Collection, Transportation, and Storage of Biomass Residues in the Pacific Northwest

**L. K. Inaba
D. E. Eakin**

November 1981

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SUMMARY

This study was conducted to identify potential methods for the collection, transportation and storage of agricultural and forest residues in the Pacific Northwest.

Information was gathered from available literature and through contacts with researchers, equipment manufacturers, and other individuals involved in forest and agricultural activities. This information was evaluated, combined, and adapted for situations existing in the Pacific Northwest.

A number of methods for collection, transportation, and storage of biomass residues using currently available technology are described. Many of these methods can be applied to residue fuel materials along with their current uses in the forest and agricultural industries.

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COLLECTION, TRANSPORTATION, AND STORAGE OF BIOMASS RESIDUES IN THE PACIFIC NORTHWEST

Lon K. Inaba
David E. Eakin

INTRODUCTION

The potential for the utilization of biomass fuels has received considerable attention in recent years as the cost and uncertainty of supply for fossil fuels continues to rise. Agricultural and forest residues appear to be ready sources of biomass fuels and their use has been studied by a number of researchers throughout the country.

The Pacific Northwest region of the United States, which includes the states of Washington, Oregon, and Idaho, appears to possess large amounts of both forest and agricultural residues. The need to identify the potential for large scale biomass utilization in the Pacific Northwest was recognized by researchers at the Department of Energy's Pacific Northwest Laboratory (PNL) operated by Battelle Memorial Institute. PNL was funded by the Department of Energy's Biomass Energy Systems Division to provide a regional assessment of producing alternative energy products from renewable biomass resources in the Pacific Northwest.

One task of this project was to assess the methods for collection, transportation, and storage of biomass residue. This document reports the results of that task. Various methods for the collection, transportation, and storage of agricultural and forest residues are described, alternative methods are discussed and costs are estimated for the implementation of these methods in the Pacific Northwest.

AGRICULTURAL RESIDUES

COLLECTION

The major portion of agricultural residues available in the Pacific Northwest occur in the form of straws of wheat and barley. They are located mainly in the regions along the Snake and Columbia Rivers in southeastern Washington, northeastern Oregon, and southern Idaho. The terrain for collecting agricultural residues can vary from the flatlands of furrow irrigated fields to rolling hills as found in the Palouse area of eastern Washington. Since these residues are on land that has been previously under cultivation, access to the fields is usually not a problem. Harvest of wheat and barley begins as early as the end of June and ends as late as mid-September depending on the geographical region and weather conditions. Collection of the residue can begin directly after the grain is harvested and extend over a 4-8 week period without interfering with the normal recropping practices. The autumn rains in some areas may limit the amount of time available for the collection of some residues.

For the purpose of this report, we will focus mainly on equipment for the collection of biomass that is currently available to the farmer since we feel that the farmer will play the major role in collecting the agricultural biomass fuels. Much of this equipment is currently used in forage harvesting operation and can be adapted to collect these residues with minimal effort. Due to the seasonal availability of many of the biomass sources and of most agricultural commodities, and thus the limited annual use of their harvesting equipment, high capital costs for this equipment can often prohibit the collection of these materials. Utilization of conventional harvesting equipment for the collection of agricultural residues in addition to conventional crops can help to reduce the fixed unit costs of operation.

As part of the normal grain harvesting operation, the wheat and barley is cut and the grain is separated from the straw and chaff at the combine (see Figure 1). The straw exits through the rear of the combine

FIGURE 1. Combining of Grain (Source: Deere and Company, 1973)

FIGURE 2. Swather/Windrower (Courtesy: Deere and Company)

and can be chopped and spread, or placed in a windrow behind the combine. When placed in windrows, the straw can then be collected and transported to a site to be used. Only about half of the available straw is normally passed through the combine during harvest. The rest remains standing in the field as stubble. This remaining material can be cut and windrowed with a swather/windrower (Figure 2) and then collected along with the straw from the combining operation.

Methods for collection and densification of agricultural residue addressed in this report include the collection of loose straw and several methods for densifying the material. Discussed are the methods of:

- Baling
- Stacking
- Cubing, and
- Pelletizing.

Estimated production rates for various methods of harvesting and comparative costs of harvesting system options are shown in Tables 1 and 2.

Baling

Balers have been used in the forage industry for many years. Most balers are pull type machines powered either by the power take off (pto) drive from the tractor unit or by an engine mounted to the baler, however self propelled models are available. Functional components of the agricultural baler include 1) a device to pick up the material from the windrow and feed it into the baler, 2) a means of compressing or wrapping the material to increase the bale density, 3) a means of securing each bale with wire or twine to prevent springback and thus maintaining the densified form, and 4) a means of ejecting the finished bale from the bale chamber. Balers currently on the market can be classified based on the size or shape of the bales they form. Balers discussed in this report produce:

- conventional sized rectangular bales,

TABLE 1. Estimated Production Rates of Various Agricultural Residue Harvesting Methods^a

<u>Method</u>	<u>Production Rate (tons/hr)</u>
Conventional bale, 3 tie	20 - 25 tons/hr
Large rectangular bale	20 tons/hr
Large round bale	6 - 7 tons/hr
Field stacker	8 - 10 tons/hr
Module builer	12 - 14 tons/hr
Field cuber	5 tons/hr
Stationary cuber	6 tons/hr
Pellet mill	4 - 5 tons/hr

(a) estimated rates for one unit as reported by manufacturers

TABLE 2. Comparative Costs of Agricultural Residue Harvesting Options^a

<u>Option</u>	<u>Total Cost Per Ton to Harvest</u>
Conventional baler ^b	\$12.05
Large rectangular baler ^b	9.20
Round baler ^b	6.95
Field stacker ^c	6.70
Field cuber ^d	15.80
Stationary cuber ^e	19.20

(a) Estimated costs for harvesting alfalfa hay at 5000 tons per year in 1979

(b) Estimated cost to swath, combine windrows, bale, and roadside bales

(c) Estimated cost to swath, stack and move

(d) Estimated cost to swath, cube, haul, and store

(e) Estimated cost to swath, combine windrows, chop, haul to cuber, cube and store.

(Source: Reed, 1979).

- large rectangular bales, and
- large round bales.

Baling capacities and bale density depend largely on the material being baled, its moisture content, and the particular baler being used. Other factors which can affect baling capacities include the amount of material available at the windrow, field conditions, and operator skill level.

Balers Producing Conventional Sized Rectangular Bales

Most balers currently in use produce rectangular bales about 4 feet in length secured with 2 or 3 wires or twines per bale (Figure 3). Smaller cross sections of 14" x 18" or 16" x 18" dimensions are usually fastened with 2 wires or twines while bales of larger cross sections of around 16" x 22" are fastened with 3 wires or twines. The bales are compressed by a reciprocating plunger driven by the tractor pto or by an engine mounted on the baler. The pto driven baler would require a tractor with about 80 pto hp, however, the baler with its own engine can be operated with a much smaller tractor. Baling capacity of the larger 3-tie balers is around 20-25 tons of straw per hour (Malkow, 1981). The 3-tie bales will weigh around 90 pounds per bale. One operator is required to run the tractor and baler. Each 3-tie bale uses about 39 feet of twine or wire. Cost of a new 3-tie baler is about \$20,000. Custom rates for baling and stacking straw at a nearby location are around \$18-20 per ton (Tomlinson, 1981).

Balers Producing Large Rectangular Bales

Large rectangular balers (Figure 4) work on the same basic concept for densification as conventional rectangular balers. The reciprocating plunger compresses the material into the bale chamber to form the bale. Bales produced with the large balers are 4 feet wide, 4 feet high, and 8 feet long. Like conventional bales, big bales are wrapped with twine to maintain their density. Capacity of these balers is reported to be about 20 tons per hour producing bales of straw up to 1400 pounds. A

FIGURE 3. Conventional 3-Tie Baler (Courtesy: J. A. Freeman & Son, Inc.)

FIGURE 4. Large Rectangular Baler (Courtesy: Hesston Corp.)

minimum power requirement of 120 hp at the pto shaft is suggested for operation on flat ground. One operator is required to run the tractor and baler.

Balers Producing Large Round Bales

The method of densification used in most large round balers (Figure 5) uses a series of belts to form and compress the material. "Bales produced by this type of system will be from five to seven feet in diameter and four to six feet in length (Schrock, 1975)". Bale weights for hay will range from 800 to 3000 pounds. Bale density for straw will be around 8 to 12 pounds per cubic foot. These round bales are normally wrapped with twine to maintain bale density. As reported by one manufacturer, a baler making bales 5 ft wide by 6 ft in diameter should be able to operate at a rate of 6-7 tons per hour producing 1200 pound bales. A round baler of this capacity would currently sell for around \$11,000. A minimum of 60 hp at the pto shaft is suggested for baler operation on flat ground. One operator is required to run the tractor and baler. As report by Kansas State University Extension Service, custom rates for baling round bales of this size were about \$6.00 per bale in 1980.

Field Stacking

Field stackers such as the one shown in Figure 6 can be used to pick up material from the field and compress it into an 8 foot wide, 11 foot high, and 20 foot long package without the use of wire or twine. Bulk density of the stacks is around 5 pounds per cubic foot. Harvesting capacity is estimated at around 8 to 10 tons per hour for straw.

The stacker is pulled behind the tractor and material is normally picked up either with tines or flails and blown into the stacker body. Tines are used to pick up material laying in the windrows, however, the flail type pick up can be used to harvest standing material. Once in the stacker body, the material is compressed either with a hydraulic press, a packer wheel, or air. (Schrock, 1975). The completed stack is unloaded from the rear of the stacker by a bed chain. The field stackers

FIGURE 5. Large Round Baler (Courtesy: New Holland Division, Sperry Corp.)

FIGURE 6. Field Stacker (Courtesy: Hesston Corp.)

are normally pto driven requiring a tractor in the 80 to 100 hp range. One operator is required to run the tractor and field stacker. Cost of a field stacker is around \$26,000.

Module Building

Module builders are currently used in the cotton industry to compact the seed cotton from the harvesting operation. As shown in Figure 7 the module builder consists of a large rectangular steel box with a carriage that moves horizontally on top rim of the box. Material is fed into the top of the box.

The carriage is first used to level the material, a tamper foot attached to the carriage then moves vertically from the carriage to successively compress the material below. In the module builders with no floor, the material can be compacted against the bare ground in a field situation or on a prepared surface. When the desired amount of material is fed into the module builder, the unit is hydraulically raised onto the transport wheels and moved from the freshly made module to a new location. One person can move and operate each module builder. The finished module size is about 32'x7'x7'. For straw, the bulk density of the modules is reported by one manufacturer to be around 12 to 14 #/ft³ (Smith, 1981). Providing the module builder is adequately supplied with material, a module of straw can be formed every 45 minutes. A module builder would cost around \$21,500 for the basic machine. This machine would require a tractor for propulsion and hydraulic power to the module builder. Self powered and completely self propelled machines are also available.

Cubing

Cubing provides a means to achieve a material form of a much higher density than field stacking or baling. This higher density can reduce many of the problems associated with transportation, handling, and storage. Cubing can be done in the field (Figure 8) or at a stationary location (Figure 9). Field cubing has the advantage of forming a dense

FIGURE 7. Module Builder (Courtesy: CMC)

FIGURE 8. Field Cubing Operation (Courtesy: Deere and Company)

FIGURE 9. Stationary Cubing Operation (Courtesy: Warren & Baerg)

FIGURE 10. Extruded Cubes

material directly in the field without having to handle and transport loose or baled material to a central location. However, there are many variables that affect quality and production rates of cubes. They include such factors as field conditions, crop uniformity, moisture content, and weather. Stationary cubing takes the cuber out of the direct influence of many of these factors. Stationary cubing allows for a more uniform rate of feeding at more consistent moisture levels. By stockpiling of feed material at the central cubing site the stationary cuber can be operated over longer periods of time than with field cubers, however, additional storage space must be provided for this feed material.

Both the stationary and field cubers work on a roller ring and die arrangement. Feed material is auger fed into the cuber and is pressed through a ring of open dies by the roller press wheel. Feed material should be around 10-12% moisture and ground to about a 1-inch screen size. Grinding can be accomplished using a tub grinder as shown in Figure 11. Extensive work on the performance of tub grinders for use on agricultural residues has been done recently by researchers at the University of California, at Davis. Foreign matter such as sand or other abrasive matter in the feed can significantly shorten the life of the dies which can be a major expense. The extruded cubes are about 1-1/4 inch square and about 2 to 4 inches long (Figure 10). Because of the friction created in the extrusion process the cubes are hot (over 120°C) as they emerge from the dies. They should be allowed to cool in shallow piles before transport or large scale storage. Cooling tends to toughen the cubes and also reduce the threat of spontaneous combustion. The cubing capacity of the field cubers is reported to be around 5 tons per hour while a rate of 6 tons per hour is reported for the stationary units. Both the field and stationary cubing operations can be run by one person. Bulk density of the cubes with the self propelled cubers is reported to be around 25 to 32 pounds. Straw cubes from modified stationary cubers have been found to have bulk densities of around 35 to 40 pounds per cubic foot. The power source recommended for the stationary cuber is either a 150 hp electric motor or a 216 hp diesel engine.

FIGURE 11. Tub Grinder (Courtesy:
Farmhand)

FIGURE 12. Pellet Mill (Courtesy:
California Pellet Mill Co.)

Pelleting

The pelleting process (Figure 12), very similar to cubing, also works on the extrusion principle using the roller press wheels and dies. The pellets formed are cylindrically shaped ranging from about 1/4 to 3/8 inch in diameter and about 1/4 to 3/4 inch long. The bulk density is around 30 to 40 pounds per cubic foot at a moisture content of 10 to 15 percent (wet basis). General parameters for the feed will be a residue free of stones and foreign material with a moisture content in a range of 10 to 20 percent wet basis and of a particle size with 100 percent passing through a Number 5 U.S. test sieve (0.157 inch sieve opening) (Simpson, 1981). Production capacity of one pellet mill operating with a 300 hp motor is expected to produce approximately 4 to 5 tons per hour. As in the cubers, dies are expected to be a major operating cost.

TRANSPORTATION

The transportation of agricultural residues can be a major factor in the feasibility of a particular system. The generally low bulk density of agricultural residues, especially straws, causes much problem in the economics of transportation, as well as handling and storage of these materials. Unit dimensions, weights, and bulk densities for various straw packaging options are listed in Table 3. Bulk density of loose straw is usually less than 4 pounds per cubic foot. Minimum bulk densities for operation at payload capacities of various transport options are shown in Table 4 from Miles, 1977.

Pickup from the field and transport to a central location can be accomplished by several currently available practices. Conventional bales can be loaded, stacked, and transported to the roadside or central location with equipment as shown in Figure 13. Large rectangular and large round bales are typically handled with specially adapted front end loaders and transported by truck or trailer. Due to the configuration of the large rectangular bales, they are especially suited for highway transportation (Figure 14). Special equipment is available for pickup and transport of field stacks and modules. Entire stacks or modules can

TABLE 3. Approximate Characteristics of Straw Packaging Options

<u>Form</u>	<u>Unit Dimensions</u>	<u>Unit Wt.</u>	<u>Bulk Density</u>
Conventional Bale	16"x22"x48"	90 lbs	8-12 lb/ft ³
Large Rectangular Bale	4'x4'x8'	1300 lbs	8-12 lb/ft ³
Large Round Bale	6'D x 5'	1200 lbs	8-10 lb/ft ³
Field Stack	8'x11'x20'	4.5-5 tons	5 lb/ft ³
Module	7'x7'x32'	9-11 tons	12-14 lb/ft ³ a
Cube	1-1/4"x1-1/4"x3"		30-40 lb/ft ³
Pellet	1/4"-3/8"Dx1/2"		30-40 lb/ft ³ a

(a) Figures based only on values reported by equipment manufacturer.

TABLE 4. General Transport Volumes and Densities

<u>Size</u>	<u>Volume Cubic Feet (CF)</u>	<u>Payload Pounds (#)</u>	<u>Minimum Bulk Density for Payload #/CF</u>
TRUCK-TRAILER			
(2) 27' Flat Bed	2,000 CF	55,000 #	14 #/CF
(2) 27' Dry Box	1,771	55,000	16
40' Flat Bed	3,200	52,000	16
40' Dry Box	2,650	50,000	19
RAIL			
50'	4,960	100,000	20
40'	3,750	100,000	27
CONTAINER (Off- shore)			
40'	2,000	44,000	22
20'	1,050	40,000	38

(Source: Miles, 1977)

FIGURE 13. Automatic Bale Wagon (Courtesy: New Holland Division, Sperry Corp.)

FIGURE 14. Large Rectangular Bales Loaded for Transport

be loaded onto trucks or trailers by a series of moving chains mounted on the beds (Figure 15). Long distance transportation of these stacks or modules of straw may be limited due to load losses if they are transported without cover to secure the load. Cubes and pellets can be handled by belt conveyors and loaded into covered or uncovered vans or containers depending on the length of haul and weather conditions.

Rates for transporting agricultural residues are shown in Table 5. Unit rates will decrease as the load and length of haul increases. These rates do not include loading or unloading of residues.

STORAGE

Because of the seasonal nature of agricultural residue fuels, storage is usually necessary. Climatic conditions at the specific site and individual characteristics of the residue can have much impact on the type of protection required for storage. In many situations the residue can be left uncovered with minimal amounts of losses or damage to the material. Several types of coverings commonly used in the forage industry include pole buildings and nylon reinforced polyethelene tarps. The polyethelene tarps generally provide lower cost storage than pole buildings, however more labor is required each season to apply and remove the covers. The tarps are usually fastened down by a series of ropes and weights cross-hatched over the top of the pile.

Besides top covering, protection from moist ground conditions may also have to be considered. Concrete or asphalt slabs can protect the material and also facilitate easier handling, lower losses, and smaller amounts of foreign material contamination of the residue. However, costs of these slabs can often be prohibitive for use of agricultural residues as a fuel. A flat, well drained area will usually prove sufficient in most cases. Stack heights can be dependent upon many factors such as the material, its form, the method of handling, and the available area for storage. Stack heights for conventional hay storage are generally less than 20 feet, mainly due to handling constraints. In Table 6, estimated storage areas are listed for selected residues at four selected process requirement levels.

FIGURE 15. Module Handler (Courtesy: CMC)

TABLE 5. Rates for Transportation of Agricultural Residues^{a,b}

<u>Distance (Miles)</u>	<u>Rate (Cents/Hundred Wt)^c</u>	<u>Rate (Cents/Hundred Wt)^d</u>
5	40	31
10	42	34
15	44	34
20	48	35
25	50	36
30	55	40
35	56	41
40	57	42
45	58	43
50	60	44

(a) Straw in compressed bales.

(b) Rates issued May 4, 1981.

(c) Minimum load 20,000 pounds

(d) Minimum load 40,000 pounds.

Source: Washington State Utilities and Transportation Commission.

TABLE 6. Estimated Agricultural Residue Storage Area Requirements for Four Selected Processing Levels^a

Daily Use (tons/day)	Annual Storage Requirement		Field Stacks ^b	Conventional Large Rectangular Bales ^c		Cubes and Pellets ^d 20 ft Piles
	(tons)	(million pounds)		14 ft Stacks	20 ft Stacks	
2	600	1.2	0.61 acres (120 stacks)	0.2 ac.	0.14 ac.	0.03 ac.
10	3,000	6	3 acres (600 stacks)	1.0 ac.	0.7 ac.	0.17 ac.
100	30,000	60	30 acres (6,000 stacks)	10 ac.	7 ac.	1.7 ac.
1000	300,000	600	300 acres (60,000 stacks)	100 ac.	70 ac.	17 ac.

(a) Assuming storage for 300 days of energy plant operation per year.

(b) Assuming 5 ton stacks (8 ft. W x 20 ft. L x 11 ft H) with 2 ft between stacks

(c) Assuming bulk density of 10 lb/ft³

(d) Assuming bulk density of 40 lb/ft³ with wall supports on the pile edges.

FORESTRY RESIDUES

COLLECTION AND PROCESSING

Collection

The major sources of residues in the forest products industry occur as forest residues left over from logging operations and mill residues. Most of the residues are located in the mountainous regions of western Oregon and Washington and northern Idaho. Mill residues generally occur in the form of wood and bark residues. These residues are readily accessible at the mill and thus, most of them are used for fuel in processing operations. Forest residues on the other hand are not so easily accessible. They consist of branches, foliage, and portions of the main stem felled and left behind after the logging operation; dead, rotten, or diseased trees; and other forms of unmerchantable material. Some of this material may be available at landing sites in the forest as yarded and piled unmerchantable material (Yum and Pum).

The larger pieces of residue remaining in logged area can often be yarded with the same equipment used for merchantable logs. Standard log trucks or short truck and trailer combinations can be used to haul this material. Smaller pieces of residue can be removed in separate logging operations using smaller and more mobile equipment than is commonly used in the main logging operation. These smaller pieces are usually more costly to load and haul. (Kierulff, 1980).

"The slope of the ground is a major factor governing the type of equipment used for harvesting timber. On gentle slopes, ground-traversing equipment can be used, whereas on steep slopes sophisticated cable systems are needed" (Comptroller General, 1981). Some common timber harvesting equipment, their optimum yarding distances, and the percent slopes for their application are shown in Figure 16.

The major methods for yarding timber in the northwest are cable and ground skidder logging.

OPTIMUM YARDING DISTANCES AND SLOPE PERCENT OF EACH LOGGING SYSTEM

FIGURE 16. Common Timber Harvesting Equipment.
(Source: Adapted from Figure Provided
by the Forest Service)

Cable Logging

As described by Bergvall, et al. in 1978:

Logging methods in which logs are transported from the harvest site to the landing either partially or totally suspended via an elevated line constitute cable harvesting. Primarily used on steep slopes because of its ability to perform where other methods prove impractical, it also has the advantage of avoiding soil compaction associated with skid trails used by motorized skidders. Practical yarding distances range up to 1500 feet, well beyond the ordinary limits of skidders.

Because of the powerful and expensive equipment required for cable systems, they are best applied to the removal of large timber. ...Removal of small size material reflects on inefficient use of the machinery. Most cable systems have limited abilities to move logs laterally. (Bergvall, 1978).

Four typical cable logging systems are shown in Figures 17-20. Actual photographs in Figures 21 and 22 show a closeup view of a cable yarder and a view of a yarder in operation at the landing.

Skidder Logging

Skidders are used to gather individual or bunches of logs in areas with flat to moderate slopes (up to 35%). Both crawler-type (Figure 23) and rubber tired skidders (Figure 24 and 25) are used in northwest logging operations. Rubber tired skidders are quicker than crawler type skidders and are more suitable for longer skidding distances. However, crawler type skidders can operate on slightly greater slopes and in rougher terrain. Skidders can be adapted with cables (Figure 25) or grapples (Figures 23 and 24). Grapples are quicker in operation for gathering logs that are easily accessible, however, cables can be used to gather logs that are more difficult to obtain. Skidders are generally lower in both capital and operating costs than cable yarding operations. (Bergvall, 1978).

Costs and daily production for harvesting by cable and skidder yarding methods using a variety of existing machines have been reported by Host in 1979 and are reproduced in Tables 7-11.

FIGURE 17. High Lead Yarding System
(Source: Dykstra, 1975)

FIGURE 18. North Bend Skyline Yarding System
(Source: Dykstra, 1975)

FIGURE 19. "Grabinski" Running Skyline Yarding System
(Source Dykstra, 1975)

FIGURE 20. Shotgun Style Yarding System (Limited to uphill yarding).
(Source: Dykstra, 1975)

FIGURE 21. Cable Yarder

FIGURE 22. Cable Yarder in Operation

FIGURE 23. Crawler-Type Grapple Skidder (Courtesy: Caterpillar)

FIGURE 24. Rubber Tired Grapple Skidder (Courtesy: Caterpillar)

FIGURE 25. Rubber Tired Cable Skidder (Courtesy: Caterpillars)

FIGURE 26. Portable Whole Tree Chipper in Operation
(Courtesy: Morbark Industries, Inc.)

TABLE 7. Cable Yarding Production Costs, in Dollars.^a

<u>Machine</u> ^b	<u>Fixed</u>	<u>Daily machine cost</u>		<u>Unit Cost</u>		<u>Piece Size</u>	
		<u>Variable</u>	<u>Total</u>	<u>Piece</u>	<u>CCF</u>	<u>ft³</u>	<u>M³</u>
U	58.97	119.39	178.39	1.62	7.19	22.55	.64
B-1	77.81	130.15	207.96	1.10	5.77	19.08	.54
B-2	77.81	127.25	205.06	2.81	13.96	20.10	.57
B-3	77.81	123.56	201.37	3.53	16.74	21.11	.60
22B	91.73	160.22	251.95	1.55	7.28	21.25	.60
F210	106.48	195.52	302.00	1.68	7.39	22.70	.64
EI-1	108.93	237.80	356.73	2.15	9.46	22.72	.64
EI-2	108.93	215.08	324.01	1.57	17.49	8.93	.25
LB78-1	111.80	152.02	263.82	1.19	7.92	15.00	.42
LB78-2	111.80	186.56	298.36	1.44	8.62	8.93	.25
LB98-1	147.43	226.81	374.24	4.30	23.90	18.01	.51
LB98-2	147.43	266.52	413.95	3.54	19.66	18.00	.51
C305	151.52	248.61	400.13	2.63	19.01	13.85	.39
LB108-1	172.00	255.47	427.47	2.95	16.17	18.23	.52
LB108-2	172.00	275.59	447.59	2.06	11.33	18.20	.52
W78	196.57	309.81	506.38	3.59	14.03	25.60	.72

a. Labor and overhead costs are not included.

b. See Table 11 for machine identification.

c. CCF = Cunit (100 cubic feet)

(Source: Host 1981).

TABLE 8. Cable Yarding Production Data

Machine Model ^a	Purchase Price	Adjusted Price	Number Pieces	No. Pieces/\$1000 Selling Price	Cunits ^b	Cunits/\$1000 Selling Price	Piece Volume		Average Yarding Distance		Inhaul Speed	
							ft ³	m ³	ft	m	ft/min	m/min
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)		(9)		(10)	
1 U	49,000	72,000	110	1.53	24.81	0.34	22.55	.64	376	115	194	59
2 B-1	39,000	95,000	189	1.99	36.06	0.38	19.08	.54	104	32	73	22
3 B-2	39,000	95,000	73	0.77	14.69	0.15	20.10	.57	219	67	64	20
4 B-3	49,000	95,000	57	0.60	12.03	0.13	21.11	.60	155	47	50	15
5 22B	60,000	112,000	163	1.46	34.63	0.22	21.25	.60	156	47	106	32
6 E1-1	90,000	133,000	166	1.25	37.72	0.28	22.72	.64	250	76	397	121
7 E1-2	90,000	133,000	207	1.59	18.53	0.13	8.93	.25	291	89	416	127
8 LB78-1	120,000	136,500	222	1.63	33.30	0.24	15.00	.42	299	91	352	107
9 LB78-2	125,000	136,500	207	1.59	18.53	0.14	8.93	.25	221	67	326	99
10 LB98-1	105,000	180,000	87	0.48	15.66	0.09	18.01	.51	222	68	221	67
11 LB98-2	90,000	180,000	117	0.65	21.06	0.12	18.00	.51	144	44	61	19
12 C305	145,000	185,000	152	0.82	21.05	0.11	13.85	.39	197	60	152	46
13 LB108-1	155,000	210,000	145	0.69	26.43	0.13	18.23	.52	324	99	221	67
14 LB108-2	170,000	210,000	217	1.03	39.50	0.19	18.20	.52	302	92	249	76
15 W78	168,000	240,000	141	0.59	36.10	0.15	25.60	.72	378	115	269	82

a. See Table 11 for machine identification

b. Cunit = 100 cubic feet

(Source: Host 1981)

TABLE 9. Skidding Production Costs in Dollars^a

<u>Skidder^b</u>	<u>Daily Machine Cost</u>			<u>Unit Costs</u>		<u>Piece Size</u>	
	<u>Fixed</u>	<u>Variable</u>	<u>Total</u>	<u>Per Piece</u>	<u>Per CCF^c</u>	<u>ft³</u>	<u>M³</u>
Horse	3.12	19.86	22.98	0.20	4.10	4.91	.14
JD420	5.32	10.54	15.86	0.14	3.11	4.46	.13
D2	8.19	16.42	24.61	0.24	2.02	11.73	.33
AC180-1	16.38	25.08	41.46	0.12	1.45	8.28	.23
AC180-2	16.38	25.08	41.46	0.19	1.10	16.88	.48
G15	18.02	13.37	31.39	0.19	3.92	4.70	.13
JD540-1	35.80	55.70	91.50	0.35	8.32	4.23	.12
JD540-2	35.80	58.40	94.20	0.48	5.81	10.53	.30
JD540-3	35.80	61.20	97.80	0.32	3.03	8.26	.23
JD540-4	49.72	60.10	109.82	0.30	2.57	11.60	.33

a. Costs do not include wages and overhead.

b. See Table 11 for machine identification.

c. CCF = Cunit (100 cubic feet).

(Source: Host, 1981)

TABLE 10. Daily Skidding Production per \$100 of Purchase Price

Machine Model ^a	Purchase Price	Adjusted Price	Pieces (PCS)	Daily Production			Vol/PC ft ³	Average Skid Distance		Average Skid Speed	
				PCS/\$100	CCF ^b	CCF/\$100		ft.	m	ft/min	m/min
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)		(10)	
1 Horse ^c	3,000	3,800	114	3.0	5.6	.15	4.91	164	50	91	28
2 JD420 ^c	900	6,500	112	1.7	5.0	0.10	4.96	260	79	76	23
3 D2 ^d	600	10,000	104	1.0	12.2	0.12	11.73	70	21	78	24
4 AC180 ^e	11,000	20,000	346	1.7	28.5	0.14	8.28	994	303	523	159
5 AC180 ^e	11,000	20,000	224	1.1	37.9	0.19	16.88	801	244	356	109
6 G15 ^c	2,500	22,000	168	0.8	7.9	0.04	4.70	254	77	102	31
7 JD540-1 ^e	26,000	43,700	259	0.6	11.0	0.03	4.23	1,092	333	364	111
8 JD540-2 ^e	29,000	43,700	304	0.7	32.0	0.07	10.53	1,125	343	357	109
9 JD540-3 ^f	29,000	43,700	197	0.5	16.2	0.04	8.24	150	46	185	56
10 JD540-4 ^f	38,000	60,700	368	1.0	42.7	0.07	11.60	300	91	117	36

a. For machine identification see Figure 11

b. CCF = Cunit (100 cubic feet)

Production data source:

c. Host, and Schlieter 1978.

d. Chase 1979

e. Host 1978

f. Unpublished in-woods chipping study data.

(Source: Host, 1981).

TABLE 11. Identification of Logging Equipment

<u>Abbreviation</u>	<u>Machine</u>
JD420	John Deere Model 420 Tractor
D2	Caterpillar Model D2 (1958)
AC180	Allis Chalmers Model 180 Farm Tractor
G15	Garrett Tree Farmer Model 15
JD540-1, 2, 3	John Deere Skidder Model 540 C
DJ540-4	John Deere Skidder Model 540 C Grapple
U	Urus 1000-3
B123	Koehring Bantam 3/8 yard converted shovel
22B	Bucyrus Eire 3/4 yard converted shovel
EI12	Ecologger I
LB7812	Link Belt Model 78 converted shovel
LB9812	Link Belt Model 98 converted shovel
C305	Koehring Model C305
LB10812	Link Belt Model 108 converted shovel
W78	Washington Yarder Model 78

(Source: Host, 1981)

Processing

Once the residue is yarded, it can be loaded onto trucks for transportation to a central processing site or chipped directly at the landing if the situation permits. One currently operating residue mill located in White City, Oregon is processing 1000 tons of logging slash per day to produce utility grade lumber, wood chips for pulp, and hogged fuel (Hanscom 1981). Cable and skidder logging methods are used to collect the material which is then transported to the mill as whole logs. Depending on the nature of the residue, it is then processed into the various wood products.

For use as a fuel, residue can be processed into various forms including chips, hogged fuel, cubes and pellets. These forms facilitate mechanized handling and fuel metering practices.

Chipping

In a chipper, the residue is cut by rotating knives fixed to a disc or drum. The resulting chips are fairly uniform in size. Operations with large amounts of dirty material may find that this may require frequent blade maintenance. The capacity of an operating chipper with a 24 inch x 24 inch opening and a 600 horsepower motor has been reported to be 50-55 units per hour. (Hanscom, 1981).

In the woods chipping operations with machinery such as that shown in Figure 26 may be used for chipping slash or whole trees to produce chips directly from the forest. However, the use of this type of operation could be limited by the accessibility to the residue sites.

Hogging

Hammer hogs rely on the action of rotating hammers to chop and tear the incoming material rather than cut as in the chippers. Material prepared with a hog is usually less uniform in particle size than that prepared with a chipper. Hammer hogs can handle dirty material, even that with light-weight tramp without damage to the machine (Schwieger, 1980). A 125 horsepower hammer hog with a 30 inch x 24 inch opening has been reported

to hog around 25 units of fuel per hour. (Hanscom, 1981).

Cubing and Pelleting

As with agricultural residues, cubers and pellet mills can produce a product with a significantly higher density than the incoming wood residue. Operation of a stationary cuber or pellet mill for wood residue is very similar to that used for agricultural residues. Moisture content around 10-12% and particle size around 1 inch is suggested with the wood residue for cubes (Warren and Baerg, 1981). Moisture content around 10-15% and particle size with 100% passing through a Number 5 U.S. test sieve is suggested for pellets (Simpson, 1980). Many of the mill residues such as planar shavings and sander dust can be cubed or pelleted with little or no modification of the material. The resulting cubes or pellets are hot as they emerge from the dies with dimensions of 1-1/4 inch square x 2 to 4 inches long for cubes and 1/4 - 3/8 inch in diameter and 1/4 - 3/4 inch long for pellets. The rate of cubing is reported to be around 6 tons per hour with a bulk density of the cubes close to 40 pounds per cubic foot. Pellets can be produced at a rate of 4-5 tons per hour with a bulk density of 30 to 40 pounds per cubic foot. The recommended power source is either a 150 horsepower electric motor or a 216 horsepower diesel engine for the cuber or a 300 horsepower electric motor for the pellet mill.

TRANSPORTATION

Some of the factors that should be considered when assessing the transportation of forestry residues are bulk density of the material, material size range, length of haul, access and road conditions, and space and facilities available for the loading and unloading processes.

The bulk density and material size can have much impact on the most effective method of transportation. Transportation of very low bulk density materials is usually limited by volume rather than the weight load. Advantages of changing the bulk density of the material should be compared with the costs associated with the alteration process. Reported

bulk densities and moisture contents of various forms of residue fuels are shown in Table 12.

Residue in the form of unmerchantable logs of sufficient size can generally be transported from the forest on conventional log trucks. Limbs, tops, small trees, brush, and other bulky materials may require processing in the field before transporting. In-the-woods chipping or baling operations are potential processing options. This and other residue in the form of wood chips and hogged fuel can be transported in chip vans. Some vans can be equipped with bed conveyors (live bottom vans) or hydraulic dumps for self unloading capability. Other vans must be unloaded with special equipment available at the site.

The length of haul can be a determinant in the most cost effective mode of transportation. Due to the relatively short hauling distances, difficult access, and non-uniform material characteristics, trucks are usually chosen for transporting logging residues. Other modes such as rail, barge, and pipeline might be considered for chips or hogged fuel if access to these facilities is available. However, the flexibility and lower handling requirements of truck transportation have often been chosen over the merits of other transportation modes.

Access and road conditions associated with logging residues can severely limit the particular method of transportation. Rough roads, sharp turns, and steep grades often limit access by vehicles not designed for operation under such conditions and usually add to the costs of transportation by suitable methods.

Lack of space for convenient truck turn-arounds or proper setup of handling facilities can detract from the operation efficiency, and thus the cost effectiveness of a particular situation.

Estimated rates for transportation of logs are shown in Table 13 along with added costs for operation under various roads conditions explained in Table 14. Estimated rates for the transportation of wood residues such as chips or hogged fuel are shown in Table 15.

TABLE 12. Reported Bulk Densities of Wood Residue Fuels

<u>Form</u>	<u>Bulk Density</u>		<u>Moisture Content</u>	
Chips	16#/ft ³	@	30%	a
	22#/ft ³	@	46%	b
	25#/ft ³	@	52%	b
Hogged Fuel	21#/ft ³	@	40%	a
	20#/ft ³	@	50%	c
	18#/ft ³	@	47%	b
Pellets	30-40#/ft ³	@	10%	d
Cubes	30-40#/ft ³	@	10%	e

a. Source: Hanscom, 1981

b. Source: Sullivan, 1981

c. Source: Schwieger, 1980

d. Source: Simpson, 1981

e. Source: Warren & Baerg, 1981

TABLE 13. Estimated Transportation Rates for Logs^a

Basic Charge Per 1000 Pounds	Transportation Charge Per Mile 1000 Pounds to be added to the Basic Charge Per 1000 Pounds					Minimum Weight Per Load
	Class of Roads					
	A	B	C	D	E	
90¢	3.8¢	5.4¢	6.9¢	10.9¢	15.5¢	b
87¢	3.7¢	5.2¢	6.5¢	10.3¢	14.7¢	47,000 lbs

- a. Rates issued May 27, 1981, for transportation within the State of Washington
- b. Rates apply only to capacity truck load lots transported on open type vehicles. Where weighing scales are available, the net scale weight will apply. Where scales are not available, the charges will be based on 95% of the net capacity (including valid permits) of the vehicle. Weights will be resolved to the nearest unit of 100 lbs. Where bridge or road weight limitations are imposed by road authorities, the net carrying capacity of the vehicle for loads transported over the affected road or route will be determined by the gross weight limitations imposed.
- c. Applies only at mills or dumps having scales where logs are weighed.

(Source: Washington State Utilities and Transportation Commission)

TABLE 14. Types of Roads

CLASS "A":	Paved or macadamized, reasonably free from chuck holes, ruts, "washboard" conditions and other hazards, not exceeding grades of 6%.
CLASS "B":	Paved or macadamized, or graveled, other than the specifications in Class "A" as applicable, not exceeding grades of 12%; also permanently and continuously maintained fine gravel, smooth surface, free from chuck holes, ruts, "washboard" conditions and other hazards, with grades exceeding 6% but not exceeding 12%; also good plank not exceeding grades of 12%. Good plank road shall be defined as at least 10 feet wide with side guards at least 6 inches high on cross planking or center guard at least 6 inches high on longitudinal planking; constructed of planks at least 3 inches by 10 inches, firmly spiked down and with sufficient turn out space for truck passing at least every 200 yards; supporting timbers to be at least 10 inches by 10 inches.
CLASS "C":	All roads with grades exceeding 12% but not exceeding 18%; also all dirt, rock or plank other than good plank specified under Class "B", not exceeding grades of 18%.
CLASS "D":	All roads with grades exceeding 18% but not exceeding 22%.
CLASS "E":	All roads with grades exceeding 22%; also roads consisting of mud or water to a depth of 8 or more inches, or any road that cannot be negotiated by the truck under its own motive power.

(Source: Washington State Utilities and Transportation Commission)

TABLE 15. Rates for Transportation of Wood Residues^{a,b}

<u>Distance (Miles)</u>	<u>Rate (Cents/hundred wt)^c</u>	<u>Rate (Cents/hundred wt)^d</u>
5	11.3	9.9
10	13.8	11.6
15	16.1	13.6
20	18.5	16.0
25	21.2	18.0
30	23.4	20.8
35	25.7	23.0
40	28.7	24.8
45	30.5	27.0
50	33.7	29.0

a. Includes wood chips, hogged fuel, sawdust, shavings, planar ends, and/or bark.

b. Rates issued May 4, 1981.

c. Rate for carriers furnishing live bottom equipment, minimum load 45,000 pounds.

d. Rate for carriers not furnishing live bottom equipment, minimum load 48,000 pounds.

(Source: Washington State Utilities and Transportation Commission).

STORAGE

The steady supply of residue from the forest is highly dependent on weather and the resulting conditions existing in the forest. Dry conditions of the forest can result in closure or restrictions of access to the residue due to the high danger of fires. Extremely wet conditions can limit access, harvest rates, and transportation of the forest residue. Expected time available for residue harvest in southwestern Oregon has been reported to be in the range of 150 to 170 days per year (Hanscom, 1981).

Logging residue may be stored in the form of whole logs or processed material such as hogged fuel, chips, pellets, or cubes. Whole logs can be stacked outdoors in large rows and may be sorted to facilitate more efficient handling techniques. Because of the residue nature of these logs, the land area required for storage may be greater than with higher quality logs harvested for conventional forest products. Large amounts of crooked, split, or hollow logs of nonuniform lengths are likely to be present in the residue lowering the density of the residue stacks. Due to the limited surface area of the exposed material in whole log storage, residue stored in whole log form is less likely to fluctuate with environmental moisture conditions than with material stored in the processed forms.

When stored in the form of chips, hogged fuel, pellets, or cubes, mechanized handling methods may be better adapted to the residue than in the form of whole logs. Material in large storage piles can be stacked and reclaimed with the use of a variety of mechanical and pneumatic conveyance systems. Spontaneous heating may occur in large piles of green chips, sometimes to the point of combustion. In some areas, covering may be suggested to prevent the absorption of moisture in dryer fuels which can reduce the heating value of the fuel (Table 16). Ground preparation in the area beneath the storage pile is suggested to facilitate easier handling and to prevent contamination of the material. Storage volumes for four selected processing levels have been estimated in Table 17.

TABLE 16. Effect of Fuel Moisture Content on Heating Value and Boiler Efficiency

<u>Moisture Content (As-Received), %</u>	<u>Gross Heating Value (As-Fired), Btu/lb¹</u>	<u>Net Heating Value (Heat Available for Steam Production), Btu/lb²</u>	<u>Boiler Efficiency, %³</u>
15	7440	5767	77
30	6125	4505	73
40	5250	3682	70
50	4375	2860	65
60	3500	2038	58

Source: North Carolina State University, School of Forest Resources.

1. Assumes a higher heating value of 8750 Btu/lb for wood and bark.
2. Assumes a stack temperature of 500F and excess air (%) equal to the percentage of moisture contained in the fuel
3. Overall efficiency is found by subtracting other losses-such as radiation, blowdown, etc.

TABLE 17. Estimated Forest Residue Storage Area for Four Selected Processing Levels^a

<u>Daily Use (Dry Tons/Day)</u>	<u>Annual Storage Requirement</u>		<u>Chips or Hogged Fuel^b (30 Ft. Fuel Piles)</u>	<u>Cubes or Pellets^c (20 Ft. Piles)</u>
	<u>Tons (Dry)</u>	<u>Million Pounds (Dry)</u>		
2	300	0.6	0.04 ac.	0.02 ac.
10	1500	3	0.21 ac.	0.09 ac.
100	15,000	30	2.1 ac.	0.9 ac.
1000	150,000	300	21 ac.	9 ac.

a. Assuming storage for 150 days of energy plant operation per year.

b. Assuming dry bulk density of 11 lb/ft³, with covered structure and wall supports.

c. Assuming dry bulk density of 38 lb/ft³, with covered structure and wall supports on edges.

REFERENCES

- Arthur, J. F., et.al. 1981. Tub Grinder Performance on Residues for Energy Utilization. University of California, Davis, California.
- Bergvall, J. A., et.al. 1978. Wood Waste for Energy Study, Inventory Assessment and Economic Analysis, State of Washington, Dept. of Natural Resources, Olympia, Washington.
- Comptroller General. 1981. The Nation's Unused Wood Offers Vast Potential Energy and Product Benefits. Report to the Congress of the United States. U.S. General Accounting Office, Gaithersburg, Maryland.
- Crossley, F.R.E. and J. Sullivan. 1980. Mobile Wood Chippers. DOE/ET/20077-1, University of Massachusetts, Amherst, Massachusetts.
- Dauve, J. and S. J. Flaim. 1979. Agricultural Crop Collection Costs. SERI/RR-353-354, National Technical Information Service, Springfield, VA.
- Deere and Company. 1973. Fundamentals of Machine Operation: Combine Harvesting, Moline, Illinois.
- Dykstra, D. P. 1975. Production Rates and Costs for Cable, Balloon, and Yarding Systems in Old Growth Douglas Fir. Forest Research Laboratory, Bulletin Number 18, Oregon State University, Corvallis, Oregon.
- Hanscom, 1981. Telephone Conversations with Harry Hanscom, Slash Utilization Corporation, White City, Oregon.
- Hartman, D. A., et.al. 1981. Conversion Factors for the Pacific Northwest Forest Industry, Institute of Forest Resources, University of Washington, Seattle, Washington.
- Herschelman, J. W., et.al. 1980. Recovery of Above-Ground Woody Biomass Using Operational Modifications of Conventional Harvesting Systems. DOE/ET/20045-T1, Alabama A&M University, Normal, Alabama.
- Host, J. R. 1981. Low Capital Investment Logging Systems, Symposium Proceedings from Harvesting and Utilization Opportunities for Forest Residues in the Northern Rocky Mountains, Nov. 28-30, 1979 in Missoula, Montana. USDA Forest Service, Ogden, Utah.
- Intermountain Forest and Range Experiment Station. 1981. Harvesting and Utilization Opportunities for Forest Residues in the Northern Rocky Mountains. Symposium Proceedings, November 28-30, 1979, Missoula, Montana, U.S. Dept. of Agriculture, Forest Service, Ogden, Utah.
- Kierulff, N. C. and T. C. Adams. 1980. Feasibility of Generating Power From Forest Residue. Bonneville Power Administration, Division of Power Resources.

Malkow 1981. Personal Conversation with Bert Malkow, Baler Manufacturer, J. A. Freeman and Sons. Portland, Oregon.

Miles, T. R. 1977. Logistics of Energy Resources and Residues, for presentation at the 174th American Chemical Society National Meeting, August 28-September 2, Chicago, Illinois.

Norwest Pacific. 1981. Feasibility Study for a Forest Residue Fueled Electric Generating Plant, EPRI CS-1819, Electric Power Research Institute, Palo Alto, CA.

Office of Technology Assessment. 1980. Energy from Biological Processes, Volume II - Technical and Environmental Analyses. U.S. Government Printing Office, Washington, D.C.

Reed, A. D., et.al. 1979. Alfalfa Harvesting Costs, Revised 1979. Division of Agricultural Sciences, University of California, Davis, California.

Reed, T. and B. Bryant. 1978. Densified Biomass: A New Form of Solid Fuel. SERI-35, Solar Energy Research Institute, Golden, Colorado.

Schrock, M. D. et.al. 1975. Hay Handling Systems, Cost, and Equipment. Cooperative Extension Service, Kansas State University, Manhattan, Kansas.

Schwieger, B. 1980. Power from Wood, Reprint from "Power" magazine, February 1980, Volume 124, New York, New York.

Simpson, 1981. Letter Correspondence with Dwight Simpson, Densification Specialist, California Pellet Mill Company, Sparks, Nevada.

Smith, 1981. Telephone conversation with Robert H. Smith, Cotton Machinery Corporation, Livermore, California.

Sullivan, J. 1981. Telephone conversation with John Sullivan, Boise Cascade Corporation, Wallula, Washington.

Tomlinson, 1981. Personal Conversation with Steve Tomlinson, Custom Hay Harvester, Pasco, Washington.

Wood Energy Institute. 1980. Advanced System Demonstration for Utilization of Biomass as an Energy Source. DOE/ET/20055-T5, National Technical Information Services, Springfield, Virginia.

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