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Fuel consumption for ground-based harvesting systems in western Canada

Contents

Abstract

The Forest Engineering Research Institute of Canada (FERIC) interviewed member companies and contractors to quantify fuel usage rates associated with ground-based harvesting, from planning to free growing. Fuel consumption rates for each harvesting system were converted to a common fuel equivalency, litres of diesel equivalent (L d.e.), megajoules of energy (MJ), and grams (g) of greenhouse gas emissions per cubic metre harvested. Finally, the weighted average volume of fuel required for one cubic metre was determined. The report also includes suggestions to reduce fuel consumption rates and greenhouse gas emissions from ground-based harvesting systems.

Keywords

Fuel consumption, Harvesting systems, Life-cycle analysis, Ground-based harvesting, British Columbia, Alberta, Saskatchewan.

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Introduction

Climate change and its relationship to greenhouse gas (GHG)[1] production from industrial activity has become an important issue in Canada, and has implications for the forest industry relating to the strategic management of the forest carbon cycle. Potential benefits could result from utilizing our forests as carbon sinks that will both capture greenhouse gases from the atmosphere and generate forest products and renewable energy.

Life-cycle assessment (LCA) is a technique used to estimate the impact of a product, service, or action on the environment. LCA combines the individual environmental impacts for all phases of a product over its life span from raw material acquisition to final disposal. The LCA technique has been used in Europe to compare harvesting and regeneration systems (Berg 1996a and b), and more recently in British Columbia to compare straw-based chemical pulp with softwood mechanical pulp (Vizcarra and Lo 1997). FERIC participated in the Vizcarra study by providing fuel consumption estimates for the softwood fibre acquisition phase. Sambo (1997) reported the results for six of the most common B.C. coastal harvesting systems in use at the time.

Natural Resources Canada (NRCan) has an initiative to determine the current contribution that Canada's forest industry makes to GHG emissions. To provide input, FERIC, under contract to NRCan, conducted a study to estimate the volume of GHG produced by ground-based harvesting systems and associated silvicultural activities in delivering wood fibre from the stump site to a forest products conversion plant. This study used an approach similar to Sambo's initial work for coastal harvesting, and estimated fuel use for the ground-based harvesting systems common to western Canadian forest operations.

[1] Greenhouse Gases (GHG) include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Objectives

The objectives of the study were to:

- Estimate the proportion of wood harvested in western Canada by each of the four typical ground-based harvesting systems: full-tree; cut-to-length at roadside, cut-to-length at-the-stump; and cut-to-length with harvesters and forwarders.[2]
- Estimate fuel consumption rates for pre- to post-harvest activities for each harvesting system, by phase and in total.
- Convert the fuel consumption rate results to grams (g) of GHG emissions per cubic metre.
- Calculate the energy benefit-cost ratio for the four harvesting systems of interest.

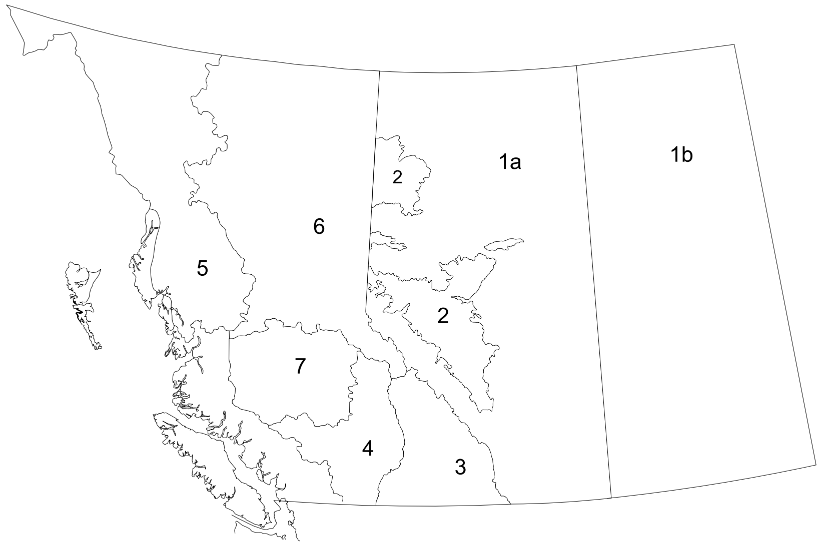
Methods

A survey questionnaire was developed and circulated to 68 FERIC members in western Canada to request information on annual harvest levels by harvesting system, average cutblock area, merchantable volumes, and one-way haul distance. Survey responses were stratified by geographic region (Figure 1) and coniferous or deciduous. An average cutblock was determined from the survey, with an average area, volume and haul distance. The period of the survey was the last year of data available to the respondents, generally 2000 or 2000/01. Comparisons were made by harvesting system, and by geographic region.

A detailed set of survey worksheets was developed that identified common tasks associated with eight harvesting phases from planning to free growing. Only tasks involving fossil fuel consumption were listed. FERIC researchers traveled to the operations of the survey respondents to

[2] In the "full-tree" system, trees are cut and skidded to the roadside/landing where they are topped and delimbed. In the "cut-to-length at roadside" system, a feller-buncher and skidder are used and the stems are manufactured by a processor into company-specified lengths at roadside. When logs are manufactured with a processor, to 15-25 m lengths, before being transported to roadside, the system is designated "cut-to-length at-the-stump," and when a harvester and forwarder are used, the system is called "cut-to-length."

Figure 1. Forest regions used to summarize the survey results.



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interview both company staff and contractors directly responsible for harvesting activities. The purpose of the thirty-seven interviews was to:

- Verify the information provided in the first survey and agree on the baseline statistics to be used for subsequent analysis.
- Identify which phase tasks applied to their specific operations.
- Quantify machine productivity and fuel usage rates associated with each task.
- Note any anomalies or omissions in the worksheets specific to their operations.
- Solicit ideas on how to reduce fuel consumption.

Fuel consumption rates were converted to litres of diesel equivalent per cubic metre (L d.e./m^3), megajoules of energy per cubic metre (MJ/m^3), and g/m^3 of GHG emissions. Table 1 shows the emission conversion factors obtained from Government of Canada (1999), and applied to each type of fuel. Averages of ranges were used where a range of factors was given for a fuel type.

The energy benefit-cost ratio is the energy content of wood produced divided by the energy used in the silvicultural, harvesting, and hauling phases of wood production (Kimmins 1987). This ratio was calculated as a measure of comparison between harvesting systems.

Finally, a weighted average value of fuel needed to harvest one cubic metre of wood was determined. This weighted average accounted for the proportion of wood harvested by each harvesting system, and the fuel consumption associated with these systems. This overall value can be applied to all ground-based harvesting in western Canada for the period of the survey (2000/01).

Results

Fuel consumption and emissions

Weighted average values

The average cutblock, determined through the survey, had an area of 24 ha, a merchantable timber volume of 244 m^3/ha, a volume of 5 856 m^3, and a one-way haul distance of 106 km (Appendix I). The fuel consumption and energy equivalent averaged 7.1 L d.e./m^3 and 273 MJ/m^3, respectively (Table 2). The energy benefit-cost ratio for ground-based harvesting systems was calculated as 26.[3] Overall, the hauling phase consumed 51% of the fuel used in the harvesting and delivery of wood to the millyard.

Table 3 summarizes the greenhouse gas emission results of the survey for the average cubic metre of wood. Emissions included 19 135 g/m^3 of CO_2, 25 g/m^3 of CH_4 and 1 302 g/m^3 of N_2O. When all emissions were converted to CO_2 equivalents, the total was 20 463 g/m^3 (Appendix II).

[3] Energy benefit-cost ratio = energy content of wood produced (i.e., 6994 MJ/m^3)/energy cost of harvesting system (i.e., 273 MJ/m^3).

Table 1. Emission conversion factors in grams per litre of fuel

	CO_2 (g/L)	CH_4 (g/L)	N_2O (g/L)
Motor gasoline	2 360	0.775 [a] (0.25 to 1.3)	0.313 [a] (0.046 to 0.58)
Diesel oil	2 730	0.1 [a] (0.05 to 0.15)	0.6 [a] (0.1 to 1.1)
Aviation jet fuel	2 550	0.08	0.25
Petroleum used for lubricants	1 410	-	-

[a] Average of range given in source table (Government of Canada 1999).

Table 2. Diesel and energy equivalent use per weighted average cubic metre

	Litres of diesel equivalent (L d.e./m^3)	Energy (MJ/m^3)	Percentage (%)
Pre-harvest, Logging, camp & Silviculture	3.5	134	49
Hauling	3.6	139	51
Total	7.1	273	100

Table 3. Greenhouse gas emissions in grams per weighted average cubic metre

	CO_2/m^3 (g/m^3)	CH_4/m^3 [CO_2 equiv.] (g/m^3)	N_2O/m^3 [CO_2 equiv.] (g/m^3)	Total CO_2 equivalents (g/m^3)
Pre-harvest, Logging, Camp & Silviculture	9 371	0.8 [17]	2.1 [651]	10 039
Hauling	9 765	0.4 [8]	2.1 [651]	10 424
Total	19 136	1.2 [25]	4.2 [1 302]	20 463

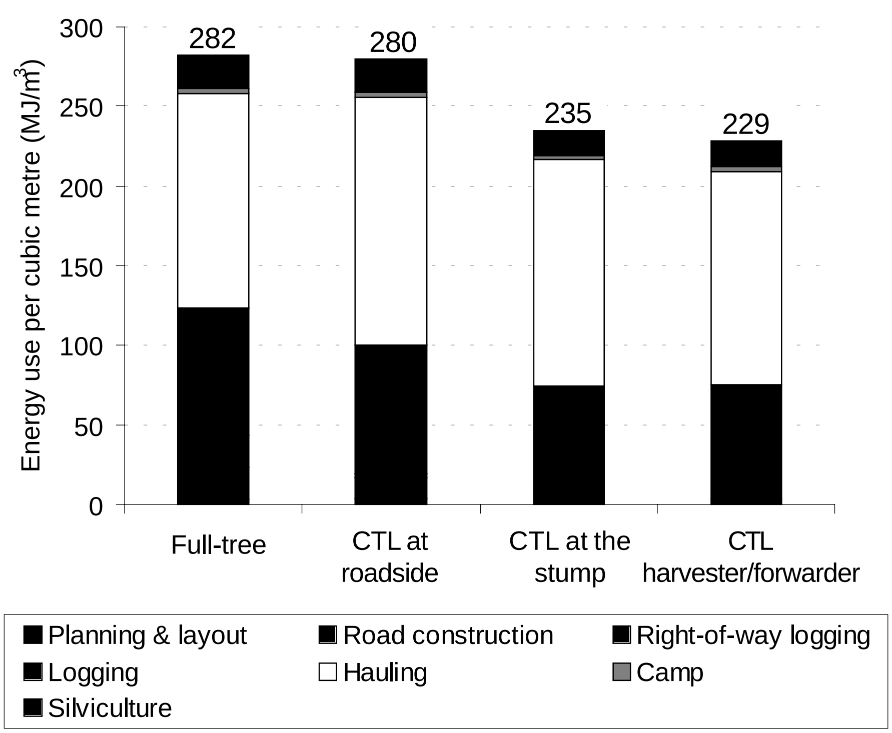
By harvesting system

The full-tree, cut-to-length at roadside, cut-to-length at the stump and cut-to-length systems accounted for 53, 7, 8 and 14%, respectively, of the harvested volume reported for western Canada. As shown in Figure 2, the full-tree, cut-to-length at roadside, cut-to-length at the stump and cut-to-length (with harvesters and forwarders) systems used 282, 280, 235 and 229 MJ/m^3, respectively (see also Appendices I and III).

The energy benefit-cost ratio for both the full-tree and cut-to-length at roadside systems was 25. This ratio was somewhat higher (more energy efficient) for the cut-to-length at the stump and cut-to-length (with harvesters and forwarders) systems, at 30 and 31, respectively.

When the components of the harvesting operation are compared, differences between systems are evident. The cut-to-length at the stump and cut-to-length (with harvesters and forwarders) systems used 17 and 19% less energy, respectively, than the full-tree system, in part due to less energy consumption in the logging phase—felling, skidding and processing. Skidding logs to roadside may consume more energy when processing is done at roadside because stems with branches and defect are dragged to the roadside compared to when processing is done at the stump and only the stem sections are skidded.

Figure 2. Energy use by ground-based harvesting system and phase.



Right-of-way logging used the most energy for the full-tree system. For this harvesting system, data were separated for right-of-way, rather than included in the overall logging database as with the other systems. It may be more accurate, then, to view logging and right-of-way logging as a combined phase.

When the results for road construction are examined, two factors come into play. Cut-to-length systems, both with skidders and forwarders, may generally have lower road densities than full-tree systems. As shown later in the report, full-tree systems may be more prevalent in areas with difficult terrain conditions, and therefore road construction is a more equipment-intensive and fuel consumptive task. When processing and sorting take place at roadside, more decking area is required and, especially under steeper terrain conditions, road construction efforts would be greater.

Figure 3 shows the difference in energy use per cubic metre between clearcut and thinning for the logging phase. Only full-tree and cut-to-length (with harvesters and forwarders) systems reported thinning operations. Generally, the clearcut operations and the cut-to-length in thinning were similar with a spread of less than 10% (73 to 80 MJ/m^3). The energy consumed with full-tree in the thinning was much higher at 126 MJ/m^3, 58% greater than in the clearcut. The main difference in fuel consumption was between the falling and the falling and processing phase. Feller-bunchers in the full-tree system use 2.5 times the energy in thinning than in clearcuts, due to small tree size and increased travel to reach target trees. In comparison, harvesters in the cut-to-length system use only 10% more energy when falling and processing in thinning than in clearcuts (Figure 3). This indicates that, from an energy perspective, the cut-to-length (with harvesters and forwarders) system is better suited to thinnings than the full-tree system.

When energy per cubic metre used in harvesting mixedwoods was compared to coniferous and deciduous stands, the differences were minimal.

Regional differences in energy use per cubic metre for the full-tree and cut-to-length at roadside systems are presented in Figures 4 and 5.

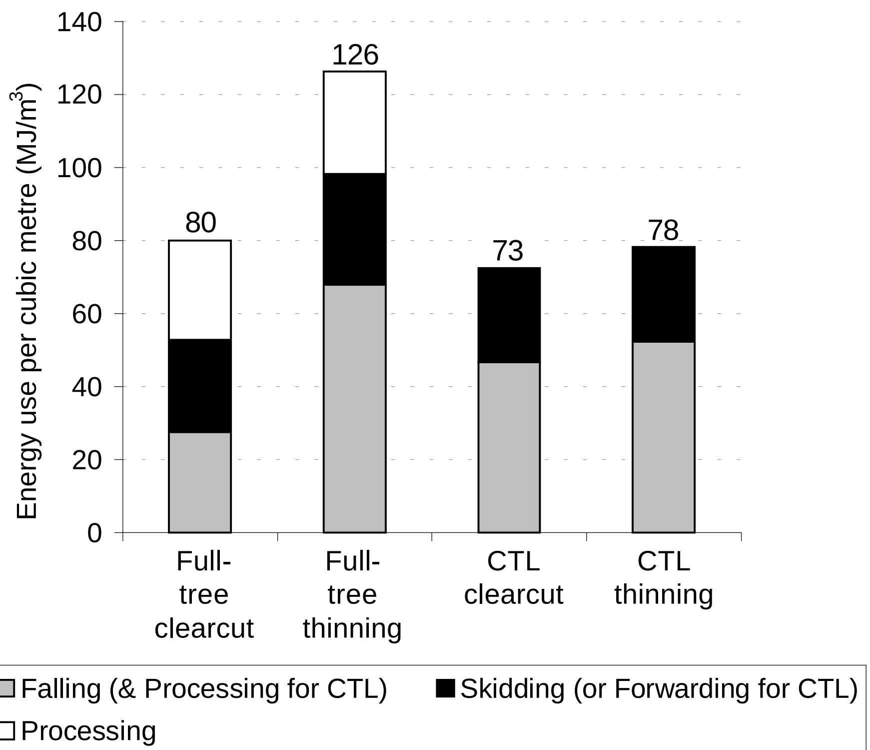


Figure 3. Energy use for the logging phase in clearcuts and thinnings.

Figure 4. Energy use by region and phase for full-tree system.

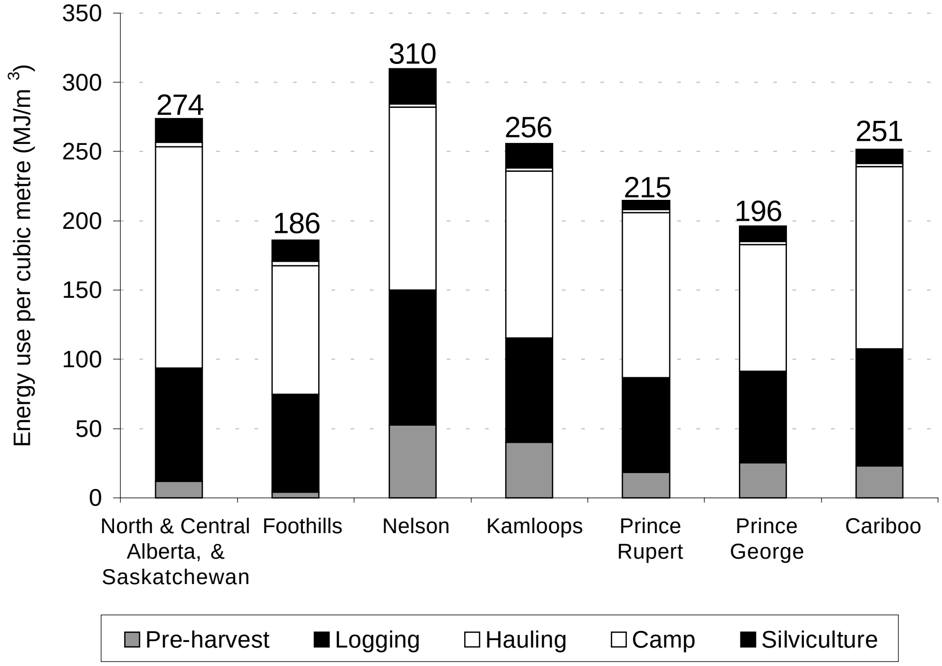
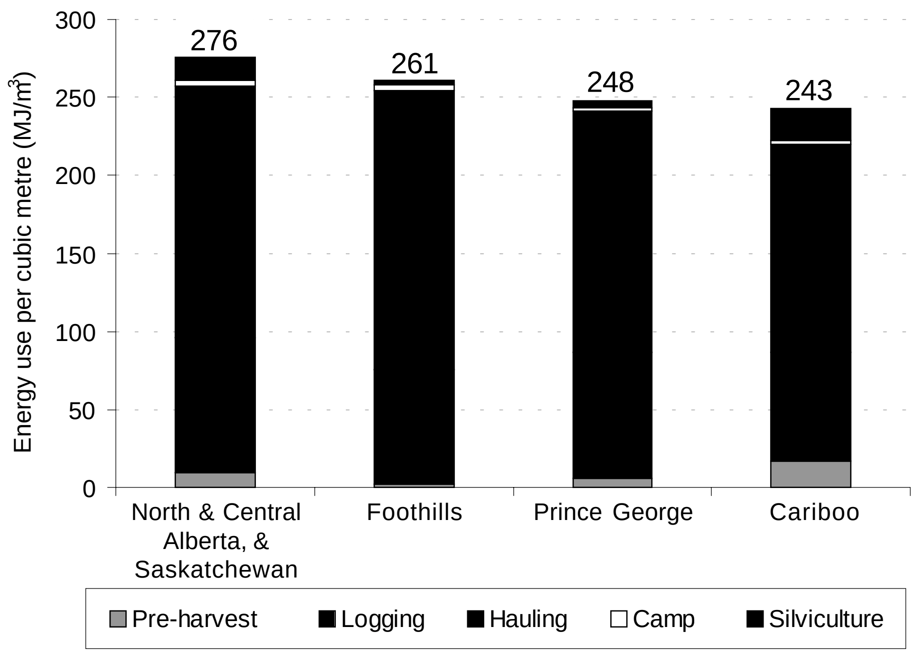


Figure 5. Energy use by region and phase for cut-to-length at roadside system.



With the full-tree system, the Nelson forest region used more energy than the other regions at 310 MJ/m^3 (Figure 4). The steeper slopes and smaller tree sizes in this region would likely have reduced machine productivity and therefore increased energy consumption per unit volume. Foothills was the lowest at 186 MJ/m^3. Pre-harvest energy use, which includes planning and layout, road construction, and right-of-way logging, is higher in B.C. than in Alberta and Saskatchewan. The legislative requirements, greater complexity of forest ecosystems, and more difficult road building requirements contributed to the geographical differences. The hauling phase had the highest energy use in North and Central Alberta, and Saskatchewan, reflecting the long average haul distance of 136 km. This phase had the lowest energy use in the Prince George region, which had a higher proportion of off-highway hauls.

Energy use per cubic metre for the cut-to-length at roadside system is presented in

Figure 5. The variation in energy consumption is not great between regions, approximately 10%. The system was used in only four regions, not in areas with difficult terrain. For the North and Central Alberta, and Saskatchewan and Cariboo regions, the cut-to-length at roadside system used similar amounts of energy as the full-tree system. In the Foothills region, it used more energy than the full-tree system, with the difference primarily in hauling. Self-loading trucks were used and this may have contributed to the greater fuel usage. The cut-to-length at roadside system in the Prince George region also used more energy than the full-tree, in this case, due to longer haul distances.

Reducing fuel consumption

Part of the interview process involved soliciting ideas on how to reduce the fuel consumed during harvesting with ground-based systems.

Ideas to reduce fuel use include:

Hauling considerations

- Trucks with electronic fuel systems can report fuel usage for a given volume or speed, e.g., Traxis at Alberta-Pacific Forest Industries Ltd. This information can highlight the fuel consumption issues surrounding a specific operation, truck, or driver.
- Computerized fuel control of truck engines leads to better fuel consumption. Newer trucks are more fuel efficient and will offer an advantage to both the trucking contractor and the industrial client. Most trucks newer than 10 years have computerized fuel control systems.
- Take advantage of available technological opportunities. Numerous trailer and tractor configurations now available can increase the payload capacity or the tractive efficiency of logging trucks, e.g., 7 or 8 axles or tridem drive tractors may be advantageous.
- With central tire inflation systems, the standard of road construction and road maintenance requirements may be reduced.
- Improve driver education, e.g., the SmartDriver for Forestry Trucks program.[4] This program can be used to educate drivers about driving techniques to reduce fuel consumption and to improve driver safety.
- Switch to another transportation mode, e.g., rail if it is a viable service.
- Use two-way payload hauls, e.g., a dual commodity B-train trailer, capable of hauling chips or logs.
- Use fuel efficiency as a criterion when selecting engines for trucks and other equipment.

Operational considerations

- Train operators to be aware of the factors affecting fuel consumption. Start a "smart logger" program that provides information on how to reduce fuel use for specific forestry machines, e.g., maintenance training.
- Contractors develop solutions to problems in their areas of expertise. Reward efficient contractors through stability of employment.
- Carpool or share a vehicle if operators are going to the same place and shift.
- Use the most appropriate size of equipment for the task.
- Integrate operations, e.g., harvest coniferous and deciduous trees at the same time rather than making two entries.
- Reduce idling time.
- Recycle waste oil.

Planning considerations

- When planning new operations, situate the forest conversion plant as close to the source of fibre as possible. Because hauling accounts for over half of the energy consumed to the millyard, any reductions in the hauling distance can have a substantial effect.
- Plan large operating areas and concentrate operations within one drainage or

[4] Developed by FERIC under contract to NRCan's Office of Energy Efficiency.

compartment at a given time. This reduces the amount of road construction and concentrates vehicles in one area. Less travelling between areas requires less fuel. The number of logging camps may also be reduced.
- Newer machines generally get better fuel consumption. When deciding equipment replacement, use fuel consumption as an important selection criterion. Otto 2000 software developed by FERIC can be used to compare options.
- Balance the fuel consumption of equipment against its productivity to determine which gives the best overall result.

Technological considerations
- Manufacturers can improve hydraulic system design. Use electronic control over servo-hydraulic systems.
- Optimize internal combustion engine design, e.g., exhaust gas recirculation, injection strategies, boost pressure, combustion chamber design, spray targeting, flow field effects and augmented mixing (Senecal 2002).
- Use alternate fuels e.g., biofuels derived from forest biomass.
- Develop hydrogen fuel cells for forestry equipment.
- Improve efficiency of biomass comminution (grinding or crushing a solid into fine particles) machines.
- Use engines with dual-fuel capability, e.g., diesel/natural gas.

Discussion

Fuel consumption

Information on fuel consumption for forestry operations is not widely available. However, during the survey, FERIC obtained estimates from three company divisions that were able to identify fuel used in their operations. Weyerhaeuser Company Limited, Grande Prairie, Alberta is the only fuel supplier to its own and contractor operations. It estimated that its ground-based harvesting systems use 7.2 L/m^3. West Fraser Mills Ltd., Slave Lake, Alberta records show a usage of 5 L/m^3; however, it is not the exclusive fuel supplier to its contractors and recognizes that this statistic is low. Cut-to-length at the stump was used by Weldwood of Canada Limited, Hinton, Alberta. When its records for fuel consumption are compared to FERIC's estimate for the logging phase, the numbers are virtually identical, 65 MJ/m^3 and 64 MJ/m^3, respectively.

Ash and Knobloch (1982) reported that logging systems in western Canada used 9.2 L d.e./m^3. Fuel consumption rates of ground-based harvesting systems have likely decreased in the past 20 years due to technological improvements and improved productivity.

The weighted average fuel use per cubic metre for coastal B.C. harvesting systems was estimated to be 6.9 L d.e./m^3 (Sambo 1997). Road construction energy use is higher on the coast than in the rest of western Canada because the coast has more steep and unstable terrain. However, energy use is less for falling because hand-falling is predominant. This may change as second growth becomes a larger component of the harvest and issues around faller safety are resolved by mechanized harvesting. The loading and hauling phase added to the sorting, booming and barging phase from the coastal report is similar to the hauling (and loading) phase of this report. Logging camps were not included in the previous study. The silviculture phases in both reports are similar though the coastal study only considered rehabilitation and planting whereas this report includes right-of-way rehabilitation, site preparation, prescribed burning, planting, fertilization, herbicide application, stand tending, and silviculture surveys.

In Sweden, Berg and Lindholm (2001) estimated that 6 L/m^3 of fossil fuel are used in forest harvesting compared to the 7 L/m^3 in western Canada (this report and Sambo (1997)). The silviculture phase energy use in Sweden is similar to this study but the logging and hauling phases use less energy. Cut-to-length with harvesters and forwarders, predominant in Sweden, is more fuel efficient than roadside harvesting systems. The hauling distances in Sweden are shorter, and many haul routes have backhauls (payload on the return trip).

Athanassiadis (2000) reported 82 MJ/m^3 for harvesters and forwarders, 11% of which was for the crude oil refining process to produce the diesel. If that 11% is removed, the result is the same as the cut-to-length logging phase energy of 73 MJ/m^3 found in this study.

Energy benefit-cost ratio

Energy benefit-cost ratios can be used to compare harvesting system efficiency. Energy benefit-cost ratios of 17 have been reported for Douglas-fir forests with high management intensity and 39 for western hemlock forests with medium management intensity (Ash et al. 1980). The overall harvesting system energy benefit-cost ratio of 26 falls roughly half way between these values. The full-tree and cut-to-length at roadside systems, with energy benefit-cost ratios of 25, are slightly less energy-efficient than the cut-to-length at the stump and cut-to-length (with harvesters and forwarders) systems, with ratios of 30 and 31 respectively.

Carbon Budget Model

NRCan researchers are developing a model to analyze different management actions that can increase forest carbon stocks. The Carbon Budget Model of the Forest Product Sector (CBM-FPS) was designed to work with a national scale model of forest ecosystem dynamics. The accounting framework uses the characteristics of different forest product types to estimate changes in the storage of carbon in forest products; it tracks carbon from the transportation of the harvested raw material through various processing steps in sawmills or pulp mills, to its final destination (product, pulp, landfill, atmosphere or recycled) (Apps et al. 1999). Fuel consumption information as presented in this report can serve as an important input into the overall model, and in making it useful as an industry tool.

Life cycle assessment

Life cycle assessment using the ATHENA model has shown that, compared to other building materials such as steel and concrete, wood products have the lowest overall effect on the environment in terms of raw materials and energy use, and emissions to air, water and land (Abusow 2002). Similarly, Vizcarra and Lo (1997) found that paper made from wood fibre had a lower environmental impact than paper made from straw fibre.

Conclusions

Through a combination of written surveys and interviews, FERIC obtained fuel consumption estimates for ground-based harvesting systems in western Canada.

The weighted average diesel consumed to deliver one cubic metre of wood to the forest product conversion plant using ground-based harvesting systems in western Canada was determined to be 7.1 L d.e./m^3. The energy equivalent was 273 MJ/m^3, and the CO_2 equivalent emissions were 20 463 g/m^3. The energy benefit-cost ratio of ground-based harvesting systems is 26.

The full-tree and cut-to-length at roadside systems used similar amounts of energy per cubic metre harvested. The cut-to-length at the stump and cut-to-length (with harvesters and forwarders) systems used 17% and 19% less energy, respectively than the full-tree system. For thinning, the cut-to-length system (with harvesters and forwarders) used less energy than the full-tree system (with feller-bunchers, skidders and processors).

Hauling uses 51% of the fuel consumed per cubic metre of wood delivered to the forest product conversion plant. Further research in log hauling fuel efficiency seems to hold the most potential for reduced GHG emissions from harvesting activities.

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Appendix I

Cutblock parameters

	Area (ha)	Volume (m^3/ha)	Total volume (m^3)	One-way haul distance (km)
By system				
Full-tree	26	255	6 630	98
Cut-to-length at roadside	28	237	6 636	119
Cut-to-length at the stump	12	200	2 400	116
Cut-to-length with harvester/forwarder	19	217	4 123	122
Commercial thinning, by system				
Full-tree	28	119	3 332	122
Cut-to-length with harvester/forwarder	12	80	960	116
Full-tree, by region				
Central Alberta & Saskatchewan	24	217	5 208	136
Foothills	22	225	4 950	122
Nelson	15	283	4 245	83
Kamloops	21	288	6 048	87
Prince Rupert	36	308	11 088	90
Prince George	40	263	10 520	98
Cariboo	32	228	7 296	73
Cut-to-length at roadside, by region				
Central Alberta & Saskatchewan	23	213	4 899	136
Foothills	22	225	4 950	122
Prince George	75	188	14 100	130
Cariboo	21	296	6 216	93
Weighted average cutblock	24	244	5 856	106

Appendix II

GHG emissions in CO_2 equivalents

Greenhouse gas	Global warming potential [a]
CO_2	1
CH_4	21
N_2O	310

Carbon Dioxide Equivalent (CO_2-equivalent) is a measure used to compare the emissions from various greenhouse gases based on their global warming potentials (GWPs). The CO_2-equivalent for a greenhouse gas is derived by multiplying the mass of the gas by its associated GWP listed in this Appendix. For example, the GWP for methane is 21; this means the emissions of one gram of methane is equivalent to emissions of 21 grams of carbon dioxide, Source: Greenhouse Gas Emission Reduction Trading Pilot, 1998.

Website: www.gert.org/kit/adx-e/htm; accessed June 27, 2002.

To convert emission quantities into CO_2 equivalents:

19 136 g-CO_2/m^3•1 = 19 136 g-CO_2 equivalents/m^3
1.2 g-CH_4/m^3•21 = 25 g-CO_2-equivalents/m^3
4.2 g-N_2O/m^3•310 = 1 302 g-CO_2-equivalents/m^3
Total 20 463 g-CO_2-equialents/m^3

[a] 100 year time horizon.

Appendix III

Energy use values in megajoules per cubic metre

	Full-tree (MJ/m^3)	CTL at roadside (MJ/m^3)	CTL at the stump (MJ/m^3)	CTL harvester/ forwarder (MJ/m^3)	Weighted average (MJ/m^3)
Silviculture	21	21	16	17	
Camp	3	3	3	3	
Hauling	135	156	142	133	
Logging	80	81	64	73	
Right-of-way logging	20	2	4	0	
Road construction	20	13	5	3	
Planning & layout	3	4	1	0	
Total	282	280	235	229	273