THE DEVELOPMENT AND TRIAL OF TWO PROTOTYPE MACHINES (RECUFOR AND LRP) FOR FOREST BIOMASS RECOVERY

by

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F O R E W O R D

This report gives an account of the development of two prototype machines (RECUFOR and LRP) aimed at recovering forest residues left on the logging site and at the roadside. FERIC's Special Projects Division had overall responsibility for this joint FERIC/ENFOR project. The firm "Logging Development Corporation (LDC)" from Montreal was contacted by FERIC to design, build and test the two prototypes.

The author's role was solely to produce this final report based on the various background documents available.

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S U M M A R Y

The energy potential of forest biomass was brought to the forefront at the end of the 1970's, during a time of increased interest in renewable energy sources. Within the framework of a FERIC/ENFOR agreement, FERIC was given the responsibility to develop a technology aiming at the recovery of logging residues and their reduction into a form compatible with conventional energy conversion systems.

The RECUFOR prototype (a mobile collecting, comminuting and transporting unit) was built in 1982 as the result of the first stage of the project. The RECUFOR was capable of doing the following:

- enter the logging site and recover, with a collecting drum, on-the-ground logging residues such as tops, branches..., on cutovers;

- comminute this material into sizes suitable for handling;

- store, transport and unload residues at roadside.

On the whole, the prototype performance during the trials established that the basic concept of recovering residues left on logging sites was technically feasible, but that the recovery costs for this type of biomass were too high to develop this machine further towards a commercial unit.

A second prototype, called the Logging Residue Processor (LRP), was then built in order to follow the change of world energy needs and Canadian logging practices that occurred in the 1980-82 period. The LRP is a self-propelled machine, which travels on logging roads recovering residues left at roadside after whole-tree delimbing operations. It is equipped with a two-stage reduction process (shearing and hammer milling), with before-and-after reduction handling facilities.

Some preliminary tests on the LRP were undertaken in 1984, and the test results indicated that a productivity level of 20 green tonnes/SMH could be reached if some modifications on the prototype were made.

I. INTRODUCTION AND BACKGROUND

The world energy situation prevailing in the 1970's prompted the Canadian government to establish programs encouraging the use of renewable sources of energy and to develop the necessary technology. Inventories carried out to assess the amount of residues left in the woods, either at the cutting site or roadside, showed these residues constituted a good potential source of renewable energy.

Forest biomass includes mill residues (sawdust, bark, liquors, etc...) and logging residues such as branches and tops. Logging residues have several disadvantages over mill residues: they are usually less accessible, they are regularly contaminated with foreign matter (soil, rocks...) and their heterogeous nature entails additional problems in their transformation. Thus, they generally constitute a more expensive form of forest biomass to exploit. However, in view of the steady increase of world oil prices (Figure 1) in the 1970's and given our limited supplies of fossil fuels, logging residues became economically more attractive and were clearly seen as a potential substitute for conventional energy.

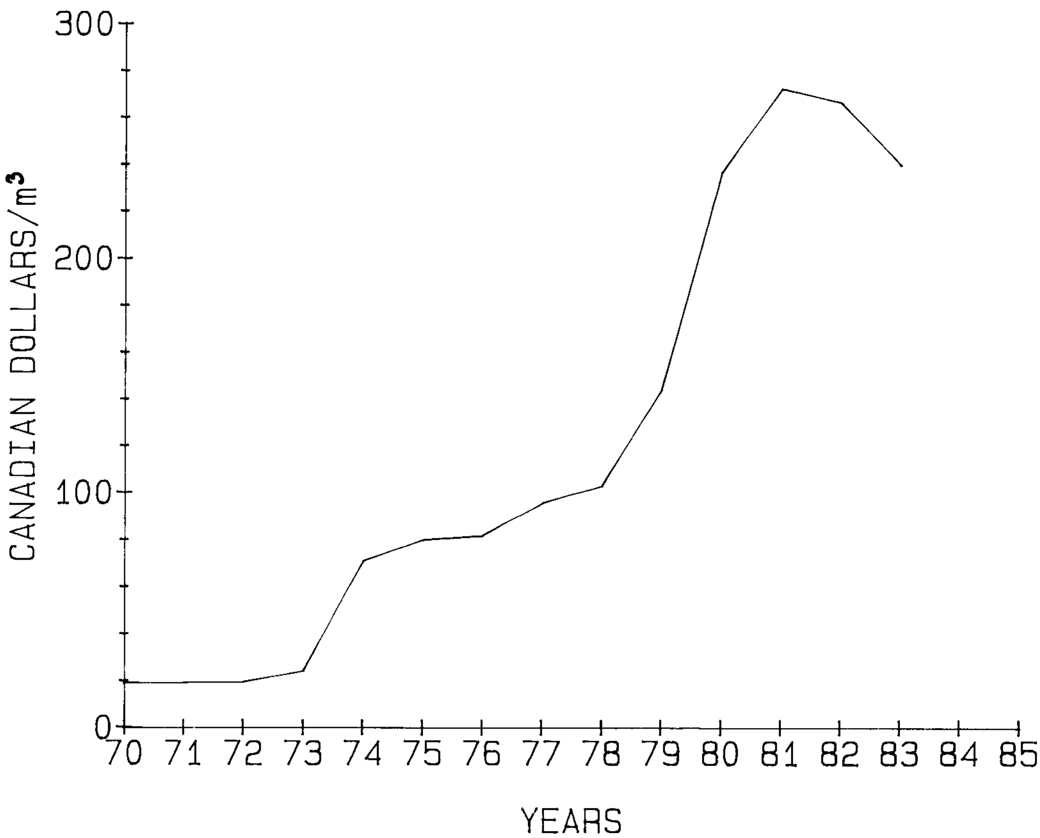

Figure 1. Averaged cost of imported crude oil in Montreal.

Location and type of logging residues available are greatly influenced by the harvesting* system used. Figure 2 presents the percentage of total roundwood production in Canada for each of the three usual harvesting systems. From 1975 to 1980, more than 80% of the total annual production was done by means of the shortwood and tree-length systems. Since both these systems leave large quantities of residues on the logging site (Table 1), priority was given to the development of technology to recuperate such residues from the cutovers.

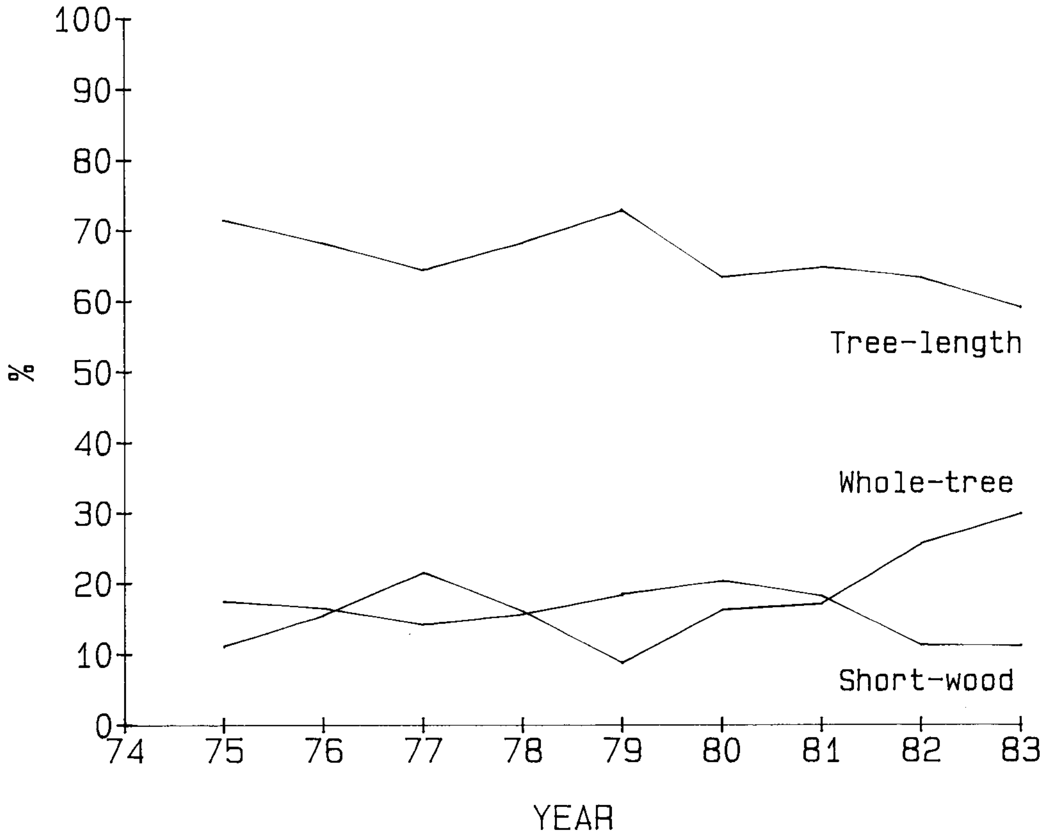

Figure 2. Percentage of total annual roundwood production in Canada for each harvesting system (C.P.P.A. 1984).

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* Harvesting systems are defined according to the degree of processing performed at the stump. In the shortwood harvesting system, the tree is cut, limbed and bucked at the stump into pre-determined lengths. In the tree-length system, the tree is cut, limbed and transported to roadside without being sectioned. In the whole-tree system, the tree is cut and transported to roadside without further processing at the stump.

Table 1. On-the-ground logging residues (o.d.t./ha) left by harvesting systems on a black spruce station (F.R.U.L. 1981).

Harvesting system	tops (t/ha)	branches (t/ha)	green stems (t/ha)	dry stems (t/ha)	total residues (t/ha)	relative proportion to full-tree
Tree-length	26.2	11.6	6.1	9.9	53.8	2.6
Shortwood	11.1	22.0	21.8	15.8	70.7	3.4
Full tree	1.2	3.2	7.9	8.4	20.7	1.0

In 1979, FERIC was mandated, under the ENFOR program, to undertake a research and development program aiming at the recovery and processing of forest biomass for energy. More specifically, FERIC was to develop an experimental machine capable of the following:

- recover on-the-ground residues like tops and branches using a collecting drum;
- reduce this material for bulk handling;
- accumulate, transport and unload the residues at roadside;
- have low energy requirements.

In March 1980, the model of a prototype was presented to ENFOR and it was decided to test the main component of the concept, i.e. the toothed drum, that summer. Test results validated the concept. FERIC subsequently undertook to design and build an experimental prototype machine. This phase was contracted to the firm "Logging Development Corporation" from Montreal. The design was completed by spring 1981 and the prototype, called the RECUFOR, was ready for field testing during the summer of 1982. On the whole the performance of this prototype conformed to expectations.

However, changes in the energy context, as well as new trends in harvesting systems appearing in the period 1981-82 (Figures 1 and 2) changed the focus of the program to the utilization and transformation of residues piled at roadsides. As the full tree system gained importance in Canada, FERIC asked LDC to design a new prototype machine that would be self-propelling, self-loading and possess a two-stage reduction process. This prototype, currently named the Logging Residue Processor (LRP), was built in 1983 and put on trial for a brief period in 1984. The results were promising and a more complete evaluation is likely to be conducted in the near future.

This report describes the different stages of development of the RECUFOR, and to a lesser extent those of the LRP, during the five-year period of 1979-84.

II. THE RECUFOR

A. First Model

1. Introduction of concept

In 1980, FERIC was presented with the model of a machine, illustrated in Figure 3, capable of gathering and comminuting logging residues and of transporting them to a landing. The collecting principle, brought forward by Mr. Armand Morin from "Les Broyeurs A.M." of Val d'Or (Quebec), consisted of two end-to-end drums equipped with long curved blades, for picking up on-the-ground residues. A chipper mounted at the rear of the drums would comminute residues collected by the drums.

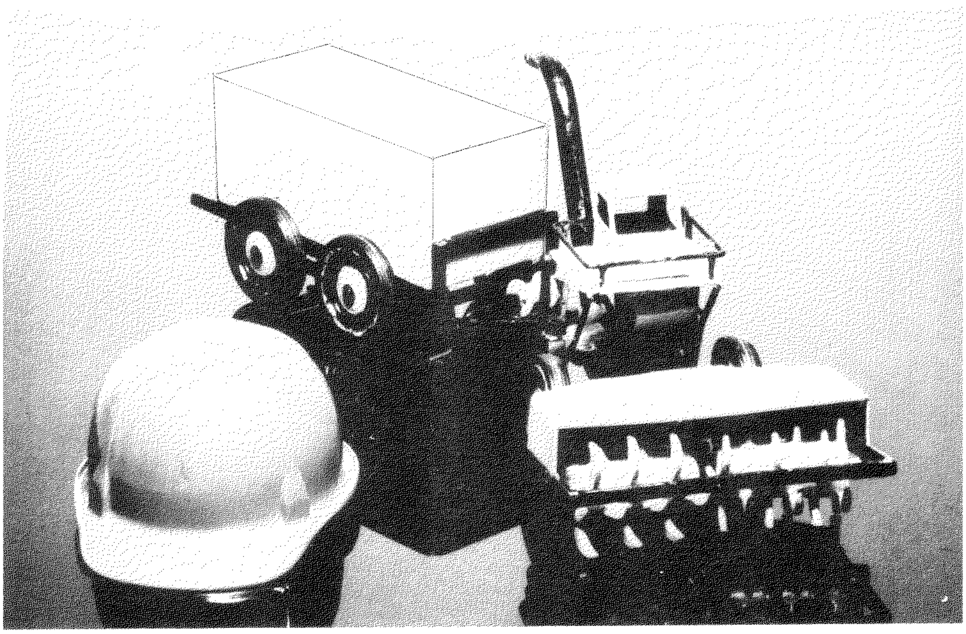

Figure 3. First model of RECUFOR.

Following the presentation of the model, it was decided to field test the collector assembly that summer and to evaluate the practicality of the gathering concept.

2. Field tests of the collecting drum

The collecting drum assembly was built by "Les Broyeurs A.M.", with technical assistance provided by LDC. The unit consisted of a single rotor equipped with 15 curved blades, spirally distributed about its circumference. A set of fixed knives was mounted behind the rotor to sever woody residues carried around by the rotor arms into 30 cm-or-so pieces. For test purposes, the rotor was mounted at the front end of a Hydro-Ax 400 loader. Because the rotor proved too heavy for the loader lifting capacity, a set of supporting wheels was added to each side of the rotor (Figure 4).

Figure 4. Field testing of collecting rotor (landing conditions).

On August 27, 1980, in Val d'Or (Quebec), a group of ENFOR and industrial representatives gathered to witness the first trials of the collecting rotor. Forest residues, consisting of tops, branches and trunks from both softwoods and hardwoods, had been spread over flat sandy terrain so as to simulate broadly logging site conditions. Trial results proved that the rotor-equipped, crescent-shaped blades collect such residues and achieve a primary reduction. The next action was to test the rotor over a real logging site before any further development would take place. The rotor was transferred to the front blade of a Terex 82-50 dozer (Figure 5). This new assembly was necessary as the rotor had to be regularly adjusted upward and downward to follow terrain irregularities and avoid large stumps found on cutovers.

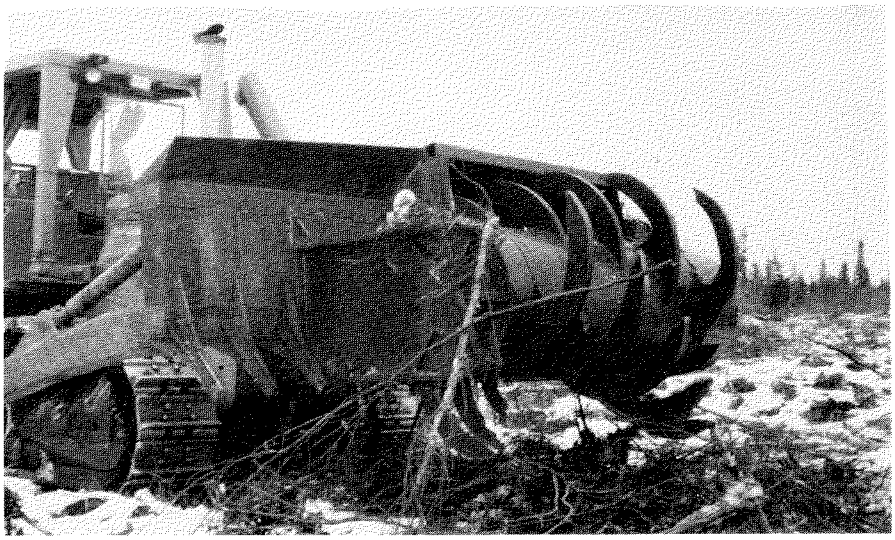

Figure 5. Collecting rotor on dozer (cutover conditions).

The second series of tests led to the following conclusions:

1. Biomass residues from a cutover could be gathered by rotating toothed drums with satisfactory efficiency.

2. Because of the random orientation and the physical characteristics of the pieces being gathered, transfer of this material from rotor to bin might present specific problems.

3. Design of transportation and storage components must reflect the low bulk density of the material collected.

It was then recommended to continue development of the RECUFOR. To this end, ENFOR Project P-210 was instituted, under which a full scale prototype was to be built and field tested. Project objectives were stated as follows:

1. Undertake a comprehensive evaluation of the collecting rotor under extensive field trials and various ground conditions.

2. Evaluate design of the main active components of the prototype and suggest corrective actions for any problem identified.

3. Determine whether the revolving action of the rotor on the ground surface would facilitate site preparation and reforestation activities.

Moreover, it was suggested that other means to use the collecting rotor than horizontally be investigated, and other practical applications for the rotor be defined.

B. Description of RECUFOR Prototype

1. Concept retained

The final concept selected differs slightly from that of the original model. It is characterized by the rotor and the conveyor mounted on the front section of the frame, the bin on the middle, and the engine on the rear section. A conventional wheeled skidder (Clark 880) was used to form the main frame of the prototype machine. The bin was inserted at the steering point, and the cabin, conveyor and rotor were mounted cantilevered over the front end (Figures 6 and 7).

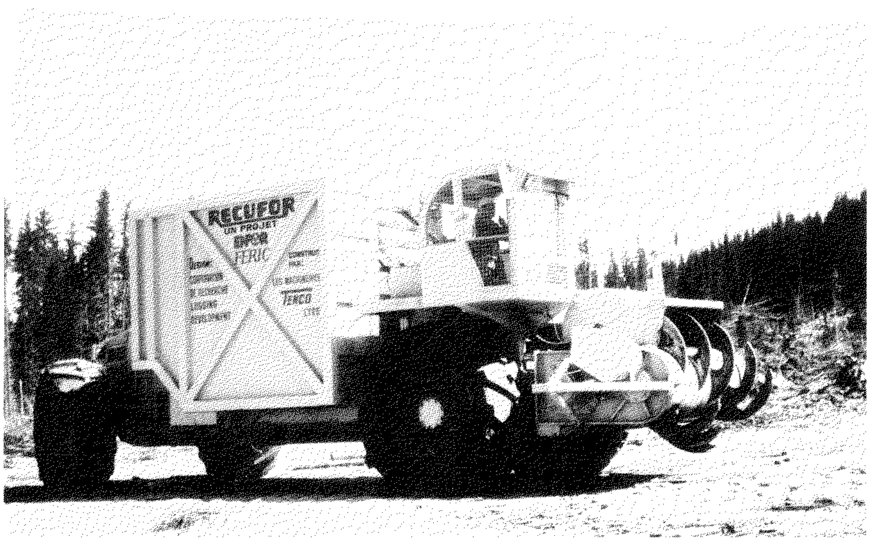

Figure 6. Sideview of RECUFOR.

The RECUFOR's collecting principle is as follows. Logging residues are picked up by the curved blades and are carried away towards the rear. As the blades reach the rear deck supporting a series of knives, residues are severed and fall on the inclined deck (Figure 8). To prevent any build up of material about the knives, a series of impellers spread out the passage of residues. After sliding down the deck, residues are caught up by the conveyor belt and transported up to the bin.

The evaluation of the original concepts, as proposed by Mr. Morin, revealed some technical problems would complicate the construction of the full prototype in its original version. Modifications to the original concept were made, and the principal changes will be found in the description of the RECUFOR following in the next sections. RECUFOR's critical components were first built and shop tested to correct any malfunctioning before final assembly.

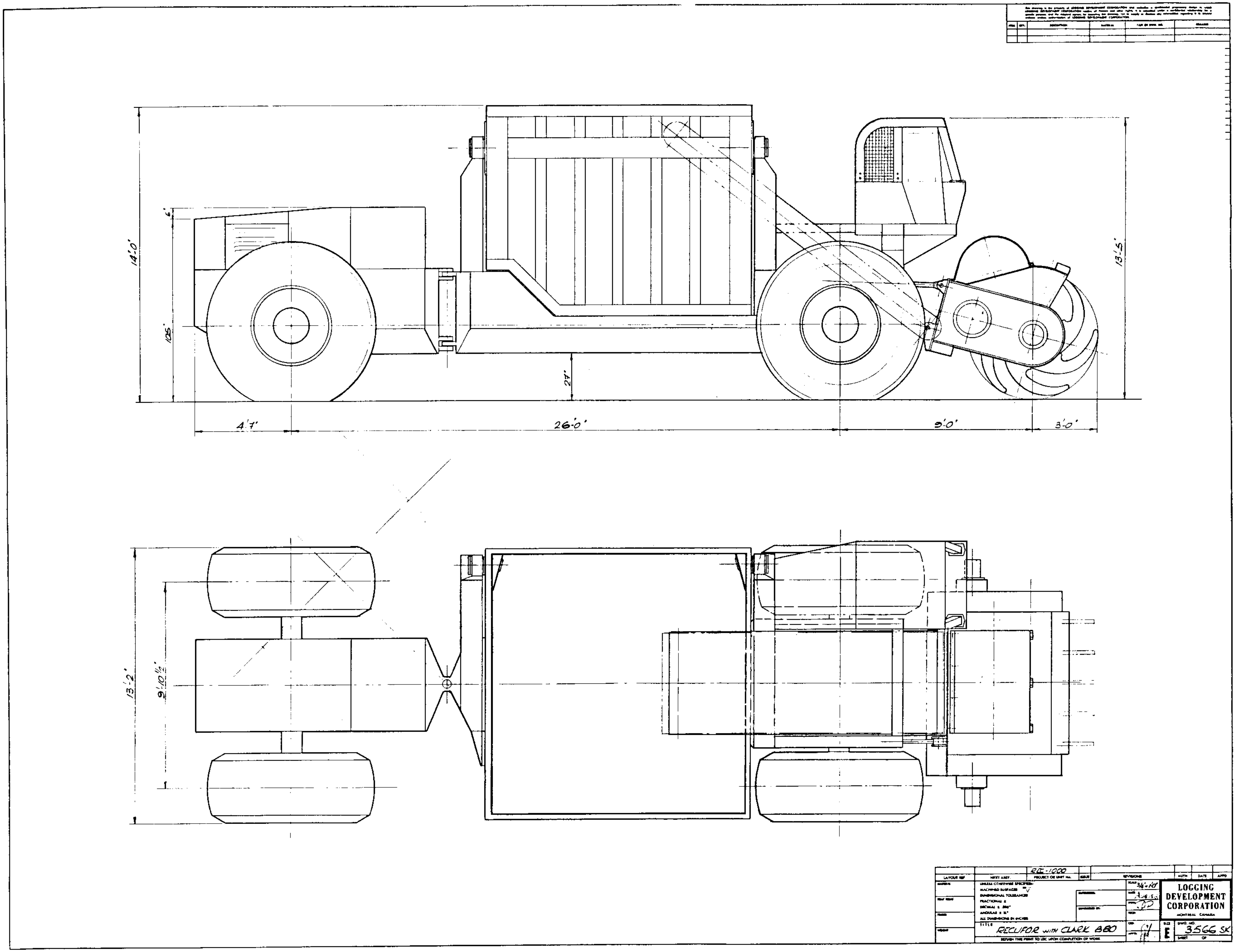

Figure 7. Design of RECUFOR.

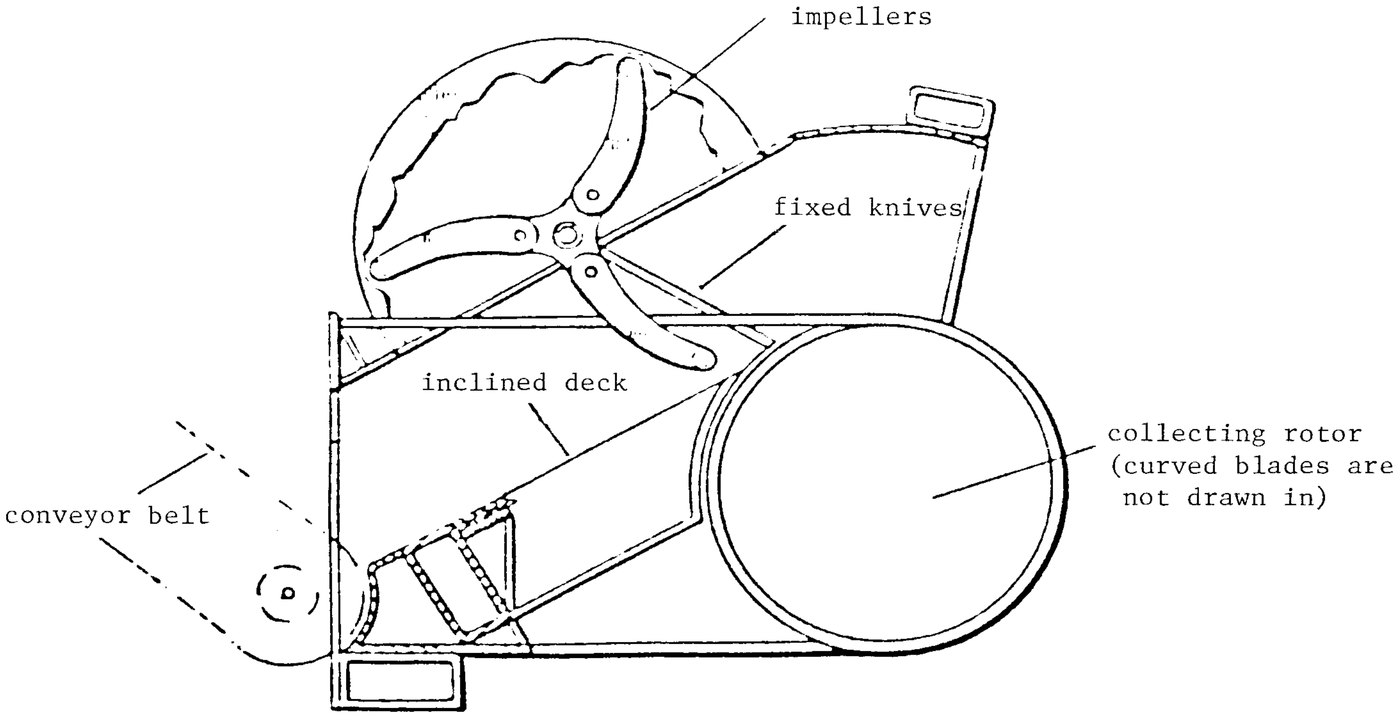

Figure 8. Rotor assembly.

2. Collecting rotor

The collecting rotor previously built was reused on the RECUFOR, mainly for economic reasons. Blade tips were bevelled and sharpened to reduce hook-ups in stumps. Figure 9 illustrates the design of the rotor. A second chain drive identical to the existing one, was added to the rotor at the other end.

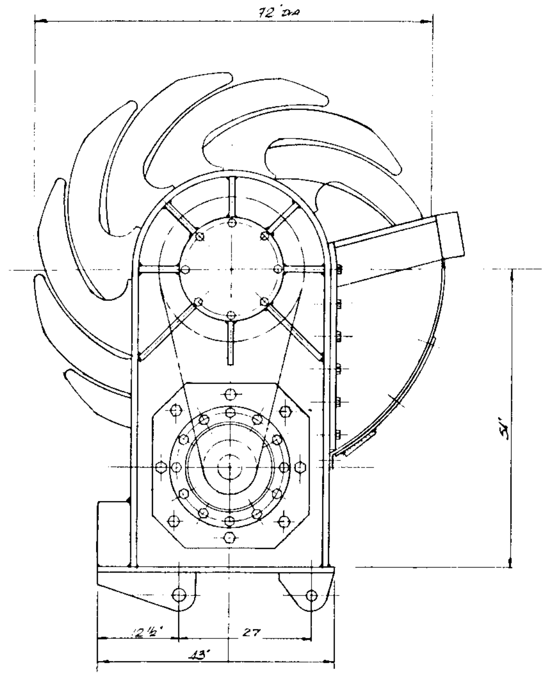

Figure 9. Design of collecting rotor.

Transfer of residues from rotor to conveyor did not turn out to be trouble free. When blades were passing through slots, residues tended to jam up the slots, causing the rotor to stop. The fixed knives were then installed at the edge of slots in such a way that each knife was paired to a blade, acting as a shear and anvil arrangement. Although this corrected one jam problem, it appeared that the sweeping force of the blades was not always sufficient to push the severed residues down the deck, hence the reason for the continual build-up. As an additional transfer mechanism became necessary, several were tested. The one which best solved the problem was the overhead impeller system with flinging arms (Figure 9).

3. Secondary reduction

Whereas the initial model proposed a chipper or a hammer mill to further comminute the material severed by the knives and blades, none was incorporated in the RECUFOR. A secondary comminution system would have increased the complexity of the machine handling system, especially for the funelling of cut residues from rotor to chipper. Power requirements would also have had to be augmented substantially. It also avoided questions relating to chip characteristics when randomly oriented pieces are fed to a chipper at this stage in the machine's development. However, in this situation the harvested residues will likely require a further reduction process before conversion to energy, adding one more stage in the handling process.

4. Bin

The bin is an integral part of the RECUFOR rather than a replaceable container as in the original concept. When loaded, the RECUFOR travels to roadside, where it dumps. The dumping arrangement is over-the-side and high enough so the material can be deposited in another container (Figure 10). This arrangement was quite satisfactory for a prototype.

5. Steering system

A frame steer system was chosen as in the original model. The hinge point, however, was placed toward the rear of the machine rather than the middle, so as to have the rotor, the conveyor and the bin on the same section. This simplified material handling from rotor to bin and allowed better weight distribution. A central hinge point would have required the construction of a whole new frame instead of using a conventional skidder as the main frame for the RECUFOR.

6. Driving system

Preliminary tests in the plant yard showed the first gear from the skidder's transmission to be too fast for its use as the prototype harvesting speed. The hydrostatic transmission powering the rotor was transferred to the drive line and a combination of auxiliary hydraulic circuits was added to power the rotor.

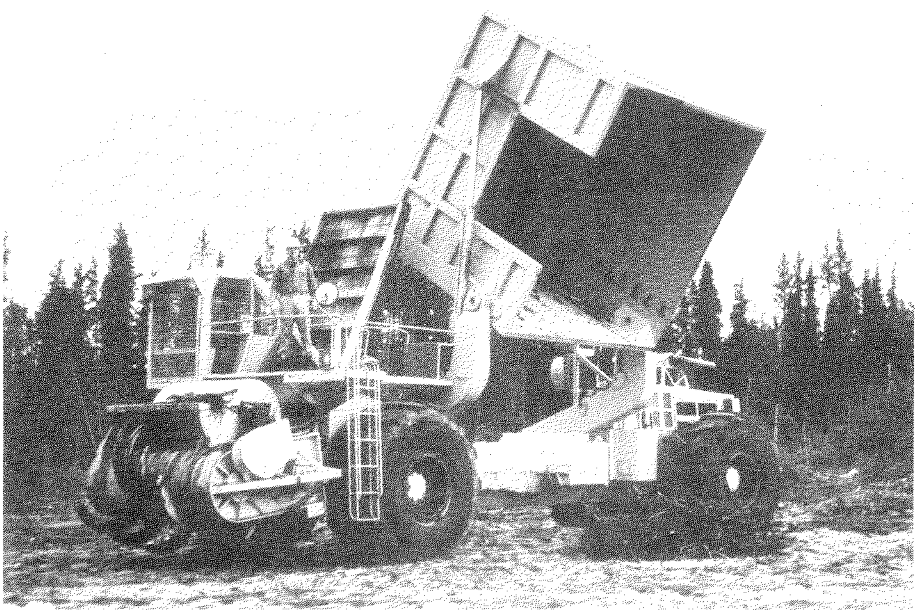

Figure 10. Over-the-side dumping of a RECUFOR load.

7. Weight

Total weight of RECUFOR was 37 750 kg, and indeed deemed excessive. Several modifications would help to reduce this weight to a more acceptable level:

1. Because of the low bulk density of collected material, design of the bin could be modified to cut its weight.

2. The main frame could be specifically designed to better meet the RECUFOR's gathering functions and requirements.

3. Hydrostatic transmissions could be used for all driving functions.

Even with a more powerful engine, it should be possible to bring down the weight of a pre-commercial unit to within the 29 000 to 30 000 kg range.

C. Evaluation of RECUFOR

The evaluation of the RECUFOR took place from July to September 1982. The test area was located on the C.I.P. Inc. (St-Maurice Division) limits near Camp Lac Elaine, approximately 200 km north of La Tuque (Quebec).

When operated for the first time, a new prototype is subject to frequent mechanical breakdowns. Therefore the first part of the trials consisted of a technical assessment of the prototype. The second part then, was a short productivity study.

1. Summary of the technical evaluation

During the first few weeks of testing, more than 80% of all technical problems encountered were linked to the hydraulic system. Many hydraulic leakages and hose ruptures were recurring at the same connecting points, indicating that some parts of the hydraulic system were inadequate and required redesign. The addition of relief valves and accumulators as temporary measures did not solve the problems. Because of this poor functioning, other parts were not operating at full capacity:

1. The collecting rotor lacked power at times for it stalled frequently.

2. The hydrostatic transmission could not transmit full power to the driving wheels: measured travel speed of RECUFOR was 0.6 km/hr whereas estimated travel speed was approximately 1.6 km/hr.

Other problems were also noted during that period and are described herein:

- appropriate manipulation of the rotor elevation was impaired by inadequate visibility. When the rotor was too high only the top portion of residues could be gathered whereas when too low, part of the organic soil was picked up, thus contaminating the woody material. Moreover the crescent-shaped blades tended to up-root stumps, which invariably stalled the rotor. The tips of the blades were then bevelled and sharpened so they could split the stumps instead of hooking them up;
- other pieces than stumps could cause this stalling of the rotor:
  . trunks with diameter larger than 20 cm,
  . trunks entering the rotor at right angle with the rotor axle would avoid being severed by the knives and jam the rotor housing;
- bin capacity was not fully used because residues transferred by the conveyor accumulated in a cone-shape manner and did not spread over as anticipated;
- capacity of the conveyor was, at times, insufficient for the amount of residues collected by the rotor. This led to system blockages which would slow down productivity.

In view of the many problems encountered, trials were interrupted in August for a thorough revision of the hydraulic system and correction of other problems relating to the driving system.

2. Summary of performance testing

Tests resumed in September '82 in the same area with the FERIC staff undertaking a short performance study, which was somewhat affected by mechanical breakdowns, although these were less frequent than before.

Test conditions

The test site consisted of a 2.2 ha cutover, harvested in the 1980-81 season with Koehring shortwood harvesters. The original stand was made of black spruce (*Picea mariana* [Mill.] B.S.P.) and jack pine (*Pinus banksiana* Lamb.), with volume averaging 90 to 130 m^3/ha and height averaging 15 to 18 m.

The ground was flat and clear of obstacles (Figure 11). Terrain was classified 1, 2, 1 according to the C.P.P.A. terrain classification (Mellgren 1980). There were no residuals or boulders; stumps were the only obstructions of note. A summary of ground conditions, based on six 50-m^2 plots (sampling intensity = 1.4%) is presented in Table 2.

Figure 11. RECUFOR operating in testing site.

Table 2. Summary of ground conditions.

SOIL CHARACTERISTICS	
Average slope (%)	0
Soil texture	sandy
Moisture regime	dry
Average humus depth (cm)	7
Average depth of parent material (cm)	30+
GROUND ROUGHNESS	
Number of stumps per hectare	800
Average stump diameter (cm)	21.4
Average stump height (cm)	25.6
Ground roughness class (%)	
10-30 cm	75
30-50 cm	21
50-70 cm	4
BRUSH	
Number of saplings per hectare	200
Average height (m)	1.8

Before the outset of performance testing, logging residues averaged 29.4 cm in depth and covered approximately 41% of the cut over. Residues were generally laid out in parallel rows, typical of Koehring shortwood operations. Table 3 provides a fuller description of pre-recovery residues, based on a 400-m^2 sample plot (sampling intensity = 1.8%).

Table 3. Description of pre-recovery residues.

RESIDUE CLASS	GREEN WEIGHT (t/ha)	%
Branches	13.1	20
Trunks	51.7	80
Total	64.8	100

Study results

During the study period, a number of criteria served as the basis for the evaluation of the RECUFOR.

a. Machine speed

Machine speed was measured in different operating conditions. All tests were conducted with an engine speed of 2600 rpm and results are presented in Table 4.

Table 4. Machine speed tests.

STATIC TEST			
Speed of rotor (rpm)			17
Speed of conveyor (rpm)			13
MOBILITY TEST			
Test conditions	Drive	Time/100 m (min)	Speed (km/hr)
Clear-cut, flat	hydrostatic	3.10	1.94
Wet sand, flat	hydrostatic	2.98	2.01
	mech. 1st gear	1.02	5.88
	mech. 2nd gear	0.63	9.52
Road, flat	hydrostatic	2.83	2.12
Road, 9% uphill slope	hydrostatic	3.32	1.81
	mech. 1st gear	1.36	4.41

b. Productivity

Table 5 gives a summary of time elements (as defined in Appendix 1) and machine productivity as well as a description of operational factors prevailing during the 3-day productivity study. A summary of delays is presented in Table 6.

Table 5. Operational factors and production.

TEST CONDITIONS	Mean	Standard Deviation
Study date	September 1982	
Terrain classification	1.2.1	
Duration of time study (PMH)	6.4	
Number of loads	8	
Travel distance empty (m)	139	35
Number of strips per load	2	0.8
Total strip length per load (m)	212	46
Travel distance loaded (m)	148	88

TIME ELEMENTS	Time per load (min)		
	Mean	Standard deviation	%
Travel empty on road	2.55	1.22	5.3
Travel empty on cutover	1.80	1.05	3.7
Collection	20.15	1.96	41.7
Move between strips	3.23	3.08	6.7
Travel loaded on cutover	2.45	1.02	5.1
Travel loaded on road	1.69	1.16	3.5
Manoeuvre	0.48	0.61	1.0
Unloading	3.53	1.77	7.3
Delays*	12.45	6.62	25.7
Total time per load	48.33	9.58	100

PRODUCTION	Mean	Standard deviation
Volume per load (m^3)	20.5	5.3
Green weight per load (tonne)	2.73	0.60
Productivity (green tonne/PMH)	3.39	

* Delays only include those between 0.05 min and 15 min. Those less than 0.05 min were included in the element in which they occurred, while those over 15 min were not considered productive time and thus excluded from the sample.

Table 6. Summary of delays.

TYPE OF DELAY	CAUSE	DELAY TIME (min)	FREQUENCY	% OF TOTAL TIME
Lifting of rotor	branches	0.32	1	0.1
	stumps	1.50	3	0.4
	unknown	9.05	16	2.3
		10.87	20	2.8
Rotor jam	branches	14.44	4	3.7
	stumps	0.21	1	0.1
	volume	7.29	38	1.9
	unknown	7.86	28	2.0
		29.80	71	7.7
Conveyor jam	branches	9.79	2	2.5
	unknown	12.57	11	3.3
		22.36	13	5.8
Mechanical	conveyor			
	blade	5.79	2	1.5
	others	11.70	5	3.0
		17.49	7	4.5
Cleaning residues		9.10	9	2.3
Operator		10.01	8	2.6
Total		99.63	128	25.7

c. Load characteristics

As indicated in Table 5, load weight averaged 2729 kg or 2.73 green tonnes of organic material. In addition, loads contained an average of 57 kg (2%) of mineral soil. Load volume averaged 20.5 m^3, with a mean density of 133 kg/m^3. Table 7 further identifies the nature of residues, and Figure 12 illustrates residues after unloading.

Table 7. Load characteristics (organic material).

TYPE OF RESIDUES	% OF TOTAL WEIGHT OF LOAD	MOISTURE CONTENT (% - DRY BASIS)
Branches	57.5	36.7
Trunks (7.5 to 17.5 cm dia.)	37.4	45.7
length <40 cm	6.2	
length >40 cm	31.2	
Trunks (17.5 + dia.)	0.2	40.8
Stumps	4.9	67.4
Total	100	41.6

Figure 12. Collected residues after unloading.

3. Discussion

Productivity of the RECUFOR prototype reached an average of only 3.39 green tonnes/PMH or 2.39 dry tonnes/PMH. Two main reasons may account for this low production rate. First, the collecting speed of the RECUFOR was much lower than expected; and second, the proportion of total time actuallly spent on collecting was rather low.

It had been anticipated that the RECUFOR would travel at a collecting speed of 1.6 km/hr, whereas in fact, the collecting speed averaged 0.63 km/hr in the study, meaning that only 40% of the projected area to be treated per collecting hour was covered.

Collection time made up only 42% of total productive time whereas delays represented 26% of total productive time. Jamming of the rotor or conveyor was responsible for 52% of total delay time, mainly because of stumps, trunks entering perpendicular to the rotor or excessive residues for the conveyor capacity.

Table 8. Productivity comparison between estimates (1980) and results (1981).

PRODUCTIVITY FACTORS	ESTIMATES 1980	RESULTS 1982
Width of rotor	1.83 m	1.83 m
Volume of bin	capacity: 40 m^3	used: 20.5 m^3
Speed of RECUFOR while collecting	1.6 km/hr	0.63 km/hr
Speed of RECUFOR while travelling	4.8 km/hr	2.5 km/hr
On-the-ground residue density (1980 estimates from FRUL-Black Spruce station)	112.8 green t/ha 56.4 dry t/ha	64.8 green t/ha 45.8 dry t/ha
Productivity	10.2 green t/PMH 5.1 dry t/PMH	3.39 green t/PMH 2.39 dry t/PMH

Because of poor spreading of the residues in the bin, load volumes reached an average of only 50% of the bin volume capacity resulting in a higher proportion of travelling and unloading times per unit of volume harvested.

With the following modifications, it is estimated that a productivity of 4.5 green tonnes/PMH could be reached:

- improve design of rotor blades and cutting arrangement in order to minimize rotor jams and material contamination; proportion of delays should be brought down to the 10% level of cycle time as for operational machines;
- modify design of conveyor for increased capacity and install a spreading system promoting full use of bin;
- reduce total weight of RECUFOR (refer to p. 12);
- increase engine horsepower of RECUFOR.

It should be noted that the test results, and those anticipated after modifications, apply to almost ideal terrain conditions (flat solid ground with no major obstacles). It is likely that the productivity of the RECUFOR would decrease under worse conditions. Therefore the modified version of RECUFOR should be tested in various slope and residue density conditions. The RECUFOR's high ground pressure could prevent its use in soft-ground conditions.

Logging Development Coporation estimated, in June 1983, that the purchase cost for an operational RECUFOR would amount to approximately $400 000, and that the machine operation costs would be as follows:

Machine operating cost calculation (June 1983)

Capital cost	$400 000
Life	20 000 hours
Operating hours/year (no winter operations)	2 000 hours
Repair as % of depreciation	200%
Average investment	$200 000
Interest & insurance as % of average investment	12%/year
Direct labour cost	$15/hour
Fuel and lubricants	$0.50/L

Operating cost

Depreciation 400 000/20 000	$20/hour
Interest and insurance 200 000 x 0.12/2000	$12/hour
Repairs and maintenance 2 x 20	$40/hour
Fuel and lubricants 70L x 0.50	$35/hour
Operator	$15/hour
Total	$122/hour

Using a mean heating value of 20 MJ/kg for dry residues actually collected (Kryla 1984), the calorific value of the 2.39 dry tonnes collected per hour would then be 45 000 MJ. Applying an energy recovery factor of 70% because of the moisture content of the residues (Tillman 1981), the recoverable energy value per hour becomes 31 500 MJ/hr. Energy recovery cost would then equal \$122/hour ÷ 31.5 GJ/hour or \$3.87/GJ.

In January 1985, 1 m^3 of crude oil cost \$253.31 in Montreal. The average energy value of one m^3 of crude oil being 39.5 GJ/m^3, we can calculate a cost of \$6.38/GJ.

The energy recovery cost at\$3.87/GJ (for ideal conditions) makes up already 60% of the energy market value of \$6.38, leaving a slim margin to absorb costs relating to transport of residues to the utilization site, a secondary reduction process, material handling to the boiler, etc...

Giving the current level of development of the RECUFOR, it seems that the trials carried out in the summer 1982 showed it was technically feasible to gather residues left on cutovers, but the concept application was not supported by its economics and profitability assessment.

D. Change of Context

The conditions that led to the set up of the ENFOR programme changed in two significant ways during 1980-82, the period of the RECUFOR's development and evaluation.

First, the international price for crude oil reached a ceiling in 1981 and regressed slightly thereafter (Figure 13), taking by surprise the price-climbing forecasts by experts. This move in oil prices suddenly made replacement energy sources economically less attractive, especially those requiring several handling and transformation steps before utilization, such as logging residues on cutovers.

Secondly, 1979 marked the year when the full tree system started gaining importance over the other two systems (Figure 14), passing from 9% of total roundwood production in 1979 to nearly 30% in 1983. The growing number of roadside delimbers suggest this trend is likely to continue in the next years. The shortwood system is expected to decrease slowly. The whole tree chipping method might also gain more acceptance by present and future users. These changes in harvesting systems have an impact on the location of logging residues.

In the full tree harvesting system, trees are mechanically delimbed at roadside, thus concentrating residues (tops, branches and trunks) in one easily-accessible area. This concentration of residues is an obvious advantage over residues left on the logging site by the shortwood system.

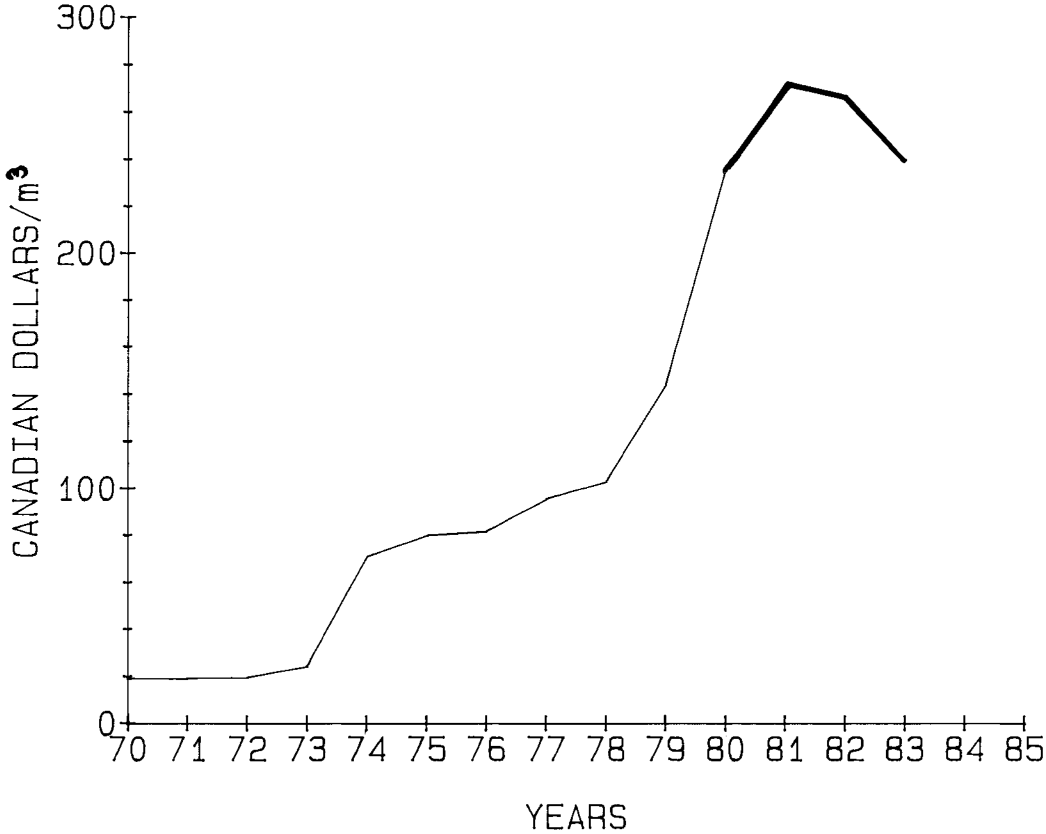

Figure 13. Averaged cost of imported crude oil in Montreal.

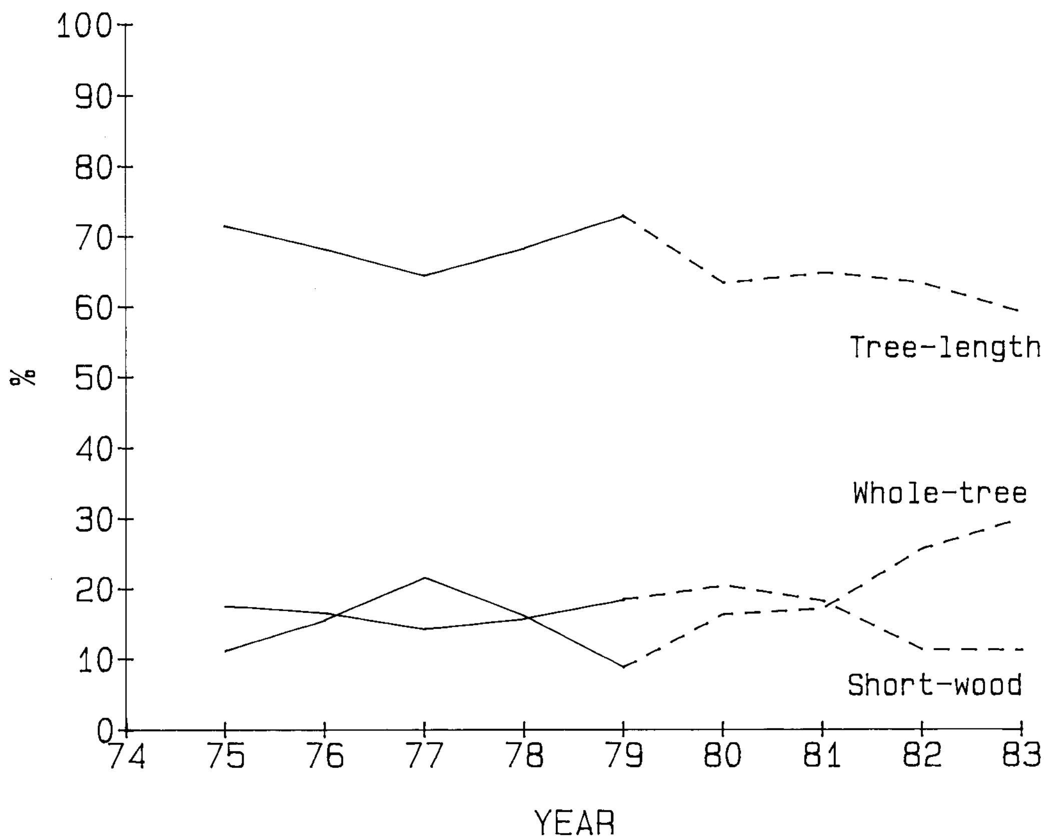

Figure 14. Percentage of total annual roundwood production in Canada for each harvesting system (C.P.P.A. 1984).

Influenced by this important change in the overall situation, noted in 1981, and the results of the RECUFOR evaluation, the FERIC programme on recovery of forest logging residues was oriented towards the recovery of residues piled at roadsides after delimbing operations.

As early as 1981, plans for a new prototype machine were developed, borrowing two important principles from the original RECUFOR idea:

1. The RECUFOR's collecting rotor was to be used for the primary reduction of residues; this rotor would be fed vertically by a sliding-boom grapple;

2. A regular hammer mill would perform the secondary reduction of residues.

This prototype, called LRP (Logging Residue Processor) was built during the 1983-84 year, and a preliminary assessment was carried out in 1984. The next section further details the LRP's development.

III. LRP (Logging Residue Processor)

A. Generalities

For each tonne of roundwood harvested, approximately one-half tonne of branches, tops foliage and trunks are left by the sides of roads. The importance of this quantity of residues is reflected in the fact that more than 300 roadside delimbers are actually in operation in Canada. This considerable energy potential is concentrated at the roadside where easy access is provided. Furthermore, the utilization of this mass of residues near the roads could liberate productive forest areas that would otherwise remain covered, and would also reduce fire hazards.

By 1981, many organizations had shown interests in recovering roadside residues for energy purposes. Several approaches to this problematical issue were undertaken and have led to different experimental prototypes, some of them reaching a commercial level. Therefore to insure any success in developing a new prototype (LRP), it was imperative to take into account the physical characteristics of the target residues, and to aim at high productivity criteria.

Within the ENFOR/FERIC framework, it was decided in 1983 to build the LRP prototype according to the plans submitted by LDC. This stage ended in 1984, when a series of preliminary tests were performed. The LRP's development, construction and tests were under LDC's (Logging Development Corporation) responsability while FERIC's special project division supervised the different stages of the project.

B. Prototype Description

The LRP illustrated in Figures 14 and 15 is a self-propelled, wheeled machine that can travel on logging roads. With a sliding boom and a grapple, it grasps delimber residues to deposit them in the shearing rotor. From the latter, sheared residues are fed into a conventional hammer mill and are then blown through a pipe to a truck bin. The main components of the LRP are briefly described in the following paragraphs.

1. Frame

Several parts of the RECUFOR were reused for the construction of the LRP. This reduced building and assembly costs considerably. The frame of the Clark 880 conventional skidder used on the RECUFOR was converted to carry the LRP components.

2. Shearing rotor

The RECUFOR's collecting rotor (hereafter called the shearing rotor) was also adapted to the LRP, requiring only small modifications. The vertical feeding principle of the rotor allows the processing of randomly-oriented residues, even when fed to maximum capacity, the shearing rotor supplies residues to the hammer mill at a constant rate.

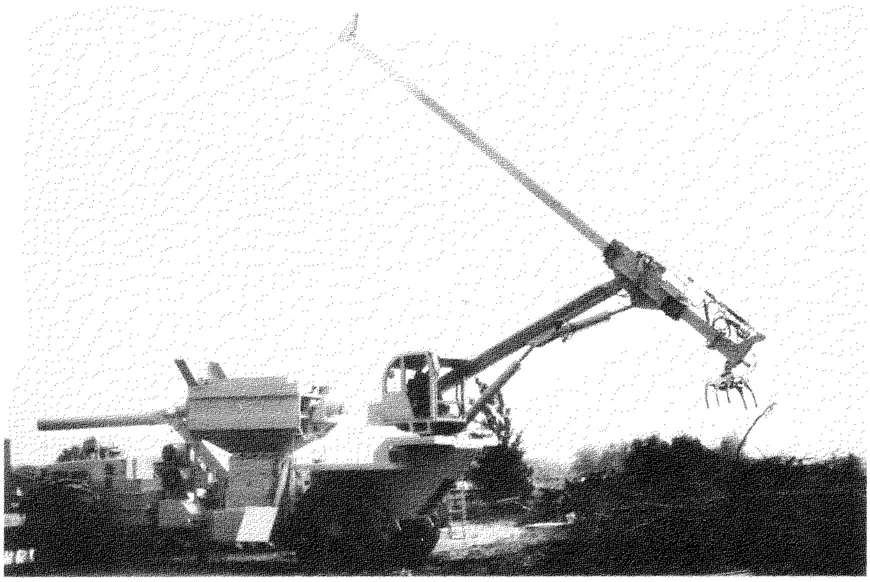

Figure 15. The Logging Residue Processor (LRP).

3. Hammer mill

A Jeffrey 45WB hammer mill was mounted on the LRP. The use of a hammer mill permits a final reduction of the infeed material. The homogeneity of the material produced should ease its handling, drying and combustion. Moreover, a hammer mill is almost contaminant resistant, relative to a chipper.

4. Horizontal blower

A horizontal blower, to which a discharge pipe is connected, delivers residues from the hammer mill to a truck. Even though the pipe has a 45° elbow, there is no choking or build-up either in the blower housing or in the pipe. Rated power of blower is 37 kW.

5. Sliding boom loader

The LRP has a sliding boom equipped with a grapple. Its 18.3 m (60 foot) range is compatible with that of most conventional roadside delimbers. Grapple capacity is approximately 500 kg. Boom and cab are turret-mounted.

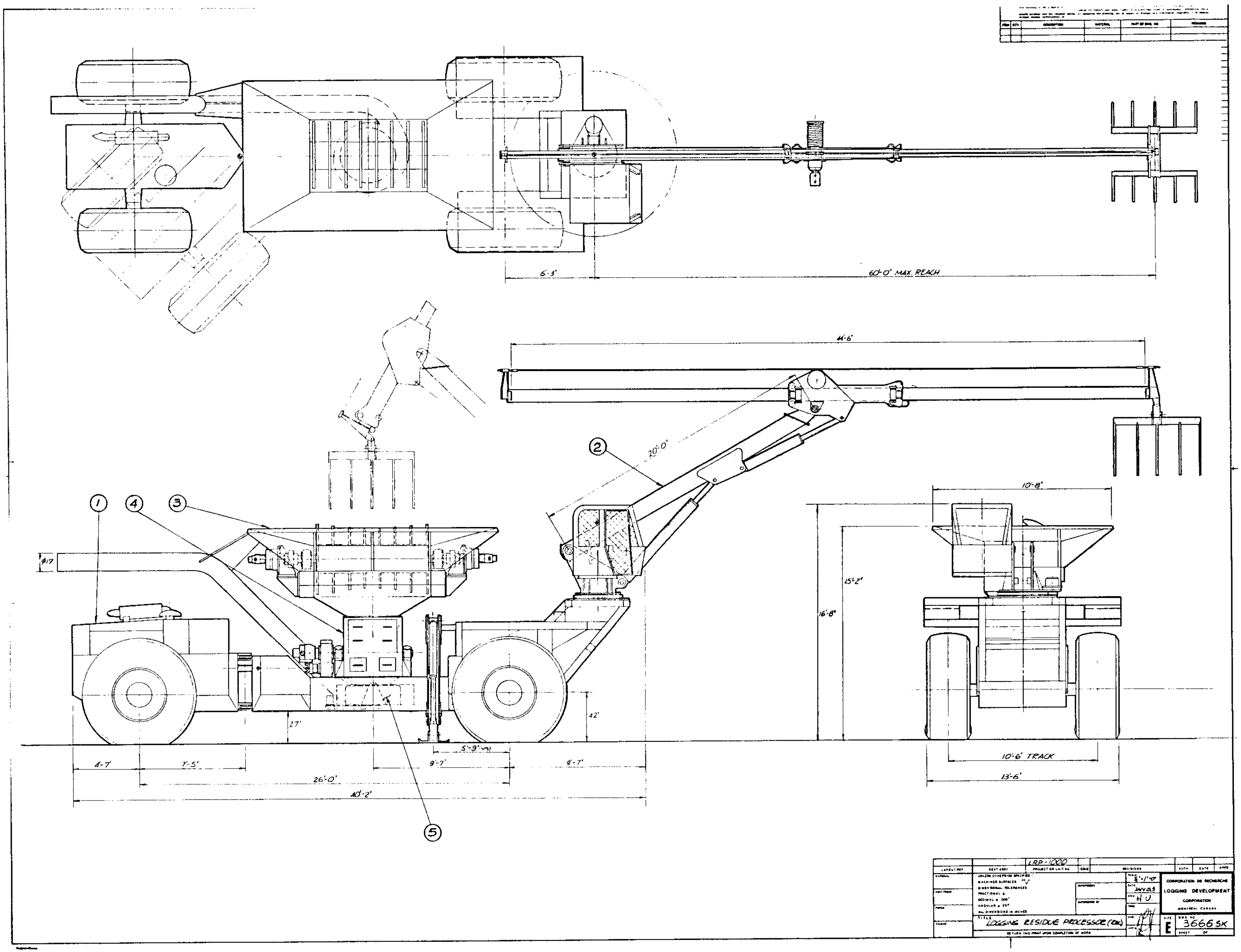

Figure 16. LRP prototype design.

C. Preliminary Evaluation of LRP

1. Objectives

A short series of tests was conducted soon after completion of the LRP final assembly in order, first, to ensure all parts were functioning well, and second, to measure a few production parameters. The reader is however cautioned that test results are preliminary and will be used for the planning of a more complete evaluation of the LRP. They should not be applied in another context.

The objectives of the tests were:

1. To measure processing times of weighed grapple loads of residues.
2. To establish feeding cycle times from the two principal positions--from the front and from one side.
3. To estimate the productivity potential of the machine.
4. To establish the maximum throwing distance of the modified blower.
5. To collect a significant quantity of processed residues and establish their density and size distribution.

2. Test conditions

The tests were conducted in the backyard of a plant, where residues were piled up to a height of six feet and laid out in rows. Residues consisted of freshly cut small hemlock, spruce, cedar and some aspen trees. Residue diameter never exceeded 13 cm.

Duration of tests was 2.5 days. Surrounding temperature was below -12°C the first day and above +3°C the next two days. Only eleven grapple loads were documented. Each bundle processed was first strapped and weighed on a crane hook scale. The bundle was then unstrapped, grappled by the booming system, positioned over the shearing rotor and then dropped into its knives. Processing time started when the grapple dropped its charge and stopped at the cessation of the principal flow of particles out of the discharge pipe.

3. Test results

Table 9 gives processing times for grapple loads studied. Processing rates, based on a full 60 minutes, ranged from a low of 9 tonnes/PMH where the rotor showed insufficient power to handle large grapple loads, to 40 tonnes/PMH with moderate grapple loads and sub-zero temperature conditions.

Table 10 presents the breakdown of the average feeding cycle time measured in the tests, totalling 1.07 min/cycle. With an average load weight of 400 kg, processing rate was established at 22.5 tonnes/PMH. The blower could throw processed particles from the pipe exit to a distance ranging from 9 to 15 m. Particle density measured by filling a 1.5 m^3 box placed at the exit of pipe was found to be 367 kg/m^3. Moisture content, bulk density, size distribution and heating value of particles were analyzed by Forintek (Ottawa) with results presented in Appendice III.

Table 9. Processing times and reduction rates of grapple loads.

Grapple load number	Load weight (kg)	Processing time (min)	Reduction rate (tonnes/PMH)
Series "A" (dry snow, temp. = 12°C)			
1	341	0.52	39.6
2	327	0.75	26.2
3	418	1.00	25.1
4	227	0.67	20.4
mean	328	0.76	25.9
Series "B" (wet snow, temp. = +3°C)			
5	386	0.57	40.9
6	364	1.62	13.5
7	369	1.93	11.5
8	409	1.72	14.3
mean	380	1.47	15.5
Series "C" (wet snow, temp. = +3°C)			
9	591	3.50[1]	10.1
10	523	2.75[1]	11.4
11	591	3.90[2]	9.1
mean	568	3.41	10.0

[1] includes regrip
[2] two stage drop

Table 10. Processing times and reduction rates of grapple loads.

Time elements	Description	Feeding - Average time measured (min/load)
Loading	Raise, retract, slew boom grapple and dump load	0.56
Return	Slew, extend and lower grapple	0.26
Search and grip	(estimated)	0.25
	Total	1.07

4. Discussion

Reduction rates achieved varied from 9 t/PMH to 40 t/PMH. The lowest rates are found in the series C, where the average load weight (568 kg) exceeded grapple rated capacity (500 kg). However, the longer reduction times of loads of series "C" are probably explained by a lack of power transmitted to the shearing rotor, pointing out that the average load weight was over the optimal load for the rotor capacity.

Following these preliminary tests, it is reasonable to estimate a processing time of 1.00 min/load with an average load weight of 410 kg for a commercial unit. Reduction rate would therefore amount to 24 tonnes/PMH, or 20 tonnes/SMH with an utilization ratio of 80%*.

The ambient temperature during operations could influence reduction rates. In frozen conditions, residues are more brittle and would therefore be easier to comminute, increasing the reduction rate. The opposite could also apply to unfrozen conditions.

Actual feeding cycle time averaged 1.07 min/cycle (or 56 loads/PMH) with an average load weight of 400 kg. Feeding rate was 22 tonnes/PMH or 18 tonnes/SMH (utilization ratio of 80%). In order to reach a minimum feeding rate of 20 tonnes/SMH, feeding cycle time would have to be brought down to 0.96 min/cycle (i.e. a minimum of 63 loads/PMH).

A systematic productivity study would be necessary at this stage to better assess the current productivity level of the LRP and to identify clearly the necessary modifications needed to improve its prototype status. The very short productivity study undertaken can, in no means, be substituted for a real short or long term study usually carried out for such a prototype. However it did indicate that a productivity level of 20 tonnes/SMH would be possible.

$$* \text{ Utilization ratio} = \frac{\text{Productive Machine Hours (PMH in Shift)}}{\text{Schedule Machine Hours (SMH)}} \times 100\%$$

CONCLUSIONS

Priorities set for the recovery of logging residues have been substantially modified in the past few years. During the implementation phase of the ENFOR Program by the Canadian Forestry Service, several conditions favoured the recovery of residues left on cutovers. In the following period, i.e. the end of the 1970's, many changes were noted in the overall context (energy, forest, logging...) surrounding the use of forest biomass. These changes altered the orientation of FERIC's mandate, switching interest from the recovery of biomass left on cutovers to the use of biomass left at roadside after full tree delimbing operations.

Under current conditions, there are many disadvantages to recovering the residues left on logging sites, therefore a research and development program in this direction is no longer timely. Residues left on logging sites are the most expensive type of forest biomass to recover. Their economic use can only be justified in a particular energy context, where the demand for energy sources other than conventional is high. This last situation appeared possitive at the beginning of the ENFOR Program but the energy predictions made at that time did not resemble actual subsequent trends; the predicted shortage of petroleum did not take place, and world consumption dropped slightly, thereby causing the international price to decrease. Moreover, the market penetration of another important energy source, natural gas, effectively reduced the demand for energy from biomass. These new elements forced a change in the approach for the harvest of forest biomass.

The experience gained through the RECUFOR project proved positive on many accounts. Although the period of development of the RECUFOR has been very short, because of the changes mentioned in the previous paragraph, the experience and technology acquired with that prototype were of valuable use for the construction of the second prototype, the LRP.

In the present energy climate, technological developments aiming at the recovery of residues at roadside for energy purposes should eventually meet the needs of the fiber users. The construction of the LRP prototype is a step in this direction. Preliminary tests, carried out in autumn '84, indicate that potentially, the LRP could be economically viable, in which case it would become an attractive alternative to slash burning. However at this stage of development, a more exhaustive evaluation of the prototype is necessary to better assess its productivity levels in different working conditions. The review of technical difficulties arising in this kind of study is suggested, to better evaluate the future potential of the LRP.

BIBLIOGRAPHY

Canadian Pulp and Paper Association. 1984. Logging operations reports summaries, 1982 or 1982-83. C.P.P.A., Woodlands Section, Montreal. 24 p.

Cheremisinoff, Nicola P. 1980. Wood for energy production. Energy technology series Ann Arbor: Ann Arbor Science Publishers. 152 pp.

F.R.U.L. 1981. Inventory of forest biomass left after logging. ENFOR Project P-28, Special Report N° RS-13. FERIC, 143 Place Frontenac, Pointe-Claire (Quebec) H9R 4Z7. 172 p.

Kryla, J.-M. 1984. Determination of available heat of combustion data for Canadian woody species. ENFOR Project P-256. Canadian Forestry Service, Ottawa. 89 pp.

Mellgren, P.G. 1980. Terrain classification for Canadian forestry. Montreal: Canadian Pulp and Paper Association, W.S.I. 2840. 13 p.

Ministère de l'Energie et des Ressources. 1984. Les statistiques de l'energie au Quebec, 1983. Direction des communications du M.E.R. 80 pp.

Tillman, D.V.; A.J. Rossi; and W.D. Kotto. 1981. Wood combustion principles, processes and economics. Academic Press. 208 pp.

APPENDIX I

RECUFOR SPECIFICATIONS

Overall length	12.98 m	42' 7"
Maximum height	4.09 m	13' 5"
Maximum width	4.01 m	13' 2"
Collecting rotor width	1.83 m	6' 0"
Rotor diameter (including blades)	1.83 m	6' 0"
Total weight	37 000 kg	83 000 lbs
Engine capacity (from Clark 880 engine)	240 kW	320 hp
Bin volumetric capacity	43 m^3	1410 ft^3
Rotor speed	16 rpm	
Theoretical travelling speed while operating...	2.4 km/hour	

APPENDIX II

LRP SPECIFICATIONS

Overall length	12.34 m
Maximum width	4.11 m
Maximum height	5.08 m
Sliding boom reach	18.28 m
Grapple capacity	500 kg
Total weight	36 000 kg
Engine capacity	240 kW

APPENDIX III

DEFINITION OF TIME ELEMENTS

Travel Empty Road

Starts with movement away from unloading site after unloading and ends when machine leaves the road to enter cutover.

Travel Empty Cutover

Begins as the machine leaves the road to enter cutover and ends when rotor begins to turn for collection of residues.

Collection

Begins when the collecting rotor starts to turn and ends after a full load has been collected and the rotor stops. Collection time may be interrupted by "Move Between Strips".

Move Between Strips

Begins as the machine leaves a strip after completing its collection and ends when collection resumes in the next strip.

Travel Loaded Cutover

Begins when rotor stops after collection is completed and ends when machine leaves cutover.

Travel Loaded Road

Begins as machine reaches road and ends when the machine starts to manoeuver prior to unloading at the landing.

Manoeuver

Time spent orienting the machine for unloading. It starts when the machine reaches the unloading site and ends when machine movement stops prior to unloading.

Unloading

Starts when machine movement stops prior to unloading and ends when the machine starts moving again for travel empty.

APPENDIX IV

ANALYSES OF HOGGED SLASH (FORINTEK)

A 13 kg sample of hogged softwood slash was delivered by Mr. D. Hamilton (Logging Development Corporation) December 12, 1984.

1. Moisture Content

Three sub-samples were taken from the material as-received and oven-dried at 105°C. The moisture contents, wet basis, were:

Sample #1 - 45.7%
Sample #2 - 49.1%
Sample #3 - 50.6%

for an average MC of 48.5%

2. Bulk Density

Bulk density of the material as-received was determined using a 0.0283 m^3 (1 ft^3) plywood cubic box. Determinations were made for loose gravity packed, shaken, and lightly compacted (about 10 kPa [2.5 psi]).

	Green Weight/Green Volume		Dry Weight/Green Volume	
	kg/m^3	lb/ft^3	kg/m^3	lb/ft^3
gravity packed	294	18.3	151	9.4
shaken	414	25.9	213	13.3
lightly compacted	553	34.5	285	17.8

3. Size Distribution

The material was air-dried in the lab at room temperature with forced air circulation to promote rapid drying and prevent biological degradation. It was then passed through a KASON model K.18.1.CS seperator fitted with 1M (1-inch), 2M (1/2-inch), 4M (1/4-inch) and 20M (1/20-inch) woven wire screens.

Mesh		Weight (air-dry g)	Percent
1M	(1-inch plus)	1908.3	29.0
2M	(1/2 - 1 inch)	2191.2	33.3
4M	(1/4 - 1/2 inch)	1451.7	22.0
20M	(1/20 - 1/4 inch)	949.1	14.4
fines	(1/20 inch minus)	85.0	1.3
	Total	6585.3	100

4. Heating Value and Ash Content

From each of the screened materials (5 size groups) a 1/10 sample by weight was collected and recombined, i.e. a total of 659 g. This was passed through a N°1 Wiley mill fitted with a screen having 6.4 mm (1/4-inch) holes. The coarsely ground sample was thoroughly mixed and a 50 g sub-sample removed for fine grinding using a screen with 0.5 mm (0.02-inch) holes. The small samples for HHV and ash content analyses were taken from this material. Heating value was determined in a Parr oxygen-bomb calorimeter on the air-dry sample (5.7% MC) and corrected by calculation to a dry wood basis. Ash content was determined by heating in a muffle furnace at 600°C.

Higher Heating Value:

as tested 19.36 MJ/kg (8330 BTU/lb)
corrected to dry 20.54 MJ/kg (8834 BTU/lb)

Ash Content: (% of dry wood weight) 2.93