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Recovery and transport of forest biomass in mountainous terrain

A.W.J. Sinclair

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FOREWORD

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

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

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ABSTRACT

Field tests were conducted to document the costs and productivities of conventional and integrated systems for recovering and transporting roadside biomass in mountainous terrain. The recovered biomass was scaled to determine the quality and quantity of material removed. The conventional system costs $15.51/m³ and at present is uneconomic if biomass is to be used as a source of hog fuel. The integrated systems performed better and recovered biomass at costs ranging from $9.19 to $9.62 m³. The container system has the most promise and, with design and size changes to the system, has the potential of achieving recovery costs of $5.00/m³. Further development and test work is recommended for the container system.

RÉSUMÉ

Grâce à des essais sur place on a déterminé les coûts et le rendement des dispositifs traditionnel et nouveaux de récupération et de transport de la biomasse laissée sur le bord de la route en terrain montagneux. On a déterminé la qualité et le volume de la matière récupérée après cubage. Le dispositif traditionnel revient actuellement à 15,51 $/m³ et n'est pas rentable si la biomasse doit servir de combustible sous/orme de dechets de bois. Les dispositifs nouveaux ont un meilleur rendement et reviennent a 9,19 a 9,62 $/m³ récupéré. Le plus prometteur est le dispositif à conteneur, qui, moyennant des modifications de conception et de dimensions, pourrait revenir à 5,00 $/m³ récupéré. Il est recommandé de la perfectionner et de l'expérimenter davantage.

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EXECUTIVE SUMMARY

Field trials were conducted on the West Coast of Vancouver Island to document the costs and productivities of recovering roadside biomass using an existing recovery system and three integrated systems. The existing system of a choker-skidder and a self-loading logging truck recovered biomass after active logging was completed. The integrated systems were tested in conjunction with active logging and used the excess capacity of the log loader to load the biomass into the recovery units. The minimum utilization standards were 10 cm diameter tops, 2.4 m lengths and all grades. The integrated systems used three different types of units: a highboy, four-bunk trailer (System I), a demolition trailer (System II) and a container system (System III). All units tested were conveniently available, highway legal units and were not modified to reflect off-highway operating conditions. We felt that if one of the systems showed potential, then future design and size changes could be made for precommercial prototype tests.

The summary results of productivities and costs are given in Table S-1

The existing skidder/self-loading logging truck combination should not be used to recover lower quality, smaller sized material from landing piles and roadside. Using the rule-of-thumb that a cubic metre of solid wood converts to 2 m^3 of hog fuel, this system will cost $7.76/$m^3$ for recovery and transport and this is not economically attractive at present. It does not appear that changes can be made that will significantly increase this system's productivity and reduce its costs.

The productivity of the integrated systems was less than the existing system but the cost per cubic metre of material recovered was considerably lower (41 to 44%). Recovery and transport costs approximately $4.60 to $4.81/$m^3$ of hog fuel. The main reason for this was the lack of a skidder and crew with the integrated systems. The existing yarder and log loader were utilized without affecting productivity of their prime logging functions.

The container system (System III) had the lowest cycle time and delay time of the integrated systems. It also took up less space in the

Table S 1. System Productivities and Costs — Summary

Item	Existing	Integrated Systems		
	Self-loading Truck	Four-bunk Trailer (System I)	Demolition Trailer (System II)	Containers (System III)
Number of Test Days	9	9	2	8
Number of Loads	36	26	7	39
% Delay Time	2	26	24	20
Size of Load (m^3)	20.3	21.8	15.9	10.9
Volume Recovered (m^3)	730.07	565.77	111.07	425.01
Piece Size (m^3/Piece)	0.43	0.68	0.69	0.34
Time per Load (Hours)	2.04	2.61	2.03	1.52
Production/ 8-Hour Shift (m^3)	79.8	66.6	61.7	57.2
Cost/m^3 Recovered	$15.51	$9.19	$9.24	$9.62

landings, which were somewhat confined. It had less difficulty maneuvering in the landings and getting into the landings. Its load capacity was less than the other units and this affected its cost adversely. However, changes in design and size of the container can overcome this. The feature of being able to detach the container from the truck and service several landings with one truck has real advantages when trying to dispatch these recovery units during active logging and results in lower delay times.

Considering the productivity and cost results, as well as field observations and operator comments, the container system has the greatest potential of the three systems tested for recovering roadside biomass at a reasonable cost. It may be possible to reduce recovery and transport costs by 50 percent through design and size changes of the containers and truck. The features of servicing several landings with one truck, the quick pick-up and drop-off time for the containers, the ability to load the container for a longer period of time, and the reduced interdependence on active logging operations are the main benefits of the container system. It is recommended that size and design changes be made to the truck and containers and further field testing be carried out on the container system when recovering roadside biomass in mountainous terrain.

INTRODUCTION

On British Columbia coastal logging operations, many merchantable logs that are too short or small in diameter to load on conventional trucks during prime logging are recovered later. Choker equipped skidders pile the logs at roadside for pick-up by self-loading logging trucks. The skidders also recover logs at the landing. The production of this system will vary with terrain, piece size, total volumes available and transportation distance; an average estimate is 90 to 100 m^3/day. Recovery of biomass for energy purposes may be accomplished in a similar manner.

In the case of cable logging systems, most lower grade biomass remaining after prime logging is found in the landing or within 30 m of the roads. Biomass discarded in the landing results from:

- the yarding crew sending in logs that do not meet the utilization specifications;
- logs that are too short to load on the trucks;
- portions of logs bucked in the landing; and
- log breakage during yarding.

Roadside biomass accumulates when lower grade material is dragged in by the turn of logs and from log breakage during unhooking and piling of the logs at roadside. In some logging operations the build-up of residue on the landing is such that a skidder is used to clean the landing in order to reduce congestion.

Should the forest products industry begin to utilize more biomass as a further source of fiber and energy, they will most likely revise the logging specifications and extend the use of the conventional skidder/self-loading logging truck system. Alternatively, a more effective system may be used. The objectives of these trials were to measure and record the productivity and cost of the existing methods and of other, possibly more effective, integrated systems.

Test of Existing Recovery and Transport System

An area representative of coastal British Columbia terrain and timber types which had been logged the previous year with a highlead cable system and chokers was chosen for the field trials. The utilization standard during prime logging had been a 15 cm diameter top, a 3 m length and no pulp grades. The recovery standard during the field trial was a 10 cm diameter top, 2.4 m length and all grades. In addition, any large diameter chunks were taken even if they did not meet the length specification. A skidder and operator, a chokerman and self-loading logging truck and driver were hired for ten days of trials. Figures 1 and 2 show the area where the biomass was recovered.

The operation was timed and all loads of biomass recovered were scaled to determine the volume and species removed. Productivity was calculated from these records. In addition, a waste survey was conducted after the trials so original and final volumes of biomass could be determined.

Tests of Integrated Systems

Three systems for recovering biomass during active logging using the prime yarder and loader to recover and load the biomass were tried. The major disadvantage of these systems was that the recovery of biomass was limited to the material that was available to the loader operator. To a large degree the piece size recovery standard was the same as that used by the yarding crew (15 cm diameter top and a 3 m length) and the biomass available for recovery was generally the lower grade logs. The major advantage of these systems was that skidder and chokerman costs were not incurred.

Figure 3 shows the location and detail of these field trial areas. Initially only one active logging landing was used but the volume of biomass was not great enough to fully utilize the equipment. A second landing was added and if a third landing had been available then equipment utilization would have been increased even further.

The biomass was loaded into three types of trucks and trailers. Each was selected to overcome the need for longer logs to bridge the distance between the tractor and trailer bunks. The

Fig. 1 General area of field trials

Fig. 2 Area of field trial — existing system

Fig. 3 Area of field trial — integrated systems

first type was a conventional highboy trailer with four sets of bunks. The second type was a self-dumping demolition trailer. Both these units were pulled by the same Kenworth 924 tractor. The third unit was a waste container. Two containers and a self-dumping tractor were used.

The same test procedure, timing records and scaling methods were used for all systems to determine cost and productivity. During the trials it was necessary to dispatch the units into the landings because we could not interfere with the active logging productivity. Loading of the prime logging trucks took priority so the test units and to be scheduled to be in a landing with biomass available but without a prime logging truck. This was not always possible and delay resulted.

THE TESTS

Existing System

a. Test Conditions

The area of the recovery trial had been logged the previous fall to intermediate standards (15 cm diameter top by 3 m length, no pulp grades). The setting had been yarded downhill and the logs accumulated in the landing. A boundary approximately 30 m wide on the upper side of the road and 180 m along the road was indicated by paint marks. The landing and the pile of logs extending from it on the lower side of the road were added to the setting boundaries. The actual areas were 0.41 ha and 0.06 ha, respectively. The skidder crew was instructed to recover all material that had greater than a 10 cm diameter top and 2.4 m length and chunks that had equivalent volume within the marked boundaries. Recovering enough longer logs (greater than 6 m in length) to bridge the bunks and stakes was a continual problem for the skidder crew. Consequently, they would alternate their operation between the setting and the landing as the landing was the main source of longer logs. This did not adversely affect productivity.

The crew finished skidding the setting boundary but did not have enough time to break down the landing pile completely. Also, because the skidder had slightly higher productivity than the logging truck, there were some logs left over that had been skidded but not loaded. Time records were kept on all machines. All logs hauled away from the test site were scaled and their species identified.

b. Material Recovered During Trial

Each truckload of biomass recovered was transported to an abandoned sortyard, unloaded and scaled (Figure 4). The scaling data was categorized by diameter and length classes in pieces, volume and species. Summary results are given in Tables A1 to A3 (Appendix).

In the nine days of trials, 1 708 pieces or 730.07 m^3 were recovered and loaded from the test area. A significant proportion of the pieces and volume were larger logs (3.7+ m length, 25+ cm diameter). The majority of these logs came from the landing pile. Cedar and hemlock were the main species recovered and the fir recovered was mainly in the largest size class (67%).

c. Material Remaining After Trial

All pieces in the test area that had an estimated top diameter greater than 10 cm or were longer than 2.4 m were scaled after the trial (Figure 5). In addition, any pieces that were shorter than 2.4 m but had significant volume because of diameter size were included in the waste survey. Their volume was estimated by counting pieces and multiplying by a piece average which had been determined by sample scaling a number of chunks. Summaries of the number of pieces and the volume (m^3), by diameter and length class, in the waste survey are given in Tables A4 and A5 (Appendix).

The waste survey also identified the location of the waste in the test area. Locations were classified as unrecovered in the setting, unrecovered in the landing and recovered at roadside but not loaded onto truck. Table A6 (Appendix) is a summary of the results.

d. Total Material Available

The total material available in the roadside strip and landing area of 0.47 ha (Table 1) was calculated from the scaling information on the truckloads and the waste survey.

These volumes of material did not exist throughout the setting. The material in the landing pile was accumulated from the whole setting and as mentioned earlier in the report, the cable yarding process tends to build up residue on a strip along the road. However, in an area of 0.47 ha that included a roadside strip 30 by 180 m and a logging landing, there were 938.9 m^3 (2 856 pieces) of material suitable for pulp chips or hog fuel.

e. Skidder Productivity

The time distribution for the skidder is given in Table 2. The time distribution was also categorized as to whether the skidder was recovering material from the setting or the landing and this is given in Table 3. Field observations were substantiated by the time elements in Table 3, particularly "pull mainline and hook-up chokers" for the setting and "drag logs" for the landing pile. Uphill terrain and the distance of the material from the skidder made this time element longer for recovery along the road. However, it took longer to drag the logs once they were hooked up when recovering from the landing pile because the logs were interwoven and required more winching effort to break them apart. A heavier, more powerful skidder may have reduced this time but would have added to costs. Overall, the skidder size was considered adequate for the job.

The scaling information and time results were combined to calculate the skidder's productivity

Fig. 4 Recovered material ready for scaling

Fig. 5 Test area after recovery

(Table 4).

Field observations of the skidder and crew indicate that it would be difficult to improve on the productivity shown in Table 4 given the terrain, piece average, volume per hectare and logging system.

f. Logging Truck Productivity

The elements of the logging truck's duty cycle were measured and are shown in Table 5. The transport time element is the most significant one and is controlled by the hauling distance (64 km round trip). It was observed that the loading time is directly influenced by availability of long logs. Also, the diameter of some logs exceeded the capacity of the grapple and a wire strap was used to load them. In some instances, the weight of a log exceeded the lifting capacity of the loader and it was bucked into smaller pieces.

Using the scaling information and load count, the load size was calculated (Table 6). Two different self-loading trucks were used during the trials. The main difference between them was the minimum adjustable distance between the bunks on the trailers (6.1 m versus 4.9 m) and the operator of the truck with the 6.1 m distance complained more about the lack of longer logs. The inside width and height of the bunks were identical (2.45 m X 2 m). The trailers normally can carry 28 m^3 when transporting sawmill quality logs. The effect of shorter and smaller diameter logs can be seen as the load average on these trials was only 20.3 m^3.

g. Fuel Consumption

Records were kept of the fuel consumption for the skidder and logging trucks. The skidder consumed 513 L of diesel or 0.67 L/m^3 of material skidded. The logging trucks consumed 1319 L of diesel or 1.81 L/m^3 of material transported.

h. Estimated Operating Cost of the Existing System

The equipment and crew were paid according to standard rates in the area. That is, the trucks and drivers were paid a portal-to-portal time of 10 hours even though they only transported logs for 8 hours and the skidder crew was paid 8 hours operating and 1 hour travelling per shift. Consequently, the costs reported in Table 7 are real costs.

Mainly because of differences in distances between the test sites and the sortyard, the costs in Table 7 should be adjusted so that the four systems can be compared directly. Other factors, such as the amount of adverse grade, road condition, braking capacity, weight on driving wheels, etc. also influenced the truck cycle time. However, it is felt that if the travel times of the container truck, which was the most similar to the self-loading logging truck, are substituted for the self-loading logging truck's travel times, then direct cost comparisons between systems can be made. Table 8 shows the adjusted costs. Substituting the container truck's travel time of 0.78 hours/load for the self-loading truck's travel time of 1.05 hours/load reduced daily truck time for 10 hours to 9 hours and costs by $65 per day.

Using the rule of thumb that a cubic metre of solid wood converts to 2 m^3 of hogged fuel, then it will cost $7.76/$m^3$ of hog fuel for recovery and transport. This is not economically attractive under conditions prevailing in the fall of 1983 on the coast of B.C.

If the transport distance increases from those in the field trials (32 km one way) or the industry returns from intermediate to close utilization standards for logging, then the cost of the conventional system will increase even more.

Integrated Systems

a. Test Conditions

The terrain, timber types (cedar-hemlock predominantly) and stand density in the test area for the new systems were representative of average British Columbia coastal conditions. Two adjacent logging landings were used for the trials. Conditions between landings varied significantly.

Yarding in the lower landing had started three weeks earlier and a large landing pile had accumulated. The demolition trailer and four-bunk trailer could not be turned around in the lower landing and had to be backed in the 0.5 km from a junction. This increased cycle time. However, the container truck could turn around in the landing and drove directly into the lower landing. The yarder was set across the landing. This meant that the trailers could only be loaded over the end which resulted in smaller loads than if the trailer was placed alongside the loader.

Yarding in the upper landing started the same time as the trial. Consequently, there was no landing pile and there was little build-up during the trials. The road from the junction to the upper landing was steep (maximum pitch was 14%) and on three occasions the truck and trailer had to be towed by a prime logging truck. Initially the landing was very small and the trailer had to be swung around by lifting it with the log loader. Also, the cab on the trailer tractor was unprotected and initially the loader operator requested that we detach the tractor from the trailer and move the tractor away to prevent damage. Both these factors increased cycle time for the four-bunk trailer. However, after four days of trial the landing was widened enough that the trailer could be turned around and backed alongside the loader without assistance. Also, the loader operator had gained enough confidence that he loaded the trailer with the tractor attached. The yarder was set up parallel to the road in the upper landing so that the trailer could be loaded beside the loader. This permitted larger loads because the trailer could be moved and this increased the effective reach of the log loader.

In both landings our trailer had to wait if a prime logging truck was in the landing when it arrived or if a prime logging truck arrived while it was being loaded (unless the load was complete), adding to the delay time.

The container system encountered fewer problems than the trailer systems. The truck could be turned easily, it only took about three minutes to pick up a loaded container or drop an empty one, the container took less space in the landing and containers could be juggled between the two landings to ensure a container was on the landing which had material. However, the container was small and it was difficult to get an adequate load. Also, because of the tailgate there was always a void in the back third of the container.

All three types of units added to the congestion in the landing but did not adversely affect yarder or loader productivity. The loader operators had to use more judgement as to where and how they stockpiled logs for the prime logging trucks. Both loader operators preferred the container system because it took up less space in the landing, was easier to load and was available for loading for a longer period.

During the test one person timed the operation and dispatched the units into the landing. Two other people scaled the recovered material in the abandoned sortyard, 14.9 km from the test area. A waste survey was not practical and was not conducted.

b. Highboy Trailer with Four Bunks (System I)

Two trailers with different spacing of the stakes along the trailer and one with and one without a wooden deck were used (Fig. 6). Neither of these differences affected load size or cycle time, although the loader operator in the softyard found one easier to unload because of the spacing of the bunks. The overall dimensions of the trailers were as follows:

i. trailer length = 12.1 m
ii. bunk width inside = 2.15 m
iii. stake height = 1.9 m

The scaling results for the loads are summarized in Tables 9 and 10.

The majority of the pieces recovered were long length, large diameter cedar and hemlock logs (25+ cm diameter, 3.7+ m length). Because it is low grade, this material would normally have gone into the landing pile.

The duty cycle of this system was measured and the results are presented in Table 11.

The most significant time element was the delay time and it primarily consisted of waiting for the prime logging truck to be loaded. On an operational basis this delay could be reduced by servicing more landings and dispatching into the landings with material available but without a prime logging truck being loaded.

The timing and scaling results were combined to calculate productivity and costs (Table 12).

Fig. 6 Highway trailer with four bunks

This cost is lower than the existing system.

The fuel consumed transporting the material from the landing to the scaling area was 72.8 L of diesel or 1.29 L/m3 of material recovered.

c. Demolition Trailer (System II)

The four-bunk trailer was replaced by a demolition trailer (Fig. 7) but the same truck was used. The same landings and loading configurations and methods were used as in the previous tests. The inside measurements of the demolition trailer were 1.3 m high by 2.1 m wide by 8 m long. The trailer had an upwards sloping lip at the back that was designed to retain material. The demolition trailer was self-unloading which reduced system costs and unloading time. An 8-day trial was intended for this system but the trailer was too heavy for the tractor and the trailer was discontinued after two days. The results of this very limited trial are given in Tables 13 to 16.

As with the four-bunk trailer, the larger diameter, longer logs formed a significant proportion of the volume and pieces of material recovered. The results of time measurements on the demolition trailer (System II) are given in Table 15.

This cost is lower than the existing system and the four-bunk trailer system (System I). It is unfortunate that the field trials were not longer so more confidence could be placed in the results.

The fuel consumption on the 29.7 km round trip averaged 28 L of diesel per load or 196 L total. This converts to 1.76 L/m^3 of material recovered.

d. Container System (System III)

A tractor and two containers (Fig. 8) were used to test this system. The material was collected from the same two landings used in the tests on the four-bunk trailer and demolition trailer. The

Fig. 7 Demolition trailer

Fig. 8 Waste container and tractor

inside measurements of the containers used were of 6 m long by 2.35 m wide by 2.15 m high. The procedure used with the containers was to pick up a full container in the landing, transport it to the sortyard (29.7 km round trip), dump the contents for scaling, transport and empty container back to the landing, drop it in the landing and then go to the second landing and repeat the process. Sometimes a landing would not have enough material while the other one had an abundance. In these cases, the empty container would be dropped in the landing where the full one was recovered. However, because of confined landings it was necessary to move the empty and full containers to the road junction to achieve the exchange. This increased the travel portion of the cycle time but reduced delay time. On occasion, a container would not be full when the tractor arrived in the landing and delay time would occur.

Tables 17 and 18 give the scale results of the material recovered by the container system. Compared with the four-bunk (System I) and demolition trailers (System II), the container system had a much higher percentage of smaller pieces. The piece average of the material was 0.34 m^3/piece as compared to 0.68 and 0.69 m3/piece, respectively.

The results of the timing study on the container system are shown in Table 19. The container system had the lowest cycle time and delay time of the three new systems tested. If a third landing had been used, then the delay time could have been reduced.

Table 20 shows the cost and productivity of the container system. The container system had the lowest cycle time and delay time of the three systems but it also had the lowest load size. This offsets the advantages and resulted in a recovery cost that was higher than for the four-bunk or demolition trailer.

The tailgate on the containers was the main cause of the lower load size. First, it blocked the loader operator's view and he was unable to place the material in the container to minimize voids and maximize load size. Second, the tailgate prevented efficient use of overhang to increase load size. Any logs that overhung the container created a void which reduced the load. Containers used on an operation to recover waste wood should not have tailgates.

COMPARISON OF SYSTEMS

The costs and productivities of the four systems tested are shown in Table 21.

a. Existing System

The conventional system of a combination of a skidder and self-loading logging truck had a productivity of 79.8 m^3/shift and a cost of \$16.33/m^3 when recovering biomass along the roadside strip and in the landing pile. When costs were adjusted to reflect different hauling distances, this cost reduced to \$15.51/m^3. The recovery standard was a 10 cm diameter top and 2.4 m length. At present these costs are too high if the material is used as raw material for hogged fuel and sold at market value. However, the oil replacement value of hog fuel is considerably higher and exceeds the recovery and transport costs.

Given the terrain, volume of material per hectare, piece size and system, it would be difficult to increase skidder productivity beyond the 223.7 pieces or 81.9 m^3 recovered per eight hour shift. Also, if the travel distance was increased beyond the 64 km per round trip in this test, then truck operating cost would increase.

In the 0.47 hectare test area (0.41 ha setting, 0.06 ha landing pile) 730.07 m^3 and 1 708 pieces were recovered. Most of the volume was in material greater than 25 cm in diameter and 3.7 m in length but the majority of the pieces were chunks less than 2.4 m in length. A waste survey at the end of the field trials established that an additional 1 148 pieces and 208.81 m^3 were available but not recovered.

Although not documented, it was obvious during the field trials that much more larger-diameter, longer material was in the landing pile than the 30 m strip adjacent to the road.

A total of 1 832 L of diesel was used to skid, load and transport the biomass recovered during this trial. This can be separated into 0.67 L/m^3 of material skidded and 1.81 L/m^3 of material loaded and transported.

b. Integrated Systems

The integrated systems interfaced directly with active logging and the biomass recovery standard was that of active logging (15 cm diameter top, 3 m length, no pulp grades). The material loaded onto the test units was primarily material that met size specifications but not grade specifications or had broken or shattered during yarding. Consequently, the size of material recovered with two of the new systems was larger. The exception was the container system and its tailgate restricted the number of longer pieces that could be put on a load.

Although the productivity of the integrated systems was less than the conventional system, the cost per cubic metre of material recovered was considerably lower (41 to 44%) and this is significant if roadside biomass is going to be used as a source of hog fuel. The main reason for lower costs was the lack of a skidder and crew. The existing yarder and log loader was utilized without affecting productivity of their prime logging functions. The integrated systems hold more potential for recovery and transport of roadside biomass than the conventional system.

The container system (System III) had the lowest cycle time and delay time of the integrated systems, and also took up less space and caused the least disruption in the landings. Its load capacity was less than the other units and this increased its cost. However, changes in design and size of the container can overcome this. The feature of being able to detach the container from the truck and service several landings with one truck is an advantage.

With the four-bunk and (System I) and demolition trailers (System II), the placement of the trailer in relation to the loader had a significant effect on load size. When the trailer was alongside the loader and could be moved, then larger loads resulted. The load size on the container system was affected more by the container's tailgate and size.

The main delay element for the four-bunk and demolition trailers was "wait for prime logging truck to be loaded," whereas it was "wait for logs" with the container system. The latter delay element can be reduced by using more containers and servicing more landings. However, the former delay element will be more difficult to reduce.

FUTURE DEVELOPMENT AND TESTING

The container system (System III) has the greatest potential of the three integrated systems tested for recovering roadside biomass at a reasonable cost. The main benefits of the container system are the ability to service several landings with one truck, the quick pick-up and drop-off time, the ability to load the container for a longer period of time, and the reduced interdependence on active logging operations. Conventional equipment was used during the trials and this adversely affected load size and recovery costs. However, if an off-highway size truck with larger containers is used, the load size and recovery costs will be more attractive and the system has good potential for acceptance by industry. We recommended that the container system be developed further. Changes should be made in container design and size, and truck capacity and configuration. A further field test should be carried out on the improved container systems so the system can advance to the preproduction stage and costs and productivities determined.

Appendix 1

Table 1. Volume of Material Available in Test Area

	Volume (m^3)	Pieces	m^3 /Piece
Material Loaded	730.07	1 708	0.43
Waste Survey	208.80	1 148	0.18
Total Available	938.87	2 856	0.33
Total Test Area		0.47 ha	

Table 2. Total Distribution of Time Expenditure for Skidder

Time Element	% of Total Time	
Pull Line & Hook-up Chokers	34.7	
Skid Logs	17.0	
Unhook Chokers	9.8	
Return Travel/Maneuver	17.1	
Productive Time		78.6
Operating Delays	9.0	
Total Operating Time		87.6
Service Time	2.2	
Personal Delays	10.2	
Total Time		100.0

Table 3. Distribution of Productive Time for Skidder

Time Element	% of Productive Time	
	Landing Pile	Setting
Pull Mainline & Hook-up Chokers	40.4	49.2
Drag Logs	24.3	17.9
Unhook Chokers	12.1	13.0
Return Travel/Maneuver	23.1	19.9
Productive Time	100.0	100.0

Table 4. Skidder Productivity—Existing System

	Pieces	m³
Material Skidded & Loaded	1 708	730.07
Material Skidded but not Loaded	381	34.67
Total Material Skidded	2 089	764.74
	Hours	**%**
Total Time of Field Trial	74.7	100
Operating Hours	65.4	87.6
Productive Hours	58.7	78.6
Number of Shifts (Shift = 8 Hours)	9.34	
Productivity	**Pieces**	**m³**
Per Operating Hour	31.9	11.7
Per Productive Hour	35.6	13.0
Per Shift	223.7	81.9

Table 5. Truck Cycle Time—Existing System

Time Element	Hours /Load	Time (Hours)	%
Travel Empty	0.51	18.3	25
Load Logs	0.71	25.6	35
Travel Loaded	0.54	19.4	27
Unload Logs	0.23	8.2	11
Delay	0.05	1.7	2
Total	2.04	73.2	100
Loads		36	

Table 6. Truck Load Size—Existing System

Number of Loads	36
Volume Transported (m³)	730.07
Pieces Transported (Pieces)	1 708
Volume/Load (m³)	20.3
Pieces/Load	47.4

Table 7. Estimated Operating Cost of Existing Skidder and Self-loading Truck System

Item	Cost/Shift
Log Truck & Driver	$650
Skidder	$285
Skidder Operator	$174
Chokerman	$174
Chainsaw Rental	$ 20
Total Cost	$1 303
Volume Recovered/Shift (m^3)	79.8
Cost/m^3	$16.33

Table 8. Adjusted Operating Cost of Existing Skidder and Self-loading Truck System

Item	Cost/Shift
Log Truck & Driver	$585
Skidder	$285
Skidder Operator	$174
Chokerman	$174
Chainsaw Rental	$ 20
Total Cost	$1 238
Volume Recovered/Shift (m^3)	79.8
Cost/m^3	$15.51

Table 9. Length and Diameter Distribution of Pieces Recovered by System I. (Percentage of Total)

Diameter Class (cm)		Length Class (m)				Total	
		0-2.3	2.4-2.9	3.0-3.6	3.7+	%	Pieces
0-9		—	—	—	2	2	21
10-14		—	1	1	6	8	69
15-19		1	1	2	10	14	113
20-24		2	1	2	11	16	137
25+		6	4	6	44	60	489
Total	%	9	7	11	73	100	—
	Pieces	76	52	92	609	—	829

Table 10. Length and Diameter Distribution of Volume Recovered by System I. (Percentage of Total)

Diameter Class (cm)		Length Class (m)				Total	
		0-2.3	2.4-2.9	3.0-3.6	3.7+	%	Volume (m³)
0-9		—	—	—	—	—	1.88
10-14		—	—	—	2	2	8.63
15-19		—	1	—	3	4	24.76
20-24		—	—	1	6	7	39.60
25+		2	2	5	77	87	491.90
Total	%	2	3	6	88	100	—
	Volume (m³)	15.86	18.49	35.78	496.16	—	566.77

Table 11. Total Distribution of Time Expenditures — Four-bunk Trailer (System I)

No. of Operating Days = 9
No. of Loads = 26

Time Element	Time (Hours)	Hours /Load	%
Travel Empty	14.2	0.55	21
Load Logs	17.8	0.68	26
Travel Loaded	12.8	0.49	19
Unload Logs	5.1	0.20	8
Delay	18.0	0.69	26
Total	67.9	2.61	100

Type of Delay	Number of Events	Time (Hours)	%
No Logs Available	3	2.9	16
Wait for Prime Log Truck to be Loaded	13	9.4	52
Wait for Log Loader	5	2.1	12
Yarding Crew Lunch	3	1.1	6
Wait for Tow or Assistance	2	1.8	10
Total	27	18.0	100

Table 12. Productivity and Costs — Four-bunk Trailer (System I)

Number of Loads	26
Number of Shifts (Shift = 8 Hours)	8.5
Volume Recovered (m^3)	565.77
Pieces Recovered	829
Volume/Load	21.8
Pieces/Load	31.9
Loads/Shift	3.1
Volume/Shift	66.6
Pieces/Shift	97.5
Cost/Shift	
Log Truck & Driver	$550
Chainsaw Rental	$ 20
Front-end Loader*	$ 42
Total	$612
Cost/m^3	$9.19

* $42 = $65/Hour X 8 Hours X 8%.

Table 13. Length and Diameter Distribution of Pieces Recovered by System II (Percentage of Total)

Diameter Class (cm)		Length Class (m) 0-2.3	2.4-2.9	3.0-3.6	3.7+	Total %	Pieces
0-9		1	—	—	2	3	5
10-14		2	2	1	5	10	17
15-19		4	—	3	10	17	27
20-24		2	1	1	12	16	25
25+		6	4	4	40	54	88
Total	%	15	7	9	69	100	—
	Pieces	25	12	14	111	—	162

Table 14. Log Diameter and Length Distribution of Volume Recovered by System II

Diameter Class (cm)		Length Class (m)				Total	
		0-2.3	2.4-2.9	3.0-3.6	3.7+	%	Volume (m^3)
0-9		—	—	—	—	—	0.35
10-14		—	—	—	2	2	2.53
15-19		—	—	—	3	3	3.58
20-24		—	—	—	5	5	5.99
25+		1	3	9	76	89	98.63
Total	%	1	3	9	86	100	—
	Volume (m^3)	2.15	3.64	10.04	95.25	—	111.08

Table 15. Total Distribution of Time Expenditures — Demolition Trailer (System II)

No. of Operating Days = 2
No. of Loads = 7

Time Element	Time (Hours)	Hours /Load	%
Travel Empty	4.4	0.63	31
Load Logs	2.4	0.34	17
Travel Loaded	3.4	0.49	24
Unload Logs	0.6	0.08	4
Delay	3.4	0.49	24
Total	14.2	2.03	100

Type of Delay	Number of Events	Time (Hours)	%
Wait for Prime Log Truck to be Loaded	5	2.0	59
Yarding Crew Lunch	2	1.2	35
Wait Loader	1	0.2	6
Total	8	3.4	100

Table 16 shows the cost of the demolition trailer system.

Table 16. Productivity and Cost — Demolition Trailer (System II)

Number of Loads	7
Number of Shifts (Shift = 8 Hours)	1.8
Volume Recovered	111.07
Pieces Recovered	162
Volume/Load	15.87
Pieces/Load	23.14
Loads/Shift	3.9
Volume/Shift	61.7
Pieces/Shift	90
Cost/Shift	
Truck & Driver	$550
Chainsaw Rental	$ 20
Total	$570
$Cost/m^3$	$9.24

Table 17. Length and Diameter Distribution of Pieces Recovered by System III (Percentage of Total)

Diameter Class (cm)		Length Class (m)				Total	
		0-2.3	2.4-2.9	3.0-3.6	3.7+	%	Pieces
0-9		—	—	1	2	3	32
10-14		1	2	1	4	8	104
15-19		4	2	3	6	15	183
20-24		5	3	3	7	18	219
25+		20	5	7	24	56	698
Total	%	30	12	15	43	100	—
	Pieces	373	149	181	533	—	1 236

Table 19. Total Distribution of Time Expenditures — Container System (System III)

No. of Operating Days = 8
No. of Loads = 39

Time Element	Time (Hours)	Hours /Load	%
Travel Empty	15.1	0.39	26
Load Logs	13.7	0.35	23
Travel Loaded	15.3	0.39	26
Unload Logs	3.2	0.08	5
Delay	12.1	0.31	20
Total	59.4	1.52	100

Type of Delay	Number of Events	Time (Hours)	%
Wait for Logs	9	6.8	56
Wait for Room in Landing	4	2.7	22
Wait for Loader	1	2.2	18
Flat Tire	2	0.3	2
Maintenance	1	0.1	1
Total	17	12.1	100

Table 18. Length and Diameter Distribution of Volume Recovered by System III (Percentage of Total)

Diameter Class (cm)		Length Class (m)				Total	
		0-2.3	2.4-2.9	3.0-3.6	3.7+	%	Volume (m³)
0-9		—	—	—	—	—	2.71
10-14		—	—	—	1	1	7.21
15-19		1	1	1	3	6	19.87
20-24		1	1	1	5	8	34.52
25+		12	5	10	58	85	360.70
Total	%	14	7	12	67	100	—
	Volume (m³)	58.29	28.95	53.48	284.29	—	425.01

Table 20. Productivity and Cost — Container System (System III)

Number of Loads	39
Number of Shifts (Shift = 8 Hours)	7.43
Volume Recovered	425.01
Pieces Recovered	1 236
Volume/Load	10.9
Pieces/Load	31.7
Loads/Shift	5.25
Volume/Shift	57.2
Pieces/Shift	166.4
Cost/Shift	
Truck & Driver	$550
Total	$550
$Cost/m^3$	$9.62

Table 21. Cost and Productivity Summary

Item	Existing	Integrated Systems		
	Self-loading Truck	Four-bunk Trailer	Demolition Trailer	Containers
Number of Days	9	9	2	8
Number of Loads	36	26	7	39
% Delays	2	26	24	20
Size of Load (m^3)	20.3	21.8	15.9	10.9
Piece Size (m^3/Piece)	0.43	0.68	0.69	0.34
Time per Load (Hours)	2.04	2.61	2.03	1.52
Production/Shift (m^3)	79.8	66.6	61.7	57.2
$Cost/m^3$ Recovered	$15.51	$9.19	$9.24	$9.62

Appendix 2

Table A1. Length and diameter distribution of pieces of biomass recovered by the existing system (Percentage of total)

Diameter Class (cm)		Length Class (m)				Total	
		0-2.3	2.4-2.9	3.0-3.6	3.7+	%	Pieces
0-9		2	1	1	3	7	111
10-14		3	2	2	6	13	222
15-19		4	3	3	8	18	307
20-24		3	3	3	8	17	301
25+		10	5	7	23	45	767
Total	%	22	14	16	48	100	—
	Pieces	377	241	272	818	—	1 708

Table A2. Length and diameter distribution of volume recovered by the existing system (Percentage of total)

Diameter Class (cm)		Length Class (m)				Total	
		0-2.3	2.4-2.9	3.0-3.6	3.7+	%	Volume (m^3)
0-9		—	—	—	1	1	4.93
10-14		—	—	—	2	2	16.09
15-19		1	1	1	2	5	37.13
20-24		1	1	1	5	8	59.69
25+		6	6	10	62	84	612.23
Total	%	8	8	12	72	100	—
	Volume (m^3)	55.01	54.16	94.11	526.79	—	730.07

Table A3. Species distribution of biomass recovered by the existing system

Species	Pieces	%	Volume (m^3)	%
Balsam	146	9	24.08	3
Cedar	952	56	334.03	46
Fir	120	7	159.25	22
Hemlock	483	28	211.17	29
Other	7	—	1.54	—
Total	1 708	100	730.07	100

Table A4. Length and diameter distribution of pieces remaining after test of existing system (Percentage of total)

Diameter Class (cm)		Length Class (m)				Total	
		0-2.3	2.4-2.9	3.0-3.6	3.7+	%	Pieces
0-9		1	—	—	1	2	27
10-14		3	3	2	3	11	122
15-19		3	3	1	1	8	97
20-24		3	2	2	1	8	96
25+		6	3	2	4	15	164
Chunks		56	—	—	—	56	642
Total	%	72	11	7	10	100	—
	Pieces	829	130	79	110	—	1 148

Table A5. Length and diameter distribution of volume remaining after test of existing system (Percentage of total)

Diameter Class (cm)		Length Class (m)				Total	
		0-2.3	2.4-2.9	3.0-3.6	3.7+	%	Volume (m³)
0-9		—	—	—	—	—	1.18
10-14		—	1	—	1	2	5.88
15-19		1	1	1	1	4	7.85
20-24		2	1	1	2	6	11.50
25+		9	6	7	38	60	124.25
Chunks		28	—	—	—	28	58.14
Total	%	40	9	9	42	100	—
	Volume (m³)	83.81	19.47	18.43	87.09	—	208.80

Table A6. Summary of waste survey by location

Location	Average Volume (m³)	Pieces	%	Volume (m³)	%
Unrecovered in the Setting	0.10	269	23	27.57	13
Unrecovered in the Landing Pile	0.29	498	43	146.57	70
Recovered but not Loaded Onto Truck	0.91	381	34	34.66	17
Total	0.18	1 148	100	208.80	100
Per Hectare	—	3 017	—	444.26	—