California Biopower Impacts Project

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CORRIM Final Report

Submitted in support of
Task 4: RESIDUAL BIOMASS-TO-ENERGY LIFE CYCLE EMISSIONS ACCOUNTING FRAMEWORK.

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CORRIM
Consortium for Research on Renewable Industrial Materials

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The Go-To Place for Wood LCA

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Project Deliverables and Outcomes

CORRIM was commissioned to assist Humboldt State University's Schatz Energy Research Center (hereafter SERC) with the development of an attributional life cycle inventory (LCI) framework for a range of forest biomass-to-energy supply chain and end-use scenarios that were likely to occur in California for a given range of forest residue conditions. Data were drawn from existing sources in order to summarize the likely attributional LCI outputs per bone dry metric ton (BDT) of biomass at the landing or roadside loaded on the truck and ready for transport to a facility. The outputs were categorized across a range of harvest, feedstock handling, and management pathways. These outputs reflect the different types of management inputs and harvest equipment that are most likely to be used for each combination of scenarios. Transportation LCI data were generated by metric ton kilometer (tkm) for a range of hauling options that consider terrain, accessibility, and biomass characteristics. These data will allow SERC to integrate the LCI data into a network analysis and comparative LCA that was developed under separate tasks within the California Biopower Impacts Project.

Analysis of the common forest residue outcomes by forest type was summarized using representative stands generated from the forest inventory spatial analysis. This analysis of 177 representative stands was used to characterize the likely types of equipment by stand type, and the potential for biomass recovery. Based on this analysis, an equipment decision tree was developed to assist SERC in developing an online LCA tool that could incorporate estimates of greenhouse gas emissions from residue recovery systems that would be most appropriate for the conditions and feedstock characteristics of any given site.

Life cycle inventory data for eleven trucking alternatives, 11 roadside recovery equipment alternatives and 12 in-woods recovery equipment choices were developed. Analysis conducted to estimate the efficiency impact of partial harvest operations on in-woods recovery resulted in an additional 39 data points for in-woods recovery. LCI data on incidental emissions associated with biomass recovery, including transport of crew and equipment were also generated. Overall, a total of 77 LCI datasets were developed to quantify emission estimates from forest residue recovery.

Life Cycle Inventory of Biomass Recovery Alternatives

Life cycle assessments that meet ISO standards require four main steps: 1) goal and scope definition; 2) life cycle inventory analysis; 3) life cycle impact assessment and 4) interpretation. For this report only steps 1) and 2) were completed as the life cycle impact assessment and interpretation were included in tasks that are outside the project scope for CORRIM. The goal and scope definition characterizes the process to be followed, including details on the functional and/or reference unit, the boundary condition, excluded processes, data granularity, cutoff rules, impact indicators, characterization factors, and assumptions. No impact indicators or characterization factors are included in this report as an LCA was not conducted. Instead, data were extracted for use in a larger consequential analysis of the greenhouse gas outcome of collecting and using forest residues for biomass as an alternative to burning them in situ or burning them during wildfires.

Reference unit and boundary

In developing the California Residual Biomass-To-Energy Carbon Accounting Tool (CARBCAT), the focus is solely on the greenhouse gas emissions as measured in carbon dioxide equivalent that are directly related to recovery of forest biomass for energy. The functional unit for analysis and reporting of biomass volume and emissions associated with it is a bone dry metric ton (BDT) of residues. The system boundary (Figure 1) was set based on the assumption that the forest residues from commercial harvest would otherwise be considered waste if they were not collected and utilized for energy. Therefore, any activities related to growing, managing and harvesting the commercial trees are excluded from consideration. Likewise, for fire risk reduction treatments, all activities related to thinning, yarding, and piling are excluded from the boundary under the assumption that the primary treatment objective is fire risk reduction. This constrained boundary condition means that recovery begins at the roadside or landing within the treatment unit, unless effort is made to recover dispersed slash or slash piled in the setting (green insert - Figure 1) that would otherwise be left to decay or be burned to reduce fire risk and create plantable spots. For ground-based operations these additional recovery options are included as alternative systems for whole tree operations. For cable-based systems, they are excluded as operationally infeasible for cut to length systems, and unlikely for whole tree systems. These two assumptions regarding treatment and recovery are based on the overall assumption that collecting forest residues is a waste recovery operation since the biomass does not come from a dedicated energy crop. The only condition under which the boundary constraint is expanded is related to salvage harvest of dead and dying trees over regeneration. In such cases there is no onus to collect the materials as waste or reduce fire risk, so the entire burden is allocable to the biomass recovery.

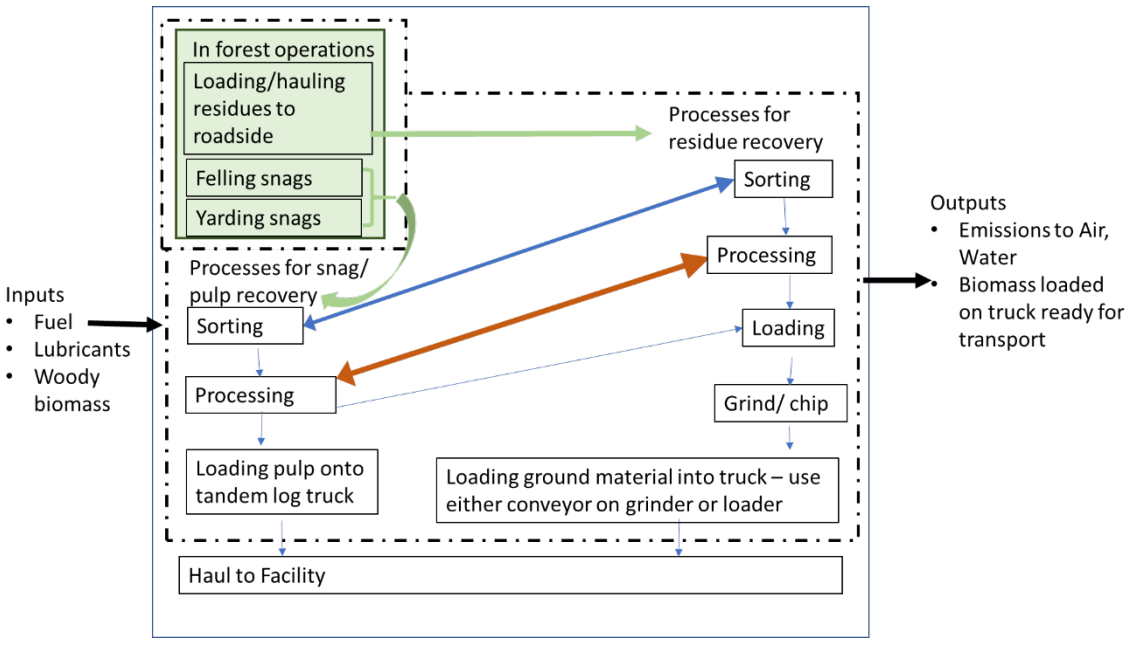

Figure 1: System Boundary for biomass recovery with insert for in-woods recovery

Excluded Processes, Data Quality, Granularity

Emissions associated with equipment manufacturing are excluded from the LCI given the choice to exclude operations upstream of the residue (i.e. no allocation to the forest harvest) which is where the majority of the equipment gets most of its use. Furthermore, there is no clear information on how much of the equipment time would be allocable to biomass recovery from forest residues as that is an industry in its nascent stage, so if it were to be included, the data quality would be highly uncertain. All emission data were developed using SimaPro 8.5.2.0 software (Pre 2018). Input data for the LCI analysis was aggregated from secondary data sources, including CORRIM equipment utilization factors and fuel data generated for Johnson et al 2012, Han et al 2014, and Oneil and Puettmann 2017. Additional data from the published literature was used to supplement these data, including primary data collected for the Humboldt State University Waste to Wisdom project (Bisson and Han 2016, Kizha and Han 2016, Waste to Wisdom 2017). Data used to derive partial harvest emission factors was generated through interpolation of relative efficiency reductions for partial harvests as reported in Handler et al 2014. Data on small scale operations were developed from similar data in Delasaux et al 2009. Efficiency differential data for turbo and naturally aspirated diesel engines were calculated for select equipment using relationships between horsepower and fuel usage from the Barrington Diesel Club (barringtondieselclub.co.za). Fuel usage and associated emissions per BDT are highly variable as they are a function of the interaction between equipment type, size, and operator skill combined with biomass characteristics such as size, moisture content, how much dirt and rocks are in the residues, and other operational constraints. As such, these representative emissions per BDT of material represent point estimates of a wide range of potentials. Uncertainty analysis regarding the range of potential emissions per BDT per system were not completed as part of this project.

Harvest System and Harvest Intensity Alternatives

Life cycle inventory data were aggregated for recovery systems for four harvest system alternatives and four harvest intensity alternatives. The harvest system alternatives are 1) ground-based, whole tree harvest; 2) ground-based, cut to length harvest; 3) cable-based, whole tree harvest; and 4) Cable-based, cut to length harvest. Harvest intensity alternatives include 100% harvest (clearcut); 80% removal, 60% removal, 40% removal and 20% removal where percentages are based on initial stand basal area and operations preferentially remove the smaller diameter trees first. Recovery systems reflect the different equipment types that are most likely to be used for the range of conditions found in the stand inventories consistent with operational feasibility. In practice what this means is that very large efficient machinery combinations are limited to where there is enough biomass to warrant their deployment. Smaller scale machinery is utilized where limited biomass is available. Some combinations of recovery systems and harvest alternatives produce so little biomass that they were excluded from the analysis due to techno-economic constraints.

For whole tree harvesting, residues are collected from the landing/roadside only under the assumption that most residues make it to the landing/roadside as part of the primary harvest

activity. No in-woods recovery is modeled. For cut-to-length harvesting, life cycle inventory data are provided for an alternative where additional residues may be collected from the field for ground-based systems. Additional recovery of residues for cable-based systems was deemed operationally infeasible.

Operations at the roadside or landing include processing, grinding or chipping, and loading. Different biomass types can have different pathways for densification based on piece size and quality. Alternatives were provided for integration into CARBCAT. Regardless of harvest system or harvest intensity alternatives, roadside operations will have a similar carbon footprint per BDT under the assumption that equipment will not come on site unless it can be fully utilized. As such equipment with very high throughput (e.g. 30-40 BDT per hour processing speed), will only come onsite, if there is a sufficiently large supply of biomass to process.

Forest Stand Condition Analysis

Forest stand characteristics drive equipment choice and efficiency; therefore, it was necessary to analyze 'binned' forestry representative stand data to assign equipment and generate representative LCI data by silvicultural operation. Stands across California were analyzed (Comnick and Rogers, 2018) and binned into 177 categories that reflect differences in stand characteristics using the following 3 step protocol. First, all GNN stands were classified into species groups by basal area. Stands with greater than 80% basal area in a single species were classified by that species (i.e. "DF" for Douglas fir). Stands with less than 80% were classified as mixed (prepended with an "M"), followed by the species with the majority or plurality of basal area, followed by other species with at least 20% basal area in descending order (i.e. "MDF" for mixed Douglas fir with minor species, "MDFBO" for mixed Douglas fir with a significant black oak component (> 20% by basal area)). All species groups that made up at least 1% of forest area in California were identified. The remaining species groups were generalized by first keeping the majority/plurality species but lumping minor species into hardwoods or softwoods (i.e. "MDFOS" for mixed Douglas fir with other softwoods or "MDFOH" for mixed Douglas fir with other hardwoods). Finally, species groups that still didn't make up at least 1% of forest area were further generalized into "MOSOH" (mixed other softwoods with other hardwoods) or "MOHOS" (mixed other hardwoods with other softwoods). Second, for each species group, k-means clustering was used to group stands with similar structural attributes. Centering and scaling were used to normalize TPA, QMD, stand height, snag tons per acre, and downed woody debris tons per acre. "Elbow" plots of within groups sums-of-squares were produced using 1 to 15 clusters, and the "optimal" number of clusters was identified for each species group. Third, for each species-structure group, a representative stand was identified. This was the stand with the minimum Euclidean distance from the mean values in normalized space. A total of 177 groups/ representative stands were identified.

Figure 2 shows three stand metrics of import in making equipment choices: density in trees per acre (TPA); pre-harvest volume in board feet per acre (bf/ac): and the total stand basal area per acre (BA) for each of the 177 representative stands. Stand metrics show that these representative stands range from newly regenerated forests with no recoverable biomass (bottom left of chart) to extremely high volume stands (>50 MMBF/acre) that include massive specimens (>40" dbh) (diameter at breast) which likely means they would be considered old growth forests

in the region. These stand metrics along with data on residues remaining at the roadside/landing and in the woods were used to assess the types of equipment that could be utilized for the volume that remains on site after harvest entries. A single stand had no standing live or dead trees but did have down dead wood (DWD) in the inventory. It was included in the analysis for potential residue recovery without treatment under the assumption that the inventory reflects an immediate past harvest. All remaining representative stands had standing inventory with metrics as displayed in Figure 2.

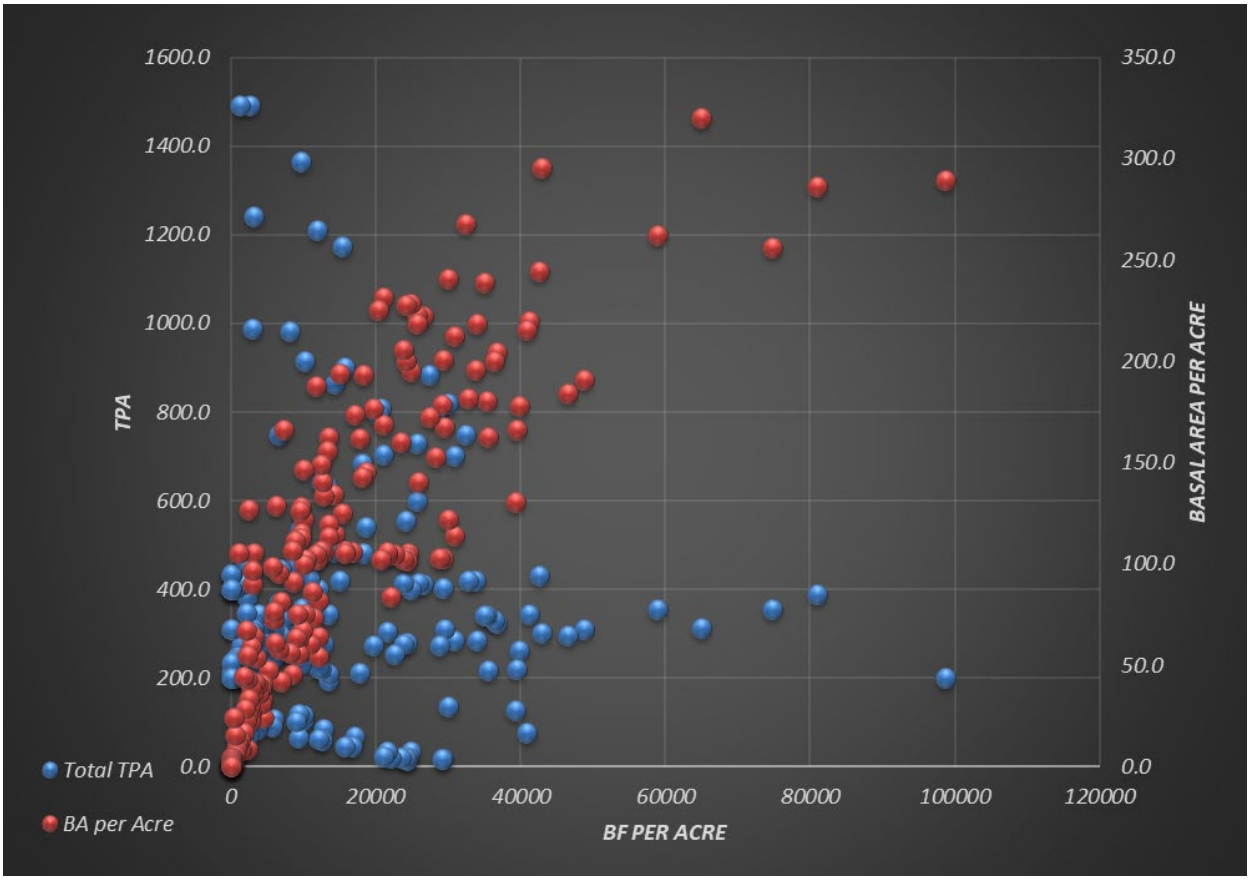

Figure 2: Stand Metrics for 177 Representative Stands

The 177 representative stands were organized into 5 major treatment options based on stand characteristics, with sub-categories based on characteristics that drive operational efficiencies. Spatial analysis to assess the number of acres represented by each treatment type generated the values shown in Table 1. Detailed summaries of the stand characteristics are provided in Appendix 1.

Treatment Option	Treatment Sub-Category	# Representative Stands	Estimated Acres	Percent of Area
Post-harvest recovery	biomass recovery opportunity	1	1,169,106	3.1%
Commercial Operation	commercial harvest	45	9,366,230	25.1%
	commercial harvest - low volume	21	4,921,251	13.2%
	commercial harvest plus Fire Risk Reduction	20	3,457,761	9.3%
	commercial harvest plus salvage	2	74,124	0.2%
Do Not Treat	do not treat - old growth	5	159,293	0.4%
	do not treat - pre-commercial	22	6,816,724	18.3%
	do not treat - pre-commercial - low density	5	3,635,982	9.7%
	do not treat - regen under small diameter snags	2	205,427	0.6%
	do not treat - regeneration	28	5,122,998	13.7%
Fire Risk Reduction Only	Fire Risk Reduction	4	538,228	1.4%
Salvage	salvage - regen under snags	14	1,639,522	4.4%
	salvage - regen under snags - low density	5	224,029	0.6%
	salvage - snags plus PCT	3	19,038	0.1%
Grand Total		177	37,349,714	100%

Table 1: Stand Category and Treatment Acres

Stands without opportunity for biomass recovery

The analysis boundary assumed that collecting forest residues is a waste recovery operation since the biomass does not come from a dedicated energy crop. That waste would only be generated during a commercial harvest operation, a stand management activity, or a fire risk reduction treatment. Given these assumptions on the system boundary, 62 of the 177 representative stands were deemed to have no opportunity for biomass recovery within the analysis timeframe. The

rationale for excluding these 62 representative stand types varies depending on stand characteristics identified in the sub-categories of Table 1 as follows.

Five of 177 representative stands with volume greater than 50,000 bf/ac and more than 250 square feet per acre of basal area were classified as likely old growth forests (right hand side of Figure 1). They are excluded from biomass recovery as they are likely excluded from harvest operations. On the opposite end of the spectrum, 30 of 177 stands with less than 30 square feet of basal area and a quadratic mean diameter (QMD) less than 5 inches were classified as regenerating stands which would not have a harvest entry for at least 35 - 50 years (bottom left panel of Figure 1). Another 22 representative stands had adequate stocking and a QMD between 5-10 inches, representing those immature stands that are the future harvestable inventory in 15-35 years. A further 5 representative stands were considered both pre-commercial and not sufficiently restocked (NSR) with a mean inventory of less than 60 square feet of basal area and less than 120 trees per acre; they would benefit from activities to increase stocking, which are unlikely to result in recoverable biomass residues. As the representative stand metrics were derived based on stand structural attributes and not total area covered by each representative stand, the overall impact on biomass availability is dependent on where the stands that are represented by these average values and treatment opportunities occur across the landscape.

Fire Risk Reduction Treatments

While any stand can have fire risk reduction activities to reduce stocking and raise the height to live crown, for operational efficiency stands that are more likely to have a marked benefit from fuels reduction activities were called out for fire risk reduction treatments. Of our 177 representative stands, four meet criteria for fire risk reduction without options for commercial harvest in that they contain high stand densities (> 900 TPA to upwards of 1500 TPA), low average diameter (3-6”), and low heights. An additional 20 representative stands have enough volume to warrant a commercial entry and would benefit from simultaneous fire risk reduction treatments due to high stocking density. If fire risk reduction activities were conducted as part of a harvest operation, the boundary condition would exclude activities that occurred on the treated area except for recovery of otherwise distributed slash

Salvage

Twenty-two representative stands had more than 50% of their standing basal area as hard snags. Of these stands, only 1 of them had any appreciable green tree volume; most were characterized by a sea of snags over very small regeneration (less than 5 years old). Salvage operations under the conditions characterized by these data (i.e. having no green volume) would be non-commercial. Under such conditions it is necessary to expand the boundary to include emissions related to the entire harvesting process as the assumption that the activity would have occurred anyway no longer has merit. The option to salvage would impact the regenerating forest to a greater or lesser degree so equipment options were chosen to minimize this impact. For recovery of small diameter snags (5-7" diameter) and for small scale operations on relatively flat terrain, a modified skid steer equipment that can be hauled using a heavy-duty pick-up was modeled based on productivity and fuel usage as provided in Delasaux et al (2009). This alternative would be

suitable around homes with small diameter trees only. The option to forgo harvest, especially where snag density is low, is also a reasonable alternative pathway.

Harvestable Stands

The remaining 68 representative stands contain enough green volume and a large enough piece size, to warrant commercial entries. In cases where there are also a large number of snags, they would be recovered along with merchantable green volume consistent with the boundary conditions used in our primary assumptions. Limitations to operations on these stands will be driven primarily by harvest system and harvest intensity alternatives.

Equipment Emission Profiles

All emissions were generated using SimaPro version 8.5.2.0 (Pre Consultants 2018) and include upstream emissions associated with fuels, lubricants, and transport, but do not include emissions associated with equipment manufacturing as that is outside the LCI boundary. Fuel and lubricant use on a per BDT biomass basis are calculated and emissions associated with their manufacturing and use are included in the LCI emissions data. Upstream emissions of consumables (fuel, lubricants) are based on national averages for what it takes to produce diesel as far back as its recovery at the well through refining, what it takes to transport that diesel to its point of eventual use (US average data) and emissions associated with combustion.

Emission profiles were generated for a wide range of biomass recovery and harvest equipment based on efficiency and utilization data for commercial operations (Johnson et al 2012, Han et al 2014, Bisson and Han 2016, Kizha and Han 2016, Waste to Wisdom 2017). Most of those operations involved high volume stands and nearly 100% removal of all merchantable stems. As such these data represent the most efficient harvest systems and harvest intensities for the region with concomitant lower emissions per BDT of biomass produced. Table 2 shows modeled biomass recovery equipment used at the roadside or landing for comminution and loading. Table 3 shows modeled biomass recovery equipment used at the roadside or landing for comminution and loading.

Operations that require retention of standing trees and/or treatment of lower volume stands will always be less efficient as the distance and time travelled per piece of material is higher and therefore energy usage is higher. Data were developed from Handler et al 2014 to scale the 100% removal data for partial harvest entries. Linearities observed in recovery productivity based on thinning percent (30%, 70%, 100%) from Handler et al 2014 were used to predict productivity and hence fuel usage for 20, 40, 60, and 80% removal treatments. These productivity assumptions do not negate the fact that there are highly variable production rates in almost all aspects of biomass recovery due to variability in site (slope, terrain uniformity etc.) and stand (diameter, stem distribution, etc.) conditions.

For operations at the landing or roadside, including chipping, grinding, loading and processing, operational efficiency can be maximized by aggregating material prior to bringing in equipment. Traditionally this is done during harvest activities, with biomass recovery occurring either immediately after harvest or after some period of drying. One assumption used for equipment

use at the roadside or landing is that if there is enough material to warrant bringing in the equipment for a minimum of 3 days of processing, then efficiency during operations is the same regardless of harvest intensity. This 3-day minimum is approximately equal to 1000 BDT of material based on equipment operating efficiencies from 30-40 BDT/machine hour. This efficiency assumption should hold true for actual operating time, but additional utilization constraints are required to account for either having to move aggregated piles, or move the equipment, or both, on sites with limited biomass supply.

Reduced efficiency estimates are incorporated to account for the loading operations at roadside and landing when volumes per acre are constrained by available biomass. Stand characteristics will preclude or suggest specific equipment types for the main harvest operation. Those choices will then drive the outcome of residue recovery. For example, seven of the merchantable representative stands had an average diameter larger than 29 inches which is essentially the upper limit for mechanized harvests using a feller-buncher (FB), thus hand falling was the only alternative for harvest operations in these representative stands. The weight limits on moving these large trees would result in falling and bucking operations occurring in the woods, with no recovery of tops and limbs thus constraining recovery. At the opposite end of the size spectrum cut to length (CTL) systems are often used for thinning operations in smaller diameter stands as the harvesting and processing steps can occur at once leaving logs that are shorter thus causing less damage as they are hauled from the woods. Using these systems constrains biomass recovery as well as the limbs are felled and used to support the machine thus reducing ground disturbance and root impacts on residual trees. Recovering tops and limbs in this instance would be very challenging and result in a very dirty product.

Equipment Code	Equipment Type	Equipment Model/HP	Scale
S.1	sawdust machine	Beaver Korea Sawdust Machine (400 HP)	high volume
S.2	sawdust machine	Morbark Beever M20R (400 HP)	high volume
B.1	large wood baler	Forest Concepts	small scale
B.2	small wood baler	Forest Concepts	small scale
C.1	Chipper	Large Morbark Chipper (875 HP)	high volume
C.2	Chipper	Peterson Micro-Chipper model 4300 (765 HP)	high volume
G.1	Grinder	Small Grinder- Peterson Pacific Horizontal Grinder (475 HP)	high volume
G.2	Grinder	Large Grinder- Peterson Pacific Horizontal Grinder (1050 HP)	high volume
L.1	Loader	feeding grinder or chipper (250HP)	high volume
L.2	Loader	for loading pulp logs	high volume
L.3	Loader	for sorting logs and pulp at landing	high volume
T.2	In Woods Truck	AWD modified Dump Truck to staging site	high volume

Table 2: Roadside Biomass Recovery Equipment.

Equipment Code	Equipment Type	Equipment Model/HP/Comments	Scale
T.1	In Woods Truck	AWD modified Dump Truck in Unit High utilization	high vol
T.3	Forwarder	Self-loading small diameter log recovery 10 ton	small scale
T.4	Forwarder	Self-loading small diameter log recovery 12 ton	small scale
SS.1	Skid Steer	120 HP diesel model for fuel reduction and mastication	small scale
SS.2	Skid Steer	120 HP turbo diesel model for fuel reduction and mastication	small scale
P.1	Processor in Unit	no sorting	high vol
Y.1	Shovel Yarder	no sorting	high vol
L.3	Loader in unit	Loading in-woods dump truck	high vol
CY.1	cable yarding	cable yarding of residues, large skyline, clearcut	high vol
CY.2	cable yarding	cable yarding of residues, large skyline, thinning 80%	high vol
CY.3	cable yarding	cable yarding of residues, medium skyline, thinning	high vol
CS.1	Chainsaw	average productivity	small scale

Table 3: In-woods Biomass Recovery Equipment.

Fixed vs Variable Emission Profiles

LCI data for each piece of equipment reflect emission profiles from operations on a per dry ton of biomass basis assuming a range of equipment utilization factors (usually 75-95% efficiency). These emissions are analogous to the variable costs in an economic model. There are also LCI emissions associated with getting the equipment to the site, and to travel between sites. The transportation emissions are independent of the tons of biomass produced at a given site, and therefore are analogous to fixed costs in an economic model. Each piece of equipment has a productivity rating based on manufacturing specifications and/or utilization studies and that rating was used to define the minimum amount of biomass that would need to be available to move a given piece of equipment to a site. For example, a Peterson Pacific Horizontal Grinder (1050 HP) can process 38 BDT of wood residues per machine hour. Effectively this means that in a 10-hour work day, the machine with process 380 BDT of material. The assumption we used for fixed emissions in this analysis is that equipment would be moved to a site if there were a

minimum of 3 days' worth of biomass for it to process, so in our example above the fixed emissions would be allocated over a minimum of 1140 BDT or larger. The total fixed emissions attributable to moving to and from the site would be added to variable emissions per BDT of biomass. Thus, for sites with a low density of material, or few acres, there is a fixed emission cost that is higher per BDT of biomass than for larger areas with more available biomass. If there are too few residues on site to utilize that machine for at least 3 days, then it would not be used.

Transportation LCI Data

Biomass characteristics including density and moisture content as generated from the Waste to Wisdom project (SERC 2016), combined with average wood properties for dominant California species (Briggs 1994), were used to estimate the volume and weight characteristics of ground biomass across a range of moisture contents. These data were then used to assess the range of conditions under which trucks hauling biomass would be expected to be weight limited or volume limited. The trucking analysis was developed using standard LCI methodologies for hauling freight that include a reference unit of tkm (tonne-kilometer). The emissions per tkm represent the emissions associated with each metric ton of material moved (converted to bone dry mass) per km of travel. Moisture included in the wood reduces the amount of bone-dry mass carried. All hauling from the in-woods location to the facilities assumes a 5.1 mpg average fuel use consistent with log trucking survey data (Mason et al 2008) for the PNW region. Using this methodology allows the CARBCAT user to input distance to facility, trucking option, and biomass characteristics (moisture content and densification if any) to determine the life cycle inventory emissions associated with moving 1 BDT of biomass. Conversions from green moisture content to BDT are included in the calculations.

There are two limits associated with moving biomass to market. The less common alternative for moving low density biomass is weight limited hauling where the truck reaches its maximum allowable weight as permitted on the roads in California. More commonly, particularly during the drier season, trucks are volume limited, unless they put very large sideboards above the main truck box to extend their available hauling space. Eleven total hauling alternatives were developed based on combinations of weight or volume limits, whether logs or chipped/ground material was hauled, moisture content, site conditions, and trucking configuration Table 4.

Limit	Material	Explanation of Alternatives
weight	Pulp logs hauled whole	two alternatives: pulp hauling assumes average 57,183 lb. payload for mule train weighted avg 5, 6, 7 axles hauling 12.99 OD metric tonnes (50% mc on green basis) or 9.62 ODT (63% MC on green basis); both weight limited (i.e. max weight is reached before max volume is reached)
weight	Chipped material, flat with easy access	chip hauling for chip van. Assume weight limited at 63% MC
weight	Chipped – steep terrain	two alternatives: chip hauling for truck only used (end) dump trucks with hoist weight limited at 30,000 lb. payload at 50% MC wet basis (equal to 6.81 OD metric Tonnes) and at 63% MC (wet basis) equal to 5.05 OD metric tonnes
weight	Chipped – flat terrain	two alternatives: chip hauling for truck plus trailer used (end) dump trucks with hoist weight limited at 30,000 lb. payload plus trailer with 32,000 lb. payload for total ODT payload of 6.81 ODT plus 7.27 ODT at 50% MC (wet basis) and 5.05 ODT plus 5.38 ODT at 63% MC (wet basis).
volume	Chipped – steep terrain	three alternatives: chip hauling for truck only used (end) dump trucks with hoist weight limited at 30,000 lb. payload but added height (sides on box) in order to haul 17 yd (4.13 ODT), 20 yd (4.86 ODT), and 25 yds (6.08 ODT) of material (does not exceed weight max).
volume	Chipped – flat terrain	chip hauling for truck plus trailer used (end) dump trucks with hoist weight limited at 30,000 lb. payload plus trailer with 32,000 lb. payload with sides added to attain 25 yd in truck and trailer both. Total of 6.08 + 6.08 ODT

Table 4 Trucking Configurations by limit, type, terrain, moisture content, and payload.

Each trucking configuration has a maximum payload and maximum volume limit. The moisture content of the wood is the primary factor determining weight or volume limits with the split occurring between 50 and 63% moisture content (wet basis). In practical terms, unless the material is removed at the same time as the primary harvest activity, it will almost always result in a volume limit on the trucking configuration.

References

Barrington Diesel Club, 2016, https://barringtondieselclub.co.za/technical/fuel-consumption.html, accessed February 7, 2019

Berry, M., and J. Sessions. 2017. A forest-to-product biomass supply chain in the Pacific Northwest, USA: A multi-product approach. Applied Engineering in Agriculture. ASABE special collection publication. In review.

Bisson, J. A., & Han, H.-S. 2016. Quality of feedstock produced from sorted forest residues. *American Journal of Biomass and Bioenergy*, *5*(2), 81-97.

Briggs, D.G. 1994. Forest products measurements and conversion factors: With special emphasis on the US Pacific Northwest. College of Forest Resources, University of Washington Seattle, WA.

Comnick, J. and L.W. Rogers. 2018. Methods to Develop the Forestland Database for the California Biopower Impacts Project, Report from the Natural Resources Spatial Informatics Group, Precision Forestry Cooperative, University of Washington, 17 pp.

Delasaux, M.J., et al. 2009. "Small Parcel Fuel Reduction with a Low-Investment, High-Mobility Operation." Western Journal of Applied Forestry 24(4): 205-213.

Han, Han-Sup, Elaine Oneil, Richard Bergman, Leonard Johnson, Ivan Eastin, 2014, Cradle-to-Gate Life Cycle Impacts of Redwood Forest Resource Harvesting in Northern California, Journal of Cleaner Production, 99:217-229.

Handler, R. M., et al. 2014. Environmental impacts of roundwood supply chain options in Michigan: life-cycle assessment of harvest and transport stages. Journal of Cleaner Production 76: 64-73.

Johnson, L., Bruce Lippke, and Elaine Oneil, 2012. Modeling Biomass Collection and Woods Processing Life-Cycle Analysis. Forest Products Journal 62(4): 258-272.

Kizha A. and H.-S. Han. 2016. Processing and sorting forest residues: Cost, productivity and managerial impacts. *Biomass & Bioenergy*. 93:97-106.

Mason, C. Larry, Kenneth L. Casavant, Bruce R. Lippke, Diem K. Nguyen, and Eric Jessup, 2008, The Washington Log Trucking Industry: Costs and Safety Analysis, Report to the Washington State Legislature by The Rural Technology Initiative University of Washington and The Transportation Research Group Washington State University, 111 pp.

Oneil, E. and M. E. Puettmann. 2017. A Life-Cycle Assessment of Forest Resources of the Pacific Northwest, USA. Forest Products Journal 67(5-6): 316-330.

Pre Consultants. 2018. SimaPro 8.2.5.0 Life-cycle assessment software package.

Schatz Energy Research Center (SERC). (2016). Biochar Testing and Results Report Waste to Wisdom: Task 3 (pp. 1–71).

Waste to Wisdom. 2017. Machine Rate Calculations for Selected Pieces of Sorting and Comminution Equipment: Task 2.

Appendix 1

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
102141281	-	0	0	-	0	0	0	0	0	0	0	151	77	75	23	biomass recovery opportunity
363591313	48,778	9.3	40	357	190.9	93%	116.0	13.7	69	19.2	204.7	292	356	51	50	commercial harvest
409342613	46,529	5.7	25	310	184.0	72%	194.7	71.8	77	22.1	255.8	550	363	81	50	commercial harvest
520272697	42,962	19.9	74	295	295.9	85%	55.0	51.7	80	22.2	347.6	591	79	180	23	commercial harvest
436682601	42,606	11.6	39	302	244.5	58%	179.2	175.4	68	22.9	419.8	326	267	57	46	commercial harvest
356472573	41,128	20.0	76	433	219.9	59%	130.4	155.6	78	22.1	375.5	628	384	205	112	commercial harvest
373150005	40,846	16.9	76	344	215.8	91%	22.7	21.8	73	19.1	237.6	284	146	251	102	commercial harvest
580140001	39,839	26.6	94	77	177.9	99%	1.1	1.1	80	23.1	179.0	218	136	231	132	commercial harvest
485702697	39,436	22.4	94	263	166.7	62%	51.6	103.7	97	24.9	270.4	469	75	152	22	commercial harvest
521982565	36,676	23.1	88	127	204.7	86%	22.0	33.3	80	23.1	238.0	602	314	209	92	commercial harvest
514852609	36,267	5.4	21	325	200.5	89%	117.3	25.6	71	22.3	226.1	284	282	47	42	commercial harvest
481112617	35,509	4.4	21	331	162.5	58%	441.9	116.1	78	21.2	278.6	588	290	90	51	commercial harvest
508390005	35,359	22.9	83	217	180.4	87%	23.4	26.2	78	23.2	206.6	266	144	332	172	commercial harvest
483860005	34,954	17.1	70	342	239.2	91%	25.1	24.2	65	18.9	263.4	340	159	386	199	commercial harvest
378232569	34,004	16.5	66	343	218.9	72%	127.0	84.8	70	21.1	303.7	568	212	154	42	commercial harvest
541820005	33,828	18.3	71	285	196.1	88%	24.3	28.0	77	22.0	224.1	275	157	252	113	commercial harvest
489362569	32,705	17.0	55	419	181.6	69%	55.7	81.3	77	25.1	262.9	655	410	232	121	commercial harvest

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
610542589	32,415	9.3	36	419	267.7	60%	180.6	182.0	66	23.3	449.7	351	330	61	57	commercial harvest
610192693	30,803	18.3	71	285	212.5	89%	21.8	27.5	84	22.5	240.0	450	65	151	18	commercial harvest
506461921	29,491	21.1	82	135	167.9	95%	15.7	9.7	80	22.1	177.6	366	206	236	57	commercial harvest
486152573	29,291	19.8	68	310	200.6	67%	117.2	100.8	72	23.0	301.3	453	194	156	57	commercial harvest
468391473	29,242	32.4	123	19	103.1	100%	0.1	0.2	112	27.3	103.3	740	45	254	12	commercial harvest
346480005	29,098	19.0	72	404	178.8	90%	26.1	19.0	74	22.0	197.8	269	171	297	190	commercial harvest
449901473	28,700	33.9	131	17	103.2	100%	0.1	0.3	115	29.0	103.5	658	49	228	13	commercial harvest
612800017	28,314	8.3	32	274	153.0	85%	21.2	27.1	62	19.6	180.0	123	427	65	182	commercial harvest
370080017	25,788	4.4	20	413	140.5	71%	210.9	57.6	59	16.2	198.1	390	879	173	325	commercial harvest
331151281	25,748	12.1	54	414	222.8	96%	29.8	8.2	44	11.9	230.9	773	222	190	59	commercial harvest
350251285	24,864	12.3	61	600	228.7	93%	39.8	17.1	69	17.0	245.7	487	268	170	78	commercial harvest
468291285	24,745	12.2	74	399	195.1	91%	44.2	18.3	72	13.5	213.4	405	231	160	67	commercial harvest
567592788	24,380	27.7	108	34	105.5	99%	0.3	0.7	100	31.9	106.2	528	124	160	24	commercial harvest
499692753	24,334	31.4	109	20	103.7	99%	0.2	0.9	94	27.5	104.6	556	48	195	14	commercial harvest
325430193	24,214	34.2	131	16	101.9	100%	0.1	0.3	102	27.3	102.3	427	32	397	24	commercial harvest
508112693	24,062	16.1	69	281	200.0	92%	22.5	18.3	71	18.2	218.2	408	67	134	20	commercial harvest
596582565	24,061	17.8	55	554	228.2	92%	38.5	18.6	61	20.4	246.9	795	395	250	117	commercial harvest
518130212	23,853	31.3	126	20	102.6	99%	0.2	0.8	107	31.3	103.4	400	58	309	21	commercial harvest
498172569	23,714	17.4	63	278	206.0	81%	59.0	48.1	63	22.1	254.1	414	120	129	35	commercial harvest

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
329491329	23,403	6.5	33	414	160.2	89%	112.1	19.3	65	16.4	179.5	429	357	61	48	commercial harvest
529092788	22,588	30.6	107	19	104.7	99%	0.3	0.9	89	27.7	105.7	512	80	157	16	commercial harvest
465752788	21,453	31.8	109	20	104.1	99%	0.3	1.0	89	29.3	105.1	474	60	143	12	commercial harvest
351182753	21,444	26.5	95	34	106.2	100%	0.2	0.5	89	23.4	106.7	551	71	181	21	commercial harvest
465052565	21,064	15.0	63	304	168.6	89%	24.8	20.7	65	16.5	189.3	454	201	156	59	commercial harvest
509160193	20,745	28.6	109	24	102.5	99%	0.3	1.0	84	24.4	103.5	382	31	433	32	commercial harvest
486732617	18,521	9.0	33	275	145.5	52%	179.0	136.1	59	19.9	281.6	219	354	40	60	commercial harvest
382691313	18,323	4.1	26	542	193.4	86%	214.1	30.9	53	11.4	224.3	816	1115	112	131	commercial harvest
517321313	18,073	4.4	21	483	143.1	82%	144.1	31.3	70	21.5	174.4	577	726	76	79	commercial harvest
480472565	17,047	17.0	58	211	173.9	89%	25.3	20.4	59	18.8	194.3	337	55	111	16	commercial harvest
517321473	16,665	20.1	79	67	106.1	100%	0.2	0.2	82	24.0	106.3	554	26	183	7	commercial harvest - low volume
465742772	15,754	20.8	79	47	106.8	99%	0.5	1.0	71	20.6	107.9	416	106	123	19	commercial harvest - low volume
548542753	15,647	24.5	82	45	105.7	100%	0.3	0.4	77	25.9	106.2	385	36	129	11	commercial harvest - low volume
148391297	14,318	5.8	26	421	114.8	78%	139.9	33.0	62	17.5	147.8	613	713	78	74	commercial harvest - low volume
328631285	13,493	9.0	45	486	162.8	94%	45.9	11.3	51	14.4	174.1	386	112	131	32	commercial harvest - low volume
451671285	13,422	12.7	55	194	119.8	90%	21.0	12.7	60	14.1	132.5	490	130	142	38	commercial harvest - low volume
596150049	13,385	2.9	10	345	113.4	86%	48.4	19.1	35	12.0	132.5	193	190	81	58	commercial harvest - low volume
491551925	13,205	13.3	56	209	156.2	89%	26.7	18.8	65	18.8	175.1	322	142	250	64	commercial harvest - low volume
179411473	12,679	16.1	76	87	106.1	100%	0.0	0.0	85	18.3	106.1	957	64	309	18	commercial harvest - low volume

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
579951285	12,649	10.8	53	277	140.4	93%	24.2	10.8	50	17.6	151.2	421	190	135	55	commercial harvest - low volume
500282788	12,455	19.2	73	60	106.8	99%	0.5	0.7	66	20.8	107.5	416	104	126	22	commercial harvest - low volume
440410049	12,089	5.4	17	220	64.5	73%	110.2	24.2	43	16.9	88.6	89	157	60	92	commercial harvest - low volume
505910001	12,060	19.2	45	64	81.9	99%	1.1	0.9	46	20.6	82.7	59	10	89	10	commercial harvest - low volume
594722593	11,982	4.3	19	223	54.2	87%	12.2	8.1	79	26.5	62.3	77	179	16	28	commercial harvest - low volume
350482581	11,879	3.1	13	400	102.6	67%	191.0	51.4	57	19.0	153.9	763	464	103	57	commercial harvest - low volume
509581969	11,655	6.6	24	246	104.6	80%	149.2	25.7	59	22.5	130.3	180	231	97	65	commercial harvest - low volume
105631297	11,318	4.0	17	370	73.5	88%	190.8	9.7	51	15.6	83.2	188	185	39	33	commercial harvest - low volume
358841313	11,260	2.7	17	464	86.3	86%	105.4	13.9	61	15.4	100.3	374	343	60	51	commercial harvest - low volume
373840242	10,818	3.4	14	274	60.3	84%	26.2	11.6	74	22.5	71.9	98	123	36	42	commercial harvest - low volume
490392593	10,282	4.9	22	424	102.7	87%	182.2	15.7	44	13.2	118.4	266	273	51	58	commercial harvest - low volume
523152593	10,230	3.0	10	264	75.2	87%	31.8	11.7	57	23.3	86.9	110	227	26	34	commercial harvest - low volume
507932676	30,854	2.9	13	748	113.9	93%	108.2	8.3	61	18.9	122.3	391	277	107	65	commercial harvest plus Fire Risk Reduction
598660116	29,946	3.3	14	702	122.3	93%	126.5	8.6	66	21.5	130.9	360	220	276	173	commercial harvest plus Fire Risk Reduction
481760005	29,914	10.8	44	821	241.2	94%	65.0	15.2	60	16.4	256.3	435	185	424	216	commercial harvest plus Fire Risk Reduction
367690116	27,336	2.6	15	793	172.3	92%	27.5	14.7	63	16.7	187.0	229	374	139	218	commercial harvest plus Fire Risk Reduction

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
507110005	26,500	10.5	46	885	222.3	94%	47.1	14.6	60	15.5	237.0	333	177	349	175	commercial harvest plus Fire Risk Reduction
581052569	25,704	15.0	54	730	218.6	88%	87.0	30.3	69	22.4	248.9	494	317	180	93	commercial harvest plus Fire Risk Reduction
407330005	20,986	10.0	50	706	231.9	94%	40.7	14.7	55	12.2	246.7	381	175	416	222	commercial harvest plus Fire Risk Reduction
369390009	20,399	10.2	46	807	225.5	91%	78.0	22.7	52	13.2	248.3	326	185	349	178	commercial harvest plus Fire Risk Reduction
599740005	19,607	9.6	56	794	177.0	91%	29.0	16.7	54	10.6	193.7	281	164	287	136	commercial harvest plus Fire Risk Reduction
350600005	17,742	9.0	47	684	162.2	93%	26.2	12.9	49	11.4	175.1	233	112	241	109	commercial harvest plus Fire Risk Reduction
384671396	15,284	2.1	14	900	125.3	94%	50.6	7.9	60	17.3	133.3	527	259	122	57	commercial harvest plus Fire Risk Reduction
371241281	15,022	7.9	51	1,174	194.2	98%	81.6	4.0	45	8.1	198.2	464	257	164	75	commercial harvest plus Fire Risk Reduction
432650065	14,192	3.1	18	865	134.6	99%	6.2	1.1	37	7.8	135.7	179	146	257	183	commercial harvest plus Fire Risk Reduction
584261297	12,699	4.0	21	630	133.6	83%	342.7	27.3	49	11.2	160.9	868	617	124	84	commercial harvest plus Fire Risk Reduction
483580009	12,376	7.7	41	643	149.3	88%	56.1	20.6	53	10.4	169.9	271	189	266	163	commercial harvest plus Fire Risk Reduction
538931281	11,753	8.2	47	1,210	187.7	98%	77.6	4.3	46	10.5	192.0	473	293	164	86	commercial harvest plus Fire Risk Reduction

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
434240005	9,973	9.3	44	915	147.0	95%	30.5	7.0	49	14.1	154.0	261	171	275	162	commercial harvest plus Fire Risk Reduction
370060005	9,652	6.8	31	1,365	128.1	95%	40.1	6.5	39	10.3	134.6	132	69	173	87	commercial harvest plus Fire Risk Reduction
392601281	7,256	7.9	45	983	166.7	98%	45.3	3.2	42	7.4	169.9	454	193	162	57	commercial harvest plus Fire Risk Reduction
502692565	6,165	6.0	31	748	128.7	95%	47.9	7.2	47	10.4	135.9	320	94	119	27	commercial harvest plus Fire Risk Reduction
487980049	39,260	10.3	44	219	130.5	48%	151.3	140.4	88	23.3	270.9	334	343	123	148	commercial harvest plus salvage
523292609	22,112	7.6	33	253	84.1	40%	193.2	125.3	70	20.8	209.4	366	568	51	67	commercial harvest plus salvage
595442561	98,630	41.0	137	37	289.5	99%	0.8	3.5	86	24.6	293.0	452	237	176	69	do not treat - old growth
500400009	80,936	32.6	105	201	286.6	63%	53.4	167.9	99	30.5	454.5	286	165	336	182	do not treat - old growth
148641297	74,753	9.9	40	389	256.2	85%	117.1	44.6	77	22.5	300.8	611	548	89	73	do not treat - old growth
502182589	64,953	11.2	47	355	320.1	51%	189.0	307.3	80	21.6	627.4	488	451	82	78	do not treat - old growth
539602585	58,823	12.0	46	312	262.6	61%	89.6	165.4	93	28.9	428.0	250	239	56	56	do not treat - old growth
562981925	9,920	13.6	50	106	99.9	83%	23.6	20.5	55	16.1	120.4	145	271	152	108	do not treat - pre-commercial
505952569	9,914	18.6	44	117	122.2	66%	51.2	62.4	42	19.6	184.6	195	3	33	0	do not treat - pre-commercial
595221285	9,616	11.4	46	232	112.9	89%	23.2	14.5	46	18.5	127.4	285	71	101	20	do not treat - pre-commercial
375262565	9,456	9.3	35	258	126.1	91%	31.0	12.5	47	13.4	138.6	412	256	150	74	do not treat - pre-commercial
348880005	9,090	10.2	36	118	75.6	85%	21.9	13.1	42	12.8	88.7	47	3	79	3	do not treat - pre-commercial
596710049	8,995	3.7	17	328	63.6	65%	96.3	33.9	41	13.6	97.4	449	698	161	232	do not treat - pre-commercial

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
508212757	8,844	14.1	54	103	111.7	84%	20.2	21.8	59	17.8	133.5	381	83	139	24	do not treat - pre-commercial
500392581	8,517	3.7	16	452	106.9	69%	166.2	47.4	46	16.7	154.3	850	932	101	92	do not treat - pre-commercial
486320017	8,087	5.1	19	259	56.5	72%	63.0	21.8	40	14.9	78.3	124	156	38	40	do not treat - pre-commercial
479732697	6,865	10.7	40	298	81.5	77%	52.2	24.4	56	17.6	105.9	248	57	97	17	do not treat - pre-commercial
512881953	6,495	4.1	19	445	95.8	79%	227.0	25.9	41	10.7	121.6	197	225	102	74	do not treat - pre-commercial
509721937	5,907	6.1	18	249	72.7	77%	16.9	21.4	45	17.6	94.2	115	217	87	62	do not treat - pre-commercial
365761285	5,861	12.0	42	109	76.3	84%	21.1	14.0	40	15.5	90.3	189	7	78	2	do not treat - pre-commercial
429242565	5,758	8.2	37	307	98.9	92%	22.6	8.3	34	9.8	107.2	425	310	157	91	do not treat - pre-commercial
472882573	3,078	9.9	27	220	64.2	56%	111.6	49.5	26	13.6	113.7	160	16	71	5	do not treat - pre-commercial
535572569	3,007	8.7	32	311	90.0	78%	51.3	25.2	33	12.2	115.3	293	90	79	27	do not treat - pre-commercial
431021929	2,816	6.7	36	435	59.2	85%	53.4	10.7	25	5.3	69.9	154	14	174	5	do not treat - pre-commercial
147471941	2,454	4.4	18	267	33.4	62%	111.0	20.8	43	12.0	54.2	104	195	86	66	do not treat - pre-commercial
579512565	2,042	10.6	30	102	67.3	84%	20.4	13.2	26	14.2	80.5	126	42	39	12	do not treat - pre-commercial
523422792	1,993	4.9	25	255	23.3	54%	21.6	19.8	35	7.1	43.1	246	95	75	22	do not treat - pre-commercial
598072561	1,868	9.7	31	346	28.7	100%	2.5	0.1	45	19.3	28.8	147	70	64	21	do not treat - pre-commercial
509311297	353	2.2	15	401	24.4	70%	175.5	10.5	16	2.9	34.9	370	87	71	22	do not treat - pre-commercial
346160001	9,261	13.0	48	67	55.5	99%	1.0	0.4	55	17.6	55.9	46	2	59	2	do not treat - pre-commercial - low density
546600005	5,096	9.6	32	90	47.8	82%	21.5	10.8	32	10.5	58.7	39	3	67	2	do not treat - pre-commercial - low density

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
377702565	3,384	11.0	34	84	53.8	81%	20.8	12.5	36	14.7	66.2	129	5	62	1	do not treat - pre-commercial - low density
427942049	2,284	10.8	25	71	55.0	99%	0.7	0.3	24	12.5	55.2	24	0	18	0	do not treat - pre-commercial - low density
375512753	568	9.5	28	30	15.4	100%	0.1	0.0	22	9.4	15.4	27	1	12	0	do not treat - pre-commercial - low density
485882589	1,718	2.1	12	450	44.3	42%	389.9	62.1	28	5.8	106.4	1610	1177	200	143	do not treat - regen under small diameter snags
352311329	324	0.7	5	241	3.9	18%	370.5	18.0	23	5.9	21.9	294	86	50	15	do not treat - regen under small diameter snags
523192609	9,756	3.2	10	262	67.3	87%	20.0	9.8	52	22.0	77.0	110	232	27	39	do not treat - regeneration
370802593	9,677	2.6	11	359	115.5	89%	23.7	14.9	37	13.7	130.4	114	243	27	50	do not treat - regeneration
600021345	9,293	1.8	9	536	63.1	100%	0.0	0.0	40	14.2	63.1	323	179	149	53	do not treat - regeneration
363062593	8,600	2.8	11	338	91.3	85%	45.3	16.0	34	12.4	107.3	169	225	40	43	do not treat - regeneration
518140033	8,438	3.6	14	259	45.8	81%	123.5	11.1	45	16.7	56.8	124	186	68	105	do not treat - regeneration
356560021	6,880	2.5	12	333	42.0	59%	112.2	29.1	50	14.4	71.0	247	294	95	97	do not treat - regeneration
483572597	6,461	2.8	13	370	58.4	60%	186.1	39.6	61	18.4	98.0	825	967	110	115	do not treat - regeneration
583521329	4,522	1.3	7	266	24.2	62%	332.2	14.7	39	13.8	38.9	320	121	59	17	do not treat - regeneration
360350017	4,386	3.0	12	311	40.7	62%	129.0	24.7	29	10.8	65.4	219	289	94	106	do not treat - regeneration
349060049	4,342	2.1	8	283	33.2	62%	59.6	20.7	38	14.9	53.9	159	235	61	75	do not treat - regeneration
579772609	4,144	1.7	8	322	31.2	79%	134.3	8.4	52	15.6	39.6	123	182	27	18	do not treat - regeneration

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
600190017	4,129	2.5	10	265	38.5	84%	29.3	7.3	30	14.3	45.8	124	135	54	64	do not treat - regeneration
465772609	3,739	1.0	5	273	36.0	68%	33.0	16.9	44	16.9	52.9	182	165	31	16	do not treat - regeneration
466480033	3,667	1.7	7	343	40.4	70%	135.4	17.6	32	14.5	58.0	317	253	136	111	do not treat - regeneration
472321297	3,334	1.6	7	287	41.2	67%	37.7	19.9	32	13.3	61.0	226	276	36	28	do not treat - regeneration
328750033	2,917	3.1	11	306	35.8	68%	44.2	16.6	29	12.3	52.4	173	281	67	97	do not treat - regeneration
369890049	2,799	3.0	10	239	26.6	60%	32.7	17.4	27	14.7	44.0	122	245	48	74	do not treat - regeneration
352762609	2,735	1.6	6	304	39.2	76%	82.8	12.3	28	12.9	51.5	245	142	41	14	do not treat - regeneration
529140049	2,661	2.5	10	240	25.2	63%	76.9	14.6	28	11.7	39.8	131	237	49	74	do not treat - regeneration
348942609	2,573	2.4	7	215	30.0	91%	2.6	2.9	36	20.8	32.9	50	61	5	7	do not treat - regeneration
579460033	2,517	1.9	8	231	22.4	68%	16.2	10.5	25	9.8	32.8	66	117	39	67	do not treat - regeneration
595952609	2,270	2.2	8	295	43.4	76%	34.9	13.4	29	12.0	56.8	195	265	34	33	do not treat - regeneration
351820033	2,259	1.9	7	381	25.6	60%	314.0	17.3	20	15.4	42.9	144	46	64	15	do not treat - regeneration
538100065	1,681	1.8	8	413	17.0	99%	0.2	0.1	26	16.2	17.1	17	0	28	0	do not treat - regeneration
369480033	1,238	0.8	4	274	13.2	54%	115.5	11.4	25	9.7	24.6	94	58	39	17	do not treat - regeneration
347800017	931	1.3	6	218	10.8	67%	10.0	5.2	24	10.7	16.0	34	96	13	29	do not treat - regeneration
522232577	894	0.8	4	250	11.2	59%	12.8	7.7	37	11.8	18.9	71	151	13	15	do not treat - regeneration
578892577	670	0.5	3	243	8.8	62%	6.8	5.4	32	12.3	14.2	83	162	36	30	do not treat - regeneration
417901921	3,022	5.8	23	1,240	105.5	96%	106.2	4.1	28	12.5	109.6	299	141	243	64	Fire Risk Reduction
478941285	2,939	4.0	28	989	96.7	96%	21.2	4.4	41	7.4	101.1	360	309	149	91	Fire Risk Reduction

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
505082565	2,471	3.8	17	1,492	127.0	91%	270.4	12.9	25	7.9	139.9	473	273	155	80	Fire Risk Reduction
464852565	998	3.3	26	1,494	105.2	95%	91.0	5.6	25	3.5	110.8	241	6	83	2	Fire Risk Reduction
479830049	2,184	1.3	7	238	9.0	26%	50.6	26.2	47	15.3	35.2	118	153	47	42	salvage - regen under snags
560092803	1,375	2.0	10	239	9.1	18%	85.6	41.8	41	11.3	50.9	169	372	26	40	salvage - regen under snags
359690017	587	1.4	5	214	5.9	20%	97.6	24.1	13	11.8	30.1	127	300	31	59	salvage - regen under snags
366461937	207	1.9	7	209	4.6	16%	63.1	24.7	21	9.9	29.3	32	19	2	1	salvage - regen under snags
359940049	60	1.0	5	236	0.6	1%	358.2	50.0	25	20.0	50.7	1047	275	224	59	salvage - regen under snags
276031729	-	0.4	5	435	1.2	15%	75.1	6.4	50	10.7	7.6	1616	262	537	76	salvage - regen under snags
470262621	-	0.1	2	235	0.1	0%	128.8	236.5	79	23.2	236.6	308	598	48	81	salvage - regen under snags
484313060	-	0.5	5	435	2.7	14%	69.5	17.2	58	19.4	19.9	894	360	271	77	salvage - regen under snags
501872585	-	0.3	4	213	0.6	1%	96.9	67.2	44	19.2	67.8	318	617	56	84	salvage - regen under snags
506523060	-	0.9	6	400	2.7	5%	105.6	57.3	46	12.6	60.0	651	872	158	181	salvage - regen under snags
507222597	-	1.1	7	309	4.6	30%	224.1	10.7	14	3.2	15.3	271	6	47	1	salvage - regen under snags
518560500	-	0.6	6	400	1.1	1%	112.5	92.9	57	16.0	94.0	425	782	278	493	salvage - regen under snags
541372585	-	0.4	5	310	2.4	15%	240.6	13.4	17	3.5	15.8	164	163	33	16	salvage - regen under snags
542062609	-	0.1	3	200	0.0	0%	90.3	89.3	19	15.3	89.4	220	338	27	40	salvage - regen under snags
348520468	-	0.6	5	435	3.8	48%	30.3	4.2	59	22.8	7.9	305	167	250	114	salvage - regen under snags - low density
360032369	-	0.5	6	400	0.8	6%	25.5	11.9	64	20.3	12.7	720	242	442	65	salvage - regen under snags - low density
360083044	-	0.6	5	435	3.9	19%	20.5	16.7	29	9.7	20.5	681	823	186	154	salvage - regen under snags - low density

Representative Stand #	Green trees BdFt	Green trees Avg DBH	Green Trees Avg Ht	Green Tree TPA	Green Trees BA	Pct live BA	Hard Snags TPA	Hard Snags BA	Hard snags height	Hard snags avg DBH	Total Standing BA	Hard DWD <6 in	Hard DWD > 6	Soft DWD <6	Soft DWD >6	Category
492830657	-	2.5	7	202	2.3	20%	18.4	9.3	22	11.3	11.6	27	58	2	1	salvage - regen under snags - low density
595493028	-	1.1	6	400	3.8	36%	23.2	6.7	16	6.4	10.6	346	605	105	127	salvage - regen under snags - low density
362652585	6,047	4.3	17	257	61.3	44%	83.7	78.0	46	20.1	139.3	251	458	37	45	salvage - snags plus PCT
504542609	1,145	6.2	20	203	7.8	5%	149.8	140.7	50	19.7	148.6	200	410	36	66	salvage - snags plus PCT
357952609	228	9.1	32	201	1.4	1%	285.1	184.3	60	24.8	185.7	452	551	55	64	salvage - snags plus PCT

Appendix 2

Trucking data derived from weight limits on trucking configurations based on moisture content of biomass

Equipment Code	Terrain Limits	Biomass Characteristics/ limits	Equipment Configuration	Haul Limit
H.1	10-35% slope with adequate turnaround	Comminuted material, moisture content > 50%	truck/trailer combo 50% mc	weight
H.2	none	Logs > 4" diameter	pulp logs 50% MC	weight
H.3	none	Comminuted material, moisture content > 50%	dump truck only 50% MC	weight
H.4	10-35% slope with adequate turnaround	Comminuted material, moisture content < 50%	hauling chipped/ground material using truck/trailer assume 25 yd each	volume
H.5	<10% slope with adequate turnaround	Comminuted material, moisture content > 50%	Chip van (63% MC)	weight
H.6	10-35% slope with adequate turnaround	Comminuted material, moisture content > 50%	hauling chipped/ground material using truck trailer combo with 63% MC	weight
H.7	Not available on steeper terrain without turnarounds	Logs > 4" diameter	haul pulp using mule train (5, 6, 7 axle combos) 63% MC	weight
H.8	Potential Height limitation (oversize load restrictions)	Comminuted material, moisture content < 50%	haul chipped/ground material using 4 axle dump truck) 25 yd	volume
H.9	none	Comminuted material, moisture content > 50%	haul chipped/ground material using 4 axle dump truck) 63% MC	weight
H.10	none	Comminuted material, moisture content < 50%	haul chipped/ground material using 4 axle dump truck) 20 yd	volume
H.11	none	Comminuted material, moisture content < 50%	haul chipped/ground material using 4 axle dump truck) 17 yd	volume