FOREST RESIDUES BUNDLING PROJECT

New Technology for Residue Removal

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1 INTRODUCTION

Forest biomass represents a huge potential resource for energy production. A recent survey for the Department of Energy (Demeter et al. 2003) indicates that the nine states with the greatest potential to generate power from forest thinning are in the western US. Potential energy production exceeds 50 MW per county in most areas of these states. In addition, Oregon, Washington, and California could produce over 500 MW from existing forest residues, while Montana and Idaho could produce more than 100 MW from current sources. Large volumes of forest biomass should be available from implementation of the Healthy Forest Restoration Act and National Fire Plan. However, the actual operations of harvesting, collecting, processing and transporting loose forest residues are costly and present an economic barrier to recovery and utilization of wood for energy.

In general, slash is less than one-fourth the density of solid wood (McDonald et al. 1994). The productivity of any handling operation (hauling, skidding, loading) is reduced by the low density material resulting in increased cost per ton. Currently, the most cost-effective system to recover forest residue for biomass is in-woods chipping as part of conventional logging or thinning (for example, Hartsough et al. 1997). Chipping operations are best suited for situations where there is:

Whole-tree skidding to roadside,
Good road access for chip vans and chippers,
Sufficient biomass volume per acre.

In-woods chipping systems are not as effective when ground-based skidding is restricted or when there are no merchantable products other than biomass. In order to recover biomass from many fuel reduction and forest health treatments, some alternative to in-woods chipping needs to be available. For many years, it has been understood that finding an effective method of densifying residues would be a key development to reduce the costs of biomass collection systems. This report describes recent tests of a biomass bundling system in the western US that may present a viable approach to residue recovery.

1.1 Biomass Bundling

Scandinavian countries have developed biomass collection systems that are compatible with their dominant cut-to-length (CTL) harvesting technology. Skogforsk, the Swedish Forest Research Institute, described field evaluations of two of these systems (Andersson et al. 2000) based on “composite residue logs” (CRL’s), or biomass bundles (Fig. 1). Biomass bundlers collect, compress, and bind forest residues into cylindrical bundles approximately 24 inches in diameter and 10 feet long. Biomass handling is greatly simplified by compacting loose slash into a form that resembles a log. CRL’s can be loaded, transported, forwarded, stacked, and processed with conventional log-handling equipment. This process has been successfully adopted in Scandinavia with hundred's of thousands of CRLs produced and consumed annually to generate energy (Timperi 2003).

Figure 1. A composite residue log made from 4-year old logging slash.

In 2003, the first biomass bundling machine was introduced to North America by Timberjack. The 1490D Slash Bundler[1] is based on the 1410 8-wheeled forwarder (Table 1). An integrated bundling unit is mounted on the rear frame and can be rotated to either side to facilitate feeding residues into the bundler (Fig. 2). In operation, the operator collects residues with the crane and places them in the infeed deck. Four compression rollers pull the material into the bundling unit and perform initial packing. Behind the feed rollers, two sets of compaction frames alternate grasping and sliding to move the compacted bundle through a wrapping unit. The bundles are simply wrapped with standard baling twine at selected intervals in one continuous string. As the wrapped bundle comes out of the machine and reaches a preset length, the cut-off saw activates, dropping the completed bundle to one side. All of the bundling functions are automatic, with an on-board computer controlling the compaction process. The operator primarily works the loader to collect and feed material, drives the machine, and maneuvers the rotation of the bundling unit to avoid standing trees and direct the drop of completed bundles.

Table 1. Timberjack 1490D Specifications

Overall length	36.5	ft
Width	9.5	ft
Weight (total machine)	54,000	lb
Engine (6-cylinder Deere 6068HF)	182	hp
Boom reach	32.8	ft
Bundling unit length	20.3	ft
Bundling unit weight	15,400	lb

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[1] Mention of tradenames is solely for the information of the reader and does not constitute endorsement by the US Department of Agriculture, Forest Service

Figure 2. The Timberjack 1490D Slash Bundler.

In the Swedish study, biomass bundling with the continuous feeding design produced 30-40 CRL's per productive hour. Analysis of total system costs found that bundling was cost-competitive with their alternative treatment of roadside chipping residues ($8.66 to $11.33/m^3). While biomass bundling is proven technology in Europe, its performance in North American conditions needed to be evaluated and compared to alternative fuel treatments.

2 METHODS

The objective of this project was to examine the operational performance of the Timberjack 1490D Slash Bundler across a wide range of conditions found on typical western US forests. Eight sites were selected, although study data were only collected at seven of the locations. The bundler operated for approximately two weeks at each location to develop a productive operating environment. Stand conditions were assessed pre and post-biomass collection. In addition, detailed data about productivity, soil disturbance, residual stand impacts, and bundle quality were recorded. Finally, each site hosted a public demonstration day for technology transfer.

2.1 Data Collection

Prior to bundling, uniformly-spaced transects were established across the stand running perpendicular to the primary extraction path. Transects were the baseline for point sampling of soil disturbance using the method described by McMahon (1995). Fixed sample points were established at regular intervals along the transects for measurement of downed woody material (Brown 1974), residual stand cruise, and residual stand damage.

The soil disturbance survey, fuel loading, and residual stand damage measures were re-sampled after bundling.

Bundling productivity was measured using standard time study techniques. The operation of the bundler was videotaped periodically in each stand. The videotapes were used to develop an elemental time study based on the following work element definitions:

Traveling—Machine time to move between bundling positions. Begins with movement of the wheels; ends when the wheels stop.
Arranging slash—Machine time to position, accumulate, or handle slash in preparation for acquiring a full grapple load. Begins with initiation of crane motion to arrange material.
Feeding slash—Machine time to grasp and position residues at the bundler infeed. Begins with initiation of crane motion to acquire residues.
Cutting—begins with initial downward motion of the cutoff saw; ends when bundle drops free of the machine.
Rotating bundler—Machine time to position bundling unit. Rotation while traveling was classified as traveling time. Begins when operator initiates rotation of bundler to align with material; position bundle drop; or maneuver through the residual stand.

A MultiDat® data acquisition system mounted on the bundler recorded gross operating times as well as positional data that defined machine travel. Handheld GPS units were used to delineate total treated areas and to mark locations of bundles within the stands. Yellow Box® activity recorders provided additional data on gross operating hours. The spatial data were combined to estimate length of trail per acre, bundles per acre, and total operating hours per acre.

A sample of bundles at each location were weighed and measured to estimate density. Moisture content was measured with an electronic moisture meter. A physical subsample of bundled material was collected by cutting off about 6” of bundle length and bagging all of the material. These samples were processed at the US Forest Service, Forest Products Lab to determine heat content using a bomb calorimeter.

3 RESULTS

3.1 Descriptive Stand Data

The demonstration sites (Table 2) covered a range of stand conditions that are typical of drier western forests.

Table 2. Key demonstration site descriptors.

Site	Forest Type	Slash type	Residual Trees/ac	Median DBH
Bonner’s Ferry, ID	mixed conifer	4-yr old slash	142	8”
LaGrande, OR	lodgepole pine	small whole trees	*	*
Idaho City, ID	ponderosa pine	whole trees	54	12”
Stevensville, MT	ponderosa pine	CTL slash	61	14”
Medford, OR	Mixed conifer, westside stand	heavy limbs, tops	70	6”
Georgetown, CA	Pine thinning, landing piles	limbs and tops	56	*
Bend, OR	Lodgepole pine	small whole trees	137	6”
Prineville, OR	Juniper treatment in grassland	whole junipers	few	*

The first site was a 30-acre unit on the Bonner’s Ferry Ranger District of the Idaho Panhandle National Forest that was commercially thinned in 1999. The unit had a northeasterly aspect and uniform slope averaging 30% with some short pitches in excess of 40%. A tracked feller-buncher and skidder were used to fell and extract merchantable logs. The thinning was followed by chainsaw felling of all small standing material and slashing of residues. All activity fuels were left down and scattered for effective needle drop and nutrient retention. At the time of the residue collection, the unit was a Fuel Model 12 (Fig. 3). The conventional fuels treatment prescription for the unit would have been broadcast burning with piling where necessary.

Figure 3. Bonner’s Ferry pre-treatment

The LaGrande, Oregon site hosted a two-day demonstration of treatment alternatives for pre-commercially thinning lodgepole pine. Slopes were relatively flat. Trees were felled with a tracked mulching/cutting machine and whole stems were bundled. While the public demonstration was well-attended, there was no detailed evaluation of performance at this site (Fig. 4).

Figure 4. LaGrande demonstration site.

The third site was a 30-year-old ponderosa pine plantation on the Idaho City Ranger District of the Boise National Forest. Lower slopes were about 15% with a generally southeasterly aspect. Trees were felled by a chainsaw crew several weeks prior to bundling. Even though the average dbh was 12”, lack of local markets precluded any product recovery. Therefore, all biomass was intended to be bundled. The heavy slash loading prior to bundling would be characterized as a Fuel Model 13 (Fig. 5). Most of the bundles were carried to a landing by a forwarder. Some, however, were transported by a grapple skidder to test the feasibility of handling bundles with more conventional logging equipment. The bundles were not immediately utilized or transported.

Figure 5. Idaho City stand pre-treatment

A 20-acre privately-owned unit was treated near Stevensville, Montana as the fourth site. The stand of mature ponderosa pine was on an east-west ridge and was prescribed for a thin-from-below to reduce stocking and ladder fuels. Surface fuels prior to thinning were primarily grasses and needle litter. At this site, a tracked harvester felled and processed trees, concentrating residues for subsequent bundling. Bundling occurred with the thinning operation and a forwarder was used to remove both merchantable logs and biomass bundles from the stand. The conventional activity fuel treatment would have been piling and burning residues. Without bundling, the stand would have been a Fuel Model 11.

Figure 6. Stevensville, Montana prior to treatment.

The fifth demonstration site was an 18-acre Bureau of Land Management unit near Medford, Oregon. The prescription for this site called for a selection harvest with the main objective to increase the stocking levels of Douglas fir while removing as much white fir as possible. A conventional feller-buncher/skidder system thinned the relatively flat unit, extracting log-length merchantable material. This treatment produced a sizeable quantity of mistletoe slash. Without bundling, the post-thinning stand would be characterized as a Fuel Model 12. Some of the bundles were utilized for energy production. Some of the bundles were transported from the site in roll-off containers, while two loads were taken on conventional straight-frame logging trailers to a facility in California.

Figure 7. Medford bundling demonstration

The original demonstration site on the Georgetown District of the Eldorado National Forest was a ponderosa pine plantation thinning that had been conducted by a CTL crew. Due to concerns about potential insect breeding, the original operation included a requirement to "trample" the slash, breaking the bark and promoting drying. In addition, the CTL operation had a high merchantability standard, recovering most of the thinned volume. At the time of bundling, slash moisture content was about 10 percent. The remaining limbs and small tops were too small and brittle to effectively bundle. For the public demonstration day, the bundling machine moved to a large landing pile of green slash from an ongoing harvesting operation.

Figure 8. Bundling from a landing pile on the Eldorado National Forest

The final demonstration sites were located in central Oregon. Two similar lodgepole pine units near LaPine, designated Bend 1 and Bend 2, were pre-commercially thinned by chainsaw crews immediately prior to bundling. The resulting slash and surface fuels would be similar to a Fuel Model 13 (Fig. 9). The terrain was flat. All of the bundles were utilized by a nearby co-generation facility.

Finally, a two-day test was conducted on the Crooked River National Grassland near Prineville. The site was a range restoration treatment with chainsaw felled western juniper on slight (< 5%) slopes. There was no residual stand and the individual junipers were widely scattered (Fig. 10). Some of the bundles from this site have been used for stream stabilization structures.

Figure 10. Range restoration on the Crooked River National Grassland

3.2 Fuel loading and removals

The bundler did not collect all downed material (Table 3). If residues were too scattered, short, or rotten it was not productive to attempt to collect the material. At some locations, there was also a requirement to leave a certain amount of slash volume or specific coarse woody debris. For example, on the Bonner's Ferry site, the District desired about 5 tons per acre left as well as all material larger than 8" diameter.

Table 3. Fuel loading at the demonstration sites

Site	**Fuel loading (dry tons/acre)**			**Coarse Woody Mean Dia. (3" +)**		**Fuel Bed Depth Mean (in)**	
	Pre	**Post**	**Bundled**	**Pre**	**Post**	**Pre**	**Post**
Bonners	21.7	18.2	3.5	4.2	4.6	6.7	2.6
Idaho City	38.8	18.4	20.4	6.8	4.9	4.7	3.7
Stevensville	10.8	10.2	0.6	4.1	4.3	4.7	3.1
Medford	25.9	17.4	8.5	5.6	4.9	4.1	7.7
Bend 1	36.2	28.9	7.3	4.8	5.0	5.1	3.3
Bend 2	23.9	9.1	14.8	4.4	0.0	6.5	1.5

The high residual fuel loading values at the Medford and Bend 1 sites reflect the presence of some very large (>20" dia) woody debris. At the Idaho City site, however, the residual volume was mostly <1" material. Since the bundler was collecting whole trees from this site, broken limbs were not concentrated to facilitate bundling and were left behind.

3.3 Bundle Characteristics

Bundles ranged in length from 8 to 16 feet during the course of the study (Table 4). Various lengths were tried in an attempt to make the CRL's more compatible with conventional trailers. The shortest bundles were intended for cross-wise stacking on flatbed transport, while the longer bundles were expected to fit the rack spacing on a standard doublebunk trailer. In European applications, the standard bundle length is about 10 ft. Bundled green material had a density that was similar to the dry density of roundwood (about 20 lb/ft^3). This highlights the problem of getting a full payload on a conventional logging trailer, particularly with dry residue. Most conventional logging trailers will be underloaded when hauling bundles.

Table 4. Bundle dimensions and density

					Mean		
Site	**Species**	***Green/Dry***	**Length (ft)**	**Weight (lbs)**	**Density (lb/ft^3)**	**Weight (Bdt)**	**% MC**
Bonners	DF/WL/WRC	Dry	12	768	17.1	0.30	
Bonners	DF/WL/WRC	Dry	14	985	15.5	0.38	
Idaho City	PP	Green	10	860	19.0	0.33	
Stevensville	PP	Green	14	1176	18.1	0.45	
Medford	Mixed Conf.	Dry	10	772	17.9	0.31	25.1
El Dorado	Mixed Conf.	Green	8	1023	26.5	0.32	58.1
Bend 1	PP/LP	Green	15	1774	26.1	0.69	28.9
Crooked River	WJ	Dry	10	518	14.1	0.23	11.3
Crooked River	WJ	Green	10	1000	21.3	0.36	*

Solid, rigid bundles were produced when the residues had some pieces that were 10 to 20 feet long and at least 3 inches in diameter. Without some longer material in the mix, bundles could become flexible or even fail. Large, short material like butt cuts doesn’t bundle well. Large diameter pieces introduce discontinuities into the bundle that can produce weak points. The bundler can adjust to more difficult material by increasing the number of twine wraps and reducing the wrap spacing, but this affects productivity and cost.

Figure 11. Failed bundle due to breakage

Samples from bundles tested for calorific heat content have found that the residue values were within ranges expected as textbook values based on species (approximately 8500 btu/ovendry lb).

3.4 Productivity and Cost

Technical specifications for the 1490D list productivity as 10-30 bundles/hour. The results of this study show that these production rates can be attained, even in less than ideal conditions. At Idaho City, with high slash loading and an open stand, the bundler achieved its highest productive output, 24 bundles per hour. Similarly, Medford and the Crooked River units had reasonable results. The lowest productivity occurred on the

Bend 1 unit due primarily to poor slash arrangement (evidenced by amount of time spent aligning and collecting residues and feeding material) and a tight stand.

Table 5. Bundling cycle elemental time study results

	Site						
Element	**Bonners**	**Idaho City**	**Stevensville**	**Medford**	**Bend 1**	**Bend 2**	**Crooked River**
Move bundle (min)	0.01	0.15	0.43	0.00	0.19	0.13	0.05
Arrange slash (min)							
Align	0.50	0.35	0.06	0.00	3.06	1.05	0.00
Density	1.04	0.00	0.00	0.00	0.81	1.06	0.31
Rocks/Dirt	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Feed (min)	1.88	1.39	2.39	2.25	4.72	2.36	1.92
Wait (min)	0.03	0.14	0.96	0.16	0.45	0.05	0.18
Travel (min)							
Cutting	0.00	0.00	0.00	0.00	0.01	0.01	0.03
Bundling	0.00	0.00	0.00	0.04	0.02	0.00	0.08
Moving	0.85	0.31	0.67	0.14	1.46	0.58	0.61
Looking	0.00	0.00	0.03	0.00	0.08	0.00	0.00
Clear bundler (min)	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Rotate (min)	0.15	0.07	0.34	0.09	0.74	0.13	0.05
Cut bundle (min)	0.12	0.12	0.21	0.45	0.21	0.17	0.18
Total time (min)	4.66	2.52	5.09	3.13	11.76	5.53	3.42
Move dist. (ft)	54.6	25.2	-	14.5	161.5	61.5	96.5
Swings/bundle (n)	5.1	3.2	3.9	4.3	6.3	4.5	4.3
Bundles/hr	13	24	12	19	5	11	18
Bone dry tons/hr	3.9	7.9	5.4	5.9	3.5	*	4.1

Slash arrangement was a critical issue that affected operation. On the two sites that had limbs and tops from in-woods processing (Medford and Stevensville), there was very little time required to position or arrange the material for feeding. At the sites where the bundler was handling whole trees, it was necessary for the operator to properly align longer pieces. While material was generally fed butt-end first into the bundler, at the Idaho City site some trees were turned top-first in order to stagger the butt ends in the bundles. At the Bonner's Ferry, Bend 1 and 2 sites, the operator spent time aligning and bunching stems in order to get full grapple loads for bundling. If the residues are properly presented for bundling by the previous operation, arranging time should be close to zero.

Slash density also affected feeding time. When the operator picked up less than full grapple loads, it increased the number of swings per bundle and the total time required to pick up a full bundle of residue. This is particularly apparent at the Bonner's and Bend 1 sites. Feeding time was the single largest work element for the bundler, accounting for nearly half of total cycle time.

Figure 12. Low slash density underutilizes the grapple

Regression analysis of feeding time found that it was significantly related to the number of swings per bundle with the following model:

$$\text{Feeding time per bundle (min)} = 0.3357 + 0.4514 \times \text{Number of Swings}$$
$$R^2=0.39$$

Traveling time per bundle was clearly related to the distance traveled to accumulate a bundle's worth of residue. Regression analysis produced the equation:

$$\text{Travel time per bundle (min)} = 0.0482 + 0.0084 \times \text{Distance(ft)}$$
$$R^2=0.91$$

With a 30-foot reach on the boom, the 1490D accesses about 0.06 acres in one spot. Making a second stop would require a 60-foot move, making a third would add another 60 feet of travel. If the slash is scattered, the travel time while making a bundle could become significant. On the other hand, if the slash has been concentrated by the previous operation multiple bundles could be made at one stop without moving. Travel time will be a linear function of fuel loading—20 tons per acre will have half the travel time per bundle of 10 tons per acre.

Cutting time was nearly constant at each site. The first two sites averaged around 0.10 min to buck the bundle. After that the time doubled to about 0.20 min per bundle. The Medford cutting times were the longest and may reflect some machine adjustments that were being conducted.

Overall, productivity of the bundler was affected by the site conditions, slash arrangement, terrain, and operator variables in this study. Understanding the effect of these factors allows an estimate of productivity under better operating conditions. If the residues were prepared by the previous operation (felling) to be correctly aligned with the bundling trail and collected into grapple-sized piles, the arranging time would be zero. Feeding time at three swings per bundle would be 1.69 minutes. With 20 tons per acre to bundle the travel time should be about 0.35 minutes. Adding a cutting time of 0.10 minutes and minimal rotating time of 0.15 minutes, the total average cycle time under good conditions would be about 2.29 minutes per bundle (26 bundles per hour). The skilled bundler operator in this study noted that his best output had been 38 bundles per hour over a day-long shift bundling after a final harvest (clearcut) operation.

The suggested retail price for the 1490D is $450,000. Using standard machine rate calculations, the hourly owning costs would be approximately $58/scheduled machine hour (SMH). This assumes a 5-year life; 14% interest, insurance and taxes; and 20% salvage value. Operating costs include fuel, lube, repair and maintenance, chainsaw, and twine. Each bundle uses about 270 ft of baling twine. At 20 bundles per hour, twine cost would be about $5 per productive machine hour (PMH). With other consumables, total estimated operating costs would be about $50 per SMH. Adding labor would bring the total cost to around $130 per SMH.

3.5 Residual Stand Damage

There was very little residual stand damage except in the densest stands. The highest level occurred on the Bend 2 unit where a dense stand coupled with more slash arranging activity resulted in skinned bark on 14% of the residual trees. Bonner's Ferry also had a tight stand, but there was less material bundled and fewer stem scars (5.4%). The only other unit with evidence of residual stand damage was a very minor amount (2.1%) observed at Stevensville.

The 1490D is nearly 10 ft wide in travel mode. When the bundling unit is rotated, the total machine width can be over 20 ft. To pass the machine through a residual stand, the operator must constantly rotate the bundling unit and crane. The minimal amount of damage on the Bonner's site where residual tree spacing averaged 17 ft attests to the skill of the operator. While not clearly evident in the data, the high travel times for Bonner's and Bend 1 reflect not only the distance moved per bundle, but also the need to drive carefully in a dense residual stand.

Figure 13. Tight spot at Bonner's Ferry

3.6 Soil Disturbance

The 1490D is based on the 8-wheeled 1410 forwarder combination with 700/50 x 26.5 tires. Olofsfors Eco-tracks were installed on the rear bogies and tire chains on the rear half of the front bogie. Timberjack features include a "balanced bogie" which equalizes the load distribution across each bogie. Based on the technical specifications for the base 1410 configuration, ground pressure under the rear bogies with the tracks would be less than 9 psi. Bundling is a one-pass operation. That is, the bundling machine will only make a single pass down any given trail. Considering boom reach, the bundler would only traffic about 7 percent of stand area to cover the entire unit. In general, with minimal passes and relatively low ground pressure, soil compaction from bundling would not be a concern.

Soil disturbance was measured pre and post bundling to determine the relative contribution of bundling to site impacts (Fig. 14). The existing soil conditions were related to the type of previous stand treatment. At Bonner's, the thinning operation had occurred four years prior to bundling and litterfall combined with vegetative regrowth had obscured some of the initial disturbance. The Idaho City unit had no machine traffic before the bundler because the thinning had been completed by a chainsaw crew. While the Stevensville site had just been harvested, the low impact of CTL thinning was apparent with nearly 77 percent of the stand appearing undisturbed. Medford, on the other hand, had been recently thinned with a skidder-based operation resulting in higher levels of initial soil disturbance. Biomass bundling did result in measurable amounts of soil disturbance. On the ash cap soils and steep slopes at Bonner's, there was an increase in "soil exposed" area. At Idaho City, with lower slopes, most of the new disturbance was in the less-obvious "litter in place" category. At Medford, bundling actually reduced exposed soil by re-arranging the residual slash and resulting in an increase in the "litter in place" class.

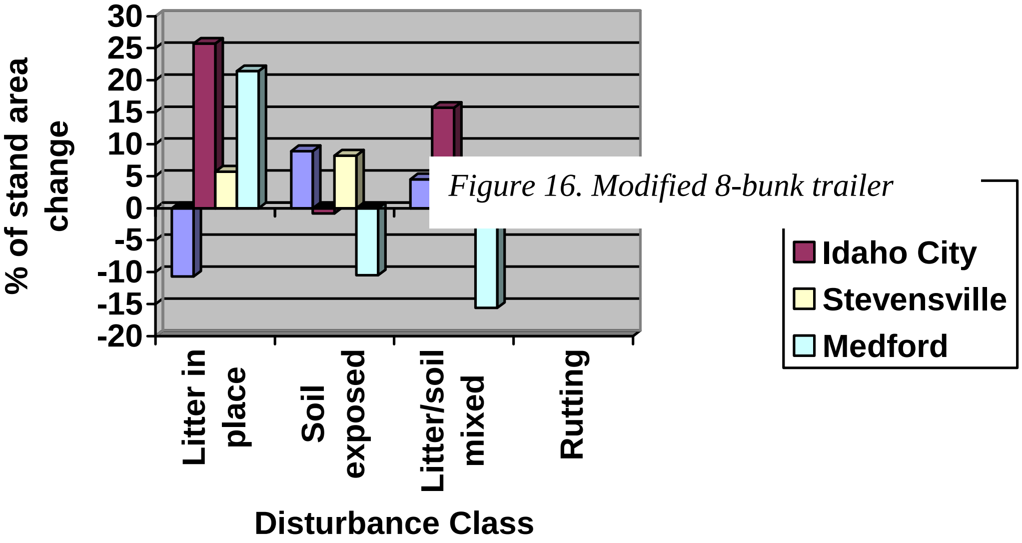

Figure 16. Modified 8-bunk trailer

Figure 14. Percent change in disturbance class resulting from bundling.

3.7 Transportation

Several different transport options were tried during the study. At Bonner's Ferry one load was hauled on a quad bunk short log trailer (Fig. 15) with the bunks moved in to support 12-foot bundles. Several problems were apparent including: a) loose material from the dry residue bundles falling from the load, b) low payload with limited bunk space, and c) marginal support with the bunk spacing that was available. While other studies have raised questions about the security of bundled material in transit (e.g. Hakkila 2003), it should be noted that these bundles were created from 4-year old slash. Additional bundles were transported in conventional dump trucks.

Figure 15. Quad bunk shortlog trailer

At the Medford site, two loads were transported on a straight-frame quad bunk logging trailer that had been modified with four additional bunks (Fig. 16). This configuration

hauled about 34 bundles per load with a load weight of about 28,000 lbs. The material was bundled green, 10 ft long, and held together well during transport. The loads passed California Highway Patrol inspection on the 150-mile interstate haul. Additional bundles were transported in roll-off bins.

3.8 Comminution

Bundles were reduced in chippers, hammer hogs, horizontal grinders and tub grinders. The best reduction (comminution) option appeared to be portable horizontal grinders or the stationary hammer hog. In order to maximize grinder productivity it is necessary to keep the infeed full. A horizontal grinder is easy to feed with the "short log" form of the bundles. However, the tub grinder was not a very efficient feeding system for whole bundles. The polypropylene twine used to wrap the bundles was shredded in the process, although some balling and accumulation of the twine was observed on one of the grinders.

Figure 17. Feeding bundles into a horizontal grinder

4 DISCUSSION

The project demonstrated the technical feasibility of densifying a wide variety of forest residues into compact bundles. Material ranging from small limbs and tops to whole trees was effectively wrapped and secured. There were some important exceptions including problems bundling excessively brittle residues or short, large diameter pieces. Residues that included rocks or trash (i.e., landing piles) resulted in additional cutoff saw maintenance and reduced utilization. The machine demonstrated the ability to operate on slopes up to 45% by traveling up-and-down the slope. In nearly 500 machine hours of operation, the only significant mechanical issue was the need to add an optional hydraulic cooling package to deal with summer temperatures in the West.

Analysis of productivity data indicates the importance of using biomass bundling as part of an integrated system of forest management. Simply using a bundling machine to "clean up the mess" from other operations is not productive. However, if the stand treatment is planned to include biomass recovery, then felling and processing operations can place residues and tops in aligned, concentrated piles. In order to maximize bundling productivity residue piles should contain at least 300 bone dry lbs (a full grapple load). Slashing residues, commonly required in timber sale contracts, is not necessary if the residues will be bundled.

Bundling residues greatly improves extraction to roadside. Forwarders commonly carried 10 bundles per cycle (~ 4 bdt) to roadside. Conventional grapple skidders would make many more trips to skid the same volume of residue. Western juniper is difficult to skid with more than a single stem, but in bundled form approximately 5 trees can be forwarded per cycle. Forwarding bundles will result in less soil disturbance than skidding loose residues.

Bundles were conveniently stacked at roadside (Fig. 18). Bundle piles are much more compact than piles of loose residues and can be stored in the stack for later transport and chipping. One of the cited advantages of CRL's is the ability to inventory biomass with a longer storage life than in chip form. By storing biomass at roadside in the form of CRL's, an energy facility could have a more secure and stable biomass supply than with chips.

Transportation of bundles is a critical issue that was not investigated in depth during this study. In Europe, bundles are transported by log truck and train. However, it is not uncommon to have 12-bunk trailers for regular timber transport. The closer bunk spacing is more compatible with CRL's. The best transport trial during the current study achieved slightly more than half of a legal load. Clearly transport costs of bundles would be higher than roundwood unless modified trailers were used.

Figure 18. Approximately 60 bdt of biomass

Assuming a potential production rate of 20 bundles per machine hour (8 bdt), the cost of collecting biomass and creating CRL's would be about $16 per bdt. Forwarding is estimated to cost $5 per bdt based on 4 loads per productive hour. With a hauling cost of $0.10 to $0.20/ton-mile, a 50-mile haul would add $5 to $10 per bdt. Finally, chipping at the energy facility may incur an additional $3 per bdt. Thus, the total cost to deliver chipped hog fuel from CRL's would be about $29 to $34 per bdt. Nearly half the total delivered cost is due to the bundling function.

The value of hog fuel would seldom support the cost of bundling with current energy prices. Hog fuel prices are limited by the cost of alternative energy sources such as coal. The average delivered price of coal to US electric utilities in 2002 was $24.74/ton (EIA 2002). Thus, the energy equivalent value of hog fuel would be about $17.50/bdt, covering only about half the cost of utilizing CRL's. The local price of hog fuel is highly variable, influenced by transportation costs, infrastructure, supply, and many other factors.

Bundling could be cost-effective, however, if the value of the forest management treatment is considered. Slash treatments and fuel reduction operations are generally cost centers. Grapple piling slash, for example, can cost $150 per acre. This preparatory step is followed by additional costs to burn slash for disposal. Burning costs are highly variable, but may be in excess of $300 per acre in some conditions. Mastication treatments that leave residues in the woods are $250 to $750 per acre. The question of whether biomass bundling is cost-effective depends on the volume of slash to be treated and the local costs of alternative fuel reduction treatments. If alternative treatments can be accomplished for less than $17 to $22 per bdt, then bundling may not be the preferred treatment. For example, if a local market paying $15 bdt was available to offset part of the costs, biomass bundling could remove 20 bdt per acre at a cost of less than $400 per acre.

Currently, biomass recovery using CRL's will generally require some supplemental funding. To help managers determine whether biomass bundling offers sufficient value to justify the cost, it is important to consider other benefits of this method. These benefits include the following:

Biomass bundling offers residue removal without restrictions on operating days. Burning, while generally less expensive residue disposal, is increasingly restricted to limited burning windows. Increasing treatment acres to implement the National Fire Plan will be impossible given restrictions on burning. Non-fire alternatives will be needed. Biomass bundling allows activity fuels to be treated immediately after a thinning operation has been completed. It is not necessary to let slash dry or to wait for safe burning conditions.

Low-impact thinning operations require low-impact residue treatments. It is generally recognized that CTL thinning operations cause less disturbance to soils and the residual stand. Biomass bundling is designed to complement the low-impact nature of CTL forest operations by removing residues with minimal additional site impacts.

Biomass bundling may be the preferred residue treatment method if there is insufficient merchantable volume to justify a conventional thinning operation. If the stand will be thinned with a conventional logging crew, it will probably be more cost-effective to extract as much residue as possible using whole-tree extraction, bunching of non-merchantable stems, and roadside chipping. However, if the stand treatment is pre-commercial, there may not be sufficient value to justify logging equipment just to handle biomass. Biomass bundling may be a better choice.

There is no single residue treatment option that will meet the needs of all situations. With the thousands of acres of forest that need management attention, agencies need a range of tools available for different kinds of treatments. Prescribed fire, thinning, mastication, and biomass bundling present the land manager with different capabilities and options for dealing with forest residues.

While this study has addressed some fundamental questions about the application of this technology, additional analysis is indicated. There have been macro-economic questions raised about how many bundling machines would be needed in a given area, the labor and economic impact associated with this new technology, and interactions with related fuels treatment operations (thinning contractors, planning teams). Questions have been raised about more detailed review of a range of ecological effects, from wildlife to soils. More evaluation of the effect of accepting significant quantities of bundles at biomass facilities is needed—woodyard handling and processing equipment, impact of storing biomass in bundle form, and effects on boiler performance.

The depth of interest evidenced by attendance at the public demonstration days, and the grass-roots commitment to this project from land management agencies, indicates the need to be examining tools for biomass recovery and fuels treatment. Clearly bundling is not economically viable in every application. However, the technology is cost-effective in some treatments, and may be the only tool that can meet special needs for fuel reduction without burning. With a developing biomass utilization industry, opportunities for biomass collection are certain to increase in the future. Findings of this project provide a better understanding of the appropriate applications for bundling equipment.

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