BIOMASS MODELING AND ASSESSMENT

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COMPLETED 2016

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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.

Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

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LIST OF ACRONYMS

C2P	Cascades to Pacific Region
FIA	Forest Inventory and Analysis
FVS	Forest Vegetation Simulator
GIS	Geographic Information System
LURA	Land Use and Resource Allocation Model
NARA	Northwest Advanced Renewables Alliance
NBM	NARA Biomass Model
TEA	Techno-Economic Analysis
TPO	Timber Products Output

EXECUTIVE SUMMARY

The Northwest Advanced Renewables Alliance (NARA) is a consortium of university, government, and private industry researchers tasked with demonstrating the conversion of logging residues to biojet fuel in an economic, social, and environmentally acceptable manner. Supply chain logistics are a key aspect in biorefinery viability and thus knowledge of the spatial allocation of logging residues as well as how that allocation may change over time is fundamental. To accomplish this the NARA Biomass Modeling and Assessment group developed and enhanced existing models of forest markets to generate a set of logging residue supply curves for a set of potential biorefinery sites across the OR, WA, ID, and MT region.

This report describes the two spatially explicit economic models used for different components of the NARA project. The first model, the NARA Biomass Model (NBM) employed in the Oregon and Washington region west of the Cascade Mountain crest to the Pacific Ocean (C2P) was developed over the first three years of the project included a detailed supply side allowing for individual tree characteristics to be maintained in the model output while demand focused on softwood log consumers with a rudimentary pulp component. The second model, The Land Use and Resource Allocation (LURA) model utilized in the final two years of the project includes less supply side detail but allows for complete utilization of the harvest in over 15 forest products across the entire conterminous United States.

The forest resource supply of each of these economic models is the individual Forest Inventory and Analysis (FIA) plot on which the simulated logging operations for products such as lumber, plywood and paper products occur. Logging residue availability at the FIA plot is further refined incorporating NARA-derived information regarding the proportion that would be in piles, the distance of those piles from the landings, and the costs associated with extraction and utilization. The combined information regarding current and potential future forest logging residue supply coupled with collection and transportation cost data are used to generate supply cost estimates specific to any desired biorefinery site across OR, WA, ID, or MT.

The logging residue marginal cost curves generated by these models provided fundamental feedstock supply information for NARA's techno-economic analysis (TEA) relating to the wood to biojet and co-product supply chain. Additional model results regarding quantity and location of extraction were instrumental in the NARA life cycle assessment and economic sustainability analyses.

INTRODUCTION

The success or failure of a biorefinery utilizing logging residues as a primary feedstock is dependent on their availability. Given that they are by definition residual from other forest commodity harvesting activities it is the demand for those products that drives residue availability. Furthermore, for a low value commodity such as logging residues, transportation costs comprise a high percentage of total cost and thus the spatial allocation of harvesting plays a large role in determining availability. To determine the potential supply of logging residues to a given biorefinery site it is therefore necessary to evaluate nearby potential primary forest products production. To accomplish this, the Biomass Modeling and Assessment team use partial equilibrium models of the forest sector to balance regional forest products supply at the FIA plot level and demand at each individual mill. The resulting harvests of FIA plots and residual tree biomass following utilization for traditional forest products provide the volumes and locations fundamental in determining logging residue availability for a potential biorefinery. This volume and location information is further refined using results from NARA Feedstock Development, Production, and Logistics studies. These studies provide key insights into how much of the unutilized biomass would be found in piles, where those piles might be located within the harvest units, and the costs of collecting, processing and loading that biomass. The resulting detailed logging residue availability and cost can then be combined with networked road data to provide project specific supply curves for any location within the NARA region.

TASK 1: DEVELOP PRELIMINARY BIOMASS SUPPLY MODEL AND SUPPLY CURVES

Task Objective

This task sought to develop a methodology for estimating the delivered costs of biomass (the biomass supply curve) to pre-treatment or intermediate treatment locations within the C2P study region. This was accomplished by modeling the demand for softwood saw and veneer logs and the generation of biomass as part of logging operations as well as the costs of collecting and transporting the biomass from woods to processing locations. The biomass supply curves were generated for multiple C2P locations.

Methodology

This project has three major parts: (i) develop an efficient and flexible means to use the FVS forest simulation model to project biomass available tributary to timber harvesting and to simulate large numbers of alternative silvicultural regimes (designed in some cases to increase biomass production); (ii) modify existing regional timber market models to recognize sale of biomass from harvests (including costs of collection, chipping and transportation to hypothetical refinery locations); and (iii) development of biomass supply curves at hypothetical locations under a broad range of scenarios on potential collection technology, constraints on types and sources of biomass, and other conditions affecting the cost of delivered biomass. As a first step, we assembled all the FIA plot data for the NARA study region, devised methods for estimating key site quality (plant association) measures not collected (or erroneously collected) in FIA sampling, and constructed methods to screen extraneous portions of the FIA database and detect errors in critical parts of the tree and condition class data. We assembled key data on production, output prices, input use and input prices for lumber and plywood mills in the NARA region and began estimation of profit functions by industry and region to provide critical log demand elasticity parameters for the market models. Demand elasticities were then estimated for Oregon and Washington (Guerrero, 2012).

To complete the first part, we successfully converted all the USFS Forest Vegetation System (FVS) variants in the NARA study region to composite model based on simplified C++ code. This allows rapid generation of 100 year projections of timber volumes and biomass under user-specified silvicultural regimes. As a quality assurance step we compared yields from the C++ code with results derived directly from FVS across the roughly 4000 condition classes of timberlands sampled in western Oregon and found only modest differences. Yield computations have been augmented to provide estimates of three components of harvest: sawlog/veneer logs, pulpwood, and residual biomass. The latter category comprises estimates of weight by tops, branches and broken portions of logs, as would be encountered in residual slash piles.

Next we revised an existing timber market model to create the NARA Biomass Model (NBM) which includes biomass collection from harvested sites and sales at user-specified locations together with extraction and sale of roundwood pulpwood volumes as shown in Figure BMA-1.1. In the model, producer decisions to harvest logs, destinations of log shipments, and the silvicultural regimes applied to both existing and future stands are endogenous. Lumber and veneer mill decisions on log consumption and capacity investment over time are endogenous, given pre-specified product prices, technological trends and non-wood input costs. In this structure, log prices are also endogenous. The NBM model was utilized to make softwood log market projections for the C2P region using timber yield inputs from the C++ code and assumptions about biomass extraction and haul costs.

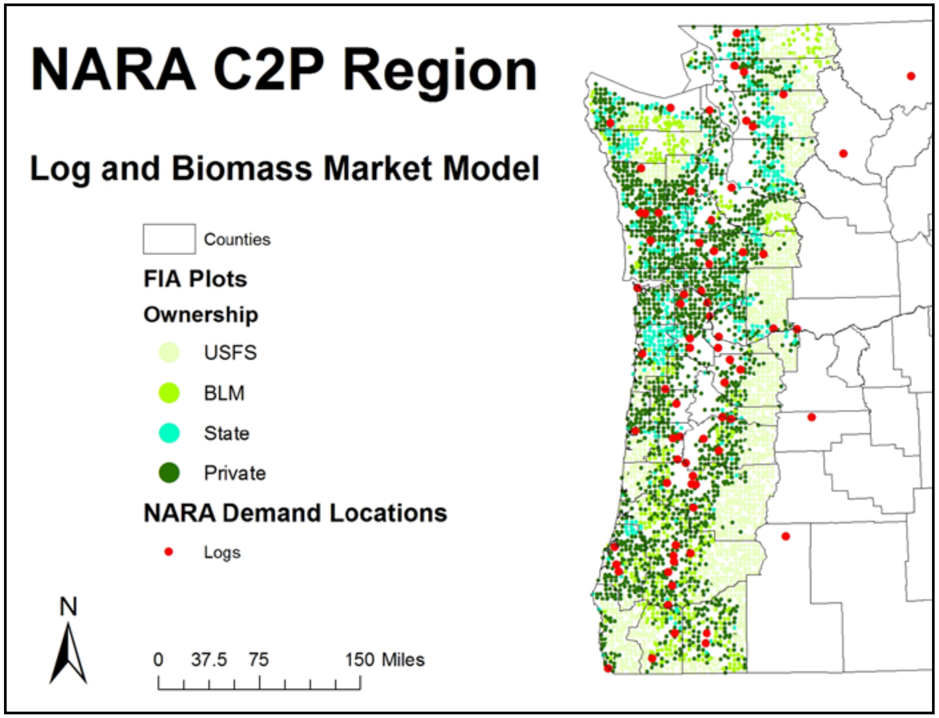

Figure BMA-1.1. Map of the log supply and demand locations for the NARA Biomass Model in the NARA C2P Region

The model was solved assuming a business-as-usual future demand scenario for the 2005 through 2075 time period in five-year periods using a discount rate of 6%. The resulting primary forest product harvest allocation was then used along with preliminary average collection, grinding and loading costs and a raster-based transportation algorithm to generate preliminary biomass supply curves for a number of potential C2P biorefinery sites.

Results

The preliminary results from the NBM provided critical insight into a number of issues to consider for the final logging residue supply curve estimation as well as a starting point for the NARA TEA team's final analysis.

Figure BMA-1.2 highlights the effect of biorefinery location and size on biomass supply marginal cost. The upward sloping marginal cost curves are a result of larger feedstock supply drawing material from a larger area and thus incurring higher transportation costs. This upward sloping marginal cost curve is in line with basic economic theory. Perhaps less intuitive is the effect of potential biorefinery location on the supply curve. In Figure BMA-1.2, at levels of annual supply less than 0.5 million bone dry tons per year Cosmopolis, WA has lower supply costs than Longview, WA yet at higher levels of required supply similar to the 840 thousand bone dry tons per year required for the NARA biorefinery Longview has lower feedstock supply costs. These relationships are the result of the complex interaction of the effects of nearby forests and sources of log demand and are not readily identified without such simulations.

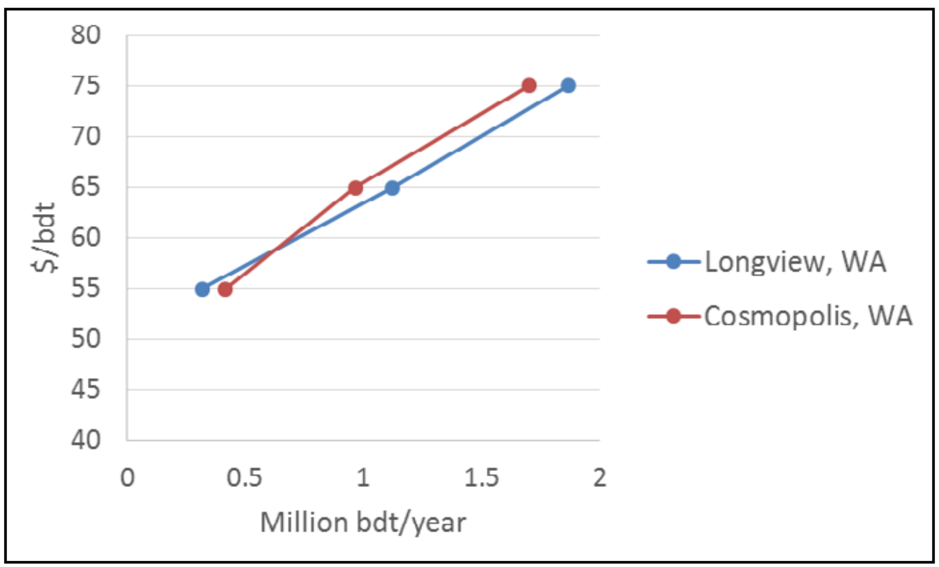

Figure BMA-1.2. Preliminary average annual logging residue marginal cost curves for Longview and Cosmopolis, WA for the 2015 - 2035 period.

Further affecting the logging residue supply curves is the proportion of log defect in the original logging operation and the extent to which pulp and paper companies utilize that material. Because the NBM reflects softwood log demand for use in lumber and plywood only, the defect parameter of 15% of total log volume represents not only damaged trees but also demand for other wood products such as pulp, poles, pilings, shakes and shingles. In an effort to better account for pulp log demand exogenous mill-level target quantities were added to the model and required to be met through either sawlogs downgraded to pulplogs or from the defect component of the harvest.

The annual average logging residue curves over the 2015-2035 period for a Longview, WA biorefinery site obtained from NBM is shown in Figure BMA-1.3. For the preliminary estimate of one million bone dry tons a year the marginal cost would be just under $65/bdt. Figure BMA-1.4 presents the geographic allocation of that biomass supply for one million bone dry tons per year at the FIA plot level. The supply area extends from Olympia in the north to Newberg in the south and from east to west extends from the coast to Cascade Mountains. Looking at potential logging residue supply in this way allows for a better understanding of not just how much logging residues comprise total supply, but the extent and perhaps more importantly the distribution of supply within that extent. In this case, the majority of supply is coming from the west out near the coast.

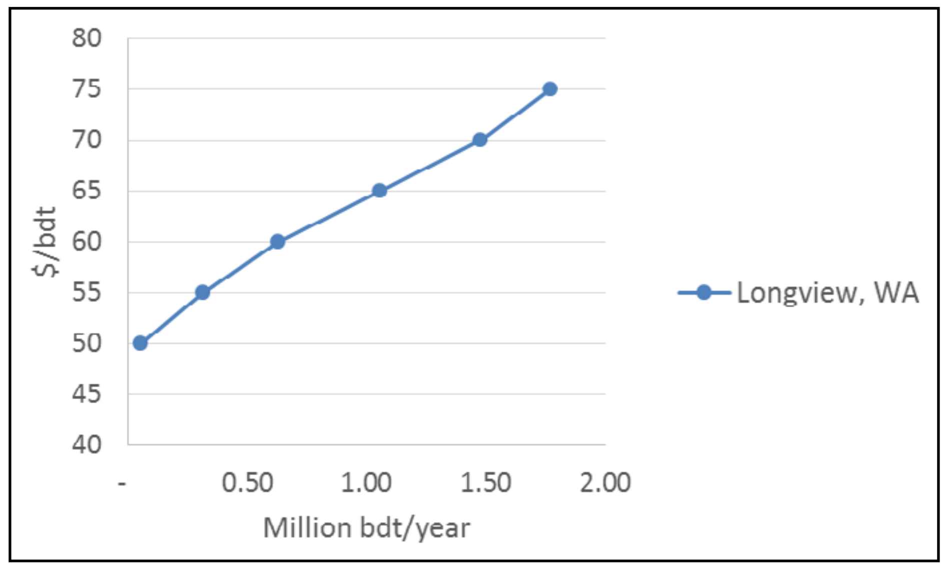

Figure BMA-1.3. Final Task 1 2015 - 2035 average annual logging residue marginal cost curve for Longview, WA.

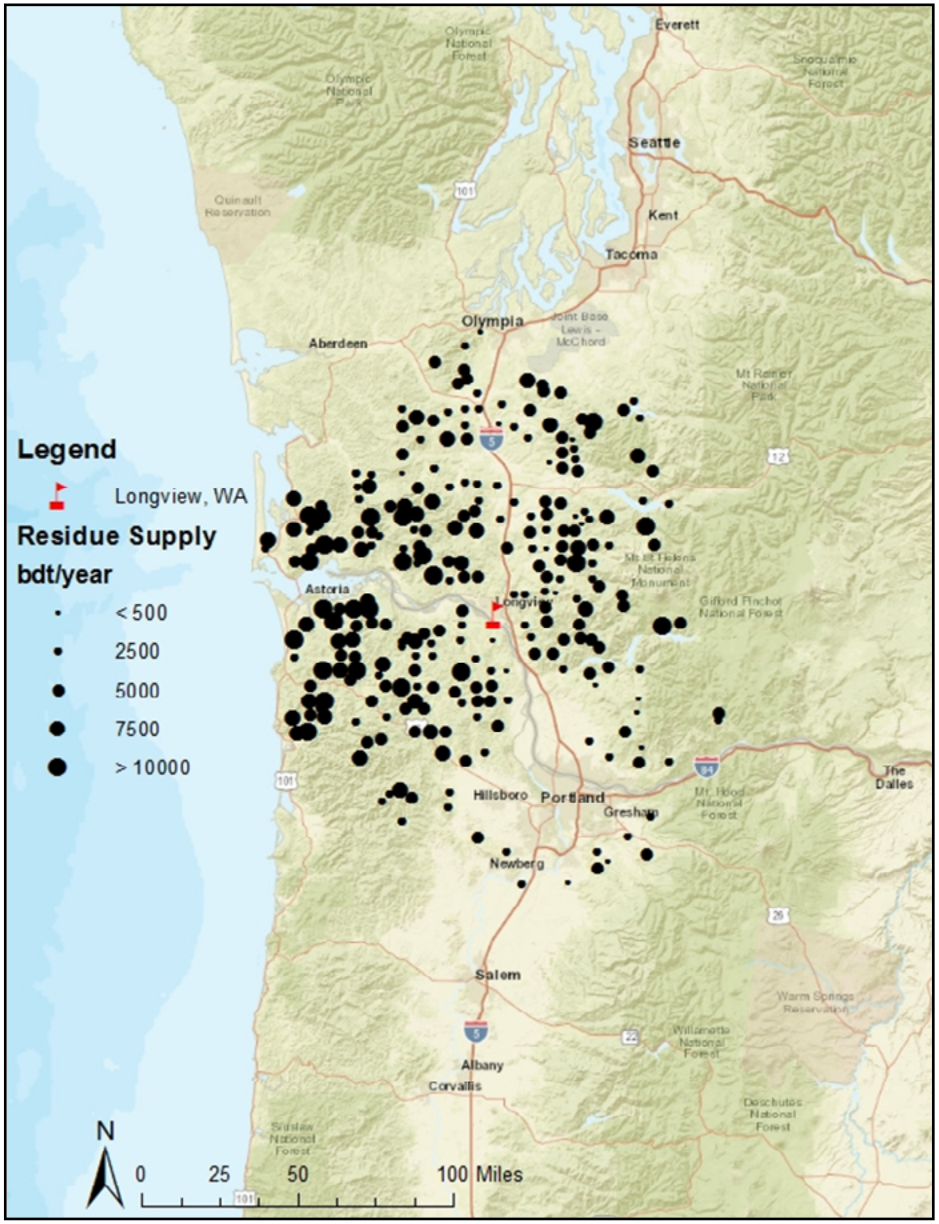

Figure BMA-1.4. Map of FIA plots contributing to a million ton per year logging residue supply into Longview, WA.

Conclusions/Discussion

The preliminary logging residue supply curve modeling analysis provided a number of key findings in addition to producing a location-quantity specific estimate for feedstock supply costs for use in the initial NARA TEA.

- The complexities of the implementing and refining the translated FVS code for generating individual tree based yield curves for FIA plots may make its use in the larger NARA region problematic.
- The potential dependence and/or interaction of logging residue availability with products other than softwood lumber and plywood make it beneficial to better incorporate them directly in the final analysis.
- The influence defect and breakage have on determining what residue material remains on a logging site highlight the importance of incorporating the NARA Timber Products Output group region and ownership specific values.
- As findings from NARA Supply Logistics Team studies become available they should be incorporated to refine the spatial supply representation.

Despite these issues the NBM analysis provides a useful tool that can be utilized at a later date to help evaluate the long-term potential for the region and its detailed forest growth system can be used to evaluate other NARA sustainability studies west of the Cascade Mountains.

TASK 2: SECOND ITERATION REGIONAL BIOMASS SUPPLY CURVES

Task Objective

The objective of this task was to expand our ability to generate biomass supply curves to include potential biorefinery locations throughout the entire NARA region. In addition the methodology should be able to better handle pulp fiber demand and encompass hardwood product markets. Finally, the resulting approach should be able to incorporate results from the NARA Feedstock Development, Production, and Logistics studies to further refine and improve the delivered cost estimates. Biomass supply curves were generated for multiple locations across the full OR, WA, ID, and MT NARA region.

Methodology

The methodological approach for this task expands on the preliminary Task 1 approach in two primary ways. First, we maintain a partial equilibrium forest supply and demand balancing strategy yet modify it encompass a larger region and a wider array of forest products. Second, we integrate the results from key NARA Supply Logistics Team studies to refine the supply curves accounting for logging residue dispersion and cost detail at the logging site.

Task 2 logging residue supply curve estimation is based on simulations of forest harvesting for forest products using the LURA model. Like the NBM, LURA model uses basic economic theory to balance forest resource supply with forest products demand. Figure BMA-2.1 shows the spatial allocation of the 130,283 FIA plots, 2,365 manufacturing facilities, and 126 ports that comprise the LURA model. Figure BMA-2.2 focuses in on the NARA region highlighting the 16 final forest products tracked in the model in addition to 8 intermediate products such as chips, shavings, sawdust and bark. The spatially explicit FIA plot based resource supply is combined with forest products processing facility locations to generate a partial equilibrium market optimization mathematical programming problem. The model moves through time sequentially determining a static phase annual market-clearing level of forest resource utilization. This single-year static solution is accomplished through linear programming by minimizing costs associated with harvest, transportation, and manufacturing of primary and secondary forest-derived commodities to meet domestic and trade exogenous forest products demand levels for the entire conterminous United States. In the dynamic phase between time periods, forest inventories are updated to account for static phase harvest levels and inter-period growth and demand at the stand level instead of individual tree. Trade levels are updated to account for changes in macroeconomic parameters, and forest products processing and port capacities are adjusted accounting for depreciation and changes in demand. Like the Task 1 approach, the resulting annual harvest locations form the foundation for the determination of logging residue supply costs.

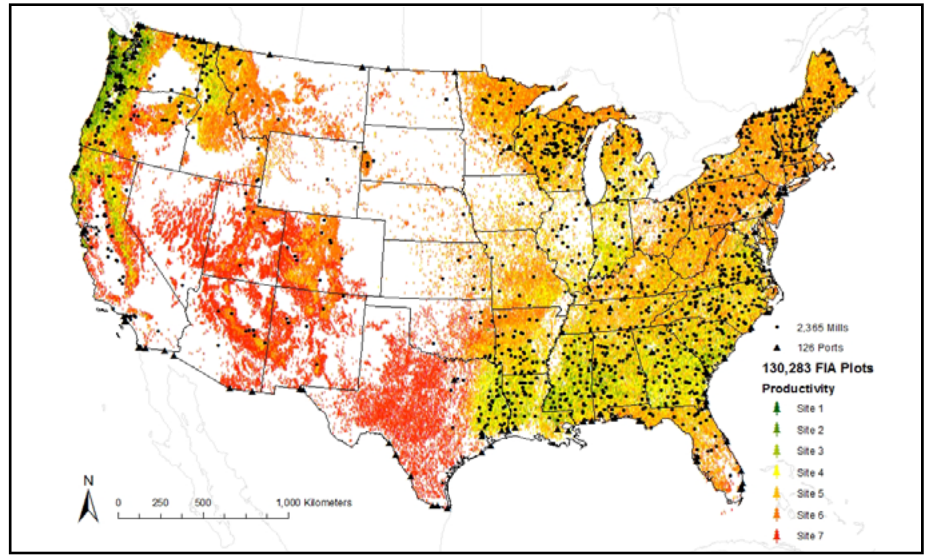

Figure BMA-2.1. Map of the LURA model log supply and demand locations for the conterminous United States.

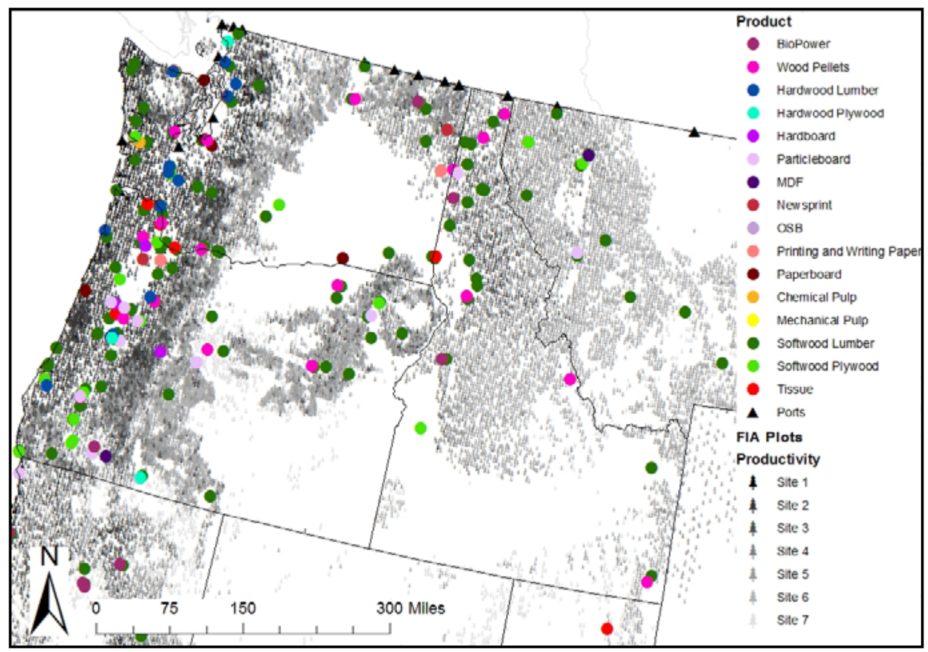

Figure BMA-2.2. Map highlighting the location of LURA forest products manufacturing facilities in the NARA Biomass Model in the NARA C2P Region

Due to the timing of various components of the NARA Supply Logistics and Sustainability studies, the preliminary results for Task 1 had to utilize simplified aggregate estimates of availability and cost parameters. By Task 2, the majority of these logistics studies had reached a point allowing for inclusion in the estimation of a more refined supply curve. The FIA plot data was refined using a geographic information system (GIS) based disaggregation first breaking the plot area into cable and ground based systems and then determining the potential area in three different distance groups from the landing (<150', 150 – 300', and >300'). Table BMA-2.1 presents further Supply Logistic Team refinements including the proportion of logging residues that would be found in piles and cost parameters. The cost components reflect activities such as move-in, grinding, and truck wait times as well as collection costs specific to whether it is a cable or ground based logging system and the distance to the landing.

Table BMA-2.1. Key NARA Supply Logistics Team information incorporated in the LURA logging residue supply curve estimation.

Logging System and Distance from Landing	Piled	Cost Components				
		Move-in	Collection	Grind	Truck Wait	Total
	---%---	---------------------------$/bdt---------------------------				
Ground System <150' from Landing	67.2	1.50	10.00	18.80	3.50	33.80
Ground System 150 - 300' from Landing	67.2	1.50	17.00	18.80	3.50	40.80
Ground System >300' from Landing	67.2	1.50	22.00	18.80	3.50	45.80
Ground System at Landing	67.2	1.50	-	18.80	3.50	23.80
Cable System Swing Bin	46.5	1.50	19.50	18.80	3.50	43.30
Cable System no Rebin	46.5	1.50	-	18.80	3.50	23.80

The model was solved using the Reference Case levels of future gross domestic product, housing starts and diesel prices from the U.S. Energy Information Agency's Annual Energy Outlook to drive future forest products demand for the 2015 through 2035 time period in one-year periods. The resulting primary forest product harvest allocation was then used along with the refined collection, grinding and loading costs and a road network based transportation algorithm to generate final biomass supply curves for a number of potential biorefinery sites.

Results

The final NARA logging residue supply curves were generated following an AEO Reference Case based LURA simulation of future U.S. harvesting and planting activities for the production of the full array of forest products (see Figure BMA-2.2). The NARA Timber Products Output Team provided logging damage and defect estimates that varied by ownership and state and the NARA Supply Logistics Team provided improved estimates of availability and cost. After incorporating these data along with a refined estimate of an 846 thousand bdt required annual supply at a marginal cost of $66.20/bdt the resulting fiber supply area for a Longview, WA biorefinery changes as shown in Figure BMA-2.3. The addition of the variable cost component at the individual FIA plot markedly changes the supply map seen in Figure BMA-1.4. First, the area nearest the biorefinery has a much larger removal footprint than the areas farther away. This is a function of the lower transportation costs allowing for expenditures to collect and utilize residue piles further away from the landings at the logging site. Similarly, the ability to utilize logging residues already gathered at the landings provides a much lower than average cost at the logging site allowing for the transportation of residues to Longview from much farther distances. This stretches the supply area halfway up the Olympic Peninsula in the north to below Corvallis in the South. In the east/west direction it expands the supply area along the Oregon and Washington coast and reduces the importance of the supply contribution in the Tillamook, OR area. We also see small contributions of logging residues from landings east of the Columbia Gorge. This change of intensity and extent of the supply area could have important sustainability consequences.

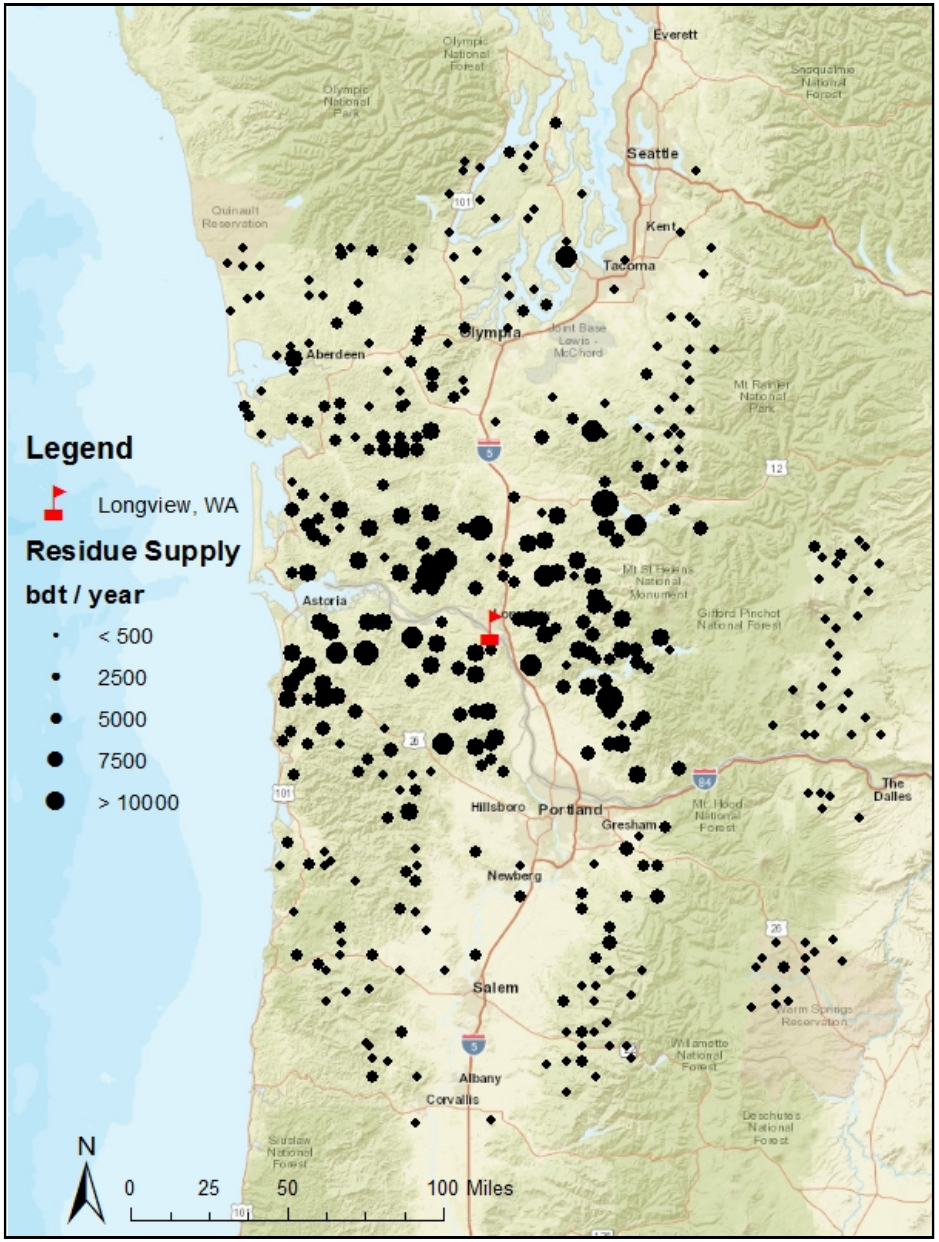

Figure BMA-2.3. Map of FIA plots contributing to 846 thousand ton per year logging residue supply into Longview, WA.

Table BMA-2.2 breaks down the 846 thousand bdt Longview annual supply into different components to further depict key details by logging system utilized and distance from the landing. In terms of contribution to annual feedstock supply the piled residues at landings of ground based logging units have the largest share with 34%. The driving factor here isn't the amount of piled residues at each landing, but rather that in every unit contributing residues to the biorefinery, the residues already piled at the landing are the cheapest to utilize and thus the first used. Equally interesting is the importance of the residues collected from greater than 300 feet from the landing on the logging sites closest to the biorefinery representing 22% of total annual supply. The average cost statistics also contribute to dispelling the myth that transportation costs are the largest factor in residue availability. For all but the landing-sourced residues the move-in, collection, grinding, and truck waiting costs were greater than the woods-to-biorefinery transportation costs. It is also noteworthy that while the marginal cost of this level of supply was $66.20/bdt, the average cost was $53.60/bdt.

Table BMA-2.2. Breakdown of cost components for Longview 846 thousand bdt annual supply by logging system and distance from landing

Logging System and Distance from Landing	Quantity	Average Cost Total	Non-haul	Haul	Haul Distance
	---bdt/year---	------$/bdt------			--- rt miles ---
Ground System <150' from Landing	119,674	53.25	33.80	19.45	62.25
Ground System 150 - 300' from Landing	88,852	56.68	40.80	15.88	50.93
Ground System >300' from Landing	184,219	58.53	45.80	12.73	40.82
Ground System at Landing	286,569	49.38	23.80	25.58	81.75
Cable System Swing Bin	96,908	57.95	43.30	14.65	47.12
Cable System no Rebin	70,127	48.58	23.80	24.78	78.85
	846,348	53.60	34.02	19.58	62.64

In addition to Longview, WA logging residue marginal costs curves were constructed for other potential biorefinery sites in the NARA region including Cosmopolis, WA, Spokane, WA, Lewiston, ID, and Missoula, MT. Figure BMA-2.4 shows the location of the alternative NARA biorefinery sites as well as the FIA plots harvested and potential logging residue locations for the 2015 – 2035 time period. For the purposes of the NARA project only the green and red indicating Private and State forest locations were considered to reduce the risk of not meeting Energy Independence and Security Act of 2007 requirements to generate Renewable Instrument Numbers (RIN). The value of the RINS was deemed necessary to ensure biorefinery success. Figure BMA-2.4 highlights the differences in both amount of nearby forest harvesting activity and degree to which that harvesting could be utilized at a biorefinery to generate biojet and RINs.

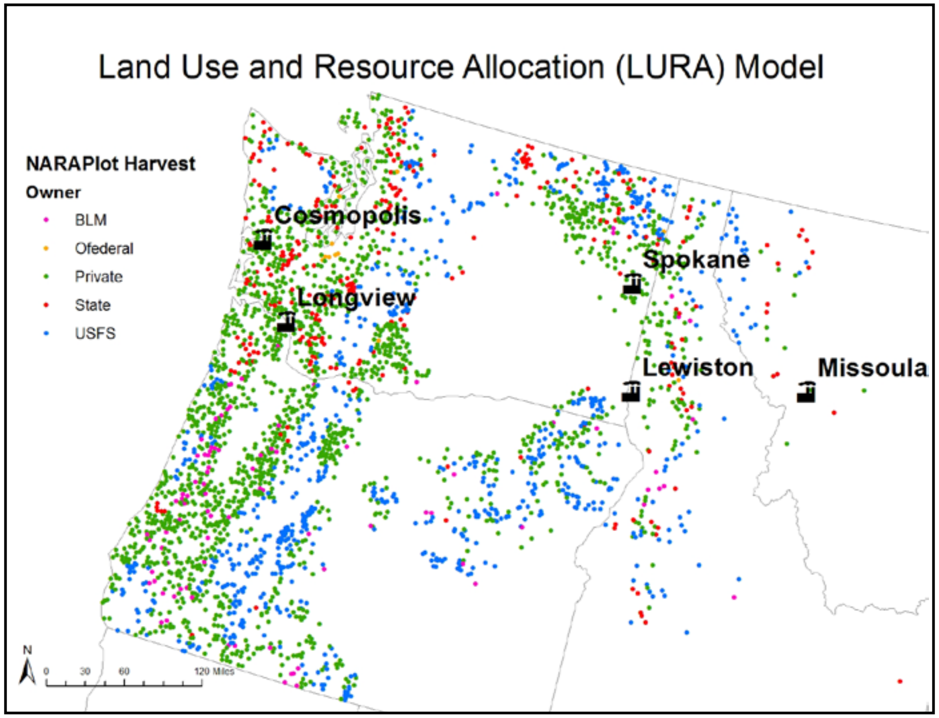

Figure BMA-2.4. Map of potential biorefinery sites and the LURA model simulated FIA plot harvest by ownership for the 2015-2035 simulation period.

The resulting logging residue cost curves for the potential biorefinery sites shown in Figure BMA-2.4 are presented in Figure BMA-2.5. The two locations west of the Cascade Mountains (Longview and Cosmopolis) have markedly lower supply costs and the potential to support a much larger facility. This is largely a function of their proximity to large area of productive private and State forestland likely to be harvested over the next 20 years as indicated by the green and red markers in Figure BMA-2.4. Unlike the results from Task 1, the supply curves for Longview and Cosmopolis do not cross as Longview has lower marginal costs of supply across all levels of total supply. The three potential facilities east of the Cascade Mountains indicate a need to combine supply areas in a "depot" approach to meet the supply needs of the NARA biorefinery. They may also be able to support other conversion technologies that favor a smaller size facility.

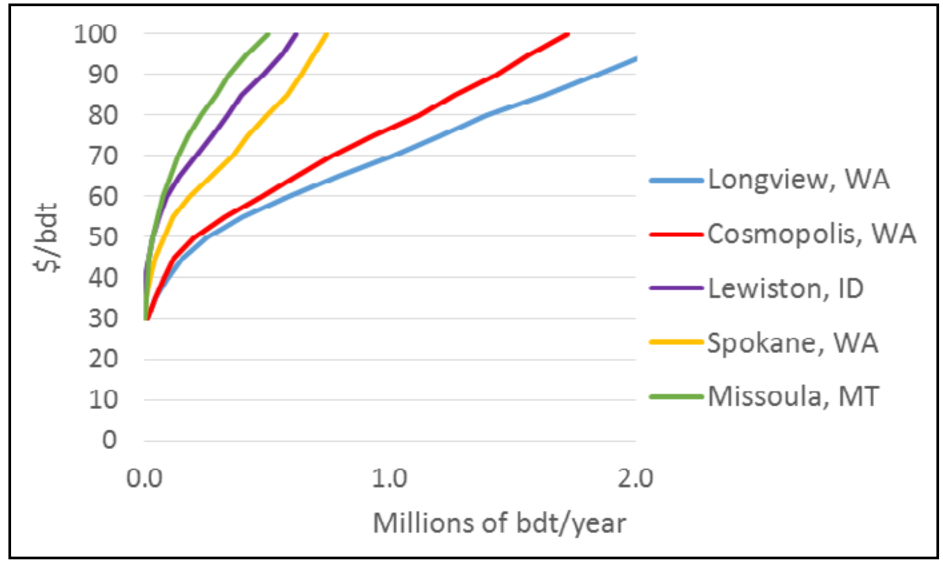

Figure BMA-2.5. Logging residue cost curves for five potential biorefinery sites.

Conclusions/Discussion

The resulting logging residue supply curves and spatial representation of supply locations provide important information for the final NARA TEA. The substantial differences between the eastside and westside location costs and potential volumes emphasize the need to locate an operation with one supply hub in the C2P region and in Longview specifically. This does not preclude siting a biorefinery in the inland NARA region, but rather points to the need for either a new technology allowing for a smaller scale facility or a multi-modal, depot approach to the supply chain.

NARA OUTPUTS

Theses and Dissertations

Guerrero, I. 2012. An econometric analysis of output supply and input demand in the Oregon softwood lumber and plywood industries. Paper submitted for MS (without thesis) in Applied Economics, Oregon State University.

Crandall, Mindy. "The effects of increased supply and emerging technologies in the forest products industry on rural communities in the northwest U.S." Doctoral dissertation in the Department of Forest Engineering, Resources and Managamenet, submitted to the Graduate School, Oregon State University, September 26, 2014.

Webinars

Morgan, T. and G. Latta. 2015. Incorporating Timber Product Output (TPO) harvest residue information and forest market models to evaluate biorefinery siting potential. Presented at: Wood-to-Biofuel | Webinar Series. November 19.

Latta, G. 2016. Incorporating traditional forest product markets in CPP biomass evaluations. Presented at: NEWBio Spring 2016 Webinar Series: The Clean Power Plan and Biomass. March 8.

Posters and Oral Presentations

Clark, J. 2013. FVS-lite: simplified FVS for large-scale yield projection. Presented at the Western Forest Economists Meeting. June 24. , Leavenworth, WA.

Crandall, M. 2013. Regional log demand estimation from profit functions. Presented at the Western Forest Economists Meeting. June 24. , Leavenworth, WA.

Adams, D. 2013. Market-based model of timber harvest and biomass residue generation. Presented at the Western Forest Economists Meeting. June 24. , Leavenworth, WA.

Adams, D., G. Latta, J. Clark and M. Crandall. 2013. Modeling the Biomass Supply Chain. Poster presentation at the NARA Annual Meeting. September 10. Corvallis, OR.

Adams, D., G. Latta, J. Clark and M. Crandall. 2014. Modeling the Biomass Supply Chain. Presented at the NW Wood-Based Biofuels Conference. April 14. Seattle, WA.

Adams, D. 2014. Supply curves for delivered biomass in western Oregon and Washington. Presented at the Western Forest Economists Meeting. May 19. Missoula, MT.

Crandall, M., D. Adams, and C. Montgomery. 2014. The feasibility of intermediate processing centers to enable greater biomass supply. Presented at the Western Forest Economists Meeting. May 19. Missoula, MT.

Adams, D., G. Latta, and M. Crandall. 2014. Economic Aspects of Sustainable Biomass Supply. Poster presentation at the NARA Annual Meeting. September 15 - 17. Seattle, WA.

Crandall, M., C. Montgomery, and D. Adams. 2015. Potential Rural Development Impacts of Increased Utilization of Forest Resources. Presented at Southern Regional Science Association Annual Meeting, March 26 - 28, Mobile, AL.

Crandall, M., C. Montgomery, and D. Adams. 2015. The feasibility of intermediate processing centers to enable greater biomass supply. Presented at the Western Forest Economists & International Society of Forest resource Economists Meeting. June 1. Vancouver, BC.

Latta, G. 2015. Incorporating FIA and TPO data into forest sector models to better evaluate logging residue availability for jet fuel production. Presented at the 2015 Forest Inventory and Analysis Science Symposium. December 8. Portland, OR.

Latta, G. 2016. Refining Forest Sector Model Output to Better Evaluate Logging Residue Availability for Jet Fuel Production. Presented at: International Society of Forest Resource Economics 2016 Annual Meeting. April 5. Raleigh, NC.

Latta, G. 2016. Key concepts for biogenic CO2 assessment. Presented at: EPA Stakeholder Workshop: Fostering Constructive Dialogue on the Role of Biomass in Stationary Source Carbon Strategies. April 7. Washington, DC.

Latta, G. 2016. NARA Potential Wood Supply Modeling to Better Evaluate Logging Residue Availability for Jet Fuel Production. Presented at: Montana Forest Products Roundtable. April 8. Missoula, MT.

Latta, G. 2016. Feedstock Supply Curves for Biojet Facilities in the NARA Region. Presented at: 2016 Northwest Wood-based Biofuels and Co-products Conference. May 3. Seattle, WA.

NARA OUTPUTS

Papers in Preparation

Martinkus, N., G. Latta, T. Morgan, and M. Wolcott. A Comparison of Methodologies for Estimating Delivered Forest Residuals Volume and Cost to a Wood-Based Biorefinery.

Latta, G. and R. Pokharel. The importance of spatial detail in logging residue supply cost estimation.

Crandall M., D.M. Adams, and C.A. Montgomery. The potential for biomass use and increased federal harvests to aid rural development in western Oregon.

NARA OUTCOMES

The evolution of the methods involved in the economic modeling of potential logging residue supply costs provided key insights fundamental to logging residue cost estimation. While initial efforts focused on the supply side detail provided by individual-tree modeling of forest attributes, the final analysis evolved to include a greater focus on demand and logistical detail. Transportation costs became less important as the importance of collection costs at the logging site became apparent. The resulting final NARA logging residue supply curves reflecting this change in knowledge provide a more robust foundation for the finalized NARA TEA.

FUTURE DEVELOPMENT

As with most research endeavors, the NARA Biomass Modeling and Assessment project ends with perhaps more issues exposed than resolved. While the supply-side focus of the individual-tree modeling was perhaps too onerous for application to the full NARA region it would be beneficial to return to the approach within the C2P region to evaluate tree species-level nutrient effects of logging residue removal regimes. The approach coupled with the NARA detailed supply logistics findings could provide important information of the range and scale of potential long-term sustainability effects associated with increased utilization and corresponding reductions in woody debris levels.

A second avenue for future research is in the optimal combinations of supply chain organization that could be the basis for a depot approach for inland forests. Such an approach could allow combinations of supply centers, or depots, to collect and densify biomass for transport to a central inland biorefinery location. The methodology would need to differ from the single supply location approach used in this project and allow for competition and interactions between multiple locations.

LIST OF REFERENCES

Guerrero, I. (2012). An econometric analysis of output supply and input demand in the Oregon softwood lumber and plywood industries. Paper submitted for MS (without thesis) in Applied Economics, Oregon State University.