.5	30.0
Fuel (fc) $/L	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Lube & oil as % of fuel (fp) %	12	12	12	12	12	12	12
Annual tire consumption (t) no.	1.5	1.0	-	-	-	-	-
Tire replacement (tc) $	4 000	2 500	-	-	-	-	-
Track & undercarriage replacement (Tc) $	-	-	-	-	-	40 000	-
Track & undercarriage life (Th) h	0	0	0	0	0	10 000	0
Annual operating supplies (Oc) $	2 200	2 200	2 200	2 200	2 200	2 200	8 208
Annual repair & maintenance (Rp) $	29 375	11 600	5 350	3 210	3 000	38 750	41 900
Shift length (sl) h	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Wages $/h	24.00	22.00	22.00	22.00	22.00	23.00	22.00
Wage benefit loading (WBL) %	39	39	39	39	39	39	39
Fuel (F•fc) $/h	17.60	9.90	14.85	15.40	20.90	13.48	16.50
Lube & oil ((fp/100)•(F•fc)) $/h	2.11	1.19	1.78	1.85	2.51	1.62	1.98
Tires ((t•tc)/h) $/h	3.00	1.25	0.00	0.00	0.00	0.00	0.00
Track & undercarriage (Tc/Th) $/h	0.00	0.00	0.00	0.00	0.00	4.00	0.00
Operating supplies (Oc/h) $/h	1.10	1.10	1.10	1.10	1.10	1.10	4.10
Repair & maintenance (Rp/h) $/h	14.69	5.80	2.67	1.60	1.50	19.37	20.95
Wages & benefits (W•(1+WBL/100)) $/h	33.36	30.58	30.58	30.58	30.58	31.97	30.58
Total operating costs (OP) $/PMH	71.86	49.82	50.99	50.53	56.59	71.54	74.11
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/PMH	89.63	56.23	53.95	52.43	64.12	94.96	101.58

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. These costs do not include supervision, profit, or overhead, and are not the actual costs incurred by the contractor or company.

Appendix II

Truck loading summary

	Load (h)	Wait (h)	Move (h)	Prepare site (h)	Change bucket (h)	Other (h)	Delay (h)	Total (h)	Excavator cost ($/h)	Production loaded (BDt)	Cost ($/BDt)
Site 1											
Block 1	13.78	6.00	0.65	1.72	0.17	0.25	0.27	22.84	94.96	352.2	6.16
Block 2	2.30	3.52	0.73	-	-	-	-	6.55	94.96	79.4	7.83
Block 3	3.28	5.10	-	0.35	0.53	0.30	-	9.56	94.96	125.6	7.23
Site 2											
Block 1											
1-yr-old slash	0.38	1.25	0.25	0.12	-	-	-	2.00	94.96	30.8	6.17
Block 2											
2-yr-old slash	2.25	5.10	1.30	0.75	-	-	-	9.40	94.96	15.8	56.50
Block 3											
3-yr-old slash	1.50	0.20	0.60	0.50	-	-	-	2.80	94.96	106.8	2.49
Block 4											
4-yr-old slash	5.62	1.95	2.35	1.88	-	-	-	11.80	94.96	135.0	8.30

Appendix III [a]

Trucking summary

	Cycles (no.)	Total time (h)	Avg time/ cycle [b] (h)	Total production (BDt)	Distance hauled (km)	Truck cost ($/h)	Haul cost ($/BDt)
Site 1							
Block 1							
P/B, mixed species, no FEL	2.2 [c]	3.21	1.46	27.0	6	64.12	7.62
P/B, mixed species, with FEL	5.5	9.51	1.73	55.7	6	64.12	10.95
P/R, coniferous, no FEL	3.3	4.58	1.37	48.3	6	64.12	6.08
P/R, coniferous, with FEL	1.0	1.48	1.48	17.9	6	64.12	5.30
P/R, deciduous, no FEL	2.7	4.17	1.57	42.0	6	64.12	6.37
P/R, deciduous, with FEL	10.3	14.10	1.37	161.3	6	64.12	5.60
Block 2							
P/R, deciduous, with FEL	6.0	7.42	1.24	79.4	6	64.12	5.99
Block 3							
P/R, coniferous, no FEL	6.0	7.98	1.33	101.5	6	64.12	5.04
P/R, deciduous, no FEL	2.0	2.02	1.01	24.1	6	64.12	5.37
Site 2							
Block 1							
W/R, 1-yr-old slash	1.5	7.5	5 [b]	30.8	85	64.12	15.61
Block 2							
W/R, 2-yr-old slash	3.0	15.0	5 [b]	15.8	85	64.12	60.87
Block 3							
W/R, 3-yr-old slash	2.0	10.0	5 [b]	106.8	85	64.12	6.00
Block 4							
W/R, 4-yr-old slash	6.5	32.5	5 [b]	135.0	85	64.12	15.43

[a] FEL: front-end loader, P/B: piles within block, P/R: piles at roadside, W/R: windrows at roadside.
[b] Average cycle time supplied by hauling contractor.
[c] Partial trips are accounted for by having hog fuel from different sources in a trailer load.