FEEDSTOCK LOGISTICS (PART 1 OF 6)

Authors	ORGANIZATION
John Sessions	Oregon State University OSU
Kevin Boston	Oregon State University OSU
Rene Zamora-Cristales	Oregon State University OSU
Francisca Belart	Oregon State University OSU
Gevan Marrs	Consultant
Glen Murphy	Consultant

NARA is led by Washington State University and supported by the Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30416 from the USDA National Institute of Food and Agriculture.

(This report is part of a larger collection: Sessions, J., Boston, K., Zamora-Cristales, R., Belart, F., Marrs, G. & Murphy, G. (2017). Feedstock Logistics. NARA Final Reports. Pullman, WA. Northwest Advanced Renewables Alliance (NARA). "Feedstock Logistics" can be retrieved at https://research.libraries.wsu.edu/xmlui/handle/2376/5310)

COMPLETED 2017

EXECUTIVE SUMMARY

Task 1: Develop Biomass Recovery Coefficients for OR, WA, ID, MT

(A complete Task 1 report is available as a separate PDF within the NARA Final Report "Feedstock Logistics" submission, which can be retrieved at https://research.libraries.wsu.edu/xmlui/handle/2376/5310)

Validation tests were conducted to accurately predict the volume of forest harvest residue (slash) piles. Two measurement methods were compared to terrestrial Light Detection and Ranging (LiDAR)-generated estimates; one uses a geometric base and the other uses a laser rangefinder. The geometric method, which has been used since the 1980s, derives volume in two steps. The first step ocularly estimates the simplified geometric shape of the pile. The second step measures the parameters to compute the volume of that shape. The second measurement method uses a laser rangefinder with an electronic compass that collects coordinates of the pile and then computes a volume. Both methods were compared to the LiDAR-generated results for 33 piles in western Oregon. The laser rangefinder produced results that were closer to the LiDAR-generated estimates than the geometric shapes, which showed larger deviations from the LiDAR-generated estimate for larger piles.

To develop biomass recovery factors for regional analysis, 50 harvest units from the NARA region were selected and classified as either cable logging or ground-based logging. Cable logging include all forms of cable yarding from live skyline systems, running skylines and yoders (yarder-loader). Ground-based systems primarily included skidders, forwarder and shovel. The forest types can be grouped into two broad categories. The first, primarily in Oregon, were the Douglas-fir forests and the second was the hemlock forest, primarily in western Washington. The data collected at each unit included measuring harvest unit perimeter using the Global Positioning Systems data. Additionally, the pre-harvest estimated Scribner sawlog volume per acre was obtained from either the purchaser or landowner. Geographic information system analysis was completed that placed each pile into 50-foot buffer strips surrounding each road. This analysis allowed us to determine the volume of material and the distance from the roads.

A greater proportion of forest harvest residues were recovered from ground-based logging units as compared to cable-based logging units. Using a harvest residue collection model developed under Task 3, biomass costs as a function of distance from landing were calculated. Available biomass volumes were affected by pulp markets. During low pulpwood prices, larger amounts of pulpwood-sized material are left in the residue piles. During high pulpwood prices, not only are pulp logs extracted during the harvesting operation, but short, larger diameter pieces may be sorted from the harvest residue post harvesting, and recovered for pulp using bin trucks.

An effort was made to develop a double sampling strategy that would utilize the Timber Product Output (TPO) data collected by the University of Montana Bureau of Business and Economic Research (BBER) to estimate the recoverable harvest residues. The spatial resolution of the TPO data is maintained at the county level and thus not easily integrated with detailed collection variables at this time. A number of different models were analyzed but none yielded a meaningful result due to the high variability from initial inventory, logging system and merchandizing practices.

To support regional biomass supply analysis by the NARA Feedstock Supply team, a four state spatial distribution of biomass by harvesting system and estimated distance to road was developed. The base resource data are the USDA Forest Service Forest Inventory and Analysis (FIA) plots. Regional data (digital elevation models, road networks, ownership, land cover) were collected from the primary federal and state agencies. Digital elevation models were processed to estimate the amount of forested land that could be suitable for either ground-based or cable equipment. We then combined the harvest system overlay with the road system. In cable terrain, residues were assumed to be at roadside. For ground-based systems we assumed part of the residues is generated at roadside landings and part is generated in the field at different distances from the road. Recoverable percentages of harvest residues from cable and ground-based units were based on our field sample of 50 harvest units.

Task 2: Develop Moisture Management Strategies and Models

(A complete Task 2 report is available as a separate PDF within the NARA Final Report "Feedstock Logistics" submission, which can be retrieved at https://research.libraries.wsu.edu/xmlui/handle/2376/5310)

As fresh harvest residues can be almost one-half water by weight, moisture management can have an important impact on delivery costs. A repeated measures experimental design was conducted to determine average branch moisture content in live trees during each season of the year in four different locations in Oregon to permit determination of the starting moisture content of forest biomass residues. At the same time, a sampling protocol was employed to determine moisture content for in-forest piled and scattered harvest residues for one year after harvest at four different Oregon sites.

These data were used to calibrate finite element analysis (FEA) models to predict residue drying rates based upon weather information such as temperature, relative humidity, precipitation and wind velocity. Using the FEA model permits pile moisture prediction throughout a pile. The physics-based model allows moisture prediction for different pile shapes, sizes, and topographic placement.

Finally, one of the FEA models was used to determine drying rates on actual Douglas-fir units harvested with different harvest systems (a case study). A mixed integer linear program using these harvest units was used to optimally deliver harvest residues considering slash pile characteristics by logging system, spatial location of harvest units, mobilization costs, drying times, and material demand. A case study provided the economic tradeoffs in transport distance, cost of collection, pile configuration by harvest system, and drying time.

In a separate study comparing fresh versus aged harvest residues, drying time was also found to affect cost per pound of sugar recovered through the pretreatment process. Aged residues had more recoverable cellulose due to less bark, foliage, and ash. The aged residues not only had lower moisture content reducing transport costs, but the higher sugar recovery meant that fewer dry tons of residues were required to be delivered to satisfy a given sugar demand. For a typical Douglas-fir tree grown on industrial lands of western Oregon and Washington, more than 50% of the above ground nitrogen and more than 25% of the calcium is in the foliage. Strategies that leave foliage in the field contribute to maintaining site productivity.

Task 3: Refine Collection and Transport Models for Regional Modeling

(A complete Task 3 report is available as a separate PDF within the NARA Final Report "Feedstock Logistics" submission, which can be retrieved at https://research.libraries.wsu.edu/xmlui/handle/2376/5310)

We developed a model and framework to analyze the economics of forest biomass processing and transportation using mixed integer programming (MIP), simulation, Geographic Information Systems (GIS) and forest operation analysis. We developed an economic costing model that accounts for the cost of machinery and truck waiting time. The study is primarily focused on difficult access steep-land regions although it can also be applied to areas with less restricted road access. A stochastic discrete-event simulation model was developed to estimate cost management strategies to improve economics of mobile chipping operations and analyze the effect of uncertainty in this type of operation. The model was successful in predicting productivity of actual forest biomass recovery operations. The model also allowed analyzing the economic effect of truck-machine interactions when using mobile equipment to process the forest residues

With stationary processing equipment, the economic effect of truck-machine interactions on closely coupled operations was analyzed through a simulation model. It was demonstrated that truck-machine interactions affect machine utilization rates and, thus, the economics of the operation. Truck-machine interaction must be accounted for when analyzing forest recovery operations to avoid inaccurate cost estimation.

Finally, a mathematical solution procedure based on mixed integer programming, GIS and simulation was developed to support planning decisions in forest biomass recovery operations, including economic modeling of the effect of waiting times. The solution procedure was incorporated into the decision support system, Residue Evaluation and Network Optimization (RENO) developed using a JAVA platform. Options within the model include comminution at individual and central landings using mobile chippers and stationary grinders, bundling, and a variety of truck-tractor combinations. The decision support system was demonstrated to be an accurate and effective tool to estimate the most cost effective processing machinery and transport configuration given road access, material physical properties, spatial location of the residue piles and accounting for truck-machine interactions.

A biomass collection model was developed for gentle terrain. The proportion of recoverable residues depends on collection costs, which are a function of the distance from roadside landing, terrain conditions, and collection method. In this study, a forest residue collection model using forwarders and excavator-base loaders was developed to estimate the potential cost of biomass extraction from the forest to roadside landings. At the operational level, the model calculates the potential forwarder paths to estimate the cost depending on slope, machine arrangement and distance from landing. The use of the excavator-base loader working alone is the most cost effective system for distances of less than 50 m, while one or two forwarders loaded by one excavator-base loader is the most cost effective system for distances beyond 50 m.

Task 4: Evaluation of Chipping and Grinding Production to Meet Alternative Feedstock Specifications

(A complete Task 4 report is available as a separate PDF within the NARA Final Report "Feedstock Logistics" submission, which can be retrieved at https://research.libraries.wsu.edu/xmlui/handle/2376/5310)

Forest residuals (tree limbs, branches, small trees and unusable trunk bits) come in all different sizes. Before they can be efficiently transported to and processed at a conversion facility for biofuels and co-products, they need to be ground up into small pieces. To break up the wood material, a diesel-powered grinder is typically used. The feed roller forces the forest residual material past bits mounted on a cutting rotor. The bits hammer or cut the wood material into smaller pieces, which are then passed through screens that separate the wood grindings based on size. The choice of bits and screens used can affect the bulk density and particle size distribution of the reduced product. A higher bulk density translates into more forest residual material per truckload, and the particle size distribution can be an important quality characteristic depending on the user.

To help wood processors understand how grinder bit and screen configurations impact forest residual processing and costs, structured tests were performed to isolate the effects of grinder bit types and screen sizes on particle distribution, bulk density and fuel cost when processing forest residuals. The impacts of two bit types (carbide-hammer and knife-edge) and three screen sizes on particle size distribution, bulk density and fuel consumption from three feedstock size classes: branches-and-tops, pulpwood, and butt-log-chunks were evaluated. The amount of bark and other non-wood particles produced were also quantified.

When grinding branches-and-tops, the screen size and bit type selected had little impact on bulk density for the final product. Bit type and screen size did, however, impact the bulk density of grindings derived from pulpwood and butt-log-chunk size classes. In this case, using knife-edge bits and smaller screen sizes provided grindings with the highest bulk density for these two feedstock classes. The bulk density of grindings from the three size classes differed with the branches-and-tops grindings reporting the highest bulk density levels. Screen size and bit type impacted particle size distribution for the branches-and-tops plus pulpwood size classes but not the butt-log-chunk size class. Knife-edge bits and smaller screen sizes produced a higher percentage of fine particles. Possibly the increased screen-residual contact provided by smaller screens contributed to producing finer particles. Large screens produced a greater amount of large particles.

Grinder fuel consumption increased as forest residual feedstock size increased. Smaller screen size use resulted in higher fuel consumption. The branches-and-tops size class contained more bark and other substances than the pulpwood and butt-log-chunks size classes respectively. The higher surface-volume ratio afforded by the branches-and-tops would partially account for the increased bark and non-wood substance content. The choice of bit type or screen size did not significantly affect bark or non-wood substance content in the grindings. The results show that the efficiencies attributed to the choice of screens and bits are dependent on the forest residual size class. The results indicate that using knife-edge bits over carbide-hammer bits to reduce forest residuals can result in increased bulk density and lower fuel cost depending on the forest residual size class, although knife-edge bits wear more quickly than carbide-hammer bits and that bit replacement costs would need to be considered.

Transportation costs of ground forest residues can be reduced by increasing the dry wood bulk density per trailer per trip. Increasing the dry wood bulk density can be achieved by compacting the material into the trailer after it is processed by a grinder. However, increasing load density is often difficult to achieve in conventional conveyor-fed, gravity drop loading methods. The effect of high speed blowing during loading of low moisture wood grindings on the final bulk density was analyzed for two feedstock piece sizes, branches-and-tops and pulpwood. A structured fully randomized field test was implemented with two factors: loading method (high speed blowing and conveyor fed) and bit type (carbide hammer bits and knife-edge bits). The high speed blowing of grindings was made using a blower system to pack the material into the trailer during loading. The resulting bulk density using high speed blowing was compared against the results obtained from the conventional conveyor-fed (gravity drop) loading. The high speed blowing method produced a significant increase in bulk density compared to conventional conveyor-fed loading. In terms of grinding configuration, knife-edge bits produced a higher bulk density compared with carbide hammer bits but only for the pulpwood piece size class. The use of high speed blowing during loading was the most powerful factor impacting truckload bulk density in these trials and demonstrated promising results that can lead to significantly lower transportation costs when processing low moisture content harvest residues.

Task 5: Demonstrate and Evaluate New Trailer Designs to Improve Transport Efficiency

(A complete Task 5 report is available as a separate PDF within the NARA Final Report “Feedstock Logistics” submission, which can be retrieved at https://research.libraries.wsu.edu/xmlui/handle/2376/5310)

Conventional delivery systems include chipping or grinding of harvest residues (comminution) at the landing or a satellite yard in the forest and transporting the material with chip trucks to a power facility. A major logistical issue is the ability to access forest landings with large trailers on road systems that have been primarily designed for stinger-steered log trucks. To address some of the challenges of conventional methods of transporting biomass in steep terrain, chip van manufacturers have been making trailer modifications to increase vehicle maneuverability on forest roads. We investigated the use of rear-steer trailers, the use of double trailers, and developed an economic decision support model to identify the optimal truck-trailer combination including the options of temporary improvements in the forest road system that would permit large trailer access of various truck-tractor combinations.

In field studies, the combination of a 6x6 truck tractor with a rear-steer trailer was able to access all log landings in steep terrain, although mobilization costs for small landing volumes suggest the most economical solution is some degree of residue aggregation to reduce mobilization costs. At long transport distances, use of intermediate yards to transfer to 6x4 trucks with conventional trailers was the most efficient.

Although double trailers permit loading up to legal weight, even in very dry material, the extra trailer volume did not compensate for field trailer decoupling and recoupling operations unless the distance for in-forest travel was short and the on-highway distance was long. Temporary road adjustments such as changing road cross slope and filling ditches with chips were effective in case studies.