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ADVANCED SYSTEM DEMONSTRATION FOR UTILIZATION OF BIOMASS
AS AN ENERGY SOURCE

MASTER

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October 1980
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Work Performed Under Contract No. AC06-77ET20055

Wood Energy Institute
Camden, Maine

U.S. Department of Energy

Solar Energy

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REPORT TO

DEPARTMENT OF ENERGY

FUELS FROM BIOMASS SYSTEMS BRANCH

ADVANCED SYSTEM

DEMONSTRATION

FOR UTILIZATION OF BIOMASS

AS AN ENERGY SOURCE

CONTRACT EG-77-R-06-1036

FUELWOOD AVAILABILITY

JUNE, 1979

REVISED--OCTOBER, 1980

PREPARED BY

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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
I. EXECUTIVE SUMMARY	1-1
A. Introduction	1-1
B. Biomass Availability Study Area	1-2
C. Basic Approach	1-2
D. Forest Biomass Availability	1-4
E. Harvesting Systems	1-5
F. Recommendations	1-6
1. Harvesting System	1-6
2. Transportation System	1-7
3. Silvicultural System	1-9
4. Educational Program	1-9
II. FUEL SOURCE CHARACTERIZATION	2-1
A. Summary	2-2
1. Purpose	2-2
2. Basic Approach	2-2
3. Biomass Availability	2-3
4. Summary of Costs	2-4
B. Mill Residues	2-5
1. Procedure	2-5
2. Results of Mill Residue Survey	2-7
3. Analysis and Evaluation of Survey Results	2-14
4. Mill Residue Costs	2-15
5. Commentary	2-16
C. Harvestable Biomass	2-19
1. Procedure	2-19
2. Biomass Inventory	2-21
3. Commentary	2-30

TABLE OF CONTENTS (continued)

<u>Section</u>	<u>Page</u>
III. HARVESTING SYSTEMS	3-1
A. Introduction	3-2
B. Analysis of Current Harvesting Systems	3-5
1. Existing Methods	3-5
2. Harvesting Operations	3-12
3. Operations Performed in Typical Harvesting Systems	3-14
4. Cost Comparison	3-17
5. Other Considerations	3-22
6. Economic and Production Considerations	3-29
7. The Integrated Harvesting System	3-32
8. Conclusion	3-35
C. Equipment Available	3-39
1. Background	3-39
2. Felling	3-41
3. Delimbing	3-58
4. Skidding-Forwarding	3-61
5. Chipping	3-85
6. Summary of Equipment by Manufacturers	3-89
D. Selection of Equipment	3-91
1. Introduction	3-91
2. Recommended Whole-Tree Chipping System	3-92
3. Advantages of Recommended System	3-93
4. Alternatives	3-95
5. Equipment Prices	3-98
E. Time Cost Studies	3-100
1. Introduction	3-100
2. Company A	3-105
3. Company B	3-113
4. Companies C and D	3-120
IV. TRANSPORTATION SYSTEMS	4-1
A. Introduction	4-2
B. Description and Evaluation of Equipment	4-4
1. Loading	4-4
2. Transportation	4-6
3. Unloading	4-13

TABLE OF CONTENTS (continued)

<u>Section</u>	<u>Page</u>
IV. TRANSPORTATION SYSTEMS (continued)	
C. Recommended Transportation Systems	4-18
1. For Whole-Tree Chips	4-18
2. Mill Residue	4-20
3. Overall Transportation Plan	4-22
4. Whole-Tree Chip Supply System	4-25
5. Summary of Supply and Transportation Plan	4-25
V. APPENDIX	5-1
A. Appendix A	5-2
B. Appendix B	5-6
C. Appendix C	5-7
D. Appendix D	5-9
E. Appendix E	5-10
F. Appendix F	5-12

I. EXECUTIVE SUMMARY

A. INTRODUCTION

Man has been burning wood to provide heat for thousands of years, but only recently has serious consideration been given to the potential of wood-burning power plants of a commercial size. This report describes the results of a 20 month study to explore the technical and economic feasibility of fuelwood utilization to operate a 50 megawatt energy conversion facility. This study investigated the availability of biomass as a fuel source, the methods of harvesting and collecting the fuelstock, the costs of providing adequate fuel to the plant, and other requirements for fueling the proposed conversion facility.

The study was authorized by the Department of Energy, Fuels from Biomass Branch, as an "ADVANCED SYSTEM DEMONSTRATION FOR UTILIZATION OF BIOMASS AS AN ENERGY SOURCE". Contract No. EG-77-R-06-1036 identifies this study and was awarded to the Wheelabrator Cleanfuel Corporation in September, 1977. The fuelwood study was conducted by the Wood Energy Institute of Camden, Maine, under the direction of Wheelabrator Cleanfuel Corporation. This volume presents the fuelwood availability study only and is one of a series of documents prepared and issued as a complete report of the work done under the contract.

B. BIOMASS AVAILABILITY STUDY AREA

An investigation into the availability of biomass as the primary fuelstock for the proposed power plant has been made and the results indicate that the supply is adequate to sustain the plant on a long-term basis. The study area was centered upon the site selected for the proposed conversion facility, which was identified by The Rust Engineering Company in conjunction with its work of preliminary plant design. The chosen site is in Westbrook, Maine, near the Atlantic seacoast. This was only one of many potential sites in New England and was selected because it featured the most favorable combination of characteristics.

The biomass study area was defined as an encircled area centered upon the proposed plant site. For the site in Westbrook, Maine, approximately one-half of the encircled area lies in the Atlantic Ocean, thus reducing the biomass supply to approximately half of that available at an inland site. In spite of this circumstance, the study shows that the biomass supply is adequate to sustain the 50 megawatt size plant for its economic life. This finding can be interpreted as indicating that other sites located well inland, with equivalent forestry resources, can support plants of a similar size.

C. BASIC APPROACH

The basic approach to this biomass study has been to determine the lowest possible cost of fuelstock and to evaluate all technical, legal, and environmental restrictions. It was determined early in the study that wood residues from various industrial plants and other operations would probably produce the lowest cost fuelstock

and this is the basis upon which the supply system has been planned. Many industries in the area produce waste materials with significant heating values: sawdust, butts, and trim slabs from sawmills; shavings, trimmings, and sawdust from furniture plants; bark from pulp and paper mills; leftover wastes from plywood and pallet plants; worn-out automobile tires; discarded railroad ties; and other waste materials. Surveys were made to assess both the availability of these materials and their suitability as fuelstock. A number of items were determined to be unsuitable for technical reasons related to their chemical content or problems in mechanical handling systems. The materials that were suitable were carefully evaluated with respect to the quantities available, location, possible supply systems, and costs. The total amount of suitable and available materials, as determined by this evaluation, was then subtracted from the total fuelstock requirements of the plant to obtain the net requirement for forest biomass. These figures are summarized as follows:

SUMMARY OF FUELSTOCK (GREEN TONS)

Total annual biomass fuelstock required	680,000 tons
Mill residues available (annually)	<u>250,000 tons</u>
Net requirement from forest biomass	430,000 tons

It is recognized that these figures are subject to certain variations as the project moves into subsequent phases. However, these are the basic criteria for the plant's design and the basis for evaluation of the supply system and its economics.

D. FOREST BIOMASS AVAILABILITY

The principal areas of investigation included the availability of forest biomass, the harvesting, collection, and transportation of biomass, the various types of mechanized equipment available, and the interest of logging contractors in serving as fuelwood suppliers for the plant when it begins operation. A large data base, complete with a considerable amount of background information, was assembled for decision-making on key issues. Forestry consultants with qualifying experience were engaged to assess the availability of forest resources, to survey the potential industrial suppliers of wastewood, and to contact logging contractors to document their interest in participation in the project.

The amount of forest biomass available was compiled from many sources of information, including U.S. Forest Service data, other reliable literature, and the personal knowledge and experience of the investigators. The results of this fuelstock study showed that the annual growth of tops and limbs within fifty miles of the biomass plant site is approximately 2.8 times the total of 680,000 tons of fuelstock required by the plant. Other figures were equally indicative of a large annual excess of biomass that could be used as fuelstock for the plant.

These facts and others developed in the study have indicated that the existence of an adequate source of biomass for the plant is beyond question. Methods for obtaining this wastewood efficiently and economically on a long-term basis have been investigated and are defined herein.

E. HARVESTING SYSTEMS

Three principal methods of tree harvesting were identified and studied for the technical aspects and from a cost standpoint. These are: (1) the shortwood method, (2) the longwood method, and (3) the whole-tree chipping method. Both the shortwood and longwood methods have been used in the pulp and paper industry for many years. The whole-tree chipping method is relatively new, but is finding more applications in existing forest products industries.

Whole-tree chipping has been selected and recommended as the most feasible method for the biomass conversion facility. This method facilitates an integrated harvesting system in which trees are brought to a landing and sorted for economic value. The sawlogs, pulpwood, and other boles of high quality are isolated and sold to appropriate users. The tops and limbs trimmed from these trees are chipped for fuelstock, along with culls. Thus, the integrated harvesting system enables the logging contractor to maximize the value of the timber tract and realize the optimum use of the forest resources. This method is sound from an environmental standpoint as well as an economic standpoint, since it enables the landowner to have his timber stand "trimmed and weeded" to provide light, air, nourishment, and growing space for the remaining trees. A demonstration of this method was conducted in the area to assess the feasibility of whole-tree chipping as a viable harvesting method. Existing whole-tree chipping operations were visited and studied to obtain actual operating cost data. Foreign operations were also visited to gain the experience of European

firms, who have been faced with more pressing forestry problems than U.S. industries due to the higher population density and the lower ratio of forested land to populated land. A large amount of information was generated and has been analyzed in reaching the conclusion that the project is feasible from the standpoint of the ability to procure the required biomass fuelstock.

The economics of the potential supply system were also investigated at length and the results show that the project should be able to obtain its fuelstock at a pricing structure adequate to assure plant viability.

F. RECOMMENDATIONS

1. Harvesting System

It is recommended that the biomass conversion facility purchase its supply of fuelstock from individual harvesting contractors, each operating as an independent firm. These contractors are available in the area and enough of them have expressed interest in the project to assure an adequate supply of fuelstock in the form of whole-tree chips. Under this method, the above ground portions of trees to be harvested are felled and skidded to a landing in the woods and reduced to chips by an in-woods mobile chipper. The chips are blown into waiting vans and transported to the biomass conversion facility for use as fuelstock.

Existing logging equipment now manufactured for use in the forest products industry is available and should be used for this project. A typical set of equipment suitable for harvesting trees and producing whole-tree chips is as follows:

Two	medium-sized feller-bunchers
Two	medium-sized grapple skidders
One	large whole-tree chipper

This combination of equipment coordinates production rates and is essential for a well balanced, smoothly flowing operation. It will produce approximately 270 tons per day of whole-tree chips in an eight hour day or correspondingly more with longer working hours. Operating at the rate of 270 tons per day, seven such systems can supply the needs of the biomass conversion facility.

Another set of equipment is also feasible as a smaller production unit. This equipment will consist of the following items:

One	small-sized feller buncher
One	small-sized grapple skidder
One	small whole-tree chipper

This system is equally well matched to provide a smoothly flowing production system. It will produce approximately 100 tons per day in an eight hour day or correspondingly more with longer working hours. If small-volume operations such as this were used exclusively in the fuelwood procurement system, approximately 18 such units would be required.

It is recommended that the system ultimately adopted be a combination of large- and small-volume producers properly matched to the forestry tracts and other conditions in the procurement area.

2. Transportation System

The transportation of the biomass fuelstock supply will utilize tractor-trailers of at least 22 tons capacity. Each of the separate harvesting operations will require an adequate number of tractors and trailers to meet its production rate. It is recommended that the individual harvesting contractors own and operate their own fleets of vehicles for transportation of fuelstock to the biomass facility.

The typical large-volume producer working at an average distance of 35 miles from the plant will need about six drivers with tractors, each driver making two round-trips per day. Each driver will pick up a loaded trailer at the in-woods landing and will deliver the trailer-load of chips to the plant, where it will be unloaded within a short time. There will be no need to unhitch the trailer at the biomass facility, and the driver will be able to return to the landing to pick up a loaded trailer. The operation will have extra trailers to be filled with chips while the drivers are enroute.

The small-volume producer will operate in the same manner but with fewer drivers, only as many as needed to match his production capacity.

Efficient harvesting and transport operations require that equipment be used to the largest extent practical, therefore the number of trucks and trailers should be tailored to the minimum necessary for any given operation. It is recommended that the number of trailers at the landing for loading

be held to the minimum necessary to assure a smooth flow of fuelstock. Each of the harvesting contractors is expected to have areas for parking equipment when it is not in use to avoid congestion at the loading point.

Harvesting operations can be carried on during daylight hours and the transportation can be continued in hours of darkness as needed to make each day's quota.

The biomass-burning facility will be prepared to receive trailer deliveries two shifts a day, five days a week.

3. Silvicultural System

A selective silvicultural system is recommended since it provides a "thinning and weeding" operation to the tract of land being harvested. The removal of culls and deadwood, along with overage trees and small trees that cause overcrowding is of great benefit to the residual stand. The services of a professional forester are essential to the proper operation of this system. The forester selects the trees to be removed and the harvesting crews move in with machines to carry out his directions efficiently. On some tracts that have been purchased for use as homesites, plant sites, or for construction of other facilities, the clearcutting method may be used.

4. Educational Program

It is recommended that an educational program be undertaken to properly inform all concerned parties of the importance of the biomass-burning facility to the nation's

energy plans and of the careful measures being taken to assure the protection of forestry resources. This program should emphasize the environmental safeguards and socio-economic benefits associated with the construction and operation of the facility. Since this project is a pioneering effort, a successful outcome will set the stage for future projects of similar nature.

A good public relations program built on a solid foundation of facts and a careful response to all objections is an absolute necessity. The data and information developed through this study can be used to support biomass conversion and convince those with a skeptical outlook that the facility is in their best interest.

II. FUEL SOURCE CHARACTERIZATION

The following sub-sections are included in this section:

- A. SUMMARY
- B. MILL RESIDUES
- C. HARVESTABLE BIOMASS

A. SUMMARY

1. PURPOSE

The purpose of this section is to describe and evaluate the fuel source characteristics, availability, and pricing structure of potential fuel sources for the proposed biomass-burning power plant.

Two basic sources of fuelstock were investigated: (1) mill residues such as sawdust, trimmings, bark, etc., and (2) forest residues consisting of cull trees, tops, and limbs.

2. BASIC APPROACH

The basic approach of this study is that mill residues will be available at a lower cost and with less negotiations and planning arrangements than required for forest residues. Thus, the primary thrust has been to identify potential sources, quantities, and costs for obtaining as much mill residue as possible. The study shows that about 37 percent of the plant's fuelstock requirements can be obtained through this source with reasonable certainty. This figure is a conservative estimate and has been used as a design basis for receiving and handling facilities at the conversion plant. There is, however, a possibility that considerably more mill residues can be obtained. In addition, large quantities of mill residues that are presently unsuitable for handling and use at the plant could be obtained and utilized with additional equipment and facilities. In addition to these sources

of mill residue, there are other potential sources of waste materials that could be used as fuel under proper conditions. Large quantities of discarded railroad ties, worn-out automobile tires, and other industrial wastes exist in the area. These sources have been investigated and rejected under the present design conditions. Further investigations and modifications to plant designs may make it possible to utilize these sources, thus greatly increasing the amounts available. It may be possible to obtain the entire 680,000 tons per year of fuelstock required for the plant from industrial wastes alone if the supply area is extended to 150 miles and if all possible sources are tapped.

For this study and report it has been essential to be conservative in supply estimates and plant design in order to give maximum assurance of credibility and a greater likelihood of success. For these reasons, the percentage of mill residue (250,000 tons per year or 37 percent) fueling the plant has been established and plant design has proceeded on that basis. The economic analysis has also utilized this figure.

3. BIOMASS AVAILABILITY

With the amount of mill residue established, the remainder of the plant's fuelstock is to be obtained from forest residues. This amounts to 430,000 tons per year. The forest inventories show large amounts of standing biomass in nearby forests. The unutilized annual growth in the study area (50 mile radius) located in Maine (about 5/6 of the total area) is almost 4 million green tons per year. This is more than nine times the annual requirements for

forest biomass fuelstock for the plant. When these figures are analyzed further, the amount of culls, tops, and limbs from the area of study is enough to supply approximately four times the needs of the plant forest residue fuelstock. Thus, the adequacy of the fuelstock existence is well established and forms a solid foundation for proceeding with the project.

4. SUMMARY OF COSTS

The mill residue can be obtained within approximately 150 miles of the plant site in Westbrook for approximately \$11.40 per ton in 1979 dollars delivered to the plant. This price covers the material cost, which averages \$4.53 per ton, and the transportation costs, which average \$6.87 per ton at 6.8 cents per ton-mile.

The forest biomass obtained within approximately 50 miles of the plant site would have an estimated 1979 cost of \$14.00* delivered to the plant. This price covers the material cost, which is estimated at \$11.62 per ton, and the transportation cost of \$2.38 per ton at 6.8 cents per ton-mile.

The total estimated cost of fuelstock delivered to the biomass conversion plant is as follows:

Mill residue (250,000 tons)	\$ 2,850,000
Forest biomass (430,000 tons)	<u>6,020,000</u>
TOTAL	\$ 8,870,000

* See page 3-103

The costs and estimated prices presented herein are to be used as approximations only. Since firm prices and contracts were not secured as a part of this undertaking, WCC has arrived at these estimates without the benefit of negotiations with suppliers.

These prices are used as "base case" conditions for economic analysis purposes. The sensitivity of the project economics to variations in the cost of fuelwood is covered in the economic analysis section of Volume I, Scope and Design Criteria.

B. MILL RESIDUES

1. PROCEDURE

The availability and cost of mill residue has been evaluated by mailing a questionnaire to selected local industries and tabulating the responses. The basic approach was to obtain lists of wood-using industries in the New England area and to contact them by letter and telephone to obtain information on the amounts of waste produced, their willingness to sell residues, possible transportation modes, the prices they might charge, and other pertinent information. A questionnaire (form) was prepared and sent with a request for information to a total of 209 wood-using industries located within 100 miles of Westbrook, Maine. (A copy of the form and letter is included on pages 2-17 and 2-18).

The questionnaire was sent to plants in several New England states within 100 miles of Westbrook, Maine, as follows:

Massachusetts	4
Vermont	9
Maine	67
New Hampshire	<u>129</u>
TOTAL	209

The names and addresses of these industries were obtained through regular business information channels and wherever possible, a screening was made to eliminate any companies that used less than

one million board feet of timber annually. This isolated the industries with potentially sizeable amounts of residue. No figures were available on the percentage of residue generated by company or industry. It is entirely possible that many other industries are in operation whose mill residues are substantial enough to be considered potential sources and that subsequent data will identify a larger supply than indicated by the responses to the survey.

Production data was not available for mills in New Hampshire, therefore no screening for production capacity was possible. The questionnaires were sent to all New Hampshire mills that are within a 100 mile radius of the plant site.

The mill residue survey was limited to mills within 100 miles of the biomass plant site to contain transportation costs. Costs for transportation by truck were determined and an average 1979 figure of 6.8 cents per ton-mile was used*. This figure was also used for transportation of mill residues by rail (if the rail transport charges are higher than this, truck transport will be used). The transportation charges were computed for two average hauling distances:

- (1) 100 mile radius of the plant site: 60 mile haul
(50 mile average plus 20 percent)
- (2) Extended distance from plant, from 100 to 150 miles:
150 mile haul (125 mile average plus 20 percent)

These extended distance figures were extrapolated from mill residue response figures for the 100 mile radius because it appears to be cost effective to obtain mill residues up to 150 miles from the site.

2. RESULTS OF MILL RESIDUE SURVEY

Of the 209 mills contacted in the survey, 89 had replied as of December 31, 1978, approximately six months after the questionnaires were sent out. This is a return of 42 percent and it was distributed as follows:

Massachusetts	1
Vermont	2
Maine	40
New Hampshire	<u>46</u>
TOTAL	89

Analysis of the response shows the following facts on residue availability:

Positive (have excess, will sell)	63
Negative (have none or will not sell)	13
Too small to include	2
Incomplete information (could not use)	<u>11</u>
TOTAL	89

Figure 2-1 shows the area covered by the survey and Table 2-1 identifies the positive respondents to the questionnaire.

Positive responses showed the following tonnages available for sale within the 100 mile radius of the biomass plant site:

Sawdust	136,000 tons
Bark	157,000 tons
Shavings	<u>48,000 tons</u>
TOTAL	341,000 tons

Other mill residues were also listed but were eliminated from consideration, including:

Sawmill slabs	17,000 tons
Chips	59,000 tons

For the purpose of this study, the sawmill slabs were eliminated because the biomass plant is not designed to handle material of this type (dimensions are greater than six inches). The ability to handle slabs can be overcome by having them size-reduced to the six inch limit at either the source or at the biomass plant with future equipment and systems. The chips were eliminated because the cost was considerably higher than for the other residues.

A reduction factor of 40 percent was applied to the total tonnage available from the positive respondents to the survey, thus reducing the anticipated tonnage to 136,000.

TABLE 2-1

POSITIVE RESPONDENTS TO MILL RESIDUE SURVEY

1. Ames Company*, Box 293, Pittsfield, Maine 04967
2. Bear Paw Timber Corp., Box 20, Fryeburg, Maine 04037
3. Cousineau Lumber Co., Inc., Strong, Maine 04983
4. Dirigo Dowel, Inc., New Portland, Maine 04954
5. Frost Cedar Products, Box 363 RFD 1, No. Anson, Maine 04958
6. Thomas Hammond & Son*, East Hiram, Maine 04026
7. M. S. Hancock, Inc., Casco, Maine 04015
8. Hunt Brothers Lumber, Inc.*, Upper Main Street, Damariscotta,
Maine 04543
9. Industrial Box & Lumber Co., P. O. Box 147, Kezar, Maine 04047
10. Isaacson Lumber Co., Livermore Falls, Maine 04254
11. Kerschner Enterprises*, Woodlands & Wood Products Operations,
Jay, Maine 04239
12. Keyes Fibre Co.*, Shawmut, Maine 04975
13. Lavalley Lumber, Inc., Newdam Road, Sanford, Maine 04073
14. Lovell Lumber Co., P. O. Box 106, Lovell, Maine 04051
15. Madison Paper Products, Maine Street, Madison, Maine 04950
16. Maine Dowel Corp.*, 84 North Main Street, Farmington, Maine
04938
17. Maine Fence Company, Pittsfield, Maine 04967
18. Maine Lumber Co., 1037 Forest Avenue, Portland, Maine 04101
19. Marriner Lumber Co., Church Road, Brunswick, Maine 04011
20. Maschino & Sons, New Gloucester, Maine 04260
21. Masse Lumber Co., E. Vassalboro, Maine 04935

22. Moose River Lumber, Co., Inc., P. O. Box 454, Jackman, Maine
04945
23. Pearse's Mill, Searsmont, Maine 04973
24. Penley Corporation, West Paris, Maine 04289
25. Robbins Lumber, Inc., Searsmont, Maine 04973
26. Solon Manufacturing Co., Solon, Maine 04979
27. Starbird Lumber Co., Strong, Maine 04983
28. Stowell Wood Products, Inc.*, Bryant Pond, Maine 04219
29. J. A. Thurston Co., Inc., Route 120, Rumford, Maine 04276
30. Timberlands, Inc., Dixfield, Maine 04224
31. S. D. Warren, Westbrook, Maine 04092
32. F. E. Wood & Sons, East Baldwin, Maine 04024
33. Woodtek, Inc., No. Anson, Maine 04958

NEW HAMPSHIRE MILLS

34. Allen-Rogers Corporation, Wentworth Division, Wentworth, New
Hampshire 03282
35. Avery Campbell Lumber Co., Chester Road, Raymond, New Hampshire
03077
36. K. Barton & Barton Brothers, Range Road, Epsom, New Hampshire
03234
37. Blackman Mill, Mansion Road, Dunbarton, New Hampshire
38. Bowlan Lumber Co., Inc., P. O. Box 491, Henniker, New Hampshire
03242
39. Brown's Mill, Inc., RFD No. 1 Box 306, Manchester, New Hampshire
03104
40. Colby Lumber Co., Boscawen, New Hampshire 03301

41. Cole Mill, RFD, East Kingston, New Hampshire 03827
42. Holt Lumber, 545 Main Dunstable Road, Nashua, New Hampshire
03060
43. Thomas Johnson Forest Products, RFD, Temple Road, Henniker,
New Hampshire 03242
44. Kearsarge Reel Corporation, Sawmill Division, Warner, New
Hampshire 03278
45. Monadnock Forest Products*, Jaffrey, New Hampshire 03452
46. New England Lumber, Box 226, W. Ossipee, New Hampshire 03890
47. Northeast Hardwoods Co.*, North Haverhill, New Hampshire 03774
48. Onnela Lumber Co., 97 Summer Street, Newport, New Hampshire
03773
49. Perras Lumber Inc., RFD. No. 2, Lancaster, New Hampshire 03584
50. Red Water Lumber Co., P. O. Box 658, Claremont, New Hampshire
03743
51. Riley Brothers Lumber, Inc., Christmas Tree Lane, Milford, New
Hampshire 03055
52. Seacoast Mills, Inc., RFD No. 4, Pine Road, Exeter, New
Hampshire 03833
53. Spaulding & Frost, 100 Maine Street, Fremont, New Hampshire
03044
54. Timber Products, Inc., RFD No. 3, Littleton, New Hampshire
03561
55. Trepanier Sawmill, Spaulding Road, Pelham, New Hampshire 03076
56. Triple L Lumber Co., Inc., Foster Hill Road, Henniker, New
Hampshire 03242

*railroad access

- 57. True & Noyes Lumber, Inc., Box 6 Lane Road, East Derry, New Hampshire 03041
- 58. Twin Pine Lumber Company, P. O. Box 115, West Springfield, New Hampshire 03284
- 59. Kenneth Whitcher, Inc., Warren, New Hampshire 03279
- 60. Wilkins Lumber Company, Davis Lane, Amherst, New Hampshire 03031
- 61. H.G Wood Industries, RFD No. 2, Bath, New Hampshire 03740
- 62. Woodward Lumber, Blake Road, West Epping, New Hampshire 03042

VERMONT MILLS

- 63. Mountain View Lumber, Inc., West Burke, Vermont 05871

* railroad access

3. ANALYSIS AND EVALUATION OF SURVEY RESULTS

Six respondents stated that they give their residue away with only a loading charge. Others indicated problems in disposing of mill residues due to environmental regulations. One owner indicated that he is producing 120 tons per day and has no market for it, stating that he would be willing to contract for disposal.

Survey results and other information developed during the study indicate that the mill residue area could be extended to 150 miles in some cases. This extended delivery distance would include additional mills in Piscataquis and Penobscot counties in Maine, and greater portions of Vermont and Massachusetts. Environmental laws make it difficult for mills to dispose of their wastes.* Traditional incineration pollutes the air and is now prohibited in most communities. Dumping is an eyesore and causes runoff pollution, and seepage from landfills leaches pollutants into waterways. The combustion and handling systems necessary to recover the energy from these wastes require significant capital outlays and are usually not economically feasible for a small to medium-sized mill.

The amount of residues available within the 100 mile radius may be greater than the 136,000 tons indicated from the survey. It is estimated that an additional 114,000 tons of mill residue could be available, for a total of 250,000 tons annually, if the radius is extended to 150 miles. This projection would indicate that 37 percent of the total biomass fuelstock required could be supplied from mill residues.

*Raymond L. Saries; "The Use and Value of Wood and Bark Residues in the Northeast", Northeastern Loggers Congress, Session 2.

4. MILL RESIDUE COSTS

Analysis of the returned questionnaires and telephone contacts has revealed the following average cost structure for mill residues:

AVERAGE PRICE PER MILL RESIDUE TYPE
PER TON--LOADED AT THE MILL
1979 PRICES

Sawdust	\$4.89
Bark	4.39
Shavings	3.95

Transportation has been assumed to be by truck, however a considerable portion of the residue could be shipped by rail. A number of the mills contacted indicate that they have rail service. The cost of shipment has been estimated at 6.8 cents (1979) per ton-mile based upon figures obtained from several sources.* This figure has also been used for rail service, otherwise, truck shipments would be used. Based upon this transportation cost and the average costs for the various types of residues, the following table shows the mill residue supply and total cost to the biomass power plant on an annual basis.

*See page 3-102

MILL RESIDUE SUPPLY

Average hauling distance (miles)	60	150
Cost per ton (1979)		
Material cost	\$4.53	\$4.53
Transport cost (at .068/ton-mile)	<u>4.08</u>	<u>10.20</u>
Unit cost	\$8.61	\$14.73
Tonnage (annual)	136,000	114,000
Total Cost	\$1,171,000	\$1,679,000
Grand Total Mill Residue Cost		\$2,850,000/year

5. COMMENTARY

A conservative approach has been used in this survey to avoid over-estimating supply. All tonnages have been calculated as green tons, when in fact, about 15 percent of the mills responded with oven dry tons. Similarly, the lack of response from 58 percent of the mills surveyed cannot be construed to mean a lack of mill residue or interest in selling it. Surveys of this type have been conducted before and many mill managers may feel that it is a waste of their time to respond to another survey, since nothing has come of the previous surveys.

In addition to this effort, others in the forestry field have made estimates of the mill residue available in this area from their own private sources of information and have come up with figures in the same general range, some larger, some smaller. We are aware of estimates ranging from 200,000 tons to 380,000 tons. Thus the final figure of 250,000 tons per year appears to be reasonable and attainable.

R

J. P. R. ASSOCIATES, INC.
REGISTERED LAND SURVEYORS & CONSULTING FORESTERS
Box 1195
Stowe, Vermont 05672

Stowe Office: 802-253-7220

August 23, 1978

We are conducting a survey regarding the amounts of mill residue (bark, slabs, sawdust) that might be available to fuel a proposed wood-fired electrical generating plant to be built in Maine. Choice of the plant site will depend in part on the results of this survey.

We feel this plant would have many benefits to the area in which it is located, including providing a long-term, year-round, dependable market for currently unmerchantable mill residues.

We would greatly appreciate your taking a few minutes of your time to complete the enclosed form. A stamped, self-addressed envelope is included for your convenience.

If you have any questions, please call us collect at (802) 253-8430.

Sincerely,

J. Phillip Rich
Project Manager

JPR:csg

Enclosures

RETURN TO: J.P.R. Associates, Inc.
P.O.Box 280, Stowe, Vt. 05672

MILL RESIDUE SURVEY

Name of Mill _____ Phone () _____

Address _____

Your name _____ Title _____

RESIDUES PRODUCED

Type of residue _____

Check one:

_____ hogged _____ unhogged Moisture content (if known) _____ %

Amount of residue produced _____ per _____ day _____ week _____ year
(tons, yards, truckloads-state truck size, etc.)

Amount of residue you use or sell now _____ per _____

Current selling price _____ per _____
(cord, truckload, ton, yard, etc.)

FUTURE AVAILABILITY

Do you expect the amount of excess residue you produce to:

_____ increase _____ decrease _____ remain about the same

Would you be willing to contract for the disposal of residues:

_____ yes _____ no

Over what time period:

_____ 1 year _____ 2 years _____ 3 years _____ 4 or more yrs

Your requirements for terms or prices for a long-term contract:

RAIL SERVICE

Do you use rail transport? _____ yes _____ no

Name of rail line _____

Do you have rail car loading facilities for mill residue? _____ yes _____ no

What type? _____

TRUCK TRANSPORT

Do you have truck loading facilities for mill residues? _____ yes _____ no

What type? _____

C. HARVESTABLE BIOMASS

1. PROCEDURE

The harvestable biomass study contracted the consulting services of the James W. Sewall Company, Consulting Foresters, of Old Town, Maine. The purpose of their efforts was to determine the amount of harvestable biomass within a 50 mile radius of the proposed plant site at Westbrook, Maine.

The study area consists of specific geographical and forestry statistics (see Figure 2-2). The outer boundary is the nearest municipal line corresponding to a fifty mile radius from the proposed site. The total land area encompassed by this study is 3,371,000 acres. It extends into the eastern portion of New Hampshire and includes the following geographic units in Maine: Western Maine, Capital Region, and Casco Bay. The geographic unit in New Hampshire is the southern unit.

This report and the tables herein rely upon U.S. Forest Service data as to trees and volumes per acre by geographic sampling units for growing stock of four inches and up (diameter at breast height--DBH). To make estimates for those trees and volumes per acre below 5 inches (DBH), additional data was obtained from the U.S. Forest Service at Upper Darby, Pennsylvania. The stocking and volume per acre figures are as of the date of the field work for these inventories, which was 1970 for Maine and 1973 for New Hampshire.

Based upon local knowledge and experience with the forest of Southern Maine, the consulting foresters believe that the percentage of volume by individual species has not changed significantly during the past eight or nine years and the growing stock has remained nearly constant.

2. BIOMASS INVENTORY

The following summary tables have been prepared based upon the report submitted by the James W. Sewall Company entitled "Biomass and Volume Estimates for Westbrook Study Area, 1978" and other pertinent documents.

These tables show a vast inventory of biomass standing in the forests today. They show large quantities of unutilized annual growth. The term "growing stock" represents merchantable wood--sizes and species of trees that have market value as timber, pulpwood, etc. The term "culls" represents trees that are "rough and rotten", diseased, deformed, or otherwise unsuitable for commercial use. The source of biomass for use as fuelstock to the proposed conversion facility is (1) culls, and (2) tops and limbs from the harvested merchantable growing stock.

Table 2-2 shows the estimated above-ground biomass in Maine and New Hampshire by forest type and class, a total of 214,668,778 green tons for the projected 50 mile harvesting radius of Westbrook.

Table 2-3 shows the current above-ground growing stock inventory and growth rates, as well as the timber cut and annual growth less the timber cut for Maine only (timber cut figures are not available for New Hampshire).

This table indicates that when the annual drain (timber cut) is subtracted from the annual growth, nearly three million green tons of surplus annual growth remains in Maine within the Westbrook study area.

In Table 2-3, only the utilized growing stock is considered when subtracting the timber cut. However, culls are also growing at the same annual rate (3.5 percent). Table 2-4 shows the projected total unutilized annual growth (almost 4 million tons).

TABLE 2-2

EXISTING ABOVE-GROUND BIOMASS
(50-MILE RADIUS OF WESTBROOK, MAINE)
 (green tons)

	<u>Merchantable Growing Stock</u>		<u>Culls</u>		<u>Total Biomass</u>		<u>Total</u>
	<u>Maine</u>	<u>New Hampshire</u>	<u>Maine</u>	<u>New Hampshire</u>	<u>Maine</u>	<u>New Hampshire</u>	
Hardwood	57,642,536	27,825,516	22,674,693	4,716,721	80,317,329	32,542,237	112,859,566
Softwood	65,070,264	23,777,730	6,911,824	6,049,394	71,982,088	29,827,124	101,809,212
Subtotal	122,712,901	51,603,246	29,586,517	10,766,118	152,299,417	62,369,361	214,668,778
Total	174,316,147		40,352,635		214,668,778		

TABLE 2-3.

UNUTILIZED ANNUAL GROWTH OF GROWING STOCK
(green tons)

	<u>Total Westbrook Study Area</u>			
	<u>Total Above-Ground Growing Stock</u>	<u>Annual¹ Growth</u>	<u>Timber² Cut 1977</u>	<u>Annual Unutilized Growth</u>
Bole	119,842,352	4,194,482		
Tops and Limbs	<u>54,473,797</u>	<u>1,906,583</u>		
Total	174,316,149	6,101,065		
<u>Maine Only</u>				
Bole	84,365,120	2,952,775	953,270 ³	
Tops and Limbs	<u>38,347,781</u>	<u>1,342,172</u>	<u>428,971⁴</u>	
Total	122,712,901	4,294,947	1,382,241	2,912,706 ⁵

(See notes, next page)

NOTES FOR TABLE 2-3

¹3.5% of biomass inventory per Sewall report.

²For the area in Maine, the 1977 timber cut was 6% lower than that for 1976, as opposed to a 2% increase for the entire state. From Roland H. Ferguson and Neal P. Kingsley, "The Timber Resources of Maine", Northeastern Forest Experiment Station, Upper Darby, Pennsylvania, 1972.

³Converted from cords at 2 tons/cord from the Maine Bureau of Forestry, "Maine Timber Cut Report for 1977", Augusta, April, 1978. See attached copy.

⁴This figure represents 45% of the bole. The Sewall Company has calculated that under "current harvesting practices", i.e. not whole-tree chipping, an additional 296,000 green tons are available in "harvestable topwood biomass" in the entire study area (page 8). However, when the weight of the bole cut in Maine in 1977 is multiplied by 45% (the ratio of tops and limbs to bole), the resulting weight of tops and limbs resulting from that cut is 428,971 green tons, which in theory would be available for a whole-tree chipping harvesting system.

⁵For Maine only. Annual growth less 1977 timber cut.

TABLE 2-4

MAINE UNUTILIZED ANNUAL GROWTH
(WITHIN 50-MILE RADIUS)

Green tons unutilized annual growth (See Table 2-3)	2,912,706
Green tons annual cull growth ¹	<u>1,035,528</u>
Green tons annual unutilized growth	3,948,234

¹29,586,517 (Chart I) x 3.5% = 1,035,528

The amount of fuelwood in the Westbrook area (a 50 mile radius from the proposed plant site) that could be available to supply the conversion facility's needs is the total of the annual growth of culls plus the totals of the tops and limbs available from the annual timber harvest. The percentages of tree components are shown in the accompanying illustration (Figure 2-3) from a report prepared by the North Central Forest Experiment Station, U. S. Department of Agriculture, St. Paul, Minnesota.

The timber cut figures and percentages of tops and limbs have been provided by the Sewall report from published figures. The timber cut for the portion of New Hampshire is not available, however, an estimate can be made using the same relative percentage of timber cut to the total annual growth in both states. When this is done as in the following table, the result shows that there is approximately four times the conversion plant's requirements in annual growth within the 50 mile radius.

TABLE 2-5

ANNUAL FUELWOOD IN WESTBROOK AREA
(green tons)

Culls	1,035,528
Tops and Limbs (Maine) ¹	428,971
Tops and Limbs (New Hampshire) ²	<u>180,000</u>
Total	1,644,499
Plant Requirements *	430,000
Number of Times Plant Requirement	4

¹From annual timber cut

²Assuming same percentage timber cut as in Maine

*Harvestable biomass

FIGURE 2-3.
COMPONENT PROPORTIONS OF FRESH WEIGHT OF
COMPLETE TREES AND SHRUBS.

3. COMMENTARY

a. Topography

Approximately 95 percent of the total land area within the 50 mile radius has less than a 15 percent slope. Mechanized harvesting systems in general, and fellerbunchers in particular, can operate effectively and economically on slopes up to 25 percent.

Topographical limitations in the study area do not eliminate a significant amount of the harvest area due to biomass source inaccessibility.

b. Accessibility

The study area has an excellent public road network and a well developed private road system.

Logging contractors and landowners have always evidenced a willingness to build roads as necessary to harvest timber. There is no reason to think that whole-tree chip harvesters will be different in this respect. As an example, a large landholder in upper New York State has found it economically feasible to construct roads up to 10 miles long for removal of timber almost entirely in the form of whole-tree chips at current market prices.*

Unless there are other limiting factors, accessibility within reasonable skidding distances to a large portion of

*Correspondence with R. L. Meyer, resident forester, Sher-Don Associates, P. O. Box 427, Massena, New York.

the commercial forest acreage in the radius of the Westbrook study area would not be an issue.

Richard Wagner, professional forester and local logger, and David Clements, forester for S. D. Warren Company, estimated that 75 percent of the commercial forest land within the study area falls within one-half mile of an existing roadway, either public or private (personal interview, J. Phillip Rich, December 14, 1978). These statements indicate that at least 75 percent of the commercial forest land is within a reasonable skidding distance of an existing roadway. In addition, there is the historic willingness of loggers and landowners to build access roads.

c. Expected Yields in Actual Harvesting Situations

On an experimental harvesting demonstration by the Percival Logging Company under the supervision of S. D. Warren's forester, David Clements, the cruise statistics (estimates) for sawlogs and pulpwood were considerably lower on all products except oak sawlogs and showed no fuelstock at all. Actual harvesting data was consistently over the estimates. The most significant statistic indicated that 275.5 tons of whole-tree chips (fuelstock) were removed in addition to the standard products, and had not been included in the original cruise estimate.

The acreage was computed to be 5.4 acres from data supplied by S. D. Warren. This results in a harvest of 51 tons per acre of whole-tree chips, in addition to all

ordinary timber products. In the opinion of David Clements, this was an average harvesting site for the area, in terms of forest lands they normally harvest in the Westbrook study area.

There are two important factors to be considered in using this data:

- (1) This was a clearcut site conversion. It is expected that whole-tree chip harvesting in the study area will not be clearcutting except for site conversions.
- (2) All merchantable products were removed, including pulpwood, and only residues and culls were chipped. Still, there were 51 tons of whole-tree chips per acre delivered to the S. D. Warren mill.

According to the S. D. Warren forestry staff, 25 to 30 tons per acre could be expected on a partial cut, after separating out all merchantable products. (Private correspondence, David B. Clements, forester, S. D. Warren Company, 27 March 1979.)

On a thinning of a 20-year-old red pine plantation in the same area, Richard Arbour reported that in addition to timber and pulpwood in amounts far exceeding the cruise data, 336 tons of whole-tree chips were removed in a 50 percent selective thinning of four acres--a total of 84 tons of biomass fuelstock per acre in whole-tree chips alone. (Personal interview, J. Phillip Rich, 19 May 1978.)

The Sewall report shows a total of 85 tons per acre for all biomass on trees 4 inches DBH and up (69 tons/acre of growing stock and 16 tons/acre of cull).

d. Prices

Prices for harvested biomass as fuelstock for the proposed conversion facility have been determined using the best available information. Data has been utilized from a wide variety of sources, including published information, actual on-site time-cost studies of harvesting operations, interviews with loggers, and engineering judgment based upon experience.

It should be understood that the requirements of the biomass plant are unique and that there is no existing harvesting system and operations data available that precisely matches for comparison purposes. Operations have been studied in which the products were sold to pulp-paper mills and other firms who use chips primarily for processes, not as fuelstock. Furthermore, there are no contractual arrangements as yet for obtaining fuelstock for the proposed facility and none can be made until subsequent phases of the project are initiated. Thus, the figures presented here are offered as the best estimate of the price for fuelstock in 1979 dollars. These estimates are based upon utilizing the whole-tree chipping method in an integrated harvesting system in which trees are sorted at the landing and sold at their highest value, leaving only the tops and limbs and cull trees for fuelstock. On this

basis, the estimated costs in 1979 dollars for fueling the proposed biomass conversion facility from harvested biomass are:

Felling, forwarding, and chipping	\$10.52
* Stumpage (paid to landowner)	1.10
Truck transport (35 mile average haul)	2.38
	<hr/>
Total price per green ton (delivered to the plant)	\$14.00

The cost of felling, forwarding, and chipping includes the actual day-to-day operating costs, plus the purchase of capital equipment and financing portions thereof through normal channels available to the prospective logging contractor. It is based on the harvesting systems recommended elsewhere in this study for best combinations of equipment for efficient harvesting under the conditions in the Westbrook area. All known factors that enter into the overall cost-price structure have been taken into account--equipment life cycles, operator productivity and labor rates, contractor's costs such as insurance and fringe benefits to his employees, maintenance and repair costs, salvage values of equipment upon retirement, and other factors that add to the overall operating costs.

*The stumpage paid to the landowner is for the fuelstock only, that is, the \$1.10 per ton is the portion of the overall stumpage price allotted to fuelstock.

e. Contractor Availability

A study and report on contractor availability was made by W. Robert Dineen, Consulting Forester, of Bridgton, Maine. The results of this study indicate that there are adequate existing harvesting contractors in the area who would be interested in providing fuelstock to the biomass conversion facility.

Mr. Dineen interviewed 38 individuals who were loggers or represented wood-using industries and were closely associated with the logging field. With only a few exceptions, all thought that the idea of using wastewood as a fuelstock was good and should be pursued further. Some said they had been interested in it for some time based upon articles they had read or previous contact with sawdust burners. Twenty-two of these people were interested in providing fuelstock for chipping and possibly purchasing a chipper or doing contract chipping.

The total projected contractor availability is shown in Table 2-6.

TABLE 2-6

TOTAL PROJECTED CONTRACTOR AVAILABILITY

	<u>Producers</u>	
	<u>Large Volume</u>	<u>Small Volume</u>
Interested in providing fuelstock	21	17
Good capability (financial, managerial, experience)	15	6
	<u>Chippers</u>	
	<u>Large</u>	<u>Small</u>
Would purchase chippers	12	3

The harvesting system recommended by this report indicates that seven large chipping contractors can produce the required amount of fuelstock and that a combination of large and small-volume operations will be anticipated. The projections above will meet the requirements even if only half the contractors actually enter the field as suppliers to the conversion facility.

Several other important facts were also brought out during this study:

- (1) Loggers and logging contractors will require considerable education and training in the methods and practices required to make this operation successful. Their understanding of the machinery, economics, and silvicultural requirements is imperfect and a demonstration program is essential.

(2) A well-planned and organized forestry management plan is a necessity for the proposed fuelstock procurement system. Good forestry practices must be followed and the harvested trees must be utilized to their highest economic values. Landowners and the general public are becoming more aware of the forestry resources of the area and are very sensitive to poor practices.

(3) Both the large- and small-volume producers would continue with their existing business and provide their present products, but would adapt their operations to the production of fuelstock as an added source of income.

(4) The best interests of the logging industry in the area require that adequate prices be paid for the fuelstock to assure a profit incentive and a long-term availability for fuelwood.

III. HARVESTING SYSTEMS

The following sub-sections are included in this section:

- A. INTRODUCTION
- B. ANALYSIS OF CURRENT HARVESTING SYSTEMS
- C. EQUIPMENT AVAILABLE
- D. SELECTION OF EQUIPMENT

A. INTRODUCTION

The purpose of this section is to describe and evaluate harvesting systems and recommend the systems for obtaining fuelstock for the proposed biomass-burning power plant in the Westbrook area of Maine.

Harvesting by definition consists of removing trees from the forest and delivering the biomass to a suitable place for transportation to the use point. In selecting harvesting systems, all aspects of the operation must be taken into account and any system with a "fatal flaw" should be removed from further consideration. Particular aspects of harvesting that must be considered include: (1) compatibility with succeeding operations, (2) environmental standards, and (3) good silvicultural practices. This section presents the results of a study covering all aspects of harvesting; it is organized in a logical sequence as follows:

- B. ANALYSIS OF CURRENT HARVESTING SYSTEMS
- C. EQUIPMENT AVAILABLE
- D. SELECTION OF EQUIPMENT

In Section B., Analysis of Current Harvesting Systems, harvesting systems have been described and analyzed, not only in the Westbrook area of Maine, but generally in the U. S., Canada, and the Scandanavian countries, where forest management is more intensively practiced than in the New England area. Current

harvesting systems have been devised for supplying wood to existing industries, that is, primarily the lumber industry, the pulp-paper industry, and closely related forest products industries. There are no existing harvesting systems that supply wood as fuel-stock for a biomass-burning power generation plant of the size proposed for the Westbrook complex (50 MW). There is one small utility power plant (10 MW size) in Burlington, Vermont, that has been operating at the 6-7 MW level using biomass as a partial fuel-stock with oil as a supplementary fuel (25 percent).⁽³⁻¹⁾ This plant has received fuel from an experimental program and from independent contractors.⁽³⁻²⁾ Numerous other power plants and associated harvesting systems are in the planning stages, but most of the plants are also in the 10 MW range.

The purpose of this study is to develop information and determine the most feasible harvesting methods for a 50 MW power plant in the Westbrook area of Maine. Therefore, the approach of this study has been to evaluate the harvesting of wood for existing commercial purposes, and to examine the possibilities and potential for using existing methods and equipment for the proposed biomass-burning facility.

Systems are first considered from the technical standpoint and then, if technically feasible, from the economic standpoint. Any equipment with a "fatal flaw" is removed from further consideration.

In Section C., Equipment Available, the various types of equipment used for harvesting wood are described and evaluated as

to their suitability in supplying fuelstock for the proposed biomass-burning power plant. Specifications are given for machines of typical size ranges and operating characteristics. A comprehensive list of equipment by make and model number is given at the end of this section.

In Section D., Selection of Equipment, recommendations are made for compatible sets of equipment that will be technically and economically feasible under varying harvesting conditions--terrain, weather, tract size, tree size, etc. No single set of equipment will provide both technical and economic viability under all sets of conditions.

B. ANALYSIS OF CURRENT HARVESTING SYSTEMS

1. EXISTING METHODS

Harvesting systems in use today have been designed primarily to serve the existing forest products facilities--pulp and paper mills, sawmills, plywood and veneer plants, etc. There are no harvesting systems in existence designed specifically to serve a 50 MW biomass-burning power generation facility, since the proposed facility is the first of its kind. Therefore, in analyzing, evaluating, and selecting a suitable harvesting system for the biomass power generation facility, we have started with existing methods that serve facilities with similar requirements. Three such methods are employed and are classified in relation to the materials they produce, as follows: (1) shortwood method, (2) longwood method, and (3) whole-tree (above-ground) chipping method. (3-3) The practice of classifying logging systems into these three categories is widely accepted--even on a world-wide basis as explained by J.A. McNally of the Canadian Pulp and Paper Association. (3-4)

Some experimental work has been done in the harvesting of roots as well as the above-ground portion of trees, however, at present there are no existing applications of this method as a large scale operation for an industrial application. Additional information on this approach is given in the Appendix. The three methods listed above represent the historical development of harvesting systems for industrial uses.

Harvesting of wood in New England was simply performed for many years. Axes and saws were used for felling, de-limbing, and cutting up trees, and horses or oxen were used to drag the logs out of the woods to a site where they could be shipped to the mill--by river, railroad, or highway truck. This image of logging persisted until the late 1950's when chainsaws became readily available for felling trees, and tractors and crawlers gave mechanical assistance to the logger. In the mid-to-late 1950's, articulated rubber-tired skidders became available for dragging trees out of the woods. The early to mid-1960's saw the development of knuckleboom loaders that lift logs and load them onto vehicles. In-woods transport vehicles were developed further as clambunk skidders and forwarders were introduced. These vehicles went into the forests and were loaded with wood, delivering it to the landing, where it was transferred to highway trucks. The late 1960's through the early 1970's saw the introduction of tree-length logging and grapple skidders--machines with hydraulically operated arms that grasp bunches of logs and drag them to a landing. In 1971, the concept of whole-above-ground tree harvesting was introduced to the logging industry as an off-shoot of the need for removing dead and diseased trees in urban areas. With this approach applied to logging, the entire tree is dragged to a landing and converted into chips in a matter of seconds. Since 1971, whole-tree harvesting and new equipment development has increased at a rapid pace, enabling the logging profession to design harvesting programs to meet exacting conditions. Whole-tree chipping now

supplies a significant percentage of the wood for the paper industry. A wide variety of high specialized equipment is now available to handle almost any task in the harvesting process. The three methods of harvesting are described in more detail as follows:

- Shortwood Method (See Figure 3-1): Shortwood consists of logs in lengths of 4 feet to 8 feet as commonly used for pulpwood by the pulp and paper industry. This is the oldest conventional logging method. The trees are felled, de-topped and de-limbed, cut into the desired lengths, and hauled to a suitable collection point for transport to the pulp mill as "roundwood". The tops and limbs are commonly left on the ground in the woods (the "stump" area). This method is widely used in the forest products industry and is practiced to supply a major portion of the pulpwood used at the Westbrook complex, the proposed location for the biomass-burning power generation plant. The shortwood method requires de-barking and chipping of the roundwood at the mill to provide fiber for the pulping process. Chipping (but not de-barking) would also be required if this method were used to provide fuel for the biomass-burning facility.
- Longwood Method (See Figure 3-2): Longwood is defined as any logs over 8 feet long up to the full length of the tree minus its top (tops are cut off at some nominal diameter such as 4 inches). This method is used in the forest products industry where trees are harvested for lumber and

FIGURE 3—1 SHORTWOOD HARVESTING METHOD

FIGURE 3—2 LONGWOOD HARVESTING METHOD

and transported to sawmills. In recent times, paper mills have also begun using this method to a large extent. It requires the trees to be felled, de-topped, de-limbed, and transported to a landing, where they can be loaded onto highway trucks. When used for pulpwood, long logs are usually cut into shorter lengths at the mill to get typical pulpwood lengths, and then de-barked and chipped, the same as for shortwood. If this method were to be used for the biomass-burning facility, the same operations would be required (except de-barking), since the biomass facility would require chips.

Whole-Tree Chipping Method (See Figure 3-3): Whole-tree chipping is a relatively new method that is finding increasing applications in the forest products industry as an "integrated harvesting system". Essentially, it consists of felling the trees and transporting them to a landing, where they are sorted into piles by economic value--logs for lumber, veneer, turning stock, etc. (highest), pulpwood (next), and fuelstock (lowest). The fuelstock trees are then converted entirely to chips--trunks, limbs, and foliage--and blown into a waiting van for transport to the using industry. It is also technically feasible to chip the pulpwood at the landing and ship the pulpwood chips to the paper mill.⁽³⁻⁵⁾ Some paper mills can use a significant percentage of their pulpwood as whole-tree chips. In addition, equipment has been developed for

A. FELLING AND BUNCHING

FIGURE 3—3 TYPICAL INTEGRATED HARVESTING SYSTEM

debarking chips as received at the mill, thus improving the outlook for whole-tree chipping for the pulp-paper industry. Other industries, such as particleboard manufacturing, can use large percentages of whole-tree chips, and represent a steady market for this operation. (3-6)

This method makes full use of forest biomass and leaves the forest in a clean condition after harvesting. It would be ideal for a biomass-burning facility, since it harvests the entire tree and all types of chips have good fuel value.

This method is presently in use in the Westbrook area and it has been used in Central Maine as a source of chips for a particleboard plant. The proprietor of these operations, David Percival, has indicated his interest in establishing a whole-tree chip harvesting operation for supplying fuel to the proposed biomass-burning facility in the Westbrook area.

2. HARVESTING OPERATIONS

Regardless of the harvesting system used, there are four basic harvesting operations that must be performed: (1) felling, (2) processing, (3) skidding or forwarding, and (4) loading on transport vehicles. Felling is always the first operation but processing may follow skidding or forwarding; loading is always the last operation. Some other operations such as collecting and bunching trees in a pile, piling of shortwood after cutting, and loading of shortwood in the woods may also be required. The four items listed, however, can be considered as typical for

the usual logging operation. Each operation adds an increment of cost and the costs for these basic operations can be used to compare the costs of the three harvesting methods. These operations are defined as follows:

- Felling: Felling consists of cutting off the tree at or near ground level. Felling has been done manually by chainsaw for many years but mechanized vehicles equipped with hydraulically operated shears, saws, or augurs are now available to reduce the manual labor and increase the logger's productivity.
- Processing: Processing consists of cutting off the tops and limbs, cutting into shortwood, or converting the entire above-ground portion of the tree into chips. In conventional logging, the trees are usually trimmed where they fall, and then dragged to a landing near a road, where they may be cut into shortwood or collected as tree-length longwood.
- Skidding or Forwarding: Skidding consists of dragging the whole tree or portions thereof along the ground. Forwarding is a newer operation in which the felled tree is lifted and placed on a trailer-type vehicle or a flat-bed open framework (bunks) for transport to the landing.
- Loading: Loading consists of placing the biomass on an over-the-road transport vehicle for a shipment to the user (or, in some cases, to a railroad for shipment to the user).

3. OPERATIONS PERFORMED IN TYPICAL HARVESTING SYSTEMS

The operations that are performed in typical harvesting systems are shown in simplified form on the attached block diagrams (See Figure 3-4). While these are considered as typical of what is used today in the Maine woods, many variations and other combinations can be found (in Maine and elsewhere). Two distinct areas are identified on each diagram: (1) the stump area, where the standing trees are felled, and (2) the landing, where the biomass is loaded onto highway trucks for transport to the plant.

The typical shortwood harvesting system requires the operations of felling, de-limbing, topping, bucking, piling, forwarding or skidding, and loading for transport to the user's plant. Two versions of this system are shown as alternates on the diagram. The operations of de-limbing, topping, bucking, and piling may be performed in the stump area before forwarding to the landing, or they may be performed at the landing, in which case the trees are skidded to the landing. The loading of shortwood is normally performed by a loader mounted on the transport truck.

In the typical longwood system, the felling, de-limbing, and topping operations are performed in the stump area and the longwood is skidded or forwarded to the landing for loading onto highway trucks. In some harvesting systems, it is cut into pulpwood length before loading onto transport trucks.

FIGURE 3—4

In the typical whole-tree chipping system, the felling and bunching is done in the stump area; the trees are skidded or forwarded to the landing where they are sorted for economic value. If there is a market for sawlogs and the timber stand has an adequate supply of sawlog trees to make processing economical, then these trees are set aside at the landing and only the trees of lower value are chipped. The sawlog trees are also set aside, de-limbed, topped, and loaded for transport to a sawmill. If there is a market for pulpwood as roundwood, then these trees are also set aside, delimbed, topped, and shipped to a paper mill. Only the remainder of the harvest--the rough and rotten, thinnings and weed trees, etc. are chipped as fuelstock. The chips are blown into a trailer for transport to the biomass burning facility.

Analysis of these systems as a historical sequence shows a trend towards reduction in the number of operations and increasing mechanization. This trend is a reflection of the efforts toward cost reduction, increased labor productivity, improved working conditions, safety, greater utility of forest resources, and simplification of logging procedures. This trend continues at present and has as its ultimate objective the complete mechanization of harvesting--the delivery of raw wood from standing tree to the mill in usable form untouched by human hands and at a viable cost. (3-4)

4. COST COMPARISON

A table of comparative costs for harvesting systems is given on the following page. This table is based upon data presented in a study of harvesting methods, costs, and productivity made by the LSU/MSU Logging and Forestry Operations Center. This study, entitled "Harvesting Cost Analysis" was written by Glenn M. Plummer, Harvesting Development Manager, Georgia Kraft Company, Rome, Georgia. (3-3) It is based upon data accumulated by Georgia Kraft through eight years of record keeping on the cost of harvesting, machine rate surveys, and productivity rates. The LSU/MU report was used because it is the only single source found that could be considered consistent in its data. Concerning the data base and accuracy of results, the author states: "With the wealth of factual data which we have been able to accumulate, this analysis is very accurate and valid."

The data in the attached cost comparison table are valid for comparison purposes but do not necessarily represent absolute values that would be encountered in today's market. They are taken from the Southeast and from species that differ from those in New England, however, as a comparison of harvesting methods, the operations are similar and the relations between costs for various operations will be relevant. The purpose of the study, as stated in the FOREWORD by the director of the LSU/MSU Logging Center, is to provide information that will enable the reader to make a management decision as to which method fits his operation best.

TABLE III-1

TYPICAL HARVESTING SYSTEMS COST COMPARISON *

1. <u>Shortwood Method</u>		Unit Cost \$ Per Ton
Felling (chainsaw)		1.12
Processing (de-limb, buck)		1.95
Skidding (cable skidder)		3.76
Loading (truck with loader)		<u>1.89</u>
	TOTAL	8.72
2. <u>Longwood Method</u>		
Felling (chainsaw)		1.12
Processing (top, de-limb)		1.54
Skidding (cable skidder)		3.76
Loading (knuckle boom)		<u>1.96</u>
	TOTAL	8.38
3. <u>Whole-Tree Chipping Method</u>		
a. <u>Partly Mechanized Method</u>		
Felling (chainsaw)		1.12
Skidding (cable skidder)		3.76
Processing (whole-tree chipper, including loading)		<u>.71</u>
	TOTAL	5.59
b. <u>Fully Mechanized Method</u>		
Felling (feller-buncher-accumulator)		2.27
Skidding (grapple skidder)		.86
Processing (whole-tree chipper, in- cluding loading)		<u>.71</u>
	TOTAL	3.84

*Figures are valid for comparison purposes only,
not absolute values in today's market.

Data taken from LSU/MSU study (Reference 3-3,
Appendix) for Southeastern conditions and species.

The results of the study indicate that whole-tree chipping is significantly less costly than delivered roundwood at the landing.

When these costs are viewed from the standpoint of an overall fuel procurement system, the cost differential is in favor of the whole-tree chipping method, since the shortwood and longwood systems do not produce chips--the chipping operation must be performed at the mill or user's plant. This adds cost to the fuel procurement system--a cost that is not part of the harvesting cost, since the harvesting operation stops with the loading of biomass on trucks at the logging area.

To give a more comprehensive view of the cost comparison, the whole-tree chipping method has been evaluated in two ways: (1) as a partly mechanized operation typical of what might be encountered in a small operation where capital is lacking, and (2) as a fully mechanized, capital-intensive operation. The partly mechanized method uses the same means of felling and skidding as the shortwood and longwood methods, that is, chainsaws and cable skidders. The fully mechanized method utilizes wheeled or tracked vehicles for felling, collecting, and skidding the trees to the chipper. The full mechanized method has a lower unit cost than the partly mechanized method due to its greater productivity, smaller operating crew, and higher efficiency.

The partly mechanized method, with unit costs lower than the shortwood and longwood methods, shows that an existing logging operation using regular chainsaws and cable skidders (which they already have) could simply purchase a whole-tree chipper and go into business as a fuel chip supplier with a lower unit cost than their charges for harvesting pulpwood (shortwood or longwood).

Other researchers have also concluded that whole-tree chipping provides a lower unit cost than other methods. Typical examples of statements to this effect include the following:

- (1) Three research engineers from the USDA Forest Service writing in the Forest Products Journal, March, 1974, made the following statement concerning the cost of whole-tree chipping (3-7):

"We estimate that whole-tree chipping followed by bark removal is \$3 per cord less costly than conventional chips produced from debarked roundwood." (This is approximately \$1.50/ton--See Appendix C).

Notice that they are discussing harvesting methods for the pulp and paper industry, where bark must be removed either before or after chipping. In the present instance where the chips are used for fuel, bark removal is not a factor and the bark removal operation spoken of in their statement is not required.

They have given a cost of \$4.30 (\$2.15/ton) for debarking of chips at the mill, thus making a net advantage of more than \$7 per cord (\$3.50/ton) in favor of the whole-tree chipping method for fuel chips. (See Appendix C).

- (2) A report on the "Utilization of Low Grade Hardwoods for Fuel in the Washington and Hancock Counties of Maine" prepared by the School of Forest Resources, University of Maine, (3-8) states the following concerning harvesting systems: "In reviewing alternative methods for the production of chips in the context of this investigation, both the current applicable literature and discussions with prominent land management and harvesting experts endorse the view that chipping of the raw material in the woods offers substantial advantages." Among the advantages they point out later are: reduced labor costs, minimized handling costs, and substantial increases in the potential yield of chip material from raw wood.
- (3) Professor Harold E. Young of the University of Maine says in his paper "The Machines are Coming, The Machines are Coming" (3-9) (1974): "Mechanized harvesting is a response to the shortage of woods labor. Despite the high cost of the machines, there is a decrease in the cost of wood delivered to the mills."

(4) In speaking of the costs for harvesting wood using the whole-tree above-ground technique, Eric Richard Ellis, Jr., stated the following in his master's thesis December, 1977 concerning tree chipping:

"These costs are substantially lower than the costs for conventional harvesting. The cost of labor per cord (ton) is greatly reduced. (3-10)

5. OTHER CONSIDERATIONS

Having examined the advantages of whole-tree chipping, it is appropriate to report other factors that would affect the final selection of the system to be recommended for the biomass power generation facility. In addition to lower unit cost, whole-tree chipping in New England offers at least two inherent advantages over the other (older) methods of harvesting: (1) it leaves the forest in a clean condition, free of the limbs and foliage commonly left to rot on the ground with the other methods, and (2) it provides greater utilization of the forest resources. (3-11)

The condition of the forest after harvesting has become a subject of great concern in recent years. Landowners, sportsmen, and many others have objected to the unsightly conditions created by conventional logging systems, which leave large quantities of slash material after removing the merchantable trunks (see Figure 3-5).

FIGURE 3-5.

The pile of debris in the upper left is slash that will be left at the landing under currently conventional logging practices. This picture was taken on the Hannington Brothers log job near Lincoln, Maine, in March 1978.

In addition, professional foresters have pointed out that it is largely the slash left after logging operations that provides the fuel for forest fires. Live green trees do not burn unless they are subjected to intense heat from another source--typically, the brush piles and scattered biomass debris left from the conventional logging systems. The basic reason for this leftover biomass is the lack of a market for the wood and the economic burden of removing it by other means. Logging operations typically take only what is needed for the market--sawlogs for lumber, pulpwood for paper mills, etc.

Concern have also been expressed that removal of whole trees from the forest on a large scale could result in eventual depletion of essential nutrients. For the proposed biomass-burning plant in the Westbrook area, however, it is doubtful that the harvesting program will have any significant effect over the economic life of the plant. Additional research into this area is deemed advisable.

The use of whole-tree chipping as a harvesting method for a biomass-burning power plant is a good solution to the problem from the standpoint of aesthetics as well as fire prevention.

The greater utilization of forest resources through whole-tree chipping is a very significant aspect of this method, since it eliminates a great waste of natural resources. Approximately 30-35 percent of the above-ground portion of a tree consists of branches and other parts that have no commercial value as timber or pulpwood. (3-5)

FIGURE 3-6

The small pile of wood chips in the foreground are the only evidence of a landing at roadside where up to 300 tons of whole-tree chips were removed daily in the fall of 1977. (Dashnaw Logging Co., Peru, New York, September, 1978)

It could be harvested as fuelstock in the whole-tree chipping method, instead of being wasted.

The use of this biomass as fuel could eventually provide a significant amount of energy to ease our country's energy problems due to limited supplies of oil and gas.

In addition to the basic advantages already cited, whole-tree chipping has a significant advantage over other harvesting systems where the timber stand consists largely of small trees. The use of mechanized equipment to shear and collect the trees efficiently and deliver them to the whole-tree chipper can be economically feasible in places where a conventional logging system would be unable to harvest enough suitable pulpwood or timber to sustain a profit-making operation. This application to small-diameter trees is particularly important in forestry thinning and weeding, both for plantations and natural stands. Forestry thinning is a silvicultural practice in which rows or groups of trees or single trees selected by a forester are removed to provide growing space, light, and nourishment that promotes healthy growth of the remaining trees. This practice is vital for the development of timberlands to their maximum economic potential and is recognized by most forest land owners as well as professional foresters. Before the advent of whole-tree chipping, it was necessary to pay a crew to perform this thinning and weeding operation, since the trees removed were of little or no commercial value. (3-12)

The cost of thinning and weeding is so high that very little of it is being carried on in the harvesting area of concern (Westbrook area), even with the availability of federal subsidies under the Agricultural Conservation Program and the Forestry Incentives Program as administered by the Agricultural Stabilization and Conservation Service of the USDA. With whole-tree chipping and a guaranteed market in the form of a 50 MW biomass-burning plant, this thinning and weeding operation can be economically beneficial to landowners as well as good silvicultural practice for the forests.

With an industrial market for whole-tree chips, the harvesting contractor can pay the land owner a reasonable stumpage fee, cover his operating costs, and make a reasonable profit through the sale of the chips. The importance of this advantage of whole-tree chipping and its application to the provision of fuelstock to the biomass-burning power plant is graphically illustrated by the following example:

The Percival Logging Company, owned and operated by David Percival, is a small logging firm in central Maine that utilizes the whole-tree chipping method. Richard Arbour, Maine District Forester, described the benefits of forestry thinning performed by the Percival Company on a 20-year-old red pine plantation in Central Maine. (3-12) Percival had thinned the plantation by removing every third row of trees in the winter of 1977-78. (Figure 3-7).

FIGURE 3-7

Red pine plantation thinned every third row in fall of 1977. Because of the whole-tree-chip harvesting system used by the logging contractor, the landowner was paid stumpage instead of having to pay for the thinning. (Percival Logging Co., Andover, Maine, May, 1978)

He paid the landowner \$1.50 per ton or \$60 an acre for the wood, used mechanized equipment for the operations and sold the whole-tree chips to a particleboard manufacturer. Arbour went on to say that before the advent of whole-tree chipping, the landowner probably would have had to pay up to \$40 an acre to have the plantation thinned. Furthermore, the trees removed would have presented a disposal problem, since they had no commercial value. Thus, the harvesting operation was profitable to the landowner and the logging contractor, as well as being of great benefit to the plantation (see Figure 3-8).

By being able to harvest small trees economically, it is possible to both increase the amount of harvestable biomass for fuelstock and also improve the health and quality of the growing stock, enabling it to reach its maximum economic potential.

6. ECONOMIC AND PRODUCTION CONSIDERATIONS

The cost comparison given in paragraph 4 showed that whole-tree chipping is more economical than the conventional shortwood and longwood harvesting systems. It also showed that a fully mechanized whole-tree chipping system has a lower unit cost than for a partly mechanized system.

As with most industrial operations, the advantages of lower unit costs are achieved by increased capital outlays for mechanical equipment. The fully mechanized approach requires a large investment, not only for the whole-tree chipper, but also for the mechanized vehicles that fell, bunch, and drag the trees to the chipper.

FIGURE 3-8

White pine plantation showing stunted growth and poor quality due to weevil infestation. This stand was thinned with a profit both to the logger and the landowner in the fall of 1977, using the whole-tree chipping system. (Richard Arbour, Maine Forest Service, and J. Phillip Rich), (Percival Logging Co., Andover, Maine, May, 1978)

These expenditures, however, are economically justified by the increased production and high volume of material produced as long as the system is operated with reasonable efficiency. The ideal condition is when the chipper is kept in full production for the contractor's designated working period supplying chips to a favorable market. The number and combination of other machines and men that supply the chipper should be balanced so that all equipment is operating at its intended capacity and that there is enough reserve capacity in the system so that a failure of one unit does not cause a complete loss of production.

Thus, the equipment to be selected for a particular logging operation using the whole-tree chipping method is based upon economic and production considerations. It requires close consideration of many related factors--in particular, the production rates of each unit as well as the capital and operating costs. A properly balanced system with full (or nearly full) production at each unit will be highly productive and will justify the large capital outlays. A well-designed system operating on a planned harvesting site can supply even the largest whole-tree chipper. If the productivity declines or the system gets out of balance, the revenue from chip sales may no longer sustain the operation economically. Smaller chippers can be obtained and used to provide a balanced system where the timber size or quantity is insufficient to keep a large chipper in operation most of the time.

7. THE INTEGRATED HARVESTING SYSTEM

An integrated harvesting system is one in which the logging crew removes trees and skids them to the roadside landing for sorting by economic value. The high-value logs are separated, loaded for transport, and sold to appropriate users. The pulpwood can also be sorted and shipped to a paper mill. Only the leftover, low-grade wood is chipped for use as fuel. Under this concept, the logging contractor can maximize his revenue from sale of timber and can improve his economic position. This approach requires a combination of important factors, primarily markets for each of the products, but also, the skills in timber judging, and a good balance of equipment. The chipper is the key machine. Enough leftover cull wood must be available to keep the chipper reasonably busy during the workday. The size of chipper is selected to produce the required balance with the number of other machines that are supplying the trees for chipping or shipment as higher grade products.

A number of logging contractors are known to be operating in this manner in the New England states. Dashnaw Logging Inc., of Peru, New York, has been doing whole-tree chipping since August of 1974.⁽³⁻¹³⁾ Percival Logging Co. of Andover, Maine, has been in the whole-tree chipping business since 1976.⁽³⁻⁶⁾ Letourneau and Methe of New Bedford, Massachusetts, is also doing whole-tree chipping in the New England states⁽³⁻¹⁴⁾.

These operations range from small to large with whole-tree chip production in the range of 100 to 300 tons per day. The

basic reason for this small production and relatively few contractors is the lack of any significant market at this time. These chips are used in a very few mills, and practically none are used for combustion.

Dashnaw Logging initially had contracts for clearing highway rights-of-way and they had to throw away the chips because there was no market. Later on, they located a paper mill that could use a small percentage of whole-tree chips and began operations on the mill's "company land". Under their present operating method, they make only one sorting separation--sawlogs and "what's left". The market for sawlogs is poor in the area, so most of the revenue comes from the chips, which are trucked to the paper mill. The company is economically successful and has determined the proper balance of machines for its operations, as well as the silvicultural approach.

At first they used clear-cutting as the silvicultural practice but found that the regeneration in the desired species was not as great as desired. They then switched to strip cutting with alternate 100-foot strips (See Figure 3-9) and found improved regeneration but of undesirable species. Finally, they changed to selective cutting and obtained the desired results, both in quantity and quality. Initially, a forester marked the trees for removal, and the logging crew thinned the forest accordingly. When this was found to have a greater benefit in the re-growth of the forest, the method was continued, except that the logging crews who had reportedly gained sufficient experience, did the selection themselves. They save the best trees for future harvesting as high-grade timber and

FIGURE 3-9

Henry Dashnaw shows poor regeneration in desired species in experimental strip thinning his company did in 1975. Trees were clearcut in 100 foot strips, leaving similar width strips between (Dashnaw Logging Co., Peru, New York, September, 1978) By switching to selective cutting, the company has achieved satisfactory regeneration, both in quantity and quality of the timber stand.

remove the less valuable trees for chipping and pulp-making.

Mr. Dashnaw reports that this approach has proven entirely satisfactory, and both the mill and the logging company are profitting from the arrangement. (See Figure 3-10),

The logging operation of the Percival Logging Company has been described briefly before. This company is also thinning forest lands and separating the trees into sawlogs and culls. The sawlogs bring higher prices and are shipped to sawmills. The cull materials are chipped for sale to a particleboard plant, the only known user of whole-tree chips in the area of operation.

David Percival, the owner-operator, works along with his three man crew, producing a minimum of from three to four truckloads of products a day (combination of chips and sawlogs). The owner-operator is satisfied with his operation, even though the chipper is busy only half the time. His efforts at timber stand improvement have drawn praise from the district forester. Observations of this operation indicated that there was no difficulty in attaining the daily output and that the crew appeared to be happy with their work and the working conditions. Mr. Percival has expressed his desire to set up a similar operation in the Westbrook area to supply fuel chips to the biomass-burning power plant (see Figure 3-11).

8. CONCLUSION

From the foregoing data and discussion, the conclusion is that the whole tree chipping method seems to be the most economical and technically feasible approach to harvesting for the biomass-burning power plant.

FIGURE 3-10

Hardwood stand currently being operated by mechanized system for whole-tree chips. This photograph shows the effect of the selective cut that allows sunlight to reach the forest floor, thus encouraging natural regeneration of existing species, particularly sugar maple. (Henry Dashnaw, J. Phillip Rich) (Dashnaw Logging Co., Peru, New York, September, 1978)

FIGURE 3-11

David Percival delimbs and tops logs that will be sold for higher value use than wood chips in his integrated system. (Percival Logging Co., Andover, Maine, May, 1978)

It is also concluded that the integrated approach is a sound way to assure financial success of a logging operation. With this approach, the trees are brought to a landing and sorted by economic value, and marketed for their highest sale price. Sawlogs bring the highest price, pulpwood next, and biomass for fuelstock the lowest. One or more independent logging firms can enter into contracts for obtaining harvesting rights from landowners and can contract with the biomass plant to supply fuelstock, at the same time selling high-grade products to other industrial plants. This approach is silviculturally sound and makes the optimum use of the natural forest resources. Using selective thinning and weeding it leaves the forest in a clean condition with adequate light and growing space to promote healthy development and regeneration of standing forest resources with improved characteristics and growth potential. At the same time, the logging companies can have a steady, profitable, ongoing business and the user firms will have a reliable supply of raw materials.

C. EQUIPMENT AVAILABLE

1. BACKGROUND

Section C. describes and evaluates equipment used in existing harvesting systems without making any specific recommendations. Recommendations are made in Section D., Selection of Equipment, and are based upon specific harvesting applications, not merely equipment specifications and capabilities. The descriptions presented cover machines that are considered suitable for some harvesting applications in the area of interest. In a few instances, a machine is described briefly and features are pointed out that eliminate it from further consideration.

The various equipment components are listed and described in functional sequence--the order in which they are utilized in the overall harvesting process. Components that perform more than one operation or function are described in detail under the first function of the sequence and then merely mentioned in the succeeding functions.

Because of the wide variety and large group of manufacturers in the harvesting field, we have included lists of equipment by makes and model numbers as a separate Section, Part 6, Summary of Equipment by Manufacturers.

The information presented in this section is based upon a wide variety of sources, including: a three-year survey, attending equipment exhibitions, visits to field logging sites, and interviews with active participants in the logging industry.

While there is a vast amount of literature in the logging field, much of it concerning equipment and operations, the amount of consistent, factual data on productivity and operating costs is relatively small. Manufacturers' literature, for example, generally has higher productivity and lower operating cost data than found in studies by universities and research workers. These figures, in turn, are found to differ from practical information given by operating logging contractors. The effort in this study has been to present the most accurate set of data possible, using judgment as to the validity of all evidence uncovered.

In addition to the literature search and evaluation procedure, an independent study of existing whole-tree chipping operations was commissioned as part of this work. This study was undertaken by Ralph E. Clifford, forestry consultant, Orono, Maine. His report is presented in Section E., Time-Cost Study.

The magnitude of the task of determining precise figures for productivity and operating costs is illustrated by the following procedure used by the USDA Forest Service in preparing its Final Report in Forest Residues Energy Program.

Production rates are initially given as IDEAL volumes and tonnages per machine hour. These figures, however, are far from realistic because they do not take into account such factors as machine breakdowns, scheduled maintenance, operator efficiency and fatigue, operator motivation, break time, etc. These factors are accounted for by estimating machine utilization time (80 per-

cent of scheduled hours) and operator efficiency (70 percent of theoretical machine productivity).

The skill, experience, and work-attitude of the operator is often more important in productivity than the actual machine specifications. Some operators can get the same production from a feller-buncher (see page 3-49) without an accumulator as other operators get with the addition of an accumulator. Similarly, some operators devise ingenious ways of getting greater productivity and higher efficiency out of "standard" equipment that has been operated in the logging field for many years (see page 3-66). These factors make it difficult to assign an accurate figure to operator efficiency and only an "average value" can be presented based upon experience and judgment.

The figures given in this report utilize data from private record-keeping as well as published handbooks and wage rates.

Finnish and Swedish forestry equipment has been investigated in the effort to make this report complete. The Scandinavians have been leaders in the logging field and have developed machines and methods along different lines than in the U. S. and Canada.

Future possibilities in machine development include topwood processors, stump harvesters, advanced forest transport vehicles, and snowblowers for improved winter harvesting (See Appendix F).

2. FELLING

The equipment available for felling trees can be divided into two basic categories: (1) manually operated equipment, and (2) mechanized equipment. Under manually operated equipment there

is only the chainsaw and the chainsaw equipped with a felling frame. Most of the mechanized equipment available can perform felling only. Other machines and attachments which are more sophisticated can do other operations also. In general, the trend in machine development has been toward building machines to do several operations, of which felling is always the first. Machines that do felling only are called fellers; machines designed for additional operations such as bunching of trees are feller-bunchers. Machines are also available to do felling, de-limbing, bunching, and forwarding of logs to the roadside for chipping or shipment as longwood. All machines that do felling are described here, since that is the first operation in harvesting.

a. Chainsaws

The chainsaw as commonly used in the logging industry is a gasoline-powered, hand-held unit operated by one man to fell trees. This is the most common method for felling trees, since it is low in cost, easy to operate, and can be used on a wide variety of tree sizes, terrain, and weather conditions. It can be carried and used anywhere a man can go, and in many instances, is the only practical way to fell trees (for example, on steep slopes, in swamps, and for large trees).

While the chainsaw is still widely used, it has the disadvantage of requiring rather strenuous labor when used continuously and poses a hazard from exposure to the blades and the falling tree. With the introduction of mechanized

vehicles that enable the operator to fell trees without leaving the vehicle cab, there has been increasing resistance on the part of woodsmen to use the chainsaw.

The chainsaw can be fitted with a metal frame that enables the logger to operate and maneuver it without bending over. This makes his job safer, more efficient, and less physically demanding for felling small trees. The frame, however, is not in standard use in the United States, but is common in Scandinavia (See Figure 3-12). The use of the frame-mounted chainsaw for small trees has increased production by up to 30 percent in Finland (3-15).

Even in a highly mechanized harvesting system, chainsaw felling will be required where the vehicles cannot be safely maneuvered or used, such as:

- Rough terrain, fragile ground, and steep slopes (over 25 percent--see Appendix D)
- For large trees, especially trees to be used as sawlogs (feller heads are usually limited to a maximum tree diameter between 16 and 24 inches).

Chainsaw felling usually has lower productivity than mechanized vehicles with hydraulic shears. The efficiency of the chainsaw is largely dependent on the operator, but other factors such as tree size, terrain, and weather conditions will have a bearing upon productivity. Production rates for chainsaws doing directional felling are anywhere from 130 trees (72 tons) to 500 trees (275 tons) per 8-hour working day (9-34 tons/hour) (3-16, 3-17).

FIGURE 3-12

Felling small trees with chainsaw
felling frame. (Small Equipment
Demonstration, Dixfield Notch,
New Hampshire, October, 1978)

Chainsaw production for tree-length harvesting in Maine is estimated at upwards of 8 tons per hour (based on University of Maine figures) (3-18). One whole-tree chip harvesting firm reported a felling production of 19 tons per hour (3-19)

Commercial chainsaw models are manufactured by many firms and are readily available in the price range from \$300 to \$500. Typical manufacturers are Poulan, McCullough, Homelite, Stihl, Johsereds, etc.

b. Fellers (Grapple-Shears)

The feller represents a "first-step" transition from manual logging (with a chainsaw) to a fully mechanized, sophisticated operation in which everything is done by machines. The typical machine for feller mounting is a vehicle designed for other purposes such as front-end loading, skidding logs, construction work, etc. to which a mechanically operated shear has been attached. Thus the feller is a machine that can be assembled by a logging firm that already has a suitable woods vehicle and needs only to purchase and install the felling head (see Figure 3-13).

The typical feller has a shear for cutting trees that can also be used to grasp the felled tree. It is often termed a "grapple-shear feller". This feature (the grapple) enables the operator to move the tree from the stump area to a place more readily accesible to forest transport vehicles.

FIGURE 3-13

Rome feller head (grapple shear) showing
shear mechanism that grasps and cuts trees.
(Lyle Lancaster, Springfield, Maine, March,
1978)

In operating this machine, the operator can fell a tree and move it to a clearing without leaving his machine. In areas of dense brush, the vehicle can often maneuver more effectively than a man with a chainsaw by simply rolling over the underbrush. The feller is generally more productive than a chainsaw and provides for less operator fatigue and greater safety. The feller may have a reinforced roof and enclosed cab to protect the operator from falling trees and bad weather conditions. It can be operated more effectively than a chainsaw in deep snow, but will lose some of its normal productivity due to time taken by working the feller head under the snow to get a close cut.

The feller is used to its greatest advantage in moderately steep terrain (up to 25 percent slope--See Appendix D) where other vehicles cannot be safely operated and when the trees are larger than 10 inches in diameter. It loses efficiency when trees are smaller than this.

A typical example of a feller is shown in the attached picture. It consists of a John Deere 440-B tractor with a Rome feller (grapple shear) attached. It fells the trees and moves them one at a time to place where they can be skidded out of the woods (Figure 3-14).

The feller has higher operating costs and lower productivity than most of the later developments in mechanization because it has to maneuver into position to grasp individual trees and drag them to a collection point for skidding.

FIGURE 3-14

John Deere 440-B with Rome feller
(grapple shear) pulling felled tree
to cable skidder. (Lyle Lancaster,
Springfield, Maine, March, 1978)

c. Feller-Bunchers

The feller-buncher represents a "second-step" development in the mechanization of logging. This is a machine that fells trees and continues to hold them in the vertical position, while transporting them a short distance within the stump area for depositing into a bunch (pile or stack) for later transport to the landing (Figure 3-15). Except in a few cases, this machine is still a hybrid, like the feller, consisting of a "standard" woods vehicle fitted with a special feller-buncher attachment.

The feller-buncher will generally include an "accumulator", which is a third arm that is used to gather a group of trees so that the operator can reduce the number of trips to the bunch in the stump area (see Figure 3-16). This increases the productivity over the feller, particularly for harvesting small trees, thereby reducing the operating costs. Some machine operators find that they can group several trees without the accumulator, thereby achieving the same productivity and efficiency without the added piece of machinery.

The feller-buncher is more efficient than the chainsaw or the feller in harvesting the larger trees (up to 24 inches in diameter at the butt) but the advantage is not as great as for smaller trees. In thinning operations, the feller-buncher is at considerable advantage because it holds the trees vertically while moving them to a bunch, thereby avoiding the damage typically caused by falling trees and dragging harvested trees through growing stock.

FIGURE 3-15

John Deere 693-B tracked feller buncher
with Rome head drops a tree into a bunch.
(Dashnaw Logging Co., Peru, New York,
(September, 1978)

Principal advantages and applications of the feller-
buncher are:

- Where the terrain is flat or has less than a 25
percent slope
- Relatively smooth terrain
- Snow-covered ground
- Selective cutting or row thinning
- Small diameter trees

- Use with a grapple-type skidder or forwarder to take advantage of the bunching ability
- Climate-controlled cab for all-weather operation

FIGURE 3-16

Melroe Bobcat with Morbark felling head and accumulator. In the right upper corner is a bunch of felled trees awaiting removal by skidder. (Percival Logging Co., Andover, Maine, May, 1978)

Table III-2 illustrates the range of present generation feller-bunchers, which are primarily hybrids resulting from the mating of an articulated skidder, crawler tractor, or non-articulated rubber-tired chassis with a feller-buncher head. An array of combinations can be obtained from most equipment manufacturers using different brands, types, and sizes of heads; with or without accumulators; and mounted on machines varying in size, power, and undercarriage. Tracked vehicles are generally slower moving and more expensive both to purchase and operate, but they are more stable and ordinarily create less ground pressure and therefore, less soil disturbance.

Reported productivity is highly variable, but an attempt has been made to correlate available data for different machines in order to have some basis for comparison. Manufacturers' estimates of production show figures averaging 18 tons to 45 tons per productive machine hour, or 80 to 240 trees for an equal period, a difference that can be attributed more to varying conditions than to machines.

David A. Davidson, Harvesting Manager for Weyerhaeuser, shows productivity for feller-bunchers with accumulators working 6-inch stems or the equivalent basal area to be 55 to 80 stems per scheduled hour for the smallest machine and 150 to 280 for the largest, with the intermediate size machines falling between⁽³⁻²⁰⁾. At an estimated average weight per six-inch whole-above-ground tree of 320 pounds⁽³⁻²¹⁾, a

small feller-buncher can produce 9 to 13 tons per scheduled hour, or 8 to 11 tons per productive-machine hour; a large feller-buncher can produce 24 to 45 tons per scheduled hour or 20 to 38 tons per productive-machine hour in small stock.

The maximum operating grade suggested by manufacturers for feller-bunchers is shown on the chart, since the feller-buncher is the least stable of the machines being considered and will, therefore, determine the maximum slope for harvesting with the mechanized systems. The economics of harvesting steep slopes will have to be evaluated carefully on a case-by-case basis.

When sawlogs are being sorted from chipping stock, attention must be given to the problem of butt shatter that occurs with many of the felling shears, particularly in freezing weather and on hardwood trees. Recent developments are well on the road to solving this problem with shears, and auger heads are readily available that, although somewhat slower, eliminate the shatter problem. If a head is used that produces butt shatter, extra trim allowance will take care of most of the problem. For fuelstock harvesting, butt shatter is of no consequence, and it is not included as one of the criteria in feller-buncher comparison.

d. Feller-Forwarder

The feller-forwarder fulfills the harvesting portion of the overall objective of complete mechanization as visualized by J. A. McNally: "the delivery of raw wood fiber from

TABLE III-2

SPECIFICATIONS FOR FELLER BUNCHERS

(MANUFACTURERS' DATA)

Size ¹	Shear Capacity Max. Dia. at Butt	Boom Reach	Max. ² Holding Capacity	Dimensions		Ground Pressure psi	Manufacturer's Specs. Production tons/pmh	Max. Grade	Average ⁴ Price
				Width	Length				
<u>WHEELED</u>									
Small ³	16"	none	up to 3 trees	7 ft 10 in	12 ft 6 in	7.8	20	58%	\$ 45,000
Medium	15"	none	2100 lb	7 ft 6 in	24 ft	---	---	---	55,000
Large	20"	none	2-5 trees up to 10 in. dia- meter	7 ft 9 in	23 ft 6 in	---	23	25%	71,000
Extra-Large	18"-22"	20 ft	2850 lb	11 ft 10 in	30 ft	10.3	25	40%	156,800
<u>TRACKED</u>									
	16"-24"	24 ft	4350 lb	9 ft 8 in	30 ft	6.8	21	65%	101,750

¹ This division was based on the fact that available equipment, even though it is produced by several different manufacturers, falls naturally into groupings with similar specifications in all categories. Price variations are the widest, but in all cases a machine can be purchased for close to the average price in a given category.

² These were manufacturers' specifications. No attempt was made to convert to a standard measurement. For machine with booms, the holding capacity is with the boom extended. All machines were assumed to have accumulators for the purpose of this comparison.

³ The only machine in this category in the Malroe Bobcat.

⁴ Late 1978 dollars.

standing tree to mill in usable form untouched by human hands and at a viable cost"⁽³⁻⁴⁾ . It combines the operations of felling, bunching, and transporting biomass out of the woods, enabling one operator to perform all of these operations without leaving his control cab.

This is a specially designed machine (not a hybrid) in which a feller-buncher is boom-mounted on a large (truck-like) vehicle that has a flat open structure for carrying felled trees. The trees are felled and accumulated by the feller-buncher head, the same as a standard feller-buncher. The bunch of trees is then lifted over the control cab and deposited on the open flat-bed structure that carries up to 35 tons. When the vehicle is loaded, the operator drives it through the woods to the landing for unloading.

The feller-forwarder has the distinct advantage of keeping the trees clean--they never touch the ground from the stump to the landing. It is best suited to the harvesting of large tracts, especially where the silvicultural approach is clear-cutting, strip cutting, or large-patch cutting. It is most effective where there are reasonably good logging roads. It can fell and transport trees up to 70 feet tall and 20 inches in diameter at the butt.

The manufacturer of this machine states that under its most appropriate operating conditions (large tracts, good roads, clear cuts, etc.), the feller-forwarder is the most economical method of removing trees from the forest. This

machine is able to cut and deliver biomass at the rate of 15 tons per hour where the distance from stump area to landing is no more than 750 feet. As this distance increases, the machine's productivity declines sharply, since its top speed is only 3.5 miles per hour compared with at least 15 mph for most other vehicles used to transport biomass out of the woods.

There is only one manufacturer of this machine at present--the Koehring Company. It is a large vehicle--43½ feet long by 16½ feet wide, with a turning radius of 43½ feet. It is not designed for traveling on public roads and special arrangements must be made for transporting it to the working site. This dictates its use in large tracts.

e. Harvester or Processor

The harvester or processor is a machine that performs felling, bunching, delimbing, and top removal, leaving only the tree boles or tree lengths cut to a pre-determined length. Although these machines do much more than fell trees, they are included in this section since felling is the first of their functions.

The John Deere 743 Harvester is a typical example of this machine (see Figure 3-17). It shears and grasps a tree, then lifts it laying it horizontally between two

FIGURE 3-17

John Deere 743 Harvester holding felled tree in feller head. The next step in this operation is to lay the tree between the knobbed cylinders for delimbing. (W. H. Grant, Inc., Winn, Maine, March, 1978)

knobbed cylinders that remove the limbs as the tree passes between them (see Figure 3-18).

The Timberjack harvester-prebuncher also fells and delimbs trees.

Delimbing is not required for the biomass-burning power plant, therefore, the use of sophisticated machines of this type may not be indicated in the harvesting system recommended.

3. DELIMBING

Removal of the tops and delimbing of trees has been done for many years by manual operation of the chainsaw. These operations are not required for the whole-tree chip harvesting method recommended for the biomass-burning power plant, however, if an integrated harvesting method is used (as recommended), then delimbing and top removal will be required for all trees removed as sawlogs, veneer stock, or pulpwood.

Several versions of delimbing equipment are available, including the John Deere 743 Harvester which includes delimbing with the felling function. The Caterpillar 950 Delimber pulls trees through a device that removes limbs (see Figure 3-19). Both of these machines are being used in Maine.

Some delimiters include a saw attachment to remove tops.

FIGURE 3-18

John Deere 743 Harvester running tree
through delimber. (W. H. Grant, Inc.,
Winn, Maine, March, 1978)

FIGURE 3-19

Caterpillar 950 delimber pulls trees
through device that removes limbs.
(Hannington Brothers, Inc., Wytovitlock,
Maine, March, 1978).

4. SKIDDING-FORWARDING

Skidding or forwarding is used to transport trees or portions thereof from the stump to the landing. Skidding consists of attaching a cable or chain from the vehicle to a felled tree (either an individual tree or in bunches). Skidding trees are subject to damage and also can damage the standing trees that line the skidder's pathway through the woods.

Forwarding makes use of a vehicle that carries the biomass out of the woods, thereby keeping the load clean and eliminating the damage done by skidding. Forwarding vehicles are available for shortwood (4-8 ft lengths), longwood (over 8 ft lengths), and whole trees (up to 70 ft lengths).

The production capabilities of these machines depends upon many variable factors and only general principles can be set forth, as follows:

- Horsepower. The horsepower of the engine is a direct factor in the pulling power of the machine. The greater the horsepower, the greater the payload. Typical machines range from 40 to 150 horsepower. Payloads on level ground range from 1 to 25 tons.
- Skidding Distance. The skidding (or forwarding) distance per trip has an inverse effect upon productivity. The longer the distance, the lower the production rate. Typical figures show that productivity declines by about 1 ton/hour for every additional 500 feet of skidding distance. Thus,

a machine that can produce 6 tons/hour at 200 feet will drop to half its productivity (3 tons/hour) when the distance increases to 1700 feet.

- Slope of Land. Productivity decreases as the slope of the land increases. Skidder manufacturers rate their machines at a 5 percent loss in production for every 10 percent increase in grade. Most skidders can pull payloads up slopes of approximately 25 percent.
- Terrain. Flat, dry ground with sufficient open space for maneuvering the vehicle is used as the basis for rating productivity. All deviations from this condition reduce productivity. In general, the greater the deviation from flat, dry, open ground, the greater the loss in productivity.
- Operator Skill. Operator skill is an intangible but very important factor in machine productivity. Manufacturer's ratings are considered for the typical or average operator. Very experienced, highly skilled, well-motivated operators can do significantly better than average; inexperienced operators may fall considerably below average in productivity.

Many types of equipment are available for the skidding and forwarding functions, as described in the following paragraphs:

a. Crawler-Tractor

The crawler-tractor is a common industrial machine that runs on tracks and is usually equipped with a front blade

for earth-moving work, land- and debris-clearing, loading and unloading of bulk materials, etc. It has been adapted for harvesting operations by attaching a cable skidding winch and either a chain or cable described as follows:

- Chain. A series of chains that are manually attached to the logs for pulling them behind the machine.
- Cable. Steel cables instead of chains are attached to the logs. Cable skidding is the usual method in the Northeast.

In both chain and cable skidding, the operator must get out of his machine and manually attach the cable or chain to the logs and then detach them after skidding. The machine may also have a front blade that the operator can use to maneuver or stack logs, clear away brush, and build roads.

The crawler-tractor is a stable machine and is able to develop as much as one and one-half times the traction of a wheeled vehicle of equal weight, making it particularly useful on steep slopes and in slick conditions ⁽³⁻²²⁾. Compared with a rubber-tired woods vehicle, the crawler-tractor operates better in wet or soft soil but is at a disadvantage in deep snow because of lower ground clearance.

Where cable skidding is to be used, the crawler-tractor would be preferred over rubber-tired machines for:

- Steep slopes (over 25 percent) and muddy terrain
- Soft soil conditions
- Road building capability
- Short skid distances

b. Articulated Cable Skidder

According to J. A. McNally, one of the key developments in the mechanization of harvesting was the invention of the articulated, frame-steered, all-wheel-drive vehicle ⁽³⁻⁴⁾ with improved rubber tires designed for the service. This vehicle forms the basis for all manner of woods vehicles--fellers, forwarders, cable and grapple skidders, and other hybrid and specially designed machines. The cable skidder was the first of these and is now one of the most widely used vehicles in the logging industry (see Figure 3-20).

The machine is constructed with a hydraulically hinged frame (usually at mid-point) so that steering is accomplished by bending the hinge (instead of turning the front wheels). This provides unusually high mobility and small turning radius, both of which greatly improve maneuverability in the woods.

The articulated cable skidder has a skidding winch mechanism identical to that of the crawler-tractor for dragging trees through the forest. This machine, with its large wheels and heavy duty rubber tires is somewhat less stable on steep slopes than the crawler-tractor, but is faster moving and less expensive to maintain. It can maneuver better than the tractor in deep snow.

The typical cable has several branch cables and chokes for holding trees to the skidder. The operator has to maneuver the machine into position, dismount and attach the cables, and then re-mount the machine for the trip to the landing.

Figure 3-20

An articulated cable skidder . This is a Tree Farmer C5D on the Dave Percival job near Westbrook taken in March, 1979.

Some types of cable attachments are more efficient than others. David Percival has devised a cable with a single choke, allowing a metal slide to tighten around a bunch of trees. This system enables the operator to make one attachment for an entire load. If cable skidding is to be used for any given harvesting operation, this method should be considered.

Where cable skidding is to be used, the articulated cable skidder would be preferred over the crawler-tractor for:

- Flat and moderately steep slopes (up to 25 percent)
- Dry or frozen ground
- Snow-covered terrain

Articulated cable skidders are available in a wide range of size and power capabilities, as listed in Table III-3.

c. Mini-Skidders

Small, non-articulated tracked vehicles (mini-skidders) are appropriate for cable skidding work where high production is not the important factor. The Krabat 232 Mini-Skidder shown in Figure 3-21 is an example of this unit.

d. Articulated Grapple Skidder

The articulated grapple skidder is similar to the articulated cable skidder, but instead of a chain or cable for hauling logs, it has a two-jaw grapple that is supported

TABLE III-3

SPECIFICATIONS FOR ARTICULATED CABLE SKIDDERS

(MANUFACTURERS' DATA)

Size ¹	Horse- power	Weight Pounds	Dimensions		Turning Radius	Maximum Forward Speed mph	Average ⁴ Price
			Width	Length			
Mini-Skidders ²	39	5,800	6 ft	12 ft	---	10	\$ 16,000
Small	52	7,285	6 ft	12 ft	15 ft	14	29,000
Medium	84	14,950	7 ft 11 in.	17 ft 9 in.	16 ft 10 in.	17	38,800
Large--A ³	116	18,084	7 ft 11 in.	19 ft 10 in.	17 ft 10 in.	18	49,380
Large--B ³	160	28,695	9 ft 8 in.	21 ft 9 in.	17 ft 8 in.	19	68,500

¹ This division was based on the fact that available equipment, even though it is produced by several manufacturers, falls naturally into groupings with similar specifications in all categories. Price variations are the widest, but in all cases a machine can be purchased for close to the average price in a given category.

² About one-ton average load capacity. These are very small, non-articulated.

³ When a large skidder is specified, either of these two categories is a possibility.

⁴ Late 1978 dollars.

NOTE: Machines that have been included for comparison purposes. Their use is limited to small stock where production is not the important factor.

FIGURE 3-21

Krabat 232 mini-skidder pulling a payload. (Small Equipment Demonstration, Dixfield Notch, New Hampshire, October, 1978)

by an arch (see Figures 3-22, 3-23, and 3-24). The grapple has the capability of grasping a bunch of logs, lifting one end, and holding it while the machine drags the load away. The grasping and holding capacity is rated in pounds and typically ranges from approximately 20,000 to 30,000 pounds. This "self-loading" feature of the grapple skidder makes it an ideal working companion for the feller-buncher, which fells the trees and lays them in bunches. For the most efficient use of this machine, the feller-buncher operator should make bunches of the approximate size for a full grapple load. The grapple can be operated from controls in the cab, therefore, the operator remains in the cab where he is protected and can do his work efficiently. He can both load and unload this machine without leaving the vehicle cab.

The grapple skidders have a higher horsepower to payload ratio, about 9 horsepower per ton of payload on dry, level ground (compared with about 7 horsepower per ton for cable skidders). This is due to the added weight of the grapple. A higher horsepower to load ratio will be encountered for whole-tree harvesting because of the greater drag of the limbs and leaves. These machines are manufactured in a larger size range than the cable skidders, that is, a small grapple skidder has about the same payload as a medium size cable skidder, and a medium size grapple skidder is equivalent to a large cable skidder (Figure 3-25).

FIGURE 3-22

Tree Farmer C5D articulated cable skidder with payload being delivered to landing (Percival Logging Co., Andover, Maine, May 1978)

FIGURE 3-23

John Deere 740 grapple skidder picking up a load shows the hydraulic cylinders that allow the articulated steering.
(Dashnaw Logging Co., Peru, New York, September, 1978)

FIGURE 3-24

John Deere 740 grapple skidder delivers
a bunch to the landing. (Dashnaw Logging
Co., Peru, New York, September, 1978)

FIGURE 3-25

John Deere 740 grapple skidder rounds a corner on the skid road with a full load of trees. (Dashnaw Logging Co., Peru, New York, September, 1978)

TABLE III-4

SPECIFICATIONS FOR GRAPPLE SKIDDERS
(MANUFACTURERS' DATA)

Size ¹	Horse- power	Weight	Dimensions		Radius	GRAPPLE				Average ⁵ Price
			Width	Length		Maximum Forward Speed mph	Maximum Lift Capacity Pounds	Maximum Grapple Opening	Grapple Area Tip-to-Tip ² Square Foot	
Small	86	18,695	8 ft 2 in.	20 ft	17 ft 7 in.	18	19,150	6 ft	5.4	\$51,250
Medium	110	26,250	9 ft 4 in.	22 ft 2 in.	18 ft 6 in.	18	25,000	9 ft 3 in.	---	64,000
Large-A ³	122	23,017	8 ft 10 in.	22 ft 3 in.	18 ft	19	25,000	6 ft	8.3	70,000 ⁴
Large-B ³	160	31,230	10 ft 2 in.	25 ft	18 ft 6 in.	19	30,750	9 ft	---	90,000

¹This division was based on the fact that available equipment, even though it is produced by several manufacturers, falls naturally into groupings with similar specifications in all categories. Price variations are the widest, but in all cases a machine can be purchased for close to the average price in a given category.

²This is a manufacturers' specification. It is the area encompassed by the grapple when the tips are brought together.

³When a large skidder is specified, either of these two categories is a possibility.

⁴One machine in this range was reported at a price of \$52,500 and was not included in the average.

⁵late 1978 dollars

The productivity of grapple skidders is greater than cable skidders, since the operator does not have to leave his cab in the grapple skidder. A comparison of the productivity ranges of these two machines is shown below:

GRAPPLE SKIDDER

Skidding Distance (ft)	500	1,000	1,500
Productivity (tons/hour)	21	17	14

CABLE SKIDDER

Skidding Distance (ft)	500	1,000	1,500
Productivity (tons/hour)	6	5	4

Where skidding is to be used, the grapple skidder is preferred over the cable skidder for:

- Following a feller-buncher
- Flat ground and slopes up to 25 percent maximum
- Dry or frozen ground
- Snow-covered ground
- Selective cutting
- Harvesting of small trees
- Short skidding distances (up to 600 feet)

The grapple skidder has one major disadvantage in that its grapple is quite heavy and placed above the vehicle's center of gravity, thus making the machine somewhat less stable than a cable skidder of the same size and weight. It is not recommended for very rough terrain and steep slopes.

e. Clam Bunk Skidder

The clam bunk skidder is a further development in skidding techniques, with a greater payload than the grapple skidder. This machine has a two-jaw grapple, similar to the grapple skidder, but the jaw opening is upward and the jaws cannot be maneuvered to pick up a load. This requires loading by a separate loader, which commonly consists of a boom-mounted grapple located behind the vehicle cab (see Figure 3-26). The operator can load and unload the machine from his cab.

Clam bunk skidders are large, expensive machines that can be either rubber-tired or tracked vehicles. The principal advantages of the clam bunk skidder are its large payload (25,000--30,000 pounds) and its ability to add to its load enroute. In working with the feller-buncher, the size of bunches is not critical, thus simplifying the feller-buncher's work. It is not necessary to form uniform bunches of the size required for the grapple skidder. The attached boom loader can add trees until the clam bunk (jaw-opening) is full. In addition to this, the clam bunk skidder holds the trees tightly, keeping the heaviest part of the trees (main trunk) off the ground. This reduces damage to the residual stand and minimizes soil erosion.

Clam bunk skidders are generally more powerful machines than grapple skidders and they can operate on steeper grades, even pull uphill with a full load. Since they are large, expensive machines, it is essential to operate them at maximum

FIGURE 3-26

Timberjack 15-ton clamhunk skidder pulls a payload at the Canadian Pulp and Paper Association Logging Equipment Demonstration in Quebec, 1978.

carrying capacity for economic efficiency. Productivity at different skidding distances is shown in the following table (for a typical machine):

CLAM BUNK SKIDDER PRODUCTIVITY

Skidding Distance	500 ft	1,000 ft	1,500 ft
Production (tons/hour)	35	31.5	28

Only a few makes and models of clam bunk skidders are available. Typical specifications are given in the following table (Table III-5).

TABLE III-5

SPECIFICATIONS FOR CLAM BUNK SKIDDERS

(MANUFACTURERS' DATA)

Undercarriage	Horse- power	Weight Pounds	<u>Dimensions</u>		Turn Radius	Maximum Forward Speed mph	Maximum Load Capacity Pounds	Bunk ¹ Area Sq. Ft.	Boom Reach	Average ³ Price
			Width	Length						
Tracked ²	197	29,000	8 ft 7 in.	16 ft 3 in.	24 ft	15	25,000	23.5	10 ft	\$115,000
Rubber-tired	159	36,000	8 ft 10 in.	31 ft 5 in.	30 ft 6 in.	18.5	29,000	21.5	21 ft	127,300

¹This measurement is the area encompassed by the bunk grapple at its widest opening.

²The only machine in this category is the FMC 200BG.

³Late 1978 dollars.

f. Forwarders

Forwarders are wheeled or tracked vehicles that carry logs or trees completely off the ground. They have a flat bed or bunk with side posts to contain a load of wood and a boom with a grapple for loading and unloading. Some forwarders also have a tilt-up side dumping feature for rapid unloading. They vary greatly in size from small rubber-tired vehicles with 70 horsepower engines to the huge Koehring model with over 300 horsepower.

The small and medium-sized forwarders (see Figure 3-27) are designed for carrying typical wood lengths used in the pulp and paper industry--4 foot lengths, 8 foot lengths, and long logs (usually up to a maximum of 26 feet). The long-log forwarders are especially suitable for carrying small trees that would be procured in forestry thinning operations and would be chipped for fuelstock.

The principal advantages of the forwarder over the skidder is that it keeps the logs off the ground, free of dirt and other debris that is accumulated on trees that are dragged through the forest. This has a beneficial effect for chipping, since dirt, mud, and stones embedded in the wood during skidding tend to dull the knives more rapidly than clean wood.

The productivity of a typical small forwarder is eight tons per hour on a thinning operation in Maine. The small

FIGURE 3-27

Dion F-4 forwarder filled with logs. This small tracked forwarder has a separate trailer, log loader, and can be equipped with a dump device for unloading. (CPPA Logging Equipment Demonstration, Quebec, 1978)

and medium-sized forwarders are suitable for use when:

- Trees are under 26 feet long
- Land is flat or sloping no more than 25 percent
- Relatively long in-woods transport is required
- Clean wood is necessary
- The trees are small
- The terrain or standing trees will be damaged by skidding operations

Specifications for typical forwarders (see Figure 3-28) are given in the following table (Table III-6):

FIGURE 3-28

Kockums Logma forwarder with a full load of logs for transfer to the landing. (CPPA Logging Equipment Demonstration, Quebec, 1978)

TABLE III-6

SPECIFICATIONS FOR FORWARDERS
(MANUFACTURER'S DATA)

Size ¹	Horse- power	Weight Pounds	<u>Dimensions</u>		Turn Radius	Maximum Forward Speed mph	Loaded Ground Pressure psi	Load Capacity Pounds	Boom Reach	Unload	Average ⁴ Price
			Width	Length							
Small rubber- tired	73	13,680	7 ft 4 in.	21 ft 9 in.	18 ft	18	---	10,000	10 ft	Boom	\$ 42,000
Small ² tracked	165	9,300	5 ft 7 in.	26 ft 3 in.	25 ft	26	6.4	10,000	30 ft	side dump	45,000
Medium	158	31,000	8 ft 7 in.	35 ft 6 in.	31 ft	18	10.5	29,000	21 ft	Boom	113,000
Large ³	345	94,000	16 ft 6 in.	45 ft 6 in.	43 ft 6 in.	3.5	---	70,000	19 ft 8 in.	Rear Dump	219,900

¹This division was based on the fact that available equipment, even though it is produced by several manufacturers, falls naturally into groupings with similar specifications in all categories. Price variations are the widest, but in all cases a machine can be purchased for close to the average price in a given category.

²The only machine in this category is the Dion F-4.

³The only machine in this category is the Koehring KF2.

⁴Late 1978 dollars.

5. CHIPPING

Chipping at the landing (as opposed to chipping at a plant or mill) is done by a portable or mobile chipper located at a roadside landing--typically adjacent to a paved public highway such that chip vans can be loaded with chips and hauled to the user's plant by highway tractor.

Whole trees or parts of trees are brought to the chipper by skidders or forwarders that travel through the woods. The chipper normally has its own loading boom and grapple that feeds the butt end of the trees or branches into the machine while the chips are blown into a waiting van. With whole-tree chipping, the entire tree is brought to the landing, fed through the chipper, and converted into chips about the size of a paper match folder. The chipper's knives require re-sharpening regularly--normal procedure is to have several sets of knives, replacing the one in use as needed and re-sharpening the dull set when time permits. Knife-changes are usually made twice a day when a chipper is kept in constant use. The typical whole-tree chipper can produce from 75 tons to 300 tons of chips in an eight-hour day (see Figure 3-29).

Whole-tree chippers are divided into two size classes, large and small. The small chippers can handle trees up to 12 inches in diameter; they are driven by diesel engines of approximately 200 horsepower and produce from 75 to 150 tons of chips per day. Large size chippers handle trees up to 22 inches in diameter and are driven by diesel engines of approximately 375 horsepower.

FIGURE 3-29

Loading logs into Trellan D60 (18 in.) chipper with truck-mounted Prentice log loader. The chips are blown through the rectangular chute into the waiting van. (Percival Logging Co., Andover, Maine, May, 1978)

TABLE III-7

SPECIFICATIONS FOR WHOLE-TREE CHIPPERS

(MANUFACTURERS' DATA)

Size ¹	Maximum Diameter of Stock	Feed Ft/Min	Average Production Tons/Day	Loader Availability	² Low	<u>Price</u> High	⁵ Average
Small	12 in.--14 in.	50-105	75-150	Slide boom, 13 ft reach, 90 Knuckleboom	\$31,000	\$ 52,000	\$ 41,000
Large	18 in.--22 in.	75-125	300-500	Slide boom, 21 ft reach, 140 Knuckleboom, 25 ft reach	50,000	155,000 ³	111,000

¹This division was based on the fact that available equipment, even though it is produced by several manufacturers falls naturally into groupings with similar specifications in all categories. Price variations are the widest but in all cases a machine can be purchased for close to the average price in a given category.

²The lowest prices are for machines without loaders in all instances.

³This is the highest price in the category, and represents a chipper with a 22 inch diameter maximum feed. The maximum for all other machines is either 18 inches or 20 inches.

⁴Production figures are manufacturers' data. The higher tonnage figures are best considered as optimum, not average rates.

⁵Late 1978 dollars.

FIGURE 3-30

Mobark 22 Chipharvester with
slide boom loader feeding
small hardwoods into chipping
mechanism. Chips are blown
into a waiting van. (Dashnaw
Logging Co., Peru, New York,
November, 1978)

6. SUMMARY OF EQUIPMENT BY MANUFACTURERS

The attached summary of equipment is a reasonably comprehensive list of equipment designed for harvesting operations. It enables the reader to grasp the great diversity of equipment in many operations and the relative scarcity in others. This summary is organized by equipment function in the order of performance in the overall harvesting sequence. Multi-function equipment is listed under its first function in the harvesting sequence.

a. Feller-Bunchers

Medium

Hydro AX 311 with Morbark 15 inch Shear
Hydro AX 411 with Morbark 15 inch Shear
John Deere 544 with Rome SHN Shear
John Deere 555 Crawler with Rome High Speed FB
Frankling 160XL with Rome 20 inch Shear
Komatsu D31S Crawler-Loader with 15 inch Morbark Shear

Small

Melroe Bobcat

b. Grapple Skidders

Medium

Timberjack 380
John Deere 640B
Clark 666GS
Franklin 170 XLN
International S10
Caterpillar 518

Small

John Deere 440C
John Deere 540B
International S8A

c. Whole-Tree Chippers

Large

Morbark 22 RXL Chipharvester
Precision 84 inch Tree Harvester
Precision 75 inch Tree Harvester
Morbark 18 Chipharvester

Small

Morbark 12
Trelan C14
Precision 58 inch Tree Harvester
Trelan DL-60

D. SELECTION OF EQUIPMENT

1. INTRODUCTION

In the previous sections it was shown that whole-tree chip harvesting is the most economical method of harvesting biomass as fuelstock for the biomass-burning power plant, and the equipment available was described and evaluated. This section recommends the type of harvesting system best suited for the Westbrook area.

It must be recognized that no single set of equipment will be the most economical and efficient under all conditions. Some equipment is more effective for harvesting small trees than large trees; some equipment has severe limitations as the slope of the land increases; some equipment is effective in wet and swampy areas but slow and inefficient on dry ground; some machines do better than others on snow-covered ground; furthermore, the nominal production capacities of the individual components should be matched to provide a smooth-working, steady-flowing, balanced system. A machine with a relatively low production rate in the sequence of operations will act as a bottleneck to production.

Most American logging contractors utilize the "hot system," which has very little storage or stockpiling--each machine in the sequence operates upon the material just supplied by the previous machine. This requires machine compatibility and carefully

controlled operating methods to obtain balance and optimum production rates. In designing a balanced system, it is necessary to select the right combinations of equipment for a uniform flow rate. The selection of equipment must be based upon specific production sizes as provided by manufacturers--machines can be obtained and used in integral numbers only. It may be necessary to select two or three units for one operation to match the productivity of a single machine for a subsequent operation. Since the harvesting machines are very expensive, all of these decisions on machine selection will have a significant effect upon the production rate and economic feasibility of the harvesting operation.

2. RECOMMENDED WHOLE-TREE CHIPPING SYSTEM

The recommended whole-tree chipping system and equipment for the Westbrook area is based upon the following site-specific factors:

- a. The terrain in the area is generally moderate. Only a small percentage of the harvest radius has any significant slope (less than 3 percent with more than 15 percent slope).
- b. The tract size is generally in the small ownership category, that is 150 acres or less.

The recommended harvesting system has been chosen with these factors in mind. Where there are slopes of any significance, the particular tract can be omitted from the harvesting plan. This will have a very minimal effect on the fuelstock supply since the area of significant slope is so small.

The harvesting system deemed most useful for the Westbrook site consists of:

- 2 medium feller-bunchers
- 2 medium grapple skidders
- 1 large whole-tree chipper

This combination matches equipment to provide a well balanced system, based upon production rates as follows:

Feller-buncher	25 tons/hour each
Grapple skidder	20 tons/hour each
Whole-tree chipper	40 tons/hour
Total Production	270 tons/day

Based upon this system, approximately seven such chip production units will be required to furnish chips as fuelstock for the biomass-burning power plant.

3. ADVANTAGES OF RECOMMENDED SYSTEM

- a. This system provides a reasonably close match in productivity for all units, with a slightly higher productivity in the initial operation (felling and bunching). The use of the medium-sized feller-buncher instead of small-size units provides a small productivity "reserve capacity" that will allow the operator to be more careful in maneuvering and selecting trees. The operator will also have adequate time to prepare bunches of the proper size for the grapple skidders, thus increasing the efficiency in that operation. The chipper

will not quite handle the maximum production of the feller-bunchers, but the chipper can easily be operated an hour or two longer than the other machines to allow for production peaks. The chipper can be operated after dark and is located at the only place in the harvesting area where stockpiling of trees can be accommodated without disrupting the system.

- b. The use of the large whole-tree chipper is recommended because of its production rate and capacity for up to a 22-inch butt, thus utilizing large cull trees beyond the capability of small chippers. The higher production rate and the utilization factor makes up for the larger chipper's higher initial cost.
- c. The grapple skidder was selected because it is compatible with the feller-buncher, and because it is able to pick up an entire bunch of trees in the grapple while the operator remains in the machine. It is more efficient at skidding distances up to 600 feet than the clam bunk skidder. The ownership, terrain, and road pattern of the harvest area, and the mobility of the chipper, indicate that most skidding distances will be kept at 600 feet or less. The medium size of the grapple skidder makes it more maneuverable and lighter than a larger machine, reducing the possibility of damage to the residual stand. The greater pulling power of larger machines is not necessary in the moderate terrain of the harvest area.

- d. Medium-sized feller-bunchers can be equipped with feller heads to accomodate trees up to the maximum diameter (18 in. to 22 in.) for the chipper. Machines of this size are more maneuverable and lighter, therefore less likely to damage the residual stand.
- e. The use of two of the medium-sized machines rather than one of a larger machine allows the system a certain amount of flexibility. If one of the machines is down, some production can still be maintained.

4. ALTERNATIVES

An integrated system is recommended because it offers the greatest economic benefits and makes the most effective use of the biomass resource. With this system, the contractor separates the trees by economic value--sawlogs, pulpwood, and fuelstock, selling each category to the appropriate market.

Various alternatives are possible and may be economically viable. Some contractors may concentrate on the higher value trees and use the chipper for tops, limbs, and culls only, thus chipping only the biomass that would otherwise be wasted. This is becoming more and more prevalent, since landowners and government agencies are requiring contractors to clean up their slash and logging residue.

A contractor who is presently using conventional methods (chainsaws and cable skidders) may want to supply chips to the biomass-burning plant as a major part of his operation. He can install a feller-buncher head on a crawler tractor that he

already has and can use his cable skidders instead of the grapple skidders recommended. If he is particularly short of capital and still wants to enter the chip harvesting field, he may even be able to operate with the chainsaws for felling and existing cable skidders, limiting his new equipment to the whole-tree chipper.

Figure 3-30 shows various combinations of equipment that could be put together for whole-tree chip harvesting for specific requirements, depending upon the expected skid distances and maximum tree diameter.

In general, the small equipment would be best suited to a contractor who was going to engage primarily in thinning operations. The feller-forwarder, as has been pointed out earlier, is suitable only for large tracts and strip, patch or clearcuts, because of its large size.

In addition to the system terminating in a large chipper, a second system utilizing a small chipper is a possibility for the Westbrook area. Small, when applied to a chipper, relates to either the small diameter limitation (12-14 inches) or to low productivity (100 to 200 tons per day). The small chippers are considerably less expensive than the large ones.

The small system would consist of:

- 1 small feller-buncher
- 1 small grapple skidder*
- 1 small whole-tree chipper

* Two small grapple skidders may be required, depending upon skid distance.

**FIGURE 3—30
WHOLE-TREE CHIP
HARVESTING SYSTEMS**

This combination matches equipment to provide a well-balanced system, based upon estimated production rates as follows:

feller buncher	12 tons/hour
grapple skidder	12 tons/hour
whole-tree chipper	100 tons/day

The advantages of this system over the larger system are basically twofold: (1) its small size allowing for maximum maneuverability and minimum disturbance, and (2) its lower capital and operating costs.

The advantage of the small size must be weighed against the lower production rate and the inability to harvest larger trees. In addition, the only small feller-buncher currently on the market cannot effectively operate in over two feet of snow.

A combination of large systems and small systems within the harvest area would allow the greatest flexibility for the practice of silviculture, since it would allow the supervising forester to custom fit harvesting contractors to harvest sites to provide the best utilization of the resource as well as the best treatment of the forest lands.

5. EQUIPMENT PRICES (Typical quoted prices as of March, 1979)

a. Feller-Bunchers

Medium

Hydro Ax 311 with Morbark 15 in. Shear	\$52,900
Hydro Ax 411 with Morbark 15 in. Shear	63,700
John Deere 544 with Rome SHN Shear	65,000
John Deere 555 Crawler with Rome High Speed FB	55,000
Franklin 170XL with Rome 20 in. Shear	63,000
Komatsu D315 Crawler-Loader with 15 in. Morbark Shear	47,000

Small

Melroe Bobcat

\$47,000

b. Grapple Skidders

Medium

Timberjack 380

\$56,200

John Deere 640B

70,000

Clark 666GS

57,600

Franklin 170 XLN

55,000

International S10

67,000

Caterpillar 518

66,000

Small

John Deere 440C

\$35,000

John Deere 540B

53,000

International S8A

54,500

c. Whole-Tree Chippers

Large

Morbark 22RXL Chipharvester

\$134,400

Precision 84" Tree Harvester

151,700

Precision 75" Tree Harvester

139,100

Small*

Morbark 12 (with loader)

\$ 49,700

Trelan C14

29,500

Precision 58" Tree Harvester

80,300

Trelan DL-60

89,750

Morbark 18 (with loader)

80,000

* The designation "small" covers chippers that are either limited to small diameter trees or that have significantly lower production capabilities than those signified as "large".

E. TIME-COST STUDIES

1. INTRODUCTION

a. Purpose

This portion of the study was undertaken to provide meaningful cost data to be used as a basis for estimating the cost of fuel for the proposed biomass-burning power plant. The economic viability of the plant rests upon an adequate supply of fuel at a cost that will sustain its operations over its economic life. The time-cost studies described in this section are based upon examination of existing whole-tree chip harvesting operations. The studies covered actual operations of harvesting, collection, transportation, and delivery to the use point.

b. Procedure

A local forestry consultant was commissioned to visit four whole-tree chip harvesting operations in New England. These are the only four such operations known to exist as on-going, self-sustaining enterprises (several experimental operations have existed for short periods of time).

The forester visited the work areas, discussed operations with the work crews, took adequate notes and data, and then made a comprehensive cost analysis for each operation.

The forester's data and findings were further analyzed by the Wood Energy Institute to arrive at a reasonable estimate

of the cost (in 1979 dollars) of whole-tree chips delivered to the model conversion facility at Westbrook, Maine.

c. Participants

Prime Contractor

Wheelabrator Cleanfuel
Corporation
Gary Allison, Senior Vice
President

Subcontractor On
Biomass Studies

Wood Energy Institute
Andrew B. Shapiro, President

Forestry Consultant
(commissioned by
subcontractor)

Ralph E. Clifford,
Professional Forester

d. Summary of Results

The results are summarized in the table below. They show that Company A has a harvesting and chipping cost of \$8.24 per ton while Company B has a cost of \$12.18 per ton in 1979 dollars.

SUMMARY OF RESULTS*

<u>Factors Included</u>	<u>Cost/Ton</u>	
	<u>Company A</u> <u>(27.5 tons/hour)</u>	<u>Company B</u> <u>(10.11 tons/hour)</u>
Harvesting and Chipping (No Stumpage)	6.49	9.72
Road Building and Maintenance	<u>1.00</u>	<u>1.35</u>
Total - 1978 costs	\$7.49	\$11.07
1979 costs at 10% escalation	\$8.24	\$12.18

*These are estimated costs with no profit.

e. Discussion of Results

The results shown for Companies A and B represent actual costs without any profit or return on equity.

The costs for transporting the biomass to the destination have not been included for Companies A and B since the transport distances for these actual field operations differ considerably from the distances anticipated for the biomass plant located at Westbrook. Stumpage cost is also excluded from these costs. This cost is estimated at \$1.00 per ton in 1978 dollars for the biomass fuelstock share of the harvesting operation.

The transportation costs for Companies A and B operating at an average 35 mile distance from the delivery point have been calculated to provide an estimate of the cost that might be expected for the study area. The transportation costs have been estimated at 6½ cents per ton-mile (late 1978), a figure frequently encountered for truck transport in the area in Maine.* Escalating this figure 5% to \$.068 (mid-1979), the cost for a 35 mile trip would be \$2.38 per ton. With this cost added to the figures for Companies A and B, and estimated stumpage at \$1.10 per ton in 1979, the results are as follows:

<u>FACTORS INCLUDED</u>	<u>COMPANY A</u>	<u>COMPANY B</u>
Total Delivered Cost (1979 - excluding profit)	\$11.72	\$15.66

*Company A has an average transport cost of 6.4 cents per ton-mile, while Company B encounters approximately 9 cents per ton-mile. The attached sheet entitled "TRUCKING COST DATA" shows typical trucking rates for Maine and New Hampshire. Maine's average rate is 6.5 cents per ton-mile. New Hampshire's is about 8.7 cents per ton-mile for a 30-mile trip.

The productivity of Companies A and B is low because of a lack of markets, difficult terrain and poor timber. In the opinion of the Forestry Consultant and J. P. Rich their productivity could easily be raised to 37.5 and 15 tons per hour, respectively, without an increase in equipment or manpower, operating in the Westbrook harvest area.

Raising the productivity of Companies A and B to the above levels lowers the cost per ton for harvesting chipping and road-building of the two companies to \$6.04 and \$8.22 respectively. Adding stumpage of \$1.10 per ton, results in a cost through chipping of \$7.14 and \$9.32 per ton. Adding a 25 percent markup to these costs for profit and a transportation cost of \$2.38 per ton results in an estimated 1979 delivered price of \$11.90 and \$14.81 per ton, respectively. The average of these two prices is \$13.36 per ton. A conservative 1979 price of \$14.00 per ton is suggested for a "base case" price for economic analysis purposes.

TRUCKING COST DATA

NEW HAMPSHIRE

ICC RATES EFFECTIVE MAY 1978 for Reginald Currier Trucking Co., Gorham, N. H. (Received from Hawkensen Enterprises)

<u>MILES</u>		<u>PER TON</u>	<u>RATES</u>
<u>FROM</u>	<u>TO</u>		<u>PER 22 TON LOAD</u>
0	20	\$2.00	\$44.00 (mininum charge)
20	25	2.40	52.80
25	30	2.60	57.20
30	35	3.00	66.00

<u>MILES</u>		<u>PER TON</u>	<u>RATES</u>
<u>FROM</u>	<u>TO</u>		<u>PER 22 TON LOAD</u>
35	40	\$3.20	\$70.40
40	45	3.40	74.80
45	50	3.60	79.20

MAINE

MAINE PUBLIC TRANSPORTATION RATES for Gerald Davis and Sons Trucking, Portland, Maine. (Received from Gerald Davis, Sr., 2/13/79)

\$1.43 per loaded mile (\$.065 per ton per mile assuming a 22 ton load)

\$45.00 minimum charge (\$2.05 per ton assuming a 22 ton load)

NEW ENGLAND

See Reference 4-4. This study provides estimates of several private truckers' rates for New Hampshire, Maine and Vermont in 1977. The estimates range from \$.04 to \$.06 per ton/mile. The average rate of \$.05 per ton per mile escalated to 1979 at 10 percent per year would be \$.061.

2. COMPANY A

a. Description of Operation

Company A operates an integrated whole-tree logging and chipping operation on land owned by a pulp and paper company, to whom the pulpwood chips are sold. Approximately five percent of the logs are of suitable quality for lumber and these are sorted at the landing and shipped to a sawmill. The rest of the harvested timber is shipped as whole-tree pulpwood chips. The market for whole-tree chips is limited by the percentage of whole-tree chips that the pulp mill can utilize in their process (15 percent). The production could be increased from about 220 tons per day to as much as 300 tons per day with essentially the same equipment if there were a suitable market.

The operation is highly mechanized, using feller-bunchers, grapple skidders, a whole-tree chipper, tractors, semi-trailers, and associated auxiliary vehicles for repair, service, and road maintenance. The total capital investment is approximately one million dollars. Some equipment is not in regular service (on standby in case of failure).

The silvicultural practice used is selective thinning, in which the machine operator fells the poorest quality trees, leaving the better trees standing for continued growth and future harvesting as sawlog timber. The machine operators have been trained to make the decisions on tree removal. Trees are removed down to a three to four-inch butt diameter. This

approach has proven very satisfactory and the residual forestry stands show healthy development.

The topography is hilly to steep, with some outcroppings of ledge and boulders visible. The slopes observed appeared to vary from 8 to 35 percent. The steep slopes are the limiting factors on the equipment used and have the effect of adding to the costs of operation and road construction and maintenance. Skidding distances vary from 300 feet to 2,000 feet. The forestry road is on private land and has to be maintained by the logging contractor (approximately five miles).

The observed production rate was 27.5 tons per hour. The crew consisted of 13 men, as follows:

Harvesting	7
Road Maintenance	1
Trucking	<u>5</u>
TOTAL	13

b. Basic Assumption For Unit Cost Computation

Interest Cost: 12 percent of financed capital, 80 percent financing over 3 years; spread over 5 years.

Local Taxes: 1.5 percent of average investment/year. Average investment--mid-point book value of equipment on straight line depreciation basis i.e., Investment Average =
$$\frac{(\text{Initial Investment} - \text{SV}) (\text{Life} + 1)}{2 \times \text{Life}} + \text{SV}$$

Life In Years
SV = Salvage Value

Insurance:

Highway Trucks 4.5 percent of original cost/year.

All Other 1.6 percent of original cost/year.

Maintenance and
Repair (Annual
Cost):

<u>Chipper</u>	20 percent of original investment.
<u>Other Harvest- ing Equipment:</u>	10 percent of original cost
<u>Small Trucks:</u>	5 percent of original investment.
<u>Large Trucks:</u>	15 percent of original investment.
<u>Truck For Spotting Vans:</u>	10 percent of original investment.

NOTE

The above costs assume 1920 hours/year operation.

Company A operates approximately 1760 hours/year.

C. SUMMARY--COMPANY A

Cost Per Productive Hour (1978 Dollars)

	<u>No. Operators</u>	<u>Fixed Equipment Cost</u>	<u>Variable Operating</u>	<u>Labor</u>	<u>Total</u>	<u>Cost Per Ton</u>
<u>Felling-Bunching</u>						
2 Feller-Bunchers	2	\$23.57	\$14.14	\$14.74	\$52.45	\$ 1.91
<u>Forwarding</u>						
2 Grapple Skidders	2	16.09	16.43	14.74	47.26	1.72
<u>Chipping</u>						
Morbark Chip Harvester	1	22.34	22.13	7.37	51.84	1.88
<u>Support Equipment</u>						
Tank Truck		1.81	1.85			
Repair Truck		1.70	.86			
2 Pick-Up Trucks	2	2.42	1.57	14.74		
Knife Grinder		.38	.31			
3 Chain Saws		.55	.86			
Sub Total	2	6.86	5.45	14.74	27.05	.98
Total Harvesting and Chipping	7	\$68.86	\$58.15	\$51.59	\$178.60	\$ 6.49
<u>Trucking</u>						
1 Used Truck Tractor		\$ 2.87	\$ 2.70		5.57	
5 Truck Tractors	5	27.58	37.75	\$43.18	\$108.51	
8 Chip Vans		7.67	4.69		12.36	
Total	5	\$38.12	\$45.14	\$43.18	\$126.44	\$ 4.60
<u>Road Building and Maintenance</u>						
Cat Grader (Used)		\$ 3.21	\$1.79		\$ 5.00	
Bulldozer	1	8.82	3.66	\$ 7.37	19.85	
Low Bed Trailer (Used)		1.95	.62		2.57	
Total	1	\$13.98	\$6.07	\$7.37	\$ 27.42	\$1.00
Total Cost/Ton						\$12.09

d. FIXED EQUIPMENT COST--COMPANY A

		Approximate 1978 Price	Life In Years	Salvage Value	Costs Per Production Hour				
Felling-Bunching					Depreciation	Interest	Local Taxes	Insurance	Total
1	Feller Buncher JD544B	\$ 66,000	4	\$14,500	\$ 7.32	\$1.87	\$.40	\$.55	\$10.14
1	Feller Buncher JD693	86,000	4	17,200	9.77	2.43	.51	.72	13.43
<u>Forwarding</u>									
2	Grapple Skidders	170,000	5	85,000	9.66	3.85	1.16	1.42	16.09
<u>Chipping</u>									
1	Morbark Chip Harvester	175,000	5	35,000	15.91	3.96	1.01	1.46	22.34
<u>Support Equipment</u>									
1	Tank Truck (Used)	12,000	5	1,500	1.19	.27	.07	.28	1.81
1	Repair Truck and Equipment	12,000	5	2,500	1.08	.27	.07	.28	1.70
1	4-Wheel Drive Pick-Up	9,600	5	3,000	.75	.22	.06	.23	1.26
1	2-Wheel Drive Pick-Up	8,500	5	2,000	.74	.19	.05	.20	1.16
1	Knife Grinder	4,000	5	2,000	.23	.09	.03	.03	.38
3	Chain Saw	1,000	1	150	.48	.05	.01	.01	.55
<u>Transportation</u>									
1	Used Truck Tractor	25,000	5	8,000	1.93	.57	.16	.21	2.87
5	Truck Tractors	200,000	4	80,000	17.04	4.53	1.32	4.69	27.58
8	Chip Vans	60,000	5	15,000	5.11	1.70	.36	.50	7.69
<u>Road Building</u>									
1	Cat Grader (Used)	22,000	4	6,000	2.27	.62	.14	.18	3.21
1	Bulldozer	70,000	5	15,000	6.25	1.58	.41	.58	8.82
1	Low Bed Trailer (Used)	16,000	5	4,000	1.36	.36	.10	.13	1.95
Total		937,100							

e. Variable Operating Costs--COMPANY A

JD544B Feller-Buncher (With Morbark Shear)

Maintenance and Repair $\$66,000 \times 15\% \div 1920$ Hours	\$ 5.16
Fuel 1.5 gallons/hour at \$.65	.98
Oil and Lube	<u>.15</u>
Total	\$ 6.29

JD693 Feller-Buncher (With Morbark Shear)

Maintenance and Repair $\$86,000 \times 15\% \div 1920$ Hours	6.72
Fuel 1.5 gallons/hour at \$.65	.98
Oil and Lube	<u>.15</u>
Total	\$ 7.85

2 Grapple Skidders

Maintenance and Repair $\$170,000 \times 15\% \div 1920$ Hours	\$13.28
Fuel 1.5 gallons/hour at \$.65 x 2	1.95
Oil and Grease	.30
Other Operation Supplies	<u>.90</u>
	\$16.43

Morbark Chip Harvester

Maintenance and Repair $\$175,000 \times 20\% \div 1920$ Hours	\$18.23
Fuel 4 gallons/hour at \$.65	2.60
Oil and Grease	.30
Operating Supplies	<u>1.00</u>
Total	\$22.13

Used Tank Truck

Maintenance and Repair $\$25,000 \times 10\% \div 1920$ Hours	\$ 1.30
Fuel and Lube $\$22/\text{week} \div 40$ hours	<u>.55</u>
Total	\$ 1.85

Repair Truck

Maintenance and Repair $\$12,000 \times 5\% \div 1920$ Hours	\$.31
Fuel and Lube $\$22/\text{week} \div 40$ hours	<u>.55</u>
Total	\$.86

2 Pick-Up Trucks

Maintenance and Repair \$18,000 x 5% ÷ 1920 Hours	\$.47
Fuel and Lube \$44/week ÷ 40 Hours	<u>1.10</u>
Total	\$ 1.57

Knife Grinder

Maintenance and Repair \$4,000 x 15% ÷ 1920 Hours	\$.31
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3 Chain Saws

Maintenance and Repair \$1,000 x 15% ÷ 1920 Hours	\$.08
Saw Chains \$20/week ÷ 40 Hours	.50
Fuel 15 gallons/week at \$.75 ÷ 40 hours	<u>.28</u>
	\$.86

1 Used Truck Tractor

Maintenance and Repair \$25,000 x 10% ÷ 1920 Hours	\$ 1.30
Fuel \$10/Day ÷ 8 Hours	1.25
Oil and Lube	<u>.15</u>
Total	\$ 2.70

5 Truck Tractors

Maintenance and Repair \$200,000 x 15% ÷ 1920 Hours	\$15.62
Fuel--10-160 mile round trips/day	
=1600 miles ÷ 6 miles/gallon = 267 gallons x \$.65	21.69
÷ 8 hours	
Oil and Lube 1 quart/truck/day at \$.70	<u>.44</u>
Total	\$37.75

8 Chip Vans

Maintenance and Repair \$60,000 x 15% ÷ 1920 Hours	\$ 4.69
--	---------

Cat Grader

Maintenance and Repair \$22,000 x 15% ÷ 1920 Hours x 50% Utilization	\$.86
Fuel 2.5 gallons/hour at \$.65 x 50% Utilization	.81
Oil and Lube \$.25/hour x 50% Utilization	<u>.12</u>
Total	\$ 1.79

Bulldozer

Maintenance and Repair	$\$70,000 \times 15\% \div 1920 \text{ Hours}$	\$ 2.73
Fuel	2.5 gallons/hour at \$.65 x 50 percent Utilization	.81
Oil and Lube	\$.25/Hour x 50 percent Utilization	<u>.12</u>
Total		\$ 3.66

Low Bed Trailer (Used)

Maintenance and Repair	$\$16,000 \times 15\% \div 1920 \text{ hours}$	\$.62
	x 50% Utilization	

Labor--Average Hourly Cost

Logging and Chipping (7 Man Crew)

40 hours/week x \$5.50/hour base	\$220.00
Fringe Benefits at 34 percent	<u>74.80</u>
Total 40 hours at \$7.37	294.80

Trucking

45 hours/week x \$5.50/hour base	\$247.50
Fringes at 34 percent	84.15
Premium 5 hours at \$2.75/hour	<u>13.75</u>
Total	\$345.40

$$\text{Rate per 40 hour week} = \frac{\$345.40}{40 \text{ Hours}} = \$8.635/\text{hour}$$

3. COMPANY B

a. Description of Operation

Company B is a small independent logging contractor who harvests wood on relatively small tracts (up to 200 acres), moving frequently from place to place in his area of operations. He contracts with the landowners for the timber rights and sells the harvested trees as whole-tree chips to pulp and paper mills. His market is limited to the sale of pine and aspen chips to pulp mills. When other trees are removed as desired or necessary, the chips are left in the forest--having no market value.

The silvicultural practices range from clear-cutting to selective thinning, depending upon the landowner's requirements, the market, and the timber stand being harvested. His daily production depends upon the average size of the trees being harvested. A rate of 10 tons per hour was observed in an area where the average tree butt diameter was approximately 4.5 inches. Where the tree size is an average of 6 inches, the harvested tonnage is 40 percent greater with approximately the same time and labor costs. In stands of 6 to 7 inch butt diameter, the production rate could easily reach the range of 14 to 16 tons per hour, thus greatly reducing the unit cost of production.

The land on which Company B works is generally flat. The operation includes one feller-buncher, two cable skidders, one log loader, one whole-tree chipper, and the required transport

trucks and service vehicles. Equipment maintenance is performed by the machine operators. The crew consists of the following men:

Harvesting	4
Trucking	<u>1</u>
TOTAL	5

Bookkeeping and clerical work is done by the owner and no costs are charged to overhead.

b. Basic Assumptions For Cost Computations

Interest Costs: 12 percent of financed capital; 80 percent financing for 3 years, spread over 5 years.

Local Taxes: 1.5 percent of average investment. Average investment--Mid point book value of equipment on straight line depreciation basis i.e., Investment Average=

$$\frac{(\text{Initial Investment} - \text{SV}) (\text{Life} + 1)}{2 \times \text{Life}} + \text{SV}$$

 Life In Years
 SV = Salvage Value

Insurance:

Highway trucks 4.5 percent of original cost/year.

All other 1.6 percent of original cost/year.

Harvesting Equipment: 10 percent of original cost.

Small Trucks And Loader: 5 percent of original cost

Large Trucks: 15 percent of original cost

NOTE

The above costs assume an operation of 48 weeks, 40 hours/week or 1920 hours/year. Company B operates approximately 1760 hours/year.

c. SUMMARY--COMPANY B

<u>Cost Per Productive Hour (1978 Dollars)</u>						
	<u>No. Operators</u>	<u>Fixed Equipment Cost</u>	<u>Variable Operating</u>	<u>Labor</u>	<u>Total</u>	<u>Cost Per Ton</u>
<u>Felling-Bunching</u>						
Bobcat Feller-Buncher	1	\$ 9.86	\$ 5.19	\$ 8.88	\$ 23.93	\$ 2.37
<u>Forwarding</u>						
C4D Cable Skidder	1	3.40	4.39	8.88	16.67	
C5D Cable Skidder	1	3.68	4.68	8.88	17.24	
Total	3	\$ 7.08	\$ 9.07	\$17.76	\$ 33.91	\$ 3.35
<u>Chipping</u>						
Hydraulic Loader	1	6.04	3.85	8.88	18.77	
Trelan Chipper	---	8.40	7.29	---	15.69	
Total	1	\$14.44	\$11.14	\$ 8.88	\$ 34.46	\$ 3.41
<u>Support Equipment</u>						
Pick-Up Truck	---	\$ 1.20	\$.77	---	\$ 1.97	
Repair Truck	---	.93	.76	---	1.69	
2 Chain Saws	---	.44	.49	---	.93	
Knife Grinder	---	.51	.35	---	.86	
Fuel Tanks and Pumps	---	.28	.23	---	.51	
Total	---	3.36	2.60	---	5.96	\$.59
Total Harvesting and Chipping	4	\$34.74	\$38.00	\$35.52	\$ 98.26	\$ 9.72
<u>Trucking</u>						
1 Truck Tractor	2	\$ 5.26	\$ 6.38	\$ 8.88	\$ 20.52	
7 Chip Vans	---	5.13	3.28	---	8.41	
Total	2	\$10.39	\$ 9.66	\$ 8.88	\$ 28.93	\$ 2.86
<u>Road Building and Maintenance</u>						
1 Bulldozer	---	\$ 7.65	\$ 3.27	---	\$ 10.92	
2 Flatbed Trailers	---	2.03	.70	---	2.73	
Total	---	\$ 9.68	\$ 3.97	---	\$ 13.65	\$ 1.35
Total Cost/Ton						\$13.93

d. FIXED EQUIPMENT COST--COMPANY B

	Approximate 1978 Price	Life In Years	Salvage Value	Costs Per Production Hour				
				Depreciation	Interest	Local Taxes	Insurance	Total
<u>Felling-Bunching</u>								
1 Bob-Cat Feller-Buncher	\$52,000	3	\$10,000	\$ 7.95	\$ 1.18	\$.30	\$.43	\$ 9.86
<u>Forwarding</u>								
1 Cable Skidder TFC4D	36,000	5	18,000	2.04	.82	.24	.30	3.40
1 Cable Skidder TFC5D	39,000	5	19,500	2.22	.88	.26	.32	3.68
<u>Chipping</u>								
1 Prentice Loader on GMC 10-Wheeler	50,000	5	13,100	4.19	1.13	.30	.42	6.04
1 Trelan Chipper	65,000	5	12,000	6.02	1.47	.37	.54	8.40
<u>Road Building</u>								
1 Bulldozer JD450B	60,000	5	12,000	5.45	1.36	.35	.50	7.65
2 Flat-Bed Trailers (Used)	18,000	5	6,000	1.36	.41	.11	.15	2.03
<u>Maintenance and Repair</u>								
1 Pick-Up Truck	8,500	5	1,800	.76	.19	.05	.20	1.20
1 Repair Truck	8,000	5	3,500	.51	.18	.05	.19	.93
<u>Transportation</u>								
1 Truck Tractor	40,000	5	12,000	3.18	.91	.23	.94	5.26
7 Chip Vans (Used)	42,000	5	10,500	3.58	.95	.25	.35	5.13
<u>Support Equipment</u>								
2 Chain Saws	700	1	0	.40	.04	.01	.01	.44
1 Knife Grinder	4,500	5	1,500	.34	.10	.03	.04	.51
Fuel Tanks and Pumps	3,000	5	1,500	.17	.07	.02	.02	.28
Total	\$426,700							

e. Variable Operating Costs--COMPANY B

Bobcat Feller-Buncher

Maintenance and Repair	$\$52,000 \times 15\% \div 1920 \text{ Hours} =$	\$ 4.06/Hour
Fuel 1.5 gallons/hour at \$.65		.98
Oil and Lube		.15
		<hr/>
Total		\$ 5.19

C4D Cable Skidder

Maintenance and Repair	$\$36,000 \times 15\% \div 1920 \text{ Hours} =$	\$ 2.81
Fuel 1.5 gallons/hour at \$.65		.98
Oil and Lube		.15
Other Operating Supplies		.45
		<hr/>
Total		4.39

C5D Cable Skidder

Maintenance and Repair	$\$39,000 \times 15\% \div 1920 \text{ Hours} =$	\$ 3.05
Fuel 1.5 gallons/hour at \$.65		.98
Oil and Grease		.15
Other Operating Supplies		.50
		<hr/>
Total		4.68

Hydraulic Loader

Maintenance and Repair	$\$50,000 \times 5\% \div 1920 \text{ Hours} =$	\$ 1.30
Fuel 3 gallons/hour at \$.65		1.95
Oil, Grease, Hydraulic Oil		.60
		<hr/>
Total		\$ 3.85

Portable Chipper

Maintenance and Repair	$\$65,000 \times 10\% \div 1920 \text{ Hours} =$	\$ 3.39
Fuel 4 gallons/hour at \$.65		2.60
Oil and Grease		.30
Operating Supplies		1.00
		<hr/>
Total		\$ 7.29

Bulldozer

Maintenance and Repair	$\$60,000 \times 15\% \div 1920 \text{ Hours} =$	\$ 2.34/Hour
x 50% Utilization		
Fuel 2.5 gallons/hour at \$.65 x 50% Utilization		.81
Oil and Lube		.12
		<hr/>
		\$ 3.27

2 Flatbed Trailers

Maintenance and Repair $\$18,000 \times 15\% \div 1920 \text{ hours} \times 50\% \text{ Utilization}$ = \$.70

Pick-Up Truck

Maintenance and Repair $\$8,500 \times 5\% \div 1920 \text{ Hours}$ = \$.22
Fuel and Lube $\$22/\text{week} \div 40 \text{ hours}$.55
Total .77

Repair Truck

Maintenance and Repair $\$8,500 \times 5\% \div 1920 \text{ Hours}$ = \$.21
Fuel and Lube $\$22/\text{week} \div 40 \text{ hours}$.55
Total \$.76

1 Truck Tractor

Maintenance and Repair $\$40,000 \times 15\% \div 1920 \text{ Hours}$ = \$ 3.12
Fuel for two 116-mile round trips/shifts
= 232 miles/shift $\div 6 \text{ miles/gallon} = 39 \text{ gallons/shift}$
39 gallons/shift $\times \$.65 \div 8 \text{ hours}$ = 3.17
Oil and Lube 1 quart/shift at \$.70 .09
Total \$ 6.38

7 Chip Vans

Maintenance and Repair $\$42,000 \times 15\% \div 1920 \text{ Hours}$ = \$ 3.28

2 Chain Saws

Maintenance and Repairs $\$700 \times 15\% \div 1920 \text{ Hours}$ = \$.05
Saw Chains 1/week at \$10 $\div 40 \text{ hours}$.25
Fuel 10 gallons/week at \$.75 $\div 40 \text{ hours}$.19
Total \$.49

Knife Grinders

Maintenance and Repair $\$4,500 \times 15\% \div 1920 \text{ Hours}$ = \$.35

Fuel Tanks and Pumps

Maintenance and Repair $\$3,000 \times 15\% \div 1920 \text{ Hours}$ = \$.23

Labor--Average Hourly Cost

47 Hours/week x \$5.50 Base Rate	= \$258.50
Fringe Benefits at 30%	= 77.55
Premium Pay 7 Hours x \$2.75	= <u>19.25</u>
Total Cost/week/operator	\$355.30

$$\text{Average Rate/Productive Hour} = \frac{\$355.30}{40 \text{ Hours}} = \$8.88$$

4. COMPANIES C AND D

The cost data for these two firms are not presented here because their operations are not similar enough to the recommended whole-tree chipping operation for the proposed biomass power plant in Westbrook, Maine.

Company C was operating in an area of steep slopes, preventing mechanized equipment from harvesting effectively. Felling was done by chainsaws. This has the effect of increasing the costs of production and the results are not considered as representative of terrain and operating costs for the Westbrook site.

Company D was operating with two expensive forwarding machines that are costly to maintain and were not well suited to the harvesting operation. The forester's recommendation was to change equipment to large grapple skidders, increasing production from 15 to 33 tons per hour with a reduction in operating costs. For these reasons, the data on this company's operations have not been presented in this study.

IV. TRANSPORTATION SYSTEMS

The following sub-sections are included in this section:

- A. INTRODUCTION
- B. DESCRIPTION AND EVALUATION OF EQUIPMENT
- C. RECOMMENDED TRANSPORTATION SYSTEMS

A. INTRODUCTION

The purpose of this section is to describe and evaluate transportation systems for delivering whole-tree chips and mill residue to the biomass-burning facility. The equipment available for this purpose is described and evaluated, and the optimum system is recommended.

For whole-tree chips, the transportation system begins at the harvesting site, where the chips are produced by a whole-tree chipper at a roadside landing. Unlike the situation in the wood harvesting industry, there are very few innovations or advanced developments in the transportation of wood chips. Several research projects that are investigating innovative modes of transport are described in Appendix F.

Systems and equipment suitable for delivering mill residues to the biomass generating plant are generally similar to those applicable to wood chips. Mill residues suitable for use as fuelstock include sawdust, wastewood chips, bark, slabs, and other assorted shapes that have been reduced to small, uniform size.

Current systems and equipment used to collect and transport whole-tree chips in New England are exclusively limited to highway vehicles at this time. There is some shipment of pulpwood chips by rail, using hopper-bottom cars. Whole-tree chips, however, are in very limited production and are shipped only by truck. The typical vehicle is the tractor with a semi-trailer

capable of carrying approximately 2,000 cubic feet with an average weight of 22 tons. The semi-trailers used in this service are commonly called "chip vans".

The Percival Logging Company has two tractors and seven chip vans in use for this service. The Dashnaw Logging firm has eight chip vans and five tractors for hauling whole-tree chips. The Groveton, New Hampshire, whole-tree chip operation utilizes five chip vans and three tractors in its operations. A whole-tree logging and chipping operation in the vicinity of Berlin, New Hampshire uses five chip vans and three tractors for transporting whole tree chips.

In all of these operations, the whole-tree chipper chips the trees and blows the chips directly into a waiting chip van, which is normally detached from its tractor at the roadside landing. When the van is loaded, a tractor is attached and the trailer is hauled away. If no empty van is immediately available, the chipper will be shut down. The number of chip vans needed in any given system depends to a large extent upon the length of the haul and the efficiency of unloading at the destination. In the case of the Percival operation cited previously, the high ratio of vans to tractors (seven to two) is due to delays in unloading.

While this study has investigated the loading and transporting of both whole-tree chips and mill residue, it is assumed that the seller of mill residue will supply and utilize his own equipment for loading the vehicles. Only general considerations and suggestions are presented for loading mill residue at the source.

B. DESCRIPTION AND EVALUATION OF EQUIPMENT

1. LOADING

Loading consists of placing the fuelstock on the transportation device or vehicle. Equipment available for this purpose is described as follows:

a. Chipper with Integral Blower

The typical whole-tree chipper as used in the forest products industry has built-in facilities for blowing (or hurling) the chips into a waiting van or onto a storage pile. This chipper is constructed with blades or vanes on the knife wheel such that the chips are scooped up and thrown out of the "blowing hood", along with an air stream that carries them away from the chipper. The typical chipper is capable of loading a standard-size van with the chip stream directed through the open end of the van.

Ordinarily, no separate blower or other loading device is required when the whole-tree chipper is used and no costs are charged to the transportation system for loading of whole-tree chips. Any other method of loading whole-tree chips (such as conveying from a storage pile, loading with a materials handling vehicle, etc.) would add costs to the system. The whole-tree chipper with integral blower is unquestionably the most efficient and economical system for loading chips at the landing.

b. Front-End Loader

The front-end loader is a rubber-tired tractor equipped with a large scoop in the front that can be used to scoop up chips or mill residue from storage piles and dump loads of it into an open-top van or railcar. Front-end loaders are very common material handling vehicles in plants and mills--a plant with a supply of residue and an adjacent railroad siding may easily find this method the most economical way to load residue on railroad cars.

c. Crane With Clamshell Bucket

Cranes with clamshell buckets could be used to pick up chips or mill residues and load open-top railcars or chip vans. Typical cranes being used in service with clamshell buckets can be fitted with special buckets designed for unloading chips. The possible use of the crane with clamshell bucket for loading mill residue is similar to the case for the front-end loader. A plant or mill that already has a crane (possibly with only partial utilization) may find it most economical to obtain a chip bucket and load mill residue onto railroad cars or trucks.

d. Conveyors

Chips and mill residue can be carried by conveyor and discharged into a waiting transport vehicle of the the open-top variety. A portable or mobile conveyor consisting of rubber belts or buckets might be used effectively under some conditions, especially for loading mill residue.

2. TRANSPORTATION

Two methods of transportation are available and technically feasible for delivering whole-tree chips and mill residue to a proposed conversion facility in the Westbrook area:

(1) highway trucks and (2) trains. There is an adequate highway system throughout the biomass supply area and the power plant location will have railroad service. Rail service is adequate in the southeastern area of Maine, where the fuelstock for the plant will be obtained (See Figure 4-1). Rail shipments from central and northeastern Maine are also possible if economically feasible.

The economics of transportation, however, impose limitations upon the distances that can be used for any given system. The biomass availability study indicates that truck transportation will be the primary method and that rail transport will probably be limited to delivery of mill residue.

Lloyd Hawkenson, president of the Connecticut Valley Chipping Company, of Plymouth, New Hampshire, has reported that there are no regular shipments of chips by rail in Vermont or New Hampshire and very few in Maine. He also indicated that railroad sidings would not be readily available to harvesting areas, making it necessary to transfer chips from highway trucks to railcars if rail transport is used. It was his opinion that there is no way to economically transfer chips from trucks to railcars where the maximum haul was limited to 50 miles (4-1).

FIGURE 4-1

Other experts have also expressed this opinion. "The transportation of chips is best accomplished by truck...."(4-2). Unless loading and unloading facilities are at the points of production and consumption, the necessity of trucking chips to and from rail sidings would probably make rail deliveries uneconomical"(4-3).

The Adler study (4-4) computes the installation costs for truck-railcar transfer equipment at between \$435,000 and \$625,000 and the cost of railroad car unloading equipment at between \$500,000 and \$625,000. The total capital investment for effecting transfer of the harvested biomass from trucks to railcars would therefore be in the vicinity of \$1,000,000. It is extremely doubtful that these investments can be economically justified.

The cost of trucking wood chips has been estimated at \$0.065 per ton mile by several authorities, and has been used as the basis for comparison with railroad transport costs in this study. Reported railroad freight costs are higher than this for distances up to about 150 miles, at which point they are the same as trucking costs. Beyond 150 miles, rail shipments have a lower cost than trucking.

These figures are subject to more precise definition when specific loads and distances are identified. It is common practice to enter into negotiations with shipping companies to obtain the lowest rates when firm contracts can be offered. For any given source of fuelstock, it can be assumed that the least expensive transport method will be selected. This will be determined when

the project is placed into operation and only the general approach can be outlined at this time.

a. Trucks

In keeping with the harvesting sequence previously specified, whole-tree chips will be produced at forest landings, where access will be by road. Since the likelihood of a rail siding at most of these logging sites is remote, trucking will undoubtedly be the first step in transportation of the forest biomass fuelstock.

Mills producing residues will always be accessible by highway and some will be serviced by railroads. Trucks will have to be used to take the residues from those mills not on railways.

Therefore, it can be stated that trucks will be used to transport both whole-tree chips and mill residue supplies.

Trucks vary in design from two axles to six and are of two general types, those with integral cargo bodies and those with separate cargo vans (tractors with semi-trailers).

(1) Trucks With Integral Cargo Bodies

Trucks with integral cargo bodies will generally have less capacity than the tractor-semi-trailer combination and it is well established that the larger the load per trip, the less expensive the hauling costs⁽⁴⁻⁵⁾. For economic reasons, therefore, trucks with integral cargo bodies are eliminated from further consideration.

(2) Tractor With Semi-Trailer

This combination offers large carrying capacity plus the advantage of a detachable cargo container that can be left at the landing for filling while the driver hauls a filled unit to the plant site. These trucks are designed to safely handle the maximum load allowed by the state's highway regulations, which gives them an economic advantage over smaller vehicles. A fleet of tractors and trailers with the proper balance of numbers and scheduling of deliveries can be designed to provide the lowest unit cost for delivered fuelstock. All four of the logging firms whose operations were studied for this investigation use this method.

Models are available with open-top bodies as well as enclosed bodies. The open-top models can be loaded by a wider variety of loading devices than the enclosed vans but they generally require covering the load with a tarpaulin. This adds time and cost to the transportation function. Unloading can be through rear doors, the same as for the models with enclosed bodies. The enclosed models offer fewer ways of loading, but they are fully compatible with whole-tree blowing chipper, which has been designated as the optimum method of producing chips.

Various types of self-unloading semi-trailers are available, including units with "walking floors", bottom

dumpers, and rear or side dump mechanisms. This type of semi-trailer is more expensive than the conventional units and in addition requires greater maintenance and operating costs. The biomass power plant has been designed to receive and unload conventional trailers, therefore, the self-dumping type can be eliminated from further consideration.

In addition to the advantages already pointed out, the conventional semi-trailer is a standard, readily available unit. All of the makes are interchangeable, making it possible to combine tractors and trailers from different suppliers. This combination unit can be quickly and easily unloaded by the hydraulic tilt-up dumper, three of which are specified for installation at the biomass-burning power plant. The dumpers specified for the plant will accomodate all of the various makes and models of tractor-trailer, and all incoming truck-loads will be handled in the same manner. The tractors are all designed to withstand the tilting up to a 60° degree angle without damage.

b. Trains

The biomass facility will be served by the Maine Central Railroad, which provides service to the Westbrook area complex. The southeastern section of Maine and New Hampshire, from which the plant's fuelstock will be drawn, has a reasonably adequate rail network for this purpose. The power plant

facilities are being designed to accomodate rail shipments; design criteria call for approximately 18 percent of the fuel-stock to be received by rail.

Railroad transport is usually cheaper than highway trucking, especially for long hauls (150 miles or more). It may, however, entail the transfer of cargo from a truck to a rail-car, an operation that adds a substantial increment to the transportation costs. This will tend to offset any advantage due to lower shipping costs and the economics will have to be carefully evaluated for each individual source of supply.

The use of rail service for wood chips will generally be restricted to areas beyond the 150-mile radius where the lower shipping costs may offset the extra handling. The choice of rail or truck shipment for chips will be made when the need arises.

In case of mill residues, if the plant supplying the material has rail service, the extra loading operation can be eliminated and this can provide a lower transportation cost than truck shipping. With loading equipment for rail shipments already provided at the source of supply, and the unloading facilities provided at the biomass power plant, the use of rail transport for mill residue could be the most economically feasible method for many sources.

Various types of railcars have been considered for this service, including totally enclosed boxcars, hopper-bottom cars, gondolas, and high-sided gondolas (like boxcars without a top).

The major consideration in evaluating the suitability of railcars is the means of loading and unloading them. Open-top cars offer the greatest advantages for these functions and other types have been removed from further consideration. Hopper-bottom cars are not suitable because of the nature of the fuelstock, which is subject to jamming, compacting, and freezing. The use of car shakers to clear jams is not recommended because it creates high maintenance costs on the cars. Totally enclosed boxcars cannot be loaded and unloaded efficiently.

The open-top car with high sides offers the greatest carrying capacity coupled with the capability of unloading with a clamshell bucket on a knuckle-boom loader. Specially designed clamshell buckets can hold up to 1½ tons and the machine can unload a railcar in about one hour, leaving a small residue that simply travels back and forth in the car.

3. UNLOADING

a. Trucks

The trucks will be of the tractor-semi-trailer variety as previously described. They are enclosed, box type containers with rear-door openings. They can be most efficiently unloaded using the hydraulically operated tilt-up truck dumper. The truck dumper will be permanently installed at the biomass power plant. The entire tractor-trailer combination is simply backed onto the dumper platform until it reaches a permanent "stop" mounted on the platform. The tractor can be lashed

down with a chain if desired, but this is not ordinarily done in order to save time. Operation without the lash-down is common in the pulp and paper industry, where many of these dumpers are installed and in regular use. The backdoors or gates of the trailer are opened and the platform is tilted upward to an angle of 55-60° with the ground, allowing the cargo to discharge into a pit.

The typical truck dumper can unload an average of four to six trucks an hour, or 40 trucks per eight-hour shift. These units are basically trouble-free ⁽⁴⁻⁶⁾ and one firm reported using their dumper for two and one-half years without a single problem, not even a need for more hydraulic fluid ⁽⁴⁻⁷⁾. Knowledgeable sources have stated that the hydraulically operated truck dumper is the most efficient and economical method for unloading the type and volume of material required as fuelstock for the biomass-burning power-plant ⁽⁴⁻⁸⁾.

The problems that arise in the use of the truck dumper are inherent in any type of truck delivery and unloading system, that is, the uneven flow of materials. This is caused by multiple truck arrivals, frozen or jammed material, equipment outages, and other occurrences that disturb smooth flow of material. The installation of three dumpers at the plant will provide quick turn-around capability and help to assure rapid unloading of trucks.

A similar dumper is available for lifting the trailer only. The advantage of this unit is that tractors can be unhitched and released to pick up other trailers, thus getting greater usage of the tractors and spreading the unloading process more evenly throughout the work day. This method of operation requires that one tractor be kept at the dumper to move the trailers on and off, and it entails constant unhitching and rehitching of trailers. The extra time consumed by these operations outweighs the advantages, therefore, this unit has been removed from further consideration.

Other systems for unloading trailers include the use of front-end loaders, conveyors, blowers, and special combination systems developed by manufacturers. All of these systems have been carefully evaluated and eliminated from further consideration because of one or more "fatal flaws" as applied to the biomass-burning power plant project.

b. Trains

Many methods of unloading railroad cars have been investigated during the course of this study. The only methods included in this report are those that can be used for unloading the open-top boxcar or gondola, since these cars have been deemed the most feasible for this application.

Rotary and end dumpers are available and are quite commonly used for unloading coal at steam power plants. The railcar is moved into position on the dumper and securely fastened; it is then either rotated or tipped upwards until

the contents are discharged into a pit below. These dumpers are suitable for both wood chips and mill residues and the cars can be unloaded in about 15 minutes (4-9). The tilt-up dumper, of course, requires that the cars have end doors, which is a special feature that might limit the availability of cars.

Railcar dumpers are very expensive and must be kept in almost constant use to justify the capital investment. Since rail shipments will constitute only about 18 percent of the fuelstock and be used only for mill residues, the expense of installing these units outweighs their advantages, and they have been eliminated from further consideration.

Railcars can be unloaded by a clamshell bucket mounted on a knuckle-boom machine. The bucket is dropped into the material with the jaws open, and it scoops up approximately one ton of material at a time. A typical 50-ton carload can be emptied in about one hour with the clamshell unloader. This unloading method is considered effective for use in the Westbrook area, where freezing of fuelstock will be expected over several months.

Other unloading methods encounter severe difficulties with frozen biomass chips, and some users have resorted to steam heating for periods up to an hour before the material can be unloaded (4-10). This operation delays unloading and adds cost for heating the fuelstock. In using the clamshell apparatus, the weight of the bucket and the power of

the jaw-closing mechanism is expected to loosen the frozen material and facilitate expeditious unloading. The clam-shell bucket can remove approximately 98 percent of the material and the remaining material simply travels back and forth between the source and the power plant. Since the cars are weighed before and after unloading, the plant is charged only for the material actually removed and the only effect of leaving some material in the car is that it reduces the effective capacity of the car by two percent.

Blowers, vacuum systems, conveyors, and various combinations of devices have all been eliminated from consideration, primarily because of the problems associated with mill residues and freezing conditions in the area.

C. RECOMMENDED TRANSPORTATION SYSTEMS

1. FOR WHOLE-TREE CHIPS

The recommended system for the loading, transport, and delivery of the wood chip fuelstock for the biomass facility is shown in Figure 4-2. It is based upon the use of whole-tree chippers at the collection sites in the woods. The chipper will have an integral blower that will blow the chips into a waiting chip van. The chip vans will be of the semi-trailer type capable of attachment to a tractor for highway transport.

Facilities at the plant for unloading the chip vans will be back-on, tilt-up hydraulic truck dumpers capable of tilting the entire tractor-trailer without the need for detaching the vehicles or securing them to the dumper. This method will provide the capability of dumping 40 trucks per day per dumper.

The concept of operation for this system is that a tractor is hitched to a loaded trailer at the roadside landing and remains hitched throughout the trip to the plant, during the tilt-up unloading, and for the return trip to the landing. At the landing, the van is unhitched for re-loading and a loaded van is hitched to the tractor for the next trip. The driver will make as many trips per day as time permits (typically, one, two, or three trips, depending upon the length of the haul).

The recommended transportation system has been integrated into the design of the facility such that the balance between wood

FIGURE 4-2

RECOMMENDED TRANSPORTATION SYSTEM
FOR HARVESTED BIOMASS

chips and mill residue, truck shipments and rail shipments, can be accommodated efficiently at the power plant. This overall plan is described in detail in paragraph 3. Overall Transportation Plan.

2. MILL RESIDUE

The system recommended for the loading, transport, and delivery of mill residues is shown in Figure 4-3. Tractor-trailers identical to those described for whole-tree chips are recommended for truck shipments of mill residue. Open-top railcars similar to boxcars are recommended for rail shipments. Unloading at the plant will be by hydraulic dumper for tractor-trailers and by clamshell bucket for railcars.

The size and condition of the mill residue, as well as the loading onto the transport vehicles, is basically the responsibility of the producer and seller of the materials. The biomass power plant is designed with facilities for size reduction of mill residue, however, pieces of material greater than six inches in any dimension may jam the conveying equipment. Slabs and other materials of larger size must be cut up before loading for shipment. They can then be handled much the same as wood chips, using blowers, conveyors, front-end loaders, or clamshell buckets, as desired by the producer.

The shipment of mill residues is integrated into the overall transportation plan for the biomass-burning power plant as described in paragraph 3. of this section.

FIGURE 4-3

RECOMMENDED TRANSPORTATION SYSTEM
FOR MILL RESIDUE

3. OVERALL TRANSPORTATION PLAN

The recommended transportation systems for chips and mill residue are blended into an overall transportation plan that has been incorporated into facility design. The fuelstock receiving, handling, storage, and delivery facilities at the biomass-burning plant are designed to handle the biomass fuelstock required to sustain the plant as outlined in the harvesting section of this report. The basis for the harvesting and transportation systems is the fuel requirement of 1,000 oven dry tons per day, which amounts to 2,000 green tons per day considering a moisture content of 50 percent.

The plant operating schedule calls for operation 24 hours per day for 340 days a year, which results in a requirement of 680,000 tons per year of green fuelstock to sustain boiler operation. Deliveries of fuel, however, are to be made only five days a week under normal circumstances. The harvesting operations will be working and delivering fuelstock for 48 weeks out of the year (240 days), while the mill residue supplies can be received for 50 weeks (250 days).

Analysis of the mill residue availability has shown that approximately 37 percent of this fuel can be obtained as mill or plant residue, leaving 63 percent to be obtained as harvested whole-tree chips. This 63 percent chip supply amounts to approximately 1,792 tons per day.

This means that on the average weekday of delivery, the plant will receive 1,792 tons of harvested chip fuelstock and 1,000 tons of mill residue.

The average carrying capacity of the semi-trailer chip van is given as 22 tons, which means that 82 truckloads of chips must be received and unloaded each day (on the average). The tilt-up, back-on, truck dumpers as recommended in this report as specified by the plant design data have the capability of unloading 40 truckloads a day each. Two such dumpers have been specified for the whole-tree chip receiving system, for a capability of 80 truckloads per day. The other 2 truckloads will be unloaded by the mill residue truck dumper.

The number of actual chip vans required for the transportation system is less than 83, however, because the trucks can make two trips a day on the average. Using a 60-mile radius as the practical limit for truck shipment, the average truck trip will be in the range of 30 miles, which represents approximately 60 minutes' driving time each way. The truck turn-around time at each end is estimated at 30 minutes, so that the total time per trip is approximately three hours. At this rate, the typical eight-hour shift for one truck driver (7 working hours) will be two round trips. The harvesting plan will be scheduled to achieve this average as nearly as possible. With two daily trips per truck, the whole-tree chips supply system will require 42 chip vans as the minimum. Several additional vans will be required as spares in case of outage, and so that vans can be left at the landing for loading while other vans are being hauled to or from the plant. The number of tractors should also be about 42, but one or two spares must be in the system to allow for scheduled maintenance, unforeseen outages, etc.

The mill residue transportation system must be able to provide approximately 37 percent of the 680,000 green tons of biomass fuel-stock per year. This amounts to 1,000 tons per day for the 250 working days of the year. It is estimated that 50 percent of this material will be shipped by truck and 50 percent by railroad. The railroad shipments will be in cars with approximately 50 tons capacity, so that about 10 carloads per day will be required for the 500 tons to be received by rail. The clamshell bucket unloader to be installed at the plant site is capable of unloading a car in approximately one hour, so a ten-hour shift will be capable of handling the rail shipments of mill residue.

The other half of the mill residue will be received by truck and a back-on, tilt-up truck dumper has been selected for unloading the trucks. The 500 tons to be received by truck can be shipped in 23 truckloads, and the dumper can unload all of these in about 5 hours, so the additional capacity of the mill residue truck dumper can be utilized for assisting with unloading of whole-tree chips (about 2-3 truckloads per day).

All of the mill residue received, both by truck and by rail, will be passed through a hog for size reduction to facilitate handling by conveyors, chutes, and other devices designed for handling wood chips. The mill residue will be blended with the whole-tree chips in storage and will be delivered to the furnace by the same conveying system.

4. WHOLE-TREE CHIP SUPPLY SYSTEM

The supply of whole-tree chips can be furnished by seven chipping operations, each equipped with a large chipper capable of chipping 270 tons per day. Each operation will require six drivers with a tractor-trailer, such that each driver makes an average of two round-trips per day, or 12 truckloads per day per chipping operation. This makes a total of 84 truckloads per day for the system (82 required). Each chipping operation will require two extra trailers to assure that the drivers can make their scheduled trips without excessive waiting time. The number of trailers per chipping operation will then be eight, for a total of 56 trailers in the supply system. Evidently, there should be several additional trailers to fill in for outages.

5. SUMMARY OF SUPPLY AND TRANSPORTATION PLAN

(1) Fuelstock Requirements

Daily tonnage, oven dry (per DOE RFP)	1,000
Daily tonnage, green wood (50% moisture)	2,000
Annual tonnage (340 operating days)	680,000

(2) Mill Residue Available

Annual tonnage (37 percent of total)	250,000
Daily tonnage (250 working days)	1,000
Rail tonnage (estimated at 50 percent)	500
Number of railcars per day (50 tons each)	10
Truck tonnage (estimated at 50 percent)	500
Number of truckloads (22 tons each)	23
Dumper capability (truckloads per day)	40
Excess capacity for dumping whole-tree chips	17

(3) Whole-Tree Chips Required

Annual tonnage (63 percent of total)	430,000
Daily tonnage (240 working days)	1,792
Number of truckloads (22 tons each)	82
Truck dumper unloading capacity (2 dumpers)	80
Truckloads to be unloaded by residue dumper	2

(4) Summary of Trailers Required

For whole-tree chips	82
Daily trips per truck	2
Number of trailers needed	42
Spares and extras	14
Total trailers for whole-tree chips	56
For mill residue (one trip per day)	23

(5) Supply of Whole-Tree Chips

Total daily requirement (tons)	1,792
Typical large chipper capacity (tons)	270
Number of chipping operations	7
Number of drivers with tractor-trailer (for each chipping operation)	6
Total number of drivers with tractors	42
Extra trailers per chipping operation	2
Total trailers per chipping operation	8
Total number of trailers (8 x 7)	56

V. APPENDIX

The following sub-sections are included in this section:

- A. REFERENCES
- B. PERIODICALS AND PUBLICATIONS REVIEWED
- C. WOOD MEASUREMENTS AND WEIGHTS
- D. OPERATION ON STEEP SLOPES
- E. GLOSSARY
- F. FUTURE POSSIBILITIES

APPENDIX A

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- (4-10) See (4-1)

APPENDIX B

PERIODICALS AND PUBLICATIONS
REVIEWED FOR INFORMATION

M THE NORTHERN LOGGER AND TIMBER PROCESSOR
M PULP & PAPER
M CANADIAN PULP & PAPER
M JOURNAL OF FORESTRY
FORESTRY RESEARCH NEWSLETTER
FORESTRY FACTS
U. NEW HAMPSHIRE RESEARCH HIGHLIGHTS
FOREST SERVICE RESEARCH ACCOMPLISHMENTS
ANNUAL REPORTS--N. E. FOREST EXTENSION SERVICE
M TIMBER HARVESTING
M NEWSPAPER (ME. PAPER INDUSTRY NEWSLETTER)
M CANADIAN FOREST INDUSTRIES
Q GREEN AMERICA--AMERICAN FOREST INSTITUTE
SOLAR ENERGY RESEARCH & DEVELOPMENT REPORT
FORESTRY WORK TOOLS
W MAINETIME
FOREST PRODUCTS RESEARCH SOCIETY MAILINGS
FERIC MAILINGS
D BARRE/MONTPELIER TIMES-ARGUS
M FROST PRODUCTS MARKETING AND MANAGING ASSOC., DOVER-FOXCRAFT,
MAINE

M = MONTHLY

D = DAILY

W = WEEKLY

NOT MARKED = IRREGULAR

APPENDIX C

WOOD MEASUREMENTS AND WEIGHTS

A. THE CORD

The cord is defined as a stack or pile of wood 8 ft long by 4 ft high by 4 ft wide; typically, it is obtained by cutting 4-ft lengths of wood and stacking them to form this shape, which produces an overall volume of 128 cubic feet, including the open spaces due to the roundness of the wood sticks.

Wood using organizations commonly purchase their supplies by weight (tons) rather than volume (cords), and tonnages have been used throughout this study and engineering design work. Cords are occasionally referred to by quoted sources and are valid for comparison purposes, since the weights are in the same ratios as the volumes. A ratio of two green tons/cord has been used herein.

B. GREEN VERSUS DRY WEIGHT

Green wood as cut contains approximately 50 percent moisture (this varies by species, season, climatic conditions, etc.--50 percent has been used in this study as a good working average). One ton of green wood (2,000 lb) is considered as representing 1,000 lb of dry wood (for its combustion value). In general, tonnages given in this report are green tons unless stated otherwise.

The design basis for the entire study and plant configuration is given as 1,000 oven dry tons per day as specified in the DOE's RFP and subsequent contract with Wheelabrator Cleanfuel.

C. DENSITY OF WOOD

Density is defined as weight divided by volume and is normally given as pounds per cubic foot. The density of wood depends upon many factors, such as species, season, geographical area, method of determination, etc. Values for all of the principal commercial species have been determined by many different research organizations and investigators. The figures of greatest concern in this study are the density of the chips to be used for fuelstock. Chips are slightly compressible and will have a greater density in a storage pile than when removed and placed on an open surface. The values used in engineering calculations and equipment sizing for design of the biomass-burning power plant are:

Chips in storage	20 lb/ft ³
Chips on a conveyor belt	17 lb/ft ³

These values are considered to be representative of what will actually be found when the biomass-burning plant goes into operation.

D. CHIP TRANSPORT BY TRUCK

The semi-trailer used as a chip van has typical dimensions of 8 ft by 8 ft by 40 ft, for a total volume of 2,560 ft³. This volume will hold 51,200 lb of chips at 20 lb/ft³, or 25.6 tons. The chip van, however, is usually not filled to capacity due to the method of blowing chips into it from the end. At 90 percent filling, the chip van will be loaded to a weight of 22 tons, the figure used in this report as the average load of chips delivered by chip van.

APPENDIX D

EQUIPMENT OPERATION ON STEEP SLOPES

There is some variation in the definition of "steep" as applied to slopes and equipment operation. After considerable research into this topic, including discussions with equipment manufacturers' representatives, equipment operators, and others in the forest products industry, the value adopted for this report has been set at 25 percent. Anything greater than this is considered steep, and indicates a significant reduction in operating efficiency. Some machines will operate at considerably greater slopes, but their productivity is reduced and the danger of overturning is increased considerably. Members of the study team observed equipment operating at slopes up to approximately 35 percent, where there was danger of over turning.

The figure of 25 percent as used herein may be questioned by some experts, however, it is considered as the limiting slope for full production and efficient, economical operation.

APPENDIX E

GLOSSARY--SECTION III--HARVESTING SYSTEMS

biomass--as used in this report, wood that is or may be suitable for harvesting.

bole--the main or "stem" portion of the tree which, in conventional harvesting, is the merchantable part of the tree (see attached)

buck--to cut wood into shorter pieces.

bunch--in this study, to accumulate the harvested forest biomass in a pile, aligned longitudinally and of a quantity suitable for one-stop pick-up by a skidding or forwarding device.

chokes--metal slides that slip over cables used for skidding logs, making a loop of the cable that pulls tight when the cable is made taut.

chips--the product of a chipper; pieces of biomass about matchbook size.

cord--standard cord--a unit of measure for stacked bolts of wood, encompassing 128 cubic feet of wood, bark, and air space.

solid cord--85 cubic feet of wood fiber (a generally accepted conversion figure of necessity of approximation; estimates vary from 60 to 100 cubic feet [Ellis]).

crawler--a tractor that runs on two steel tracks, normally equipped with a push blade in front and a winch in the back, same as bulldozer or lag tractor.

culls or cull trees--trees or logs that are unmerchantable due to imperfections, small size, or undesirability of species.

fell--to sever a tree from its stump.

harvesting system--a combination of equipment, operators, and procedures able to cut trees and prepare them for over-the-road transport.

"hot" harvesting schedule--a harvesting system in which one or more operations is dependent upon the timely functioning of others; specifically, in whole tree chipping, where there is no holding area and trees must be supplied regularly to the chipper.

integrated harvesting system--harvesting system in which trees are sorted at the landing for highest economic value (sawlogs, veneer logs, pulpwood, chips, etc.)

landing--a place on the logging site where trees or parts of trees are stored or processed for removal by over-the-road vehicles.

logging residues or forest residues--tops, limbs, and culls left after logging; insect infested, diseased, windblown, and fire damaged trees; unused or considered unusable forest products.

pulpwood--logs that are used by the pulp and paper industry.

sawlogs--logs that are of high enough quality to be utilized by sawmills.

shear--apparatus that fells trees by hydraulically operated blades, either two opposing or one draw blade.

silviculture--the theory and practice of controlling forest establishment, composition, and growth.

skidder--a rubber-tired tractor normally equipped with a push blade in front and a winch or grapple in the back; normally articulated and four wheel drive.

slash (noun)--residue left after conventional harvesting operation including tree limbs, tops, and trees which were felled and left.

slash (verb)--see buck; to cut the merchantable bole into shorter pieces.

stumpage or stumpage fee--the money paid to a landowner for trees harvested from his or her land.

whole (above-ground) tree--all parts of the tree (bark, limbs, leaves, needles, twigs, etc.) above the point where the tree is severed from its stump.

APPENDIX F

FUTURE POSSIBILITIES

1. FELLER-ACCUMULATORS

Prince Albert Pulpwood along with FERIC has developed a prototype feller-accumulator that has been in operation for about a year, averaging 25 trees a minute in stands up to 8 inches DBH with a high of 52 trees a minute. It carries up to one and a half cords in the accumulator before dumping them for pick-up by skidders.

Timberjack had a prototype feller-accumulator working in the field at the CPPA Forest Equipment Demonstration in September 1978 that cut and placed the trees on a tilting side bunk that could accumulate trees weighing up to four tons before dumping them to the ground in a bunch suited to a standard grapple load, thereby greatly reducing bunching time required by the present generation of feller-bunchers.

2. SWATHE FELLERS

Experiments are being conducted in the South on a swathe felling machine equipped with a mobile chipper for harvesting logging residues, standing cull trees, and stumps.

NFI Inc. in conjunction with Crown Zellerbach are working on the development of a residue shredding site preparation machine that would have much the same function as the swathe feller. They are currently developing a system to capture the chipped residue resulting from brush clearing, rather than blowing it on the ground as mulch.

According to Inter-Group Consulting Economists Ltd., feller-chippers that cut and immediately chip trees then blow the chips into an attached van for transport to landing or mill are under development in France and elsewhere, but they know of none in commercial operation.

3. TOPWOOD PROCESSOR

In an experimental relogging operation being conducted by the U.S. Forest Service, a prototype topwood processor that consists of a carrier vehicle mounted with a rotating boom and highly maneuverable shear is being developed that is expected to fell and bunch small non-sawlog trees, and in addition to sever large limbs from residual tops and align the limbs with the butts of the tops. This compaction of large tops minimizes damage to the future crop trees during skidding.

4. STUMP HARVESTING

The International Paper Company in Marianna, Florida, is using a prototype Rome Tree Puller that severs the lateral roots and pulls a large portion of the tap root along with the whole-above-ground tree. They estimate anywhere from 12-10 percent more fiber can be harvested by using this machine.

Finnish wood harvesters are currently using stump harvesters for removal of stumps and roots left after conventional logging is completed. Groenfors stated that it cost 25 percent less for the stump and root fiber delivered to the mill with the Finnish system than for conventionally harvested wood.

5. FOREST TRANSPORT

In Canada experiments are being conducted in the development of the "long-distance", off- and on-road transportation concept and its place in tree harvesting systems," under the brief heading, TOOR. The object is to develop a forwarder that can move tree lengths, full trees, or even shortwood or chips over long distances in the woods to main roads in order to eliminate or shorten logging roads, cut down traffic on feeder roads, and reduce environmental disturbance.

Helicopters are being used to some extent to remove logs from the forest, but only for either inaccessible or environmentally unstable terrain where the value of the timber is sufficient to warrant the high costs of the operation.

A study of the possibilities of removing logging residues by baling them was completed in May 1977. The study showed it to be theoretically economically feasible, but there is no commercial equipment available at this time for baling residues. Experiments are being conducted in compression of small trees and efficient methods of transporting whole trees on public highways in Finland and Sweden, but to date it is not considered feasible.

A recent study proposal is looking to investigate the use of conveyor systems similar to those used in the coal mining industry to move wood in all forms from the logging site to roadside, eliminating the need for costly and environmentally damaging logging roads on steep sites.

6. SNOW REMOVAL

FERIC developed and tested snowblowers for winter harvesting in order to facilitate fast, low felling of trees. Their conclusion is that "snowblowers have a real potential for eliminating snow removal problems".