Forest Management Task Force:

Rural Economic Development Steering Committee/ Wood Utilization Work Group

Removing Barriers Team

Statewide Feedstock Availability Literature Review

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Forest-based Feedstock Availability Literature Review

Summary of Results

Studies that attempt to estimate statewide forest-based feedstock availability are difficult to conduct due to the inaccessible fine-grain data needed to create conclusive numbers. Through a literature review of five of the major reports on statewide biomass availability produced in the last five years, this document has been developed to compare results related to forest-based biomass volume and density within the state. Results from each publication provide a unique perspective to biomass availability, and when combined, can provide a general understanding of forestry-based biomass estimates. Based on forest health and fire reduction biomass removal projects, High Hazard Zone (HHZ)-incentivized biomass removal, tree mortality, and private land forest operations, the studies find there is an abundant amount of biomass to support existing power facilities, and support the development of a range of new wood based businesses through the North Coast and Sierra-Cascade Mountain Range.

The most recent models indicate a significant increase in statewide biomass availability with estimates falling around 12.4 million BDT per year available in High Hazard Zones (HHZ) and 24 million BDT per year available statewide across forest management, sawmill, and shrubs and chaparral feedstock sources as calculated by the Lawrence Livermore National Laboratory (LLNL). Older models estimate 10 million BDT per year being available through forest management sources alone. In comparison, the LLNL estimates 15 million BDT per year available only through forest management sources when modeling the Forest Carbon Plan's 1 million acre per year restoration goal. There are mixed results on the amount of financially and technically available feedstock from mortality, but research out of UC Berkeley indicates there is the potential to generate between 1.7-6.4 Terawatts from mortality numbers sourced from the 2012-2017 drought. The California Biomass Collaborative (CBC) and Spatial Informatics Group (SIG) applied their feedstock numbers into biorefinery siting models to assess financial viability and viable feedstock supply chains. The CBC found the potential to develop over 10 facilities in the North Coast and upper Sierra Nevada while SIG found the need for 30 existing or new facilities across the North Coast and all of the Sierra Nevada to normalize carbon credit prices through sustainable forestry practices.

Overview of Literature Reviewed

1. ***Potential for Biofuel Production from Forestry Woody Biomass (2015)[1]:*** A collaboration between UC Davis and UC Berkeley, this report was conducted for the California Energy Commission to assess biofuel potential from forest residue – ie. thinning and fuel reduction operations. The team utilized UC Berkeley's research on optimal forest dynamics to define limits to forestry operations and applied data from the Forest Inventory and Analysis' (FIA) and the BioSUM model[2] into UC Davis' Geospatial Biorefinery System Model (GBSM) in order to define a few scenarios of siting new biofuel facilities in California. The first model scenario showed only operations that generate *positive net*

[1] Katherine A. Mitchell, et. al; *Potential for Biofuel Production from Forestry Woody Biomass.* California Biomass Collaborative. 2015

[2] The Bioregional Inventory Origination Summarization Model (BioSUM) is a model developed by Jeremy Fried that considers the cost and effectiveness of forest health restoration, yields of timber and feedstock for existing forest biomass facilities and most promising locations for building biomass-to-energy facilities.

revenue[3] when looking at harvesting scenarios. A second model scenario went beyond economics and simulated what biomass availability would look like if statewide policy prioritized forest management to reduce wildfire risk. They analyzed availability for biofuels over a 40-year period.

2. ***Forest Biomass Utilization Project Integration Report (2016)*[4]*:*** Spatial Informatics Group was commissioned under the CEC's Alternative and Renewable Fuel and Vehicle Technology (ARFVT) Program to comprehensively evaluate the sustainability of potential extraction of forest biomass to generate transportation fuels in California. By integrating different elements of various forestry management practices over a 40-year timeline, the report investigates ecological disturbance regimes and financial policies that would be impacted by expanding the biomass utilization market. In two subtasks of the project they developed different methodologies of estimating statewide biomass availability. In the first method, they used Fire and Fuel Extension program of the Forest Vegetation Simulator (FFE-FVS), FIA data and the BioSum v5.0 model to evaluate the sustainability of 25 silvicultural prescriptions. In a separate subtask they used a similar methodology before applying it to three different policy credit price scenarios to evaluate their influence on feedstock availability. The resulting feedstock estimates were then applied to GBSM to identify the optimal number of facilities, their locations, sizes, gross revenues and total throughput to sustainably support the biomass utilization market through biofuels. This study was showcased in the state's Forest Carbon Plan (FCP), which is the leading policy guidance relating to forest health in California.[5]

3. ***High Hazard Fuel Availability Study (2019)*[6]*:*** A team of consultants prepared this report for the High Hazard Fuel Study Committee and PGE. The objective is to assess the current and future demand for and supply of biomass fuel that meets BioRAM requirements, in addition to identifying barriers to increase forest biomass fuel production. Consequently, the geographic region as outlined by BioRAM requirements limits the assessment to High Hazard Zones (HHZ) to roughly half of the forestland of California. The report also provides an analysis of feedstock competition between all existing facilities and includes merchantable timber allocation and a gamut of other economic considerations within their research. The study did take into account standing dead tree mortality, and was updated with tree mortality information from FIA and Aerial Surveys. The team employed Landscape Ecology, Modeling, Mapping and Analysis (LEMMA) modeling sourced from 2012 FIA data over a 20-year period. They used Forest Vegetation Simulator (FVS) to model forest growth date to 2017 which also adjusted for harvest and mortality from 2012-2017.

4. ***Characterization of the Woody Biomass Feedstock Potential Resulting from California's Drought (2020)*[7]*:*** Written by a team of UC Berkeley researchers, this paper combines USFS aerial survey data between 2012-2017 with forest structure maps to estimate the hard-to-calculate standing dead

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[3] Positive Net Revenue is used here as a modeling input that optimizes maximum industry profit, meaning that feedstock was not accounted for if the cost of removal was higher than the end, value-added product

[4] Saah, David, Gunn, John, Moghaddas, Jason. (Spatial Informatics Group). *Forest Biomass Utilization Project Integration Report*. California Energy Commission. Publication Number: CEC-600-10-006. 2016

[5] Forest Carbon Plan, Page 134

[6] Mason, Bruce and Girard, The Beck Group; *High Hazard Fuel Availability Study*. Prepared for the High Hazard Fuel Study Committee and PGE. Natural Resource Management Contract #C9333. 2019

[7] Carmen L Tubbesing, Jose Daniel Lara, et. al; *Characterization of the Woody Biomass Feedstock Potential Resulting from California's Drought.* Scientific Reports, Nature Research. 2020

biomass from five years of drought-stricken tree mortality. The aerial data is combined with LEMMA-Gradient Nearest Neighbor (GNN) Structure Maps and uses simple conversion factors to estimate biomass, which does not account for variation in tree size which could have a significant impact on outcomes. The results are used to estimate economic feasibility to recover feedstock for energy production with the assumption that operations will be biomass-harvests exclusively.

5. ***Getting to Neutral: Options for Negative Carbon Emissions in California (2020)[8]:*** A first-of-its-kind report, Lawrence Livermore National Laboratory delivered this assessment of negative emission pathways for California to reach carbon neutrality by 2045 using existing and deployable technologies. UC Berkeley's Dr. Daniel Sanchez and Bodie Cabiyo performed an economically-driven model to identify forest management that could contribute to the Forest Carbon Plan goals and generate *positive net revenue*. The assessment includes forest-based feedstock sources from forest operations, mill residue, and shrubs and chaparral. They employed USFS's Forest Vegetation Simulator and FIA's BioSum as their core model inputs over a 20-year period. They present original data on their forest operation modeling in addition to using UC Davis' 2015 CBC Biomass Potential publication, described above, for mill residue, shrub and chaparral numbers[9].

Table 1: Summary of Scopes for all Reports

	Cal Biomass Collaborative (2015)	SIG Biomass Utilization Project (2016)	High Hazard Fuel Availability Study (2019)	Tubbesing et al. (2020)	Getting to Neutral (2020)
Acres Studied	22 million	statewide	13.2 million HHZ	12 of 58 counties	800,000 ac/yr
Units	Million BDT/year	Million BDT	(HHZ) Million BDT/yr	Million BDT	Million BDT/yr
Model	FIA, BioSUM, GBSM	FIA, BioSUM, FFE-FVS, GBSM	FIA, LEMMA, Aerial Survey, FVS	Aerial Surveys, LEMMA-GNN	FIA, FVS and BioSUM
Modeling Period	40	40	20	2012-2017	20
Forest Operations	x	x	x		x
Mill Residue					x
Shrubs and Chaparral					x
Mortality		x	x	X	
Environmental Considerations	BAU and policy driven wildfire incentive program	in-field surveys and multi-dimensional harvest scenarios	BAU technical and economic operating constraints	does not evaluate ecological trade-offs of tree removal	Forest Carbon Plan restoration goals

[8] Sarah E. Baker, et. al; *Getting to Neutral: Options for Negative Carbon Emissions in California.* Lawrence Livermore National Laboratory. 2020

[9] Dr. Sanchez. Personal Communication. April 16th, 2020.

Introduction

Led by the Governor's Office, the Forest Management Task Force (FMTF) Rural Economic Development Strategic Wood Utilization Group (REDS WUG) has asked to compile the best available information on the state of forest biomass supply while taking into consideration biomass that is already being consumed by existing electrical generation facilities. Five publications published in the last 5 years have been selected for review that attempt various scales of a state-wide biomass availability from the forestry sector[10]. Each report employs their own methodology of biomass availability which differ in scope, geography, modeling and results. These reports serve to complement one another in many respects, providing a baseline understanding of biomass utilization potential in California. Some of the work takes into consideration feedstock competition, distance of available feedstock to facilities, the costs or technical constraints of removal based on geography or road conditions and other issues related to new facility siting scenarios. The studies will be used to focus on whether forest biomass produced by an increase in the pace and scale of forest restoration could effectively supply a new wood products-based business economy[11].

The five studies covered in this review make up the bulk of current publicly available information on statewide forest biomass availability. There are several regional and site-specific studies available. Fine-grain data utilized for project specific assessment is ideal, but the detail needed for a definitive statewide feedstock assessment is not accessible. This makes comprehensive papers troublesome and expensive despite current efforts[12] [13]. The purpose of the studies reviewed in this report is to provide broad information that shows indications of total volumes, rather than the feedstock assessments for any specific region or project type.

Review of Literature Findings- Opportunities and Challenges

Forest Biomass: Volume and Availability

Across all five publications, biomass availability exceeds current electrical facility consumption, and could sustain those facilities several times over. Currently, the existing biomass to energy feedstock consumption estimates about 4.48 million BDT per year producing between 550-560 MW throughout the state[14]. This includes waste from all forest-based waste streams (including forest operations) as well as agriculture and municipal solid waste. Comparing this to the estimates described within the studies illustrates that there is more than enough waste wood coming from the forest sector alone to add an

[10] To note, there is a persisted interest in biomass studies coming from research groups on advanced transportation and biofuels technology

[11] These reports do not analyze municipal solid waste or agricultural waste; it should be noted that the numbers found in this review are only a fraction of the total state-wide biomass availability.

[12] Personal Communication with Larry Swan, USFS Woody Utilization Program Manager.

[13] Lara, Jose Daniel. Personal Communication April 9, 2020. UC Davis school of engineering is currently attempting a new comprehensive model that applies predictive growth patterns to estimate state-wide biomass potential.

[14] Tad Mason, TSS Consultants Presentation to NorCal SAF/UC Extension Webinar. April 2015; and California Society of American Foresters. 2019. As of 2018, total biomass capacity is 560 MW.

additional 315-2,440 MW of energy to the California grid by 2045[15]. We now explore the specifics within the reports on this subject.

In 2015, the California Biomass Collaborative (CBC Report) found 277 million BDT available over a 40-year modeling period using 2012 data. This equated to about 7 million BDT per year. The CBC report excluded mill residue in order to highlight the amount of unutilized biomass availability (mill residues typically are already allocated, leaving behind at most 1.5% unutilized)[16]. The report integrated the Biomass Summarization Model (BioSUM) [17] with the Geospatial Biorefinery Siting Model (GBSM). Unifying these two models extrapolated financially feasible zones where new facilities could procure unutilized feedstock from existing facilities. Based on their annual BDT estimates, they suggested ten locations that could potentially achieve break-even costs from producing biofuels. Most of the economically viable facilities were sited in the North Coast under their first business as usual (BAU) scenario, with one location sited along the western slope of the Sierra Nevada. The second scenario applied the model to a "Fire Hazard Score" which dispersed BDT potential throughout the state based on an area's potential for crown fire, fire intensity, torching index and potential tree morbidity. When prioritizing this policy-driven scenario, five facilities were sited in the Sierra Nevada, yielding 1.6 times greater BDT potential than the economic-driven BAU scenario. This amounts to about 10.9 million BDT of forest woody biomass per year, an increase in almost 4 million BDT than the BAU scenario. The numbers found through the second scenario modeled several forest stand locations that could supply wood chips at $50/BDT or less in the Western Sierra.

Under CEC's Alternative and Renewable Fuel and Vehicle Technology (ARFVT) Program, a team of researchers at Spatial Informatics Group (SIG) conducted two different methods using BioSUM v5.0 to arrive at statewide feedstock potential under various regimes of improving forest health, carbon stock and reducing crown fire risk. The first method evaluated two feedstock supply scenarios which first considered harvest activity on private lands alone, and then private land harvest with added National Forests wherever restoration was effective. This method produced roughly 550 million gallons per year of drop-in fuels with 250 million gallons being economically viable with biofuel prices over $4/gallon of gasoline equivalent (GGE). The second method simulated 25 different silvicultural scenarios on private and federal lands and applied an optimization approach to define best prescriptions for each acre. This method found an output of about 10 million BDT per year under these forest operations. When both methods are compared, they conclude that there is a range of 8 million to 11 million BDT economically available per year. When these numbers are applied to biorefinery siting model GBSM, SIG found that an optimal scenario to provide homogenous pricing for forest residues would require thirty facilities producing 18 million gallons per year. Facility siting estimates include expanding existing facilities to accommodate biofuel conversion.

The High Hazard Availability Study (the HHZ Report) written in 2019 was tasked with determining the amount of BioRAM-eligible HHZ biomass that could be removed from California's forest. This reduced

[15] 1MW facility = 8,000 BDT/yr; using LLNL estimates of 24 million BDT/year available across forest operations, mill residues and shrubs and chaparral represent the upper bounds while CBC's 7 million BDT/year represent the lowest bound.

[16] CBC 2015 Report.

[17] Dr Dan Sanchez. Personal Communication. April 16, 2020.

the available amount to about half of what is technically available forest acreage.[18] The Study found that 248 million gross BDT of biomass would be available over a 20-year period from qualifying fuel sources in the BioRAM HHZ. The HHZ Report concluded that there is about 12.4 million BDT per year gross potential forest biomass feedstock, with 3.85 million BDT per year of that total currently unused by existing facilities. The Report applied a "financially feasible radius of operation" when performing their calculations which is discussed further later in the this literature review. As required by the BioRAM program, the Report considered feedstock that was sourced from forest operations, and not from mill residue. This provides an important distinction that may be relevant to state policy makers.

Lawrence Livermore National Lab's *Getting to Neutral* report (LLNL Report) includes an assessment of biomass from forest operations, mill residue and shrubs and chaparral feedstock across the entire State. Their results are consistent with the previous reports and conclude with total forest-based biomass amounting to 24 million BDT available per year by 2045. While mill residue and shrub and chaparral numbers were based on the CBC Report's findings, Dr. Sanchez and Bodie Cabyio presented original data within the LLNL Report by modeling the FCP's ambitious 1 million acre forest restoration goal. For forest management alone, they estimate 15 million BDT available per year. It is important to note that their findings are based off a 20-year and 40-year modeling period. Through personal communication with Sanchez and Cabyio, a 40-year modeling period would estimate biomass potential to be equivalent to the other reports reviewed in this document[19]. The reason for LLNL's higher number is because they incorporated sawmill residue and shrub and chaparral biomass, which are two sources that are not often accounted for in the other reports featured in this document. In their model, they prioritized optimal stand dynamics, wildfire regimes and increase in carbon stock as recommended by the FCP in addition to the BioSUM model. They also incorporated economic assumptions into their BioSUM model such as operating costs, labor, and wood processing fees from the biomass removal value chain to define financially feasible operations. Dr. Sanchez and Cabiyo assumed a delivered biomass value of $100/BDT.

Finally, Carmen Tubbesing and Jose Daniel Lara's *Woody Characterization of Woody Biomass* (Tubbesing et al. Report) underscores these numbers by finding 26.2-95.1 million BDT resulting from the 2012-2017 drought. Under various technical constraints, 18.4-68.9 million BDT of biomass *from only tree mortality* is available, which the study goes on to conclude could yield an energy potential of 194-730 MW[20]. The yearly estimate for biomass extraction was not rigorously studied in the paper's scope, but rather emphasizes energy potential if extracted. The Paper found that cost-effective supply of biomass was available for 16-60 years at 80% operational capacity. Tubbesing et al. explored the economic viability of biomass extraction, paying attention to distance from existing facilities and usable road conditions. The economic parameters resulted in an available 7.5-27.8 million BDT. The authors made explicit note of the wide margin that reflects the disparity between what is technically available versus economically available[21]. The authors assert that future initiatives will need to reconcile the disparity between the

[18] Implementing a series of parameters to their modeling, they conclude that 13.2 million acres is available for biomass removal in the HHZ.

[19] Dr. Sanchz and Bodie Cabyio. Personal Communication. April 24,2020.

[20] Tubbesing et al. Report

[21] Jose Daniel Lara. Personal Communication. April 9,2020.

two constraints, and provide the study as evidence of the ample amount of biomass available after the 2012-2017 California drought induced tree mortality event, mostly in the southern sierra region.

As a side note, some state policy makers may be specifically interested in tree mortality biomass, specifically. A comparison of the HHZ Report's 20-year modeling outcomes to Tubbesing et al.'s mortality numbers reveals that the papers substantiate the other[22] -- there is about 3.45 million BDT available over a 20-year period.

Report	Acres treated	Modeling period	Millions of available BDT/yr
The CBC Report (2015)	22 million	40 years	7-10.9
The SIG Report (2016)	Statewide	40 years	10
The HHZ Report (2019)	13.2 million	20 years	12.4
LLNL Report (2020)	800,000 ac/year	20 years	24
			Million BDT
Tubbesing et al. (2020)	12 out of 58 counties	n/a	18.4-68.9

Forest Biomass Feedstock Value

Current Consumption and Economics

The valuation of forest biomass continues to be an incredibly challenging aspect of forest health restoration projects and fuel reduction work statewide. It is a key factor when understanding how much forest biomass feedstock is truly "available" for use. Several of the studies considered this issue and produced similar conclusions.

Background: BioRAM versus BioMAT

When reviewing literature on feedstock competition, it is important to clarify the differences between BioMAT and BioRAM, two market mechanisms implemented by the CPUC to financially incentivize the use of forest biomass at electrical generation facilities. *Biofuel Market Adjusted Tariff* (BioMAT) was created in 2012 through SB 1122 (Rubio), directing the CPUC to procure 250 MW electricity from small bioenergy plants less than 5 MW. It uses standard long-term contracts and a market-based mechanism to arrive at offered contract prices for eligible projects. *Biofuel Renewable Auction Mechanism* (BioRAM) was developed in 2015 in response to Gov. Brown's Proclamation on Tree Mortality, directing the CPUC to expand their pre-existing RAM program to existing forest biomass to electricity facilities if they procure feedstock from the High Hazard Zone areas(HHZ) as defined by CAL FIRE. It directs state investor owned utilities (IOU) to procure at least 50 MW statewide, with 20 MW from Southern California Edison from organic waste streams[23]. Note that in 2016, SB 859 added another 125 MW of

[22] The HHZ Report was used to check Tubbesing et al.'s report due to its similarity in geography and associated biomass composition. The HHZ Report estimates 3.85 million BDT per year of unutilized biomass and applied calculations to Tubbesing et al.'s Report would equate to 3.45 million BDT per year.

[23] Swezy, et al., and California Public Utilities Commission website

forest-based biomass feedstock to the BioRAM requirements[24]. The most important distinction is that BioRAM was put in place to support existing large scale biomass to energy facilities, while BioMAT requires 250 MW statewide procurement across all organic waste streams to incentivize the development of *new* small scale (under 5 MW) electrical generation facilities.

One of the Studies, the HHZ Report, specifically considered the BioRAM program related to biomass conversion and economics[25]. Currently, 24 biomass plants exist producing over 550-560 MW of generating capacity. Seven are contracted under BioRAM and procure feedstock from lands designated at HHZ by CAL FIRE, which accounts for just under half of the forest land base accessible for harvest operations (13.2 million acres). However, these BioRAM facilities also allow for feedstock procurement from non-designated areas and sources for 20% of their needs. As required by BioRAM contracts, facilities increased HHZ-qualified feedstock consumption from 340,000 BDT in 2017 to 691,000 BDT in 2018[26]. Based on those contract requirements, BioRAM facilities will need a combined total of 940,000 BDT per year to operate going forward[27]. Outside of the HHZ, total consumption of biomass between all waste streams averaged 3.4 million BDT per year over CalRecycle's 2015-18 reporting period[28]. Forest-based biomass accounted for about 1.55 million BDT on average with mill residuals contributing over 70 percent of the total[29]. Using a generally accepted magnifier for simple calculations[30], 560 MW would calculate to about 4.48 million BDT of biomass consumption per year.

Two of the Studies Considered Options for New Facility Siting

Model Scenarios for New Facilities: CBC Report

The 2015 CBC Report developed a model to assess potential biorefinery siting based on maximizing industry profit through RNG production. The CBC Report located ten biorefineries where the lowest cost resource was financially feasible: the North Coast. There were a few located in the central Sierra, but no sites located in the Southern Sierra, where the highest percentage of tree mortality occurred. When a second scenario adjusted modeling for wildfire abatement prescriptions, biorefineries were heavily shifted to site five facilities in Northern and Central Sierra. When siting new facilities in the Sierra Nevada, the report found an increase in BDT potential to be 1.6 times greater than the original profit maximizing scenario. Total estimates rise to about 10.9 million BDT per year available when taking into consideration wildfire abatement treatments. The biorefineries production rate would range from 45 – 154 million GGE per year.

Model Scenarios for New Facilities: SIG Report

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[24] Camille Swezy, Kyle Rodgers and Johnathan Kusel, PhD. *Paying for Forest Health: Improving the Economics of Forest Restoration and Biomass Power in California*. Funded by CEC contract EPC-16-047 for the Schatz Energy Research Center, California Biopower Impacts Project. P. 13. 2020

[25] Note that the HHZ Report was published in 2019 and included Loyalton Biomass Facility into its calculations. Without Loyalton, more biomass feedstock will have no place to go in the central Sierra/Tahoe region.

[26] The HHZ Report: Mason, Bruce and Girard; The Beck Group

[27] Ibid.

[28] The HHZ Report covering CalRecycle reporting period

[29] Ibid.

[30] The Beck Group; Mason, Bruce and Girard. 1 MW facility = 8,000 BDT/yr

In a separate study, conducted by Spatial Informatics Group (SIG) for the 4^{th} California Climate Assessment, supplements the UC Davis model and was featured in the 2018 Forest Carbon Plan. It evaluated “the sustainability of increased forest biomass utilization for transportation fuels under differing management practices across public and private lands and under expected fire regimes”. In subtasks 3 and 8 of this project, they developed a BioSum model to assess 40-year impacts of optimally selected treatments to reduce severe fire probabilities, increase carbon uptake, incorporated costs of implementation, and examined how a sustainable biomass industry could be developed from these treatments. Using Forest Inventory and Analysis (FIA) data, their concluding scenarios found overall improvement in forest health in multiple performance metrics and has the potential to reduce the fire hazard across California by 50 percent.

Under modeled scenarios that cover all areas generating substantial forest residuals, several dozen facilities could be sited within the State, producing a combined total of 250 million gallons per year of economically available drop-in fuels priced above $4 per gallon of gasoline equivalent (GGE)[31]. When adding public lands to reduce fire hazard, the amount of potential biofuels doubles, adding another 275 million gallons per year for a total of 525 million gallons of economically viable biofuels. Subtask 8 concluded that forest residual biomass could provide as much as 4.5 million credits to California’s Low Carbon Fuel Standard (LCFS) credit market.

The SIG team then used the Geospatial Biorefinery Siting Model (GBSM) to evaluate the feasibility of using existing and new biomass facilities where the end-product would reduce the capital cost of the facility. Like in CBC’s model, they found a number of facilities located in the North Coast due to low cost of transportation where greater supply sources are available on private lands[32]. In an optimal scenario, the SIG report finds that a biofuel industry consisting of a combined 30 existing new facilities producing 18 million gallons per year would facilitate the best pricing for forest residues. They comment that if new facilities were to be built to cover public land restoration projects, production costs would drop 15% and better serve important regions of California’s forests[33].

Specific Economic Challenges Limiting Biomass Removal

The difficult economics of non-merchantable biomass removal is well known. Non-merchantable biomass includes slash, limbs, dead tops and trees with a BDH smaller than 10 in and understory shrubs cleared during fuel thinning[34]. The literature reviewed in this report discuss issues related to feedstock extraction, including technical, transportation and the associated in-forest labor costs. Combined they represent a significant hurdle to accomplishing more biomass removal in forest operations.

Transportation

All the publications name transportation as the central barrier to biomass extraction. Across all publications, prices for biomass removal fluctuated around $50/BDT. This number is found through an equation that essentially combines harvest and hauling costs and compares it to the value-added end product. The CBC Report uses $50/BDT as break even cost and assess the amount of biomass availability

[31] SIG Report. Subtask 8
[32] Ibid.
[33] Ibid.
[34] Forest Carbon Plan p.94

accordingly[35]. Similarly, the SIG Report uses the metric of $4 per gallon of biofuel to calculate financial feasibility[36]. The HHZ Report states a broad estimate of break-even fuel costs could be around $65-75/BDT making a 40-60 mile radius financially feasible[37]. The LLNL Report uses a different methodology and combines both sawlog value with chipping value, when other reports have only considered chipping value. LLNL Report then compared these values to harvest and transportation costs related to distance to a conversion facility. This is reflected in their higher estimate of $100/BDT as an input to their BioSUM model[38]. It is worth noting that even with LLNL's higher price of removal, they still have a significant BDT potential statewide that would necessitate a robust build out of new biomass facilities. The SIG Report points out that these high costs of removal are near unattainable for private landowners who currently contribute to a significant portion of available feedstock statewide[39].

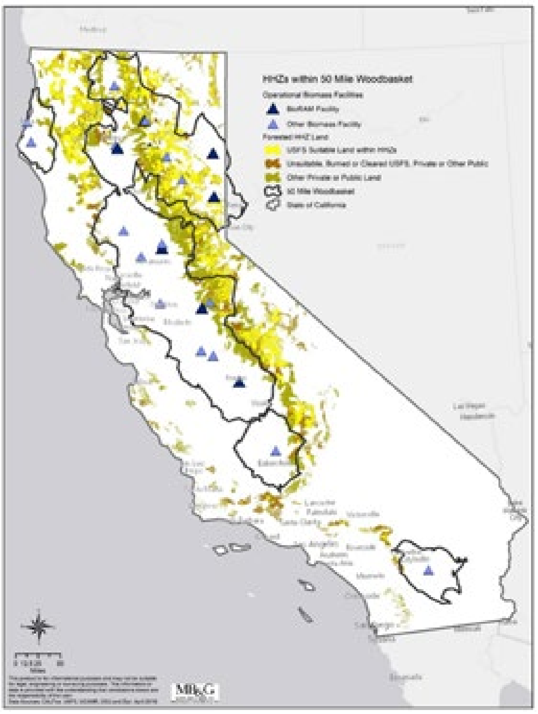

Figure 1: All existing facilities with WoodBasket of financially feasible radius - HHZ Report

Included in the financial burden to remove biomass, the HHZ Report points out that forest road conditions, the definition of "qualifying fuel" for BioRAM procurement and limited organizational capacity all contribute to the barriers of a robust non-merchantable biomass market[40].

The HHZ report goes in depth on the issue and illustrates a series of graphs that reflect their findings. As illustrated by Figure 1, operations would be economically feasible in only 23% of the HHZ for BioRAM facilities[41]. Therefore, we can infer the remaining 77% of the HHZ incurs higher hauling costs for existing facilities. Future biomass projects taking place in these areas could become viable if transportation issues are addressed. However, currently, future projects will be more expensive for biomass procurement because it is harder-to-reach[42]. Additionally, the SIG Report finds that there are multiple sources of potential woody residues like logging slash, powerline, road right of way clearance and masticated material that all represent different economic value and transportation costs complicating the economics of the issue further[43].

The Tubbesing et al. Report chose to analyze the accessibility of standing dead trees from the nearest road which gives perspective on the feasibility of access. They however did not calculate hauling costs

[35] CBC Report
[36] SIG Report
[37] HHZ Report
[38] LLNL Report
[39] SIG Report
[40] HHZ Report
[41] LLNL Report
[42] HHZ Report
[43] SIG Report

due in part because their findings were focused on the opportunity for the development of new facilities rather than hauling the available BDT to existing facilities. That being said, Tubbesing's research team did consider the Tuolumne County Pacific Ultrapower Chinese Camp biomass facility as a case study of potential standing dead BDT availability and found up to 2.5 million BDT of feedstock available within a cost-effective radius of 30 miles[44].

Consideration of Competition for Feedstock

The HHZ Report expands on their transportation research to develop a methodology on assessing feedstock competition between facilities that would compete over BioRAM eligible fuel. As shown in Figure 2, the potential biomass volume by distance to *any 23 biomass facilities* is particularly high. With the y-axis indicating biomass potential in the HHZ and the x-axis indicating miles from facilities, it shows that the next phase of biomass extraction will need to be further away from existing facilities. Notice after a certain mileage, other biomass facilities will have easier access to feedstock thereby decreasing availability. However, if more facilities develop under BioMAT or another BioRAM solicitation occurs, the HHZ feedstock supply could significantly contract and facilities could end up hauling biomass over extreme distances in order to meet BioRAM-designated material for operation. We have already seen this competition resulting in inflating prices for qualifying forest biomass feedstock an additional $8/BDT to a total of $57.97/BDT between 2017 and 2018[45].

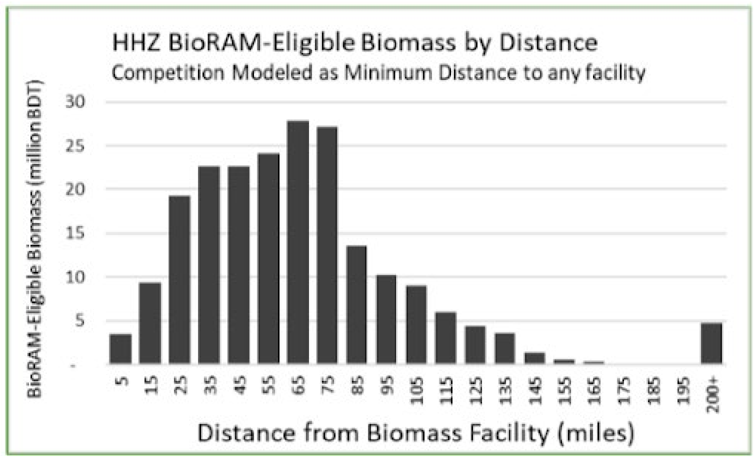

Figure 2: Feedstock Competition Availability by Distance – HHZ Report

Environmental permitting and Contracting and Technical Constraints – Operational constraints that limit biomass extraction are codified in law as best-practice silvicultural prescriptions and include but not limited to: logging systems for slope, harvest cycles, wildlife protection, tree diameter limits and cultivating a new cohort of tree saplings[46] [47] [48]. Each study culls their numbers based off these constraints.

The HHZ Report dedicates a chapter to barriers to operation. Notably, they discuss regulatory and short-term contracts that limit investment and planning. Because BioRAM contracts only offer five-year agreements, private forest operators are reluctant to invest in expensive equipment and long-term personnel[49]. The Forest Carbon Plan calls out the need to streamline environmental permitting as a solution to increase forest restoration and discusses the need to innovate through collaborative

[44] Tubbesing et al.
[45] HHZ Report
[46] Tubbesing et al.
[47] SIG Report
[48] CBC Report
[49] HHZ Report

authorities that allow for more private and state management on federal land[50]. NEPA and CEQA are required by state and federal law and are a fundamental component to ensuring environmental and ecosystem integrity during forest operations. The complexity and costs to complete these reviews, however, presents challenges. For example, due to high staff turn over rate and conditional annual federal budget allocations, permitting biomass removal projects through NEPA can be difficult to accomplish for Forest Service personnel. While it might be possible to lighten this burden through the private sector, it is difficult for third party contractors to provide NEPA analysis and project management through the same contract, leading to a slower pace and scale of forest restoration.

The Future of Forest Biomass: Author's Notes

As reflected in this literature review, there is enough biomass available to support existing facilities and support the development of new businesses. To emphasize this point, one of the Governor's 35 priority communities for fuel reduction averaged 1.5 loads of chips per acre which equates to 18 BDT per acre. This was along HWY 44 in the Shasta-Trinity Unit and can be expected to be equal to or higher in some other regions of the state with severe wildfire risk[51]. The HWY 44 project expects to treat 1,112 acres, which means this one project alone is likely to produce roughly 90,000 BDT of biomass.

The challenge is getting the biomass out of the forest, transported to businesses, and processed for use. One significant hurdle is that public landowners are not able to commit to a guaranteed feedstock supply due to the inability to predict their discretionary budget, multi-year regulatory planning processes and high staff turnover rates. Additionally, the federal agreement mechanism to allow third party operators to manage forestry projects on public land and develop feedstock contracts is highly complex, further straining the potential for streamlined action. Without a feedstock guarantee, business models are constrained, and securing a loan guarantee can be jeopardized.

In addition to feedstock contracting, building a new facility is complex. Land zoning, ownership lease and purchasing rights, and political support are the biggest hurdles to new site development[52].

Locating a site can be a highly controversial aspect of developing a facility. For example, locating biomass to energy facilities must be sited within one of the three IOU's in order to participate in BioRAM or BioMAT, while also being within feasible distance to the feedstock supply-chain. The decision to own or lease land for a long-term industrial facility also complicates matters, requiring careful legal agreements between owners and operators[53]. Air permits, water permits, grading permits and building permits are all required for facility development. In particular, air districts apply different air restrictions to their jurisdiction in addition to federal Title V air quality requirements. All of this requires a supportive local community and government staff to ensure the success of forest biomass to wood products or energy projects.

Now that it is well understood that there is a significant amount of forest biomass in California, further work should be done to determine what is needed to dispose of it in the best way possible.

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[50] Forest Carbon Plan. 2018. Section 10.3.2 Statutory Requirements for Forest Biomass.

[51] Benjamin C Rowe, CAL FIRE Shasta-Trinity Unit. Personal Communication 9/27/19

[52] Darlington, Christiana. "Stepping Stones…"

[53] Ibid.

Conclusion

According to all studies, there is enough biomass technically and economically available to support existing facilities and enough to support new business models and markets. To achieve public land restoration goals of the Forest Carbon Plan, the HHZ Report points out that current levels of operation will need to increase 200,000 acres of treatment per year, supplying a range of 150,000-300,000 more BDT per year on top of their current estimates[54]. The LLNL Report is the only study that applies a methodology to anticipate state-wide biomass availability under the Forest Carbon Plan 1 million acre forest restoration goal and concludes 24 million BDT will be available per year by 2045[55]. Several of the studies place a high value on forest health and wildfire reduction projects, in addition to employing economic modeling software, BioSUM[56] [57].

The other reports featured in this Literature Review mostly focus on procurement from forest management sources, thereby lessening the cumulative feedstock number as estimated by LLNL. Over a 40-year modeling period, report findings and personal communication with primary authors have indicated that biomass availability levels fluctuate around 10 million BDT/year. The LLNL model estimates reflect an increase for a total of 15 million BDT available per year for both their 20-year and 40-year modeling research. Combined with the HHZ Study and Tubbesing et al. reports, focusing on biomass availability in priority zones with heavy mortality numbers, we can infer that initiatives that would further expedite removal of these trees in the next 10-20 years would result in a higher BDT availability than what models suggest.

The efforts of quantifying available forest biomass have been active over the past decade and will undoubtedly continue into the future. With the biggest challenge being the ability to develop accurate granular data that can produce a higher resolution to validate a 20-year or 40-year wood supply. This literature review by no means incorporates all work done on this sector, but attempts to summarize the primary sources of information, and will now briefly mention other work and upcoming work.

Related and Forthcoming Studies on Forest Biomass Waste Availability

Joint Institute for Wood Products Innovation Literature Review Published in 2020, this report was submitted to the California Board of Forestry and Fire Protection to review forest product innovation literature, identify gaps in forest product innovation research, evaluate strategic partnerships and recommend near-term priorities to expand in-state production of various end-use timber products. The report features many useful figures and trends about forest availability for non-merchantable and merchantable timber production and suggests a new strategic partnership to develop a viable supply chain for timber markets. It was not featured in this report but serves as a companion study to help bolster woody utilization in California. While this literature review supplies some baseline numbers of feedstock availability, the Institute's literature review primarily assesses the viability of various wood utilization technologies and high value-added products.

The California Biopower Impacts (CBI) Project is managed by the Schatz Energy Research Center at Humboldt State University and supported by grant funding from the California Energy Commission. This

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[54] The HHZ Report

[55] LLNL Report

[56] SIG Report

[57] CBC Report

three-year project – which is expected to conclude in August of 2020 – investigates many of the greenhouse gas (GHG) and other environmental considerations associated with utilization of forest-derived woody biomass and agricultural residues for electricity and process heat generation, as well as investigating project economics and developing policy recommendations. This work will consider available feedstock within its analysis and could provide further insight on this topic. A methodology was developed for this report in 2018 and includes an exhaustive description on how the CBI study was conducted[58].

The Next Generation of Wildfire Models for Grid Resiliency The proposed research will advance wildfire science by incorporating the interaction of tree mortality and extreme fire weather in next-generation fire models. The project will develop zero-to-seven-day risk forecasts for the grid with predictive capabilities, computational efficiency and scalability. To support planning, the team will develop long-term fire projections using a coupled fire-climate-vegetation statistical and dynamical model to integrate the latest climate projections, tree mortality, development in the wildland-urban interface, and adaptation strategies. This work will undoubtedly contribute to relevant work and development further refined analytics related to forest biomass.

Forest Operations BioSUM and FVS Modeling In-Forest Carbon Expected to be released in the late spring of 2020, this paper is a continuation of LLNL *Getting to Neutral* report and written by the main researchers who modeled statewide forest-based biomass availability by 2045. It goes into depth on the methodology of how Dr. Dan Sanchez and Bodie Cabiyo applied forest growth models, full-cycle carbon accounting of various forest products centered around the Forest Carbon Plan 1 million acre forest restoration goal which produced their findings of 24 million BDT per year available. They discuss the effectiveness, net costs and revenues generated from five management sequences with BioSUM in addition to how they arrived at their economic calculations.

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