CHUGACH NF BIOMASS TREATMENT COST MODELS

Report Prepared for

USDA FOREST SERVICE—ALASKA REGION 10

by

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SUMMARY

INTRODUCTION

Simple costing models for various biomass treatments specific to the Chugach National Forest are presented in this report, which was prepared on the instructions of Ms. Inga Petaisto, Regional Valuation Forester, USFS Alaska Region 10. The depth of the analysis is limited by the sparsity of base data, and the cost models are preliminary in nature. They require calibration to collected costs at the earliest opportunity.

The models presented herein are incorporated in the accompanying spreadsheet. They may be used to estimate costs of a wide range of biomass treatment and recovery options for any one unit or contract area.

MEASREMENT UNITS AND CONVERSION FACTORS

Cost algorithms are expressed in acreage, cubic, cord, or ODT (oven-dry ton) units. It is assumed that green wood has a moisture content of 50%, green basis. Composite wood density was calculated from published densities, proportioned according to the growing stock inventoried for South Central.

BIOMASS TREATMENTS AND RECOVERY SYSTEMS COSTED

Biomass treatments on the Chugach primarily target dead wood, with a minor component of thinning of live trees. The following treatment and recovery options are costed.

- Hand cut and pile
  - Preparation for burning
- Machine cut and pile/deck/load
  - Preparation for burning
  - Recovery for biomass utilization as roundwood, chips, or ground wood
- Burn
  - Hand piles
  - Machine piles
  - Broadcast
- Hand cut lop and scatter
- Mulch
- Comminution
  - Chip and scatter
  - Chip or grind and haul
  - Chip hauling
- Roundwood Hauling
  - Highway logs
  - Off-highway stems
  - Box truck

INTRODUCTION

In this report is presented an analysis of the costs of, and costing models for, various biomass treatments specific to the Chugach National Forest. The project was commissioned by Ms. Inga Petaisto, Regional Valuation Forester, USFS Alaska Region 10.

The depth of the analysis is limited by the sparsity of base data, a function in turn of the limited scale of treatment operations on the Chugach. The objective is to prepare biomass treatment cost appraisal algorithms that are simple in both their construction and their application.

It is emphasized that cost models presented here are preliminary in nature. They require calibration to collected costs at the earliest opportunity; this process will likely also suggest opportunities to modify the models and thereby substantially improve their reliability and utility.

Daily and hourly machine and logging side costs shown in this report are derived from the accompanying biomass cost calculator.

ABBREVIATIONS AND VARIABLE NAMES USED IN THIS ANALYSIS

burnarea	burn size, acres
BY	base year (fiscal year for which costs collected)
ctreevol	tree volume, stem wood, cubic feet.
CCF	100 cubic feet Forest Service scale
cu.ft.	cubic feet of wood
dbh	diameter breast height
FM	Fuel Model (Anderson 1-13)
GT	green ton
hp	horsepower
mc	moisture content (green basis)
ODT	oven-dry ton, i.e. zero moisture content
pcf	dry pounds per cubic foot
pmh	productive (i.e. delay-free) machine hour
pmm	productive (i.e. delay-free) machine minute
removal	removed dry tonnage (ODT) per acre
WUI	Wildland-Urban Interface

MEASUREMENT UNITS, QUANTITIES, AND CONVERSION FACTORS

Cost algorithms are expressed in acreage, cubic, or ODT (oven-dry ton) units, depending on their likely application and the availability of data, both for algorithm formulation and for appraisal purposes. For potential cordwood products, a conversion is also made to cords.

Throughout this analysis, it is assumed that green wood has a moisture content of 50%, green basis; that is, green wood consists of 50% by weight of water.

Van Hees (2005) tabulated the following percentages of growing stock volume in South Central. It is assumed that biomass will be treated or recovered in approximately this proportion of species.

Black spruce	0.3%
Mountain hemlock	11.1%
Sitka spruce	61.4%
Western hemlock	15.9%
White spruce	3.4%
Black cottonwood	4.8%
Paper birch	2.4%
Quaking aspen	0.4%

Based on this species mix, Parrent (2011) used densities provided in the Dry Kiln Operators Handbook to arrive at a composite density of 27.17 dry pounds per cu.ft. This density, rounded to 27 pcf, is used for the purposes of this analysis.

Cubic volumes are converted to cord measure in at 80 cu.ft. of solid wood per cord, following Nichols et al. (2009).

Based on the analysis presented by Hemphill (2011), the conversion from cu.ft. to USFS CCF for Tongass second growth is estimated to be 100 cu.ft. = 0.86 CCF. The same conversion will be assumed for the Chugach, although it has not been explicitly investigated.

The resulting assumed equivalencies are:

1 ODT = 74.074 cu.ft, rounded to 74 cu.ft.

= 0.9259 cord, rounded to 0.93 cord

= 0.63704 CCF, rounded to 0.64 CCF, USFS scale

The biomass potentially available from limbs is ignored.

Ms. Nichole Longfellow, AFMO Fuels on the Seward RD, advises that removed tonnages range from 18 to 56 ODT/acre. Mostly, dead material is removed, with thinning of live trees being a much less common activity.

HAND CUT AND PILE

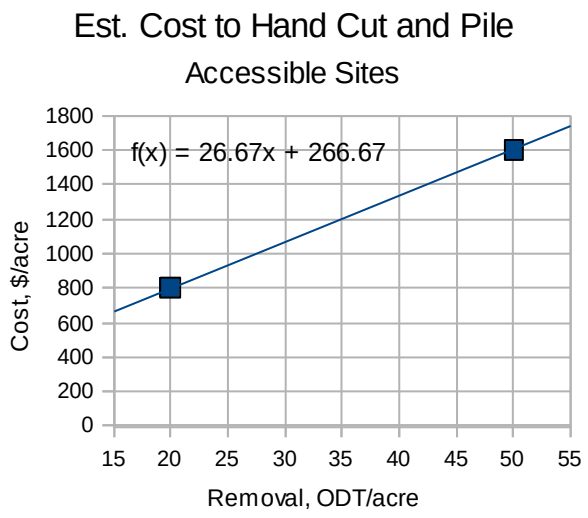
Costs experienced on the Chugach to hand cut and pile range from $800 to $1,600 per acre, depending largely on the tonnage per acre. Remote sites, requiring camping, may cost more.

Costs for accessible sites (practical for a daily commute) are modeled by assuming a linear relationship with tonnage per acre. Fitting a straight line between $800/ac. for 20 ODT/ac. and $1,600/ac. for 50

ODT/ac. results in the relationship:

Cost to Hand Cut and Pile = $(26.67*removal + 267) per acre

as expressed graphically below.



For remote sites, which are less common than accessible sites, it is necessary to construct the additional cost for camping and/or air transportation.

HAND CUT LOP AND SCATTER

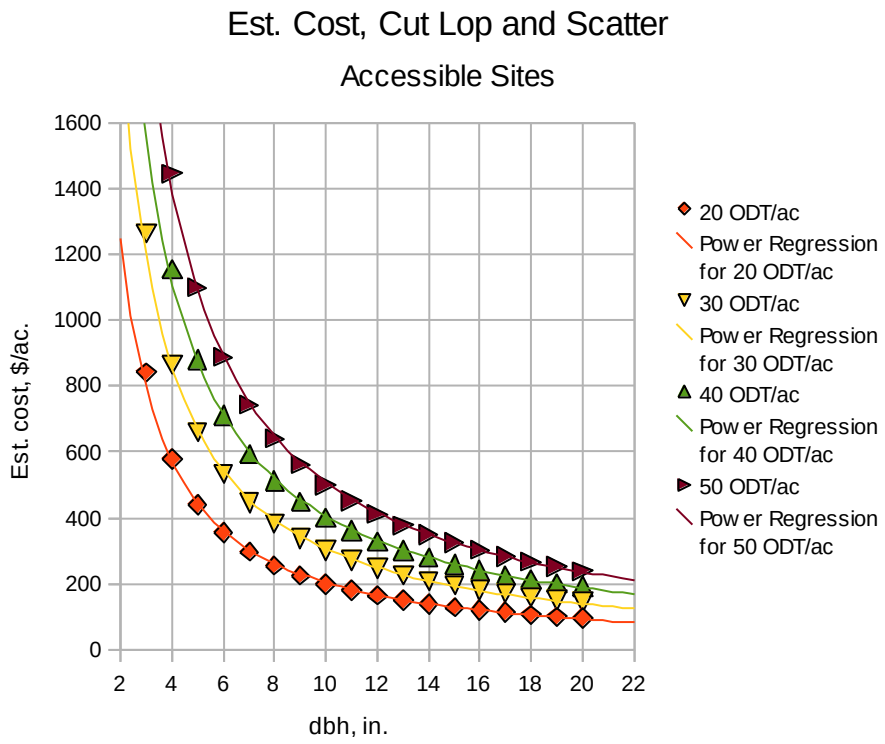
There is no recent Chugach experience for lop-&-scatter.

The Tongass cost model for cut-lop-scatter of submerch trees, derived from Kellogg et al. (1986), is:

Lop-&-scatter cost, $/ODT = 92.16/(dbh-0.81)

Kellogg sampled cutting productivity in trees down to 6” dbh, but not smaller. Therefore it is proposed to extrapolate this model down to 3” dbh, but not to smaller trees than this. The resulting relationship is expressed graphically below, converted to a per acre cost by applying the tonnages shown.

For remote sites, which are less common than accessible sites, it is necessary to construct the additional cost for camping and/or air transportation.



Validation

The model predicts costs per acre as follows:

dbh:	4”	10”
20 ODT/ac	$578/ac	201
50 ODT/ac	1445	501

Mr. Joe Ford, Forester, Seward RD, reports that PCT cut-lop-scatter costs on the Tongass are typically about $1,000/acre, fitting into the range above for small trees. Therefore the model is accepted.

BURN

CHUGACH COST EXPERIENCE

Ms. Nichole Longfellow, AFMO Fuels on the Seward RD, provided the following information.

Prescribed burning costs range from $200 to $350 per acre, excluding remote sites; $300/acre is typical. Machine-piled areas (fewer, larger piles) are near the lower end of this range, while hand-piled areas (more but smaller piles) are near the upper end. Remote sites can cost $800 to $900 per acre. There is no recent experience with broadcast burning. Fuel loadings range between 20 and 50 tons/acre. Burning on the wildland-urban interface does not cost more, but requires more planning. The wildlife prescription is a significant variable driving the cost per acre. Generally speaking, burning is prescribed to reduce a Fuel Model 10 (stands that are overmature or have had natural events that

create a large load of dead material on the forest floor, including insect or disease ridden stands) to a Fuel Model 8 (closed canopy short needle conifers or hardwoods that have leafed out such as a closed stand of birch).

Burning is practiced on other South Central ownerships, but other owners do not appear to have isolated burning costs from cutting and piling costs.

MODELING APPROACH

Calkin and Gebert (2006) presented an analysis of prescribed burning costs throughout western National Forests in the South 48 (Alaska was not included). They recorded a much lower average cost per acre than applies on the Chugach, for a different set of circumstances. However, their findings are instructive.

Calkin and Gebert found that the most important variables affecting prescribed burning cost per acre in the western South 48 were:

- the size of the burn (acreage)
- the presence of wildland-urban interface
- whether the fuel was hand- or machine-piled
- the fuel model
- the presence of T&E species
- whether aerial ignition was used

Their baseline was Fuel Model 9 (long needle conifer stands and hardwood stands); they determined that other Fuel Models had higher or lower costs but did not show a different cost for FM 10.

A study of the Calkin and Gebert analysis shows that, compared to their baseline of broadcast burning a FM 9, for each variable alone (holding the others constant) would change as follows:

- Increase burn acreage by 1%: decreased per-acre cost by 0.35%
- WUI: increased cost by 34%
- Machine pile: decreased cost by 71%
- Hand pile: decreased cost by 35%
- Presence of T&E species increased cost by 66%

These conclusions differ from the Chugach experience as follows:

- WUI is not considered to increase costs on the Chugach.
- The South 48 cost to burn machine piles is less than half that to burn hand piles; on the Chugach it is inferred to be about $225/$325 say, or 70%.

The approach taken to the Chugach burning cost models is to fit relationships to average burning costs reported by the Forest, adapting as needed from the Calkin analysis.

HAND PILES

For this analysis it is assumed that burning hand piles costs between $250 and $350 per acre for accessible sites. An average of $325 is assumed, for an accessible unit of 100 acres average size, with no wildlife complications. The conclusions of the Calkin and Gebert study suggest that cost should be increased/decreased by 0.35% for each 1% decrease/increase in burn size. It should also be adjusted from local experience for wildlife complications. For remote sites, crew transportation and camp costs should be constructed and pro-rated per acre, for addition to the cost determined for an accessible site.

Taking a simplified form of the Calkin relationship:

$$\text{Cost, \$/acre} = e^{(x-0{,}349*\ln(\text{acres}))}$$

and solving for x, for the assumed data point of $325/ac. for a 100 acre burn:

$$325 = e^{(x-0{,}349*\ln(100))}$$

$$\ln(325) = x-0.349*4.6052$$

$$5.783825 = x-1.607215$$

$$x = 7.391$$

resulting in a preliminary relationship for the Chugach:

$$\text{Cost, \$/acre} = e^{(7.391-0{,}349*\ln(\text{acres}))}$$

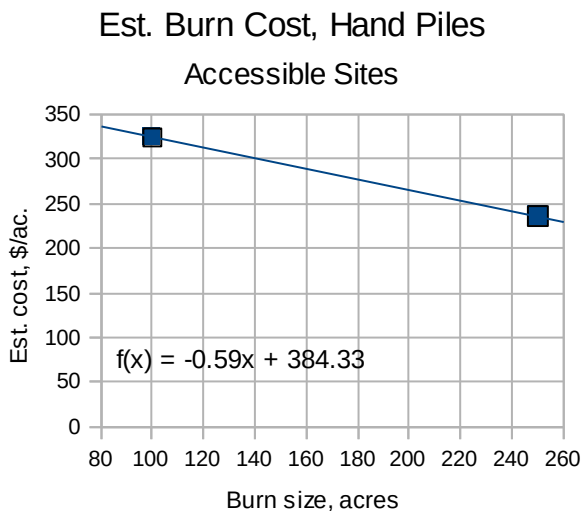
This relationship predicts what seems to be a reasonable cost for larger units: $236/acre for a 250-acre burn. However, it results in a high estimated cost for a small burn size of say 25 acres: $527/acre. Therefore a new, simple, linear, relationship is developed between two points: the 250-acre cost of $236/acre predicted by the preliminary relationship, and the assumed average of $325 for a 100-acre burn. The resulting cost prediction formula,

$$\text{Burn cost, hand piles, \$/acre} = 384 - 0.59*\text{burnarea}$$

where: burnarea = burn size, acres

is displayed graphically below.

This should be modified from local experience for wildlife complications. An adjustment must also be constructed for remote sites by calculating transportation and camping costs and pro-rating these per acre.



MACHINE PILES

For this analysis it is assumed that burning machine piles costs between $200 and $300 per acre for accessible sites. An average of $225 is assumed, for an accessible unit of 150 acres average size, with no wildlife complications.

The cost model is constructed by adapting the model derived above for burning hand piles. The hand pile model is multiplied by 225/325 (the ratio of the assumed average burn costs for the two types):

Burn cost, hand piles	= $(384 – 0.59*burnarea)/acre
Burn cost, machine piles	= 225*(384-0.59*burnarea)/325
	= $(266-0.41*burnarea)/acre

This should be modified from local experience for wildlife complications. An adjustment must also be constructed for remote sites by calculating transportation and camping costs and pro-rating these per acre.

BROADCAST

Because there is no recent Chugach broadcast burning cost experience, the Calkin & Gebert cost model is adapted to construct this cost. The Calkin & Gebert model predicts a hand-pile burn cost 65% that of a broadcast burn; in other words, a broadcast burn is predicted to cost 154% as much as a hand-pile burn, resulting in the following relationship:

Burn cost, hand piles	= $(384 – 0.59*burnarea)/acre
Broadcast burn cost	= 1.54*(384-0.59*burnarea)
	= $(591-0.91*burnarea)/acre

This should be modified from local experience for wildlife complications. An adjustment must also be constructed for remote sites by calculating transportation and camping costs and pro-rating these per

acre.

MULCH

Mulching or mastication machinery most suitable for South Central consists of a cutterhead with either a vertical shaft, usually boom-mounted on a tracked machine; or a horizontal shaft, typically mounted on the front of a skid-steered tracked machine. There has been some mechanical mulching done in the past on the Chugach, but the cost history is not presently available in a compiled form.

EXISTING COST ANALYSES

Various authors quote mulching costs anywhere from $300 to over $1,000 per acre, but very few have analyzed the relationships between costs and site characteristics.

Rodman (2011) quoted mulching costs, all within Anchorage, ranging from $1,000 to $2,087 per acre; the higher number included some manual cutting and pruning. All of these projects apparently included a component of firewood removal, which has not been quantified. She thought mulching costs might be dependent on tonnage per acre. Rodman also commented that her costs were inflated through having projects located within residential areas.

USDA Forest Service (2004 and 2009) provided summarydescriptions of the equipment and its operation, but no quantified cost relationships.

Halbrook et al. (2006) presented the results of an analysis of mastication costs on a moist western hemlock site in northern Idaho. They found that slope was the most important site variable affecting productivity, with little effect below 35% but significant effects on steeper ground. They did not find other site variables to affect productivity. They recorded an average cost of $530/acre, ranging (for units under 35% slope) from $378 to $650 per acre. Their analysis does not make it clear what tonnage per acre was treated, but it is possible that productivity was not dependent on this parameter. The Halbrook analysis is ambiguous on this point and others, and to date two of the authors of the paper have not responded to this engineer's request for clarification. Unfortunately, therefore, it cannot be used as a basis for the Chugach model.

Bolding (2006) presented a comprehensive analysis of two mulching operations in central Oregon, one in an open ponderosa pine stand and the other in a densely stocked high-elevation mixed species stand, comprised mostly of mountain hemlock, lodgepole pine, and subalpine fir, with a high loading of dead fuels. Per-acre costs ranged from $247 to $414 when residual trees were spaced widely in the pine stand. In the dense mixed-species stand, costs per acre ranged from $479 to $1,560.

The mixed species stand would be quite comparable to some stands being treated on the Chugach. Unfortunately, Bolding was not able to perform regression analysis to discover the effects of stand variables in that stand, because of insufficient data.

Bolding studied two machines: an excavator-boom-mounted vertical-shaft masticator, and a horizontal shaft masticator mounted on the front of a skid-steer KMC tracked machine. He found that the KMC outperformed the excavator in the open stand, but because of its higher hourly cost the two machines operated at a comparable rate per ton. In the mixed-species, dense stand, he found that the excavator produced at a lower cost per ton because of the much greater maneuverability of the mulching head. However, the KMC had an inexperienced operator, while the excavator operator was well experienced.

Bolding found the prime variables affecting excavator mulching productivity were the size of the trees and the tonnage per acre. For the KMC, stand density was most important, because of the maneuverability issue.

Where maneuverability was not a major issue, for both machines in the pine stand and for the excavator in the tight mixed-species stand, Bolding calculated mastication costs ranging from $22 to $28 per green ton.

CHUGACH MODEL

Mulching on the Chugach is modeled by assuming:

- Contractors would employ an excavator mulcher in stands where the residual stocking could cause maneuverability issues.
- The mid-range of the per-ton costs determined by Bolding for stands without major maneuverability issues would apply.

Therefore the mulching cost estimated for the Chugach is $25/GT, or, at the 50% assumed MC, $50/ODT. To obtain a per-acre cost, this is multiplied by the estimated tonnage per acre.

Validation

Rodman (2011) reports that mulching typically costs more than hand cut-and-pile, but less than the total of hand cut-and-pile plus burning. This model agrees with this experience for lower fuel loadings, although at higher loadings it predicts a higher cost than total hand cut-and-pile plus burn costs. In the absence of better information, the model constructed here is accepted.

MECHANICALLY CUT AND SKID

SYSTEM

The system costed for mechanical cutting and skidding consists of:

1. A Waratah 622 head on a Cat 320 carrier, or comparable harvester, severing and bunching tree lengths adjacent to a skid trail. Trees would be roughly delimbed only where necessary for subsequent utilization, and not bucked. Bunches could be sorted according to their eventual treatment or utilization (e.g. trees destined for burn piles, or for cordwood).
2. A Cat 517 or comparable tracked grapple skidder, skidding bunches of tree lengths to the landing.
3. At the landing, a Cat 320 or comparable loader would deck or load tree lengths onto trucks, a chipper, etc. depending on the treatment or utilization of the material.

Operations would largely be conducted on frozen ground, with negligible puncheon required on skid trails.

COST

Harvesting

Harvesting cost is estimated from Dempster et al. (2008). They presented representative costs for various stump-to-truck logging functions, based on a range of production studies in small trees. The

underlying models were supplied by Hartsough (2011), one of Dempster's co-authors. The Dempster cost relationship is increased by 85% to allow for a modest amount of processing that would be done at the stump, that is not done for the Dempster model.

The Dempster relationship is:

Feller-bunching cost = $\$72.35*dbh^{-1.25}$ per green ton

Converting to dry tons at 50% mc:

F-b cost = $72.35*dbh^{-1.25}/0.50$

= $\$144.70*dbh^{-1.25}$ per ODT

Allowing for limited delimbing at the stump area:

F-b cost = $1.85*144.70*dbh^{-1.25}$

= $\$267.70*dbh^{-1.25}$ per ODT

= $\$418.27*dbh^{-1.25}$ per CCF

Skidding and Loading

Skidding productivity for the selected system is most dependent on skidding distance and skidding grades. Productivity is not strongly dependent on piece size for bunched wood, and piece size is consequently not used as a predictor variable.

It is assumed here that the productive capacity of the loader will exceed that of the skidder. Therefore combined skidding and loading costs are calculated for skidding productivity.

The skidding system modeled for the Chugach is very comparable to that costed for the Tongass cost appraisal model. Compared to the Tongass, Chugach costs would be lower because of the more benign terrain and the smaller loader employed. It is assumed here that Chugach skid-and-load costs would be 90% of those on the Tongass model. Accordingly, the Chugach model is constructed by setting costs at 90% of those in the Tongass model, which is:

Tongass skidding and loading cost, $/ODT:

Skidding grade +30%:	$= 0.54 * AYD^{0.65}$
+20/-30%:	$= 0.79 * AYD^{0.56}$
+10/-20%	$= 0.78 * AYD^{0.54}$
0/-10%	$= 0.96 * AYD^{0.49}$

where: AYD = average yarding distance, feet

Adapting to the Chugach, by multiplying by 90%:

Chugach skidding and loading cost, $/ODT:

Skidding grade +30%:	$= 0.90 * 0.54 * AYD^{0.65}$	$= \$0.49 * AYD^{0.65}/ODT$
+20/-30%:	$= 0.90 * 0.79 * AYD^{0.56}$	$= \$0.71 * AYD^{0.56}/ODT$
+10/-20%	$= 0.90 * 0.78 * AYD^{0.54}$	$= \$0.70 * AYD^{0.54}/ODT$

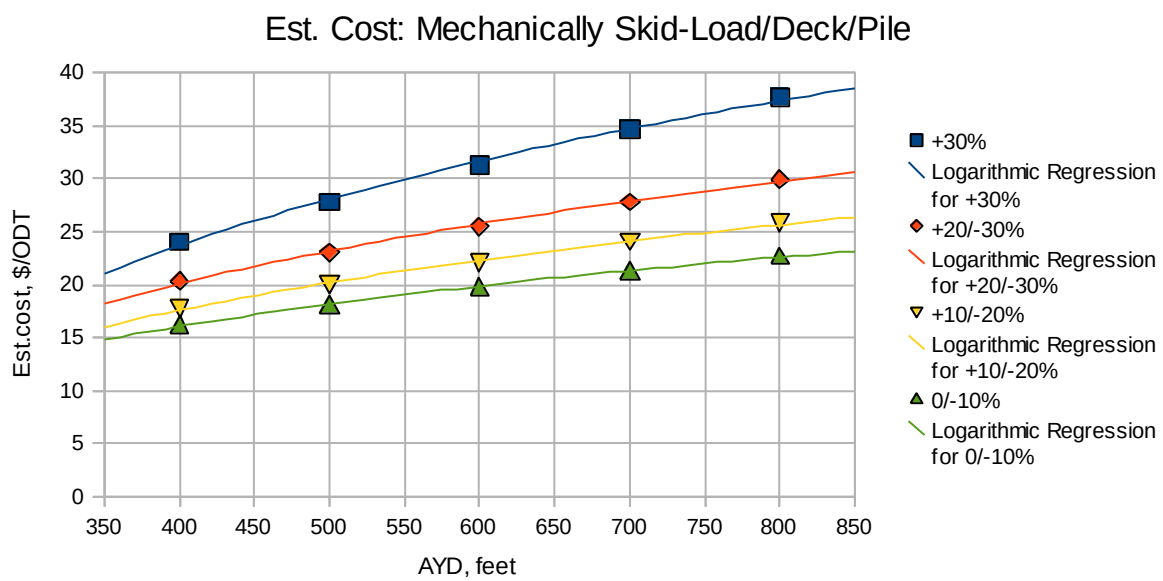
0/-10%	= 0.90 * 0.96 * $AYD^{0.49}$	= \$0.86 * $AYD^{0.49}$/ODT

Converting to cubic:

Chugach skidding and loading cost, \$/ODT:

Skidding grade +30%:	= \$0.49 * $AYD^{0.65}$/ODT	= \$0.77 * $AYD^{0.65}$/CCF
+20/-30%:	= \$0.71 * $AYD^{0.56}$/ODT	= \$1.11 * $AYD^{0.56}$/CCF
+10/-20%	= \$0.70 * $AYD^{0.54}$/ODT	= \$1.09 * $AYD^{0.54}$/CCF
0/-10%	= \$0.86 * $AYD^{0.49}$/ODT	= \$1.34 * $AYD^{0.49}$/CCF

as expressed in the graphic below.



Validation

The model predicts cost per acre as follows:

dbh:	10”	16”
20 ODT/ac	\$791/ac	617
50 ODT/ac	1978	1542

Haus (2011) quoted a range of \$700 - \$1500 per acre, but it was not clear what characteristics applied to the highest and lowest costs. The order of magnitude appears about right, so the model is accepted.

COMMINUTION

The focus of this section of the report is on preliminary estimates of cost, rather than on the fuel characteristics of the biomass or the Alaska markets, which are described by Wilson et al. (2010) and Brackley et al. (2010) respectively.

POTENTIAL MARKETS FOR COMMINUTED BIOMASS

Biomass, comminuted by either chipping or grinding, has potential markets as fuel and as landscaping material. It is assumed that it is not feasible to develop a market for pulp chips, and that there is insufficient raw material to supply a pellet plant on an economic scale.

Landscaping Material

Chips used as playground surfacing must meet the following particle sizing specification:

	Percent passing:	
Sieve Size	Minimum	Maximum
3⁄4 inch	99 %	100 %
3⁄8 inch	75 %	100 %
No. 16	0 %	15 %

Bell (2011) stated that woods biomass is not readily chipped to this specification, since the nature of the raw material is apt to result in excessive fines and overs. Rather, playground dressing must be derived from clean wood. Therefore this product is not further explored in this analysis.

The specification for landscaping mulch is much less demanding. Valley Sawmill in Anchorage produces landscaping mulch by grinding landclearing waste with a horizontal grinder. The quantity of the demand in South Central has not been investigated for this analysis.

Fuel

Comminuted biomass is presently not widely used as fuel in south central Alaska.

The most common feedstock for direct fired wood burners is 3” minus ground wood. Low moisture and dirt content are desirable. Horizontal grinders produce this material most economically.

Suspension burners require short fiber wood, typically less than 2/10”, with a moisture content less than 20%. A short fiber length is also required for some, but not all, gasification processes. Such material would need to be re-manufactured from woods chips.

An intermediate chip dimension of about 1”-1.5” has wide application in various burners and could be used in a multi-fuel system as an alternative to pellets. Such a chip can be produced by woods chippers.

CHIPPERS AND GRINDERS

Grinders comminute wood by means of metal bits mounted on a rotating horizontal drum through which the biomass is fed. Two examples present in Alaska are the Rotochopper used to grind feedstock for the Tok school furnace, and the Morbark 4600 used by Valley Sawmill to produce mulch. Grinders are tolerant of dirt contamination and even tramp metal. They produce a coarse product, typically 3” minus, acceptable to some but not all burners. Screens can be employed to reduce the particle size, but the consequent re-grinding of overs means reduced productivity. Most dirt is screened

out.

Tub grinders use rotating hammers to beat the biomass apart in a large cylindrical tub. There is one known to exist in South Central, but an Industry source states that it is an unreliable, unsafe machine. This type of machine is not further considered in this analysis.

Chippers comminute wood by means of knives mounted on either a vertical rotating disk or a horizontal drum. Compared to grinders, they produce a more consistent and smaller particle size, but are less tolerant of contamination. Disk chippers are less tolerant of contaminants than drum chippers. Several chippers are present in central and south-central Alaska.

To comminute biomass efficiently means that the chipper or grinder must have an adequate feed deck to handle its somewhat amorphous form. Horizontal drum models are preferred for biomass comminution since they have a larger opening than disk chippers, thereby accepting a greater cross-sectional area of feedstock.

Large feed deck and throat on a horizontal drum grinder.

Chippers and grinders are either trailer-mounted or self-propelled tracked models, the latter being more mobile and therefore most commonly seen on woods landings in the Pacific Northwest.

One chipper model, the Bruks 805, is mounted on a forwarder, and transports chips in an integrally mounted self-dumping bin (pictured below).

Bruks mobile chipper blows chips into an integral bin.

Therefore it is capable of off-road operation, and typically shuttles chips in its bin down rough spur roads for transfer to conventional chip vans on a higher-standard road. The Bruks is expensive, costing almost a million dollars, has a small feed deck, is not tolerant of dirt, is not currently present in Alaska, and has roughly half the productivity of a conventional woods chipper. It might well find a niche application in a large biomass operation, but there seems little prospect that biomass recovery on the Chugach will achieve a large scale. The Bruks is therefore not further considered in this analysis.

Chipper and Grinder Productivity

In the Pacific Northwest, a 700-800 hp horizontal grinder or chipper producing ground wood or 1”+ chips from slash produces a 30-GT (15 ODT) truckload in about 22 to 27 pmm. Additionally, minimum delays caused by truck movements at the landing are about 8 pmm, for a total cycle of 30-35 pmm. In practice, truck availability usually constrains chipper productivity to a lower level than this. Operators quote productivities ranging from 225 to 420 GT per 10-hour day, the latter applying to the best-managed operations with company trucks. Most commonly, productivity is about 240 GT (120 ODT) per 10-hour day, for slash with few whole trees.

Aman, Baker, and Greene (2010) quoted whole tree chipper productivity for a number of machines in the South at about 70 GT/pmh, and a chipper utilization of only 44%. They reported trucking related delays at 30%. This is consistent with reports by other authors. This converts to 308 GT per 10-hour day, in operations that are primarily chipping whole trees.

For the Chugach case, where most of the biomass is likely to be whole trees, productivity is assumed to be 70 GT or 35 ODT per pmh. Because it is likely that chip truck availability will be low in South Central, as a result of the small population of chip trucks, utilization for a whole tree chipper is anticipated to be 40%. Therefore, in an 8.8-hour day, a horizontal grinder or chipper such as a Morbark 4600 Wood Hog is estimated to produce only 123 ODT.

If the chips are to be scattered at the landing, utilization will be higher as there are then no truck delays. Assuming 50% utilization since frequent chipper moves are required, daily production would be 154 ODT.

Chipping and Grinding Cost

The daily cost of a chipper side, consisting of a Cat 320 or comparable loader and a Peterson 4310 or comparable horizontal drum chipper both run by a single operator, is estimated at $1,770.81. The cost of producing chips or ground wood at the woods landing is therefore estimated at $1,770.81/108 = $16.40/ODT = $25.62/CCF.

For a chipping yard or to chip-and-scatter at the woods landing, assuming 50% utilization, chipping or

grinding is estimated to cost $1,770.81/154 = $11.50/ODT = $17.97/CCF. To chip-and-scatter, a chipper would be used, not a grinder, as the former can scatter chips by blowing them. The use of a grinder for chip-and-scatter is feasible only if an additional machine is available to scatter the ground wood by dozing it.

CHIP TRANSPORTATION

Central to the choice of comminution system is the chip or ground wood transportation issue. (In this section of the report, the term "chip" also refers to ground wood.) Four primary options appear to merit consideration.

1. Conventional chip vans: Chip liners will negotiate only good-standard logging roads with excellent vertical and horizontal alignment, a well-maintained surface, and adequate curve widenings. They require a large turn-around space near the woods landing. Empty chip trucks spin out on a moderate grade on a gravel road. Skilled drivers with good woods experience are required. Many forest roads on the Chugach could not be negotiated by conventional chip van without extensive reconstruction. Chip van dry payload is highly dependent on the moisture content of the chips, especially since either dimensions or weight may be limiting. Based on Pacific Northwest experience, a load size of 31 GT is assumed for a 3-axle chip van for the Alaska case, or 15.5 ODT at 50% mc. A very few chip vans of this type are present in South Central.

Conventional chip van being retrieved after attempting to reverse up a spur.

2. Off-highway chip trucks: In the Pacific Northwest there is limited application of chip liners customized for logging roads, through the employment of steering axles on the chip van and 4" increased ground clearance, using a 6x6 tractor unit. Such a chip truck-and-trailer costs about $70,000 more to purchase than a conventional unit, but one operator stated that its variable

costs were no more than for a conventional unit. The payload is the same as a conventional chip van. Based on Pacific Northwest experience, a load size of 28 GT is assumed for a 3-axle 6x6 steering chip van for the Alaska case, or 14 ODT at 50% mc. This type of truck is not present in Alaska and it is not further considered.

Off-highway chip truck with steering trailer can traverse all logging roads.

3. Walkers: Another Pacific Northwest approach is to use a walking-floor chip van to shuttle chips or ground wood from the woods landing to a yard adjacent to a highway and accessible to conventional chip vans. The walker has adequate ground clearance, but requires a good standard of horizontal alignment and curve widenings. Chips are dumped on the ground by the walker, then reloaded into a highway chip van with a larger front-end loader. Re-loading takes about 15 minutes per load. At the end of the operation, about 1 load of chips is wasted through contamination on the ground. Operators report that walking-floor vans hire for about the same hourly rate as a conventional van. The payload is smaller, at about 10 ODT, even in an off-highway application. There is at least one of these trailers present in South Central.

Walking-floor chip van unloading ground wood in a biomass fuel transfer yard.

4. Chipping yard: Trees may be transported on logging roads to a chipping yard adjacent to a highway. In this approach, there is no need to improve roads beyond the standard required for log trucks, or to provide large turnarounds near woods landings. Enough room is required to carry an inventory of unchipped wood and for chip and log trucks to turn. If production were great enough to keep a chipper going full time, a spot truck would be kept at the yard to keep feeding empty vans to the chipper. Improved access to the chipping site is likely to result in a more efficient chipping operation than at a woods landing. There are several ways to transport trees to the chipping yard:

   a) Trees can be transported as tree-length stems in a conventional log truck, being roughly delimbed in the woods for safe transportation and to achieve a full load.
   b) Trees could be transported by log truck with limbs, but with a much lower load factor because of the included voids, and with a safety hazard introduced by overhanging limbs. This option will not be considered further in this analysis
   c) An approach used in the South for whole-tree hauling is to employ a "possum belly" trailer, a semi-trailer with similar characteristics to a chip van and therefore not well suited to Alaska logging roads. This option will not be considered further in this analysis.
   d) Alternatively, trees could be roughly delimbed and segmented directly into a box truck (pictured below) at the landing by a processor, then dumped at the chipper. This method would have the advantage of removing all the slash from the woods landing. A British Columbia test of this method was reported by Forrester (2004). In that case the processor produced chunks only 10" long, with a cost of $Can131/ODT delivered, for a 3-hour round trip travel time. Forrester also projected costs to produce 40" chunks at about $Can54 per ODT for a 3-hour round trip travel time, but assumed that the processor could operate unconstrained by trucks. In Oregon operations where box trucks are used to recover chunkwood on hot landings, it is common to set up a box very close to the landing chute, with the loader transferring chunks into the box immediately after they are bucked by the processor. An essential difference from the Alaska situation is that in Oregon practically all stemwood that can be bunked is merchandized for either sawlog or pulp in log truck lengths, whereas in Alaska either the entire tree or a long top would be bucked for box truck transportation. Based on discussions with an Oregon operator, the method proposed for the Chugach would be to process tree-lengths directly into a box, generally without handling by the loader. This would require that a spot be excavated low enough in the landing for a processor to process over the top of a 10-foot box, in order to maximize payload. The box truck is less efficient than a log truck, having a higher cost and a lower payload. However, it can transport short stems, tops, and slash that cannot be transported in a log truck, and it unloads itself. Box trucks for woods application need to have a hydraulic retrieval boom, not the cable-and hook arrangement seen on municipal waste trucks. Nevertheless, it is assumed that the woods type could find althernative application for municipal waste in the Anchorage area, making it a candidate for woods application in Alaska.

Slash being loaded in a box; truck with retrieval boom far right.

Chip Transportation Productivity

Chip trucks travel at about the same speed as log trucks, and the same round trip travel times may be assumed for both. Loading time with minimal maneuvering at the landing is 30 minutes, but delays may add significantly to this time, especially for conventional vans, depending on the landing situation. For this analysis, a fixed load-scale-dump time of 1 hour is assumed, hauling from either a chipping yard or a very accessible woods landing.

For a conventional 3-axle chip trailer, a payload of 15.5 ODT is assumed for this analysis. For a walking-floor trailer, a payload of 10 ODT is assumed.

Chip Transportation Cost

Highway-legal truck-and-trailer units, of various types (log truck, chip truck, semitrailer end-dumper) are generally charged in South Central at roughly $125/hour, according to Bell (2011), who stated that the rate is essentially set by the construction industry. However, this engineer is of the opinion that a logging company should be able to own and operate its own trucks for much less than this.

Chip truck rates are quite variable in the Pacific Northwest, apparently depending on the level of competition within each region. Generally, they appear to be charged at 90-120% of the prevailing log truck rate; probably overall, at about the same rate as a log truck. Walking-floor trucks are charged at about the same rate as a log truck.

The collected cost (BY 2009) for log trucks on the Tongass is $76.50/hour. At current fuel costs, this will likely have since increased to $85/hour. It is assumed that $100/hour is a realistic cost for all types of truck-and trailer unit in Southeast, whether hauling logs or chips.

For a conventional 3-axle chip trailer, haul cost is estimated as:

Haul cost, $/ODT = $100*(1+rttt)/15.5

where: rttt = round-trip travel time

For a walking floor trailer, haul cost is estimated as:

Haul cost, $/ODT = $100*(1+rttt)/10

ROUNDWOOD HAULING

HIGHWAY HAUL

Markets exist in South Central for roundwood used as sawlogs, house logs, and firewood.

Roundwood may be purchased by firewood merchants to be cut into stove lengths, split, and delivered. One of these merchants advised that he can obtain dead State wood at zero stumpage. This sets a low floor for the value of green roundwood, which must be seasoned for a couple of years. Firewood logs can be any diameter.

Haus (2011) quoted a legal log truck load at 28 GT. At an assumed 50% mc, this translates to 14 ODT, equivalent to 12.96 cords or 8.96 CCF.

Round trip travel time is estimated at 1 hour of fixed time for load-scale-dump, plus round trip travel time. Haul cost is therefore estimated as:

Haul cost = H * (rttt + 1)/14 $/ODT

= H * (rttt + 1)/12.96 $/cord

= H * (rttt + 1)/8.96 $/CCF

where: H = hourly truck cost, $/hour

The hourly truck cost is assumed to be $100/hour, from the foregoing analysis of chip transportation costs.

OFF-HIGHWAY HAUL

The method most likely to be successful for producing chips for sale would be to haul delimbed stems off-highway to a chipping yard:

Trees would be roughly delimbed by the harvester at the stump area. Merchantable logs or firewood logs could be merchandized out as appropriate. Delimbed trees would be loaded out hot, i.e. concurrently with the skidding operation. They would be hauled by conventional log truck, which would be unloaded at the chipping yard by the chipper loader which would concurrently feed the chipper or else deck the wood.

<u>Productivity</u>

An off-highway load size of 16 ODT is assumed for this analysis; this compares to a highway-legal load of 28 GT or (at 50% mc) 14 ODT. Production is estimated by allowing 1 hour per load for load and dump, and adding the round-trip travel time:

Time per ODT, hours = (1+rttt)/16

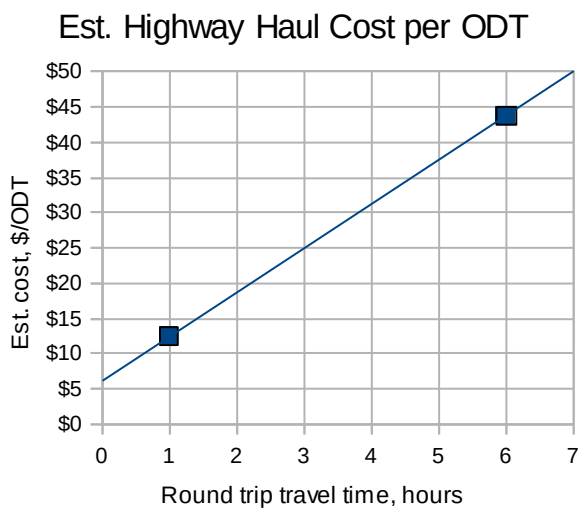
<u>Cost</u>

The hourly rate for a log truck is assumed to be $100. Therefore the off-highway haul cost is estimated as:

Off-highway haul cost = $100*(1+rttt)/16 per/ODT

= $(6.25 + 6.25*rttt) per ODT

as expressed in the graphic below.



BOX TRUCK

System

It is proposed that a processor would buck lengths of about 10-15 feet directly into a box set in a low spot excavated at the landing edge. The box would be retrieved by a truck-and-trailer unit for transportation to an appraisal point.

Productivity

Potential processing productivity is estimated at 120 trees/pmh, based on the Tongass biomass cost model; that is, 120 * ctreevol cu.ft./pmh. Converting at 27 pcf yields a productivity estimate of 1.620*ctreevol ODT/pmh, or, at 60% utilization, 8.55*ctreevol ODT per 8.8-hour day.

However, based on Pacific Northwest experience, productivity is assumed to most commonly be truck-constrained. It is assumed here that a box truck would be economic to operate part-time in South Central, given that it could alternatively be used for municipal waste in the Anchorage area; but that there would never be a surplus of this type of truck.

Loading, assembly, and dumping time for the truck and trailer is estimated to average 1.5 hours. Round trip time is therefore:

RTT = 1.5 + rttt hours

Daily box truck production is therefore: 8.8/(1.5+rttt) loads per 8.8-hour day.

Legal box truck load size in Pacific Northwest experience is 23.5 GT for Douglas fir. Assuming a similar load size for the Chugach, and 50% mc, the payload is estimated at 11.8 ODT.

Daily production is therefore estimated at 11.8* 8.8/(1.5+rttt) = 103.84/(1.5+rttt) ODT.

Cost

The daily rate for a Waratah 622 harvesting head mounted on a Cat 320, or comparable processor, and operator is estimated at $1,234.90.

The daily cost of operating a process, load, and haul side (1 processor, 1 box truck and trailer) is estimated at:

Processor	$1,234.90
Truck	1130.80 per 8.8-hour day (log truck rate * 128.5%)
	$2,365.70

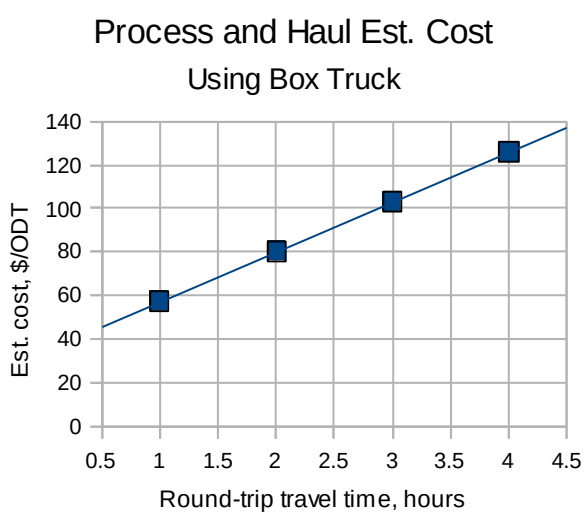
The cost to process, load, and haul is therefore:

Cost = 2,365.70/(11.8*8.8/(1.5+rttt)

= 22.78*(1.5+rttt)

= $34.17+22.78*rttt/ODT

as expressed in the graphic below.



COMMENTARY

It is emphasized that the models presented in this report are necessarily preliminary in nature. To construct truly robust models, it is necessary to conduct formal cost collection to properly compile local cost experience against which to calibrate and modify the analysis.

The models presented herein are incorporated in the accompanying spreadsheet. They may be used to estimate costs of a wide range of biomass treatment and recovery options for any one unit or contract area. This information may be used for appraisal, or to compare the economics of alternative treatments.

To arrive at a total cost per acre, it may be necessary to add the per-acre costs for multiple components. For example, if it is desired to haul stems off-highway to a chipping yard, then to haul chips to an appraisal point, it is necessary to add the following cost components:

- Mechanically cut and skid
- Haul off-highway
- Chip
- Haul chips, conventional truck

Or, if it is desired to hand pile and burn:

- Hand cut and pile
- Burn hand piles

On the other hand, some treatments may be able to be treated in isolation, each of them representing a total per-acre cost, such as:

- Broadcast burn
- Hand cut lop and scatter
- Mulch

An example of the array of treatment options that may be costed is presented in the accompanying calculator, in the "Introduction and Instructions" worksheet. Note that only some of the options that can be costed are presented in that example.

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