High Hazard Fuels Availability Study

Prepared for
The High Hazard Fuel Study Committee
And PG&E
Natural Resource Management
Contract #C9333

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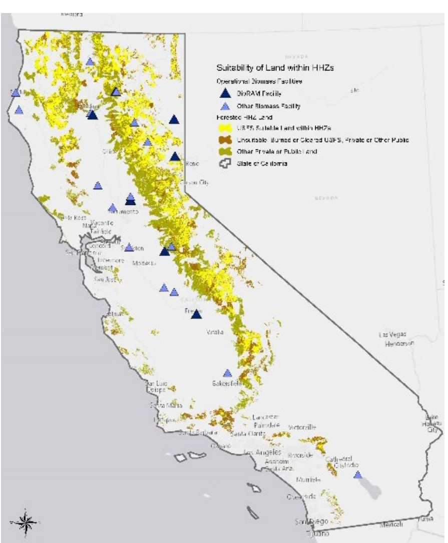

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EXECUTIVE SUMMARY

The Governor's 2015 Emergency Proclamation led to the delineation of High Hazard Zones (HHZs) and to contracts with certain biomass fueled power plants to source electricity production from biomass removed from the HHZs.

To date, seven biomass plants with about 172 MW of generating capacity obtained BioRAM contracts -- five have "BioRAM 1" contracts and two have "BioRAM 2" contracts. A similar BioMAT program was approved for procuring 50 MW of generating capacity from small-scale biomass power facilities. Several BioMAT plants are well advanced in planning and development, but to date none are in operation.

During the early implementation of the BioRAM contracts, contract holders raised concerns about whether there is enough qualifying fuel to support those contracts over the long term. Others have raised questions about how much impact the BioRAM contracts can have on the State's efforts to restore health and resiliency of California's forests. To that end, the HHZ Fuel Study Steering Committee commissioned this status report to: (1) evaluate the demand for HHZ fuel from the BioRAM contracts; (2) determine whether there is sufficient qualifying fuel to sustain the contracts; and (3) identify barriers in the HHZ biomass fuel supply chain.

Findings: The demand for qualifying fuel

1. Seven BioRAM plants consumed an estimated 1.12 million Bone Dry Tons (BDT) of fuel in 2018. Of that, 691,000 BDT (60%) was qualifying fuel. The HHZ qualifying fuel requirements have increased from 40% to 80% of total feedstock supply needs. Going forward, the seven BioRAM plants are expected to consume about 930,000 BDT of qualifying fuel annually. This will be some mix of forest residues and mill residuals.

2. Currently, about 65-70% of the forest-based biomass comes from forest residues and the remainder was from mill residuals.

3. To date, the implementation of BioRAM at the seven plants has increased the proportion of forest derived fuel (i.e., HHZ) utilized by 230% relative to the amount of forest derived fuel consumed prior to implementation of BioRAM at the plants.

4. The cost of qualifying fuel is greater than the cost of non-qualifying fuel. The average cost of qualifying fuel increased 33% to about $60/BDT from 1Q17 to 2Q18. During the same period, the price of non-qualifying fuel at the BioRAM plants dropped 33% to $23/BDT. These price changes are due to the competition between BioRAM plants for qualifying fuel.

5. Increasing fuel cost is due to: (1) competition for qualifying fuel between BioRAM contract holders; and (2) higher production cost of fuel from forest residues relative to fuels from other sources like agricultural and urban wastes.

Findings: BioRAM power plants raised concerns about the supply of qualifying fuel

6. The BioRAM 2 restrictions on forest biomass fuel from clearcutting limits availability of qualifying fuel from private industrial forest lands, which is the source of most of the timber harvested in California. While the BioRAM 1 contracts do not have this restriction, the difference has created some confusion in the biomass marketplace. As BioRAM 1 contracts are extended pursuant to SB 901, they will be subject to the same clearcut provisions as the BioRAM 2 contracts.

7. The cost of hauling forest biomass fuel is often considerable relative to the value the fuel provides when it is combusted to produce power. Some plants have difficulty finding enough qualifying fuel within a cost-effective haul distance.

8. Even with the favorable power price afforded by the BioRAM contracts, some BioRAM plants reported difficulty obtaining enough qualifying fuel within an economically viable haul distance to meet contract obligations.

Findings: The potential supply of forest biomass fuel

9. This study finds that the HHZ land base currently contains a surplus of forest material suitable for biomass fuel. Economic and forest management factors, however, limit the amount of forest biomass fuel actually delivered to the biomass power plants.

10. Forest biomass fuel is wood that has no higher-valued use, namely: (1) forest processing residues – the tops and branches of trees harvested for higher-valued wood products; (2) small trees with no merchantable value – typically cut to reduce fire hazard and make stands more resilient; and (3) larger dead trees, which because of decay are not suitable for higher-valued wood products.

11. A current in-place inventory developed for this project identifies potentially 248 million BDT of biomass on 13.1 million acres suitable for management in the HHZ.

12. There are 3.6 million acres of HHZ within an economically viable 50-mile haul distance of the BioRAM plants. Those acres contain about 42 million BDT of potential biomass. Given that the BioRAM plants will need about 930,000 BDT per year, there is no shortage of potential biomass material in the HHZ. ("Potential biomass" is the wood currently existing in the forest uncut that is suitable biomass fuel).

13. Actual production of biomass material, however, is limited by economic factors and the extent of forest management activities and treatments. The total amount of forest-based biomass delivered to all biomass power plants in 2017 was about 450,000 BDT. The portion of this that qualifies as BioRAM fuel is at least 340,000 BDT as that was the amount delivered to the BioRAM plants.

14. Mill residuals are also considered qualifying forest biomass fuel for the BioRAM contracts. In 2017 about 1.1 million BDT of mill residuals was consumed by all biomass power plants. About 176,000 BDT of mill residuals were consumed at the BioRAM plants.

Findings: The economics of biomass production

15. Using forest fiber for fuel provides a less favorable economic return than use for manufacturing any other wood product. As a result, forest biomass fuel is comprised of wood that has no better use.

16. Interviews with public and private land managers indicate that forest biomass fuel production costs are high relative to the fuel's value, and many report that post-harvest biomass is sometimes left in the forest because the costs of chipping, loading, and hauling exceed the value of the biomass delivered to the power plant. Specific third-party estimates of how much material is left behind in the woods are not available. In this study we estimate that between 40% and 80% of the biomass associated with annual commercial harvest does not make it to the biomass power plants.

17. US Forest Service (USFS) land managers subsidize biomass production or transportation on some forest restoration and hazardous fuels reduction projects. In these cases, it may be more cost effective to remove the material as biomass fuel than to burn the material in the field, but not always. Land managers report that supplemental funding to increase the amount of biomass removed is very limited.

18. In-woods biomass produced from tops and branches of commercial logs usually has the lowest cost because the material is already on log landings next to a road. In contrast, costs for producing biomass from small trees and larger dead trees are higher as the logger must fell and skid the material to the landing and there are no associated sawlogs to offset those costs. It should be noted that not all roads are accessible to chip vans because of trailer clearance and curve tracking, and the only biomass that might be removed – without additional investment – are delimbed tree tops that can be transported using a normal logging truck to a central location for chipping.

19. Given the low value to weight ratio of biomass, transportation costs can be a significant portion of the delivered cost of forest biomass. Biomass plants have an economic incentive to focus on fuel close to the plant, leaving more distant biomass unutilized.

20. Break-even prices for fuel delivered to biomass power plants are based on plant revenue as impacted by power contract prices and operating costs specific to each power plant – data that were not available for this study. Using broad estimates, we expect that the BioRAM plants could break-even with average fuel costs around $65-$75/BDT. This is a broad estimate and results for each plant will vary.

21. Regarding the rate of harvest, more forest-residue biomass should become available as public and private forest managers accelerate forest restoration efforts:

    A. Expedited hazardous fuel removal treatment projects in the Tier 1 HHZ have provided a substantial amount of forest biomass – at least 330,000 BDT from CalTrans and PG&E alone. Delivery of this material to the power plants has been subsidized.

B. The USFS forest restoration treatments currently cover about 287,000 acres per year. About 110,000 acres of treatment might produce biomass fuel. Current USFS biomass fuel production is about 150,000 BDT per year. These figures apply to USFS acres across California, not just the HHZ.

   The USFS intends to accelerate forest restoration to achieve around 500,000 acres treated per year – roughly twice the current rate. Assuming the current ratio of biomass-producing treatments to total treatments, biomass fuel production could approach 300,000 BDT annually.

C. Private landowners currently conduct harvest on about 110,000 acres per year. We estimate that biomass cut as part of harvest could be as much as 1.4 million BDT annually, but that only about 300,000 BDT is delivered to the biomass power plants. A sizeable but unknown portion of this biomass is from clearcutting which does not qualify under BioRAM 2 contracts and BioRAM contracts modified under SB 901.

   The California Forest Carbon Plan establishes goals to increase treatments on private lands to 250,000 acres by 2020 and 500,000 acres by 2030. This could generate even more biomass fuel.

BARRIERS

Section 9 of this study identifies barriers to greater production and utilization of HHZ forest biomass fuel.

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1 INTRODUCTION

The Governor's Emergency Proclamation of 2015 focused the attention of state and federal agencies and other interested parties on strategies for utilizing forest biomass for energy production to facilitate removal and utilization of trees killed by insect and drought. To that end, certain bioenergy facilities have been awarded BioRAM[1] power contracts that provide favorable energy prices in exchange for an agreement to utilize feedstock that originates in High Hazard Zones (HHZ) and meet other requirements.

The BioRAM power plants have raised concerns about their ability to meet the sourcing requirements of the BioRAM contracts. An ad hoc committee of interested parties contracted with Mason, Bruce & Girard, Inc. (MB&G) and The Beck Group (BECK) to investigate a variety of resource-based questions regarding the supply and demand of forest biomass fuel, along with barriers to increased use of forest biomass.[2] We reviewed literature, gathered and analyzed data, conducted interviews, developed inventory and supply models, and provide analysis of opportunities and challenges. This report summarizes our findings and identifies barriers to forest biomass production and utilization.

2 BIORAM PROGRAM BACKGROUND

California forests are experiencing a period of stress characterized by drought (Baguskas, Peterson, Bookhagen, & Still, 2014), (Freeman, Stow, & An, 2007), mortality (Olson, 2018), (Preisler, Grulke, Heath, & Smith, 2017), and large and destructive forest fires (Hood, Smith, & Cluck, 2007). At the same time, California seeks to reduce GHG emissions through shifting power production from fossil fuel to renewable sources such as solar, wind and biofuel (Simet, 2017), (Levin, 2016).

On October 30, 2015, California Governor Brown issued a state of emergency proclamation concerning dead and dying trees. The emergency proclamation directed the Department of Forestry and Fire Protection, the California Natural Resources Agency, the California Department of Transportation, and the California Energy Commission to identify areas that represent High Hazard Zones (HHZ) for wildfire and falling trees. The emergency proclamation also directed the CPUC to extend contracts at existing forest biomass plants that receive feedstock from HHZs.

In response to the Governor's emergency proclamation directive, the CPUC issued Resolution E-4770 on March 17, 2016, requiring that each of the Investor Owned Utilities (IOUs), including Pacific Gas and Electric (PG&E), Southern California Edison (SCE) and San Diego Gas & Electric Company (SDG&E), enter into contracts to purchase their share of at least 50 MW of collective generating capacity from bioenergy facilities that use fuel from the HHZ. The calendar year HHZ minimums were set as follows:

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[1] BioRAM – Biomass Renewable Auction Mechanism

[2] See Appendix M for company bios of MB&G and BECK

40% in 2016, 50% in 2017, 60% in 2018, and 80% for each subsequent year. The IOUs were required to provide five-year contracts to facilities, with the right to extend the five-year contract term for one year at a time, up to a cumulative total of ten years so long as HHZ fuel is available at the minimum fuel requirement. Contracts executed pursuant to the terms of Resolution E-4770 are known as BioRAM I contracts.

A later directive also affecting the BioRAM program, SB 859, was signed by the Governor and filed with the Secretary of State on September 14, 2016. It included a new requirement for Investor Owned Utilities and Publicly Owned Utilities serving more than 100,000 customers to procure their proportionate shares of 125 MW of power from existing bioenergy facilities using prescribed amounts of dead and dying trees located in HHZs as feedstock. Of the 125 MW the IOUs share is 96 MW. The legislation required that at least 80% of the feedstock of an eligible facility on an annual basis must be a by-product of sustainable forestry management, which includes removal of tress from HHZs and is not from lands that have been clear cut; and that at least 60% of the feedstock must come from HHZs. SB 859 also specified that procurement pursuant to CPUC Resolution E-4770 that is in excess of the procurement requirement in CPUC Resolution E-4770 shall count towards meeting the utility's share of the 125 MW goal.

On October 21, 2016, the CPUC issued Resolution E-4805 to implement the IOU procurement requirements of SB 859. E-4805 allowed IOUS to meet their proportionate shares of the 125 MW goal using any combination of: 1) the BioRAM ordered by Resolution E-4770; 2) a subsequent RAM, or BioRAM 2 authorized in the Resolution; and 3) bilateral procurement. To allow procurement under option 2, the IOUs were required to create an updated BioRAM 2 standard contract rider. BioRAM 2 contracts only differ from BioRAM 1 contracts in that they contain the feedstock requirements established in SB 859; specify that the contract length is five years; require that the contracted facility is an existing bioenergy project that commenced operation prior to June 1, 2013; and update administrative details such as date deadlines and process requirements.

Additional developments in the BioRAM program came about from SB 901, which was signed into law in the Fall of 2018 and CPUC Resolution E-4977 issued in early 2019. Their impact on the BioRAM program is described later in this chapter.

3 OBJECTIVES

The objective of this report is to provide information that leads to a better understanding of both the current and future demand for and supply of biomass fuel that meets the BioRAM qualifications, and to identify barriers to increasing forest biomass fuel production.

This report is organized into Sections as follows:

- Section 4 summarizes the current forest biomass market.
- Section 5 evaluates the current and projected use of forest biomass fuel from the existing BioRAM contract holders, and reports on difficulties and recommendations raised by these contract holders.
- Section 6 provides an inventory of potential biomass fuel from California's forests, develops biomass fuel cost curves for each BioRAM facility, describes the competition for forest biomass and evaluates the potential demand for biomass against the potential supply in the HHZs.
- Section 7 describes factors affecting the current production of forest biomass fuel.
- Section 8 explores the role that forest biomass production plays in California's efforts to increase the pace and scale of forest restoration.
- Section 9 identifies barriers to increased forest biomass production.

To keep this report concise, technical descriptions of analytical procedures and forest management methods are found in an extensive set of appendices.

4 THE MARKET FOR FOREST BIOMASS

While this study focuses primarily on the demand for qualifying biomass fuel from the biomass power plants with BioRAM contracts and the potential supply and production of forest biomass from the HHZs, this is only a portion of the biomass power market in California. This section paints a broader picture of the biomass economy to give context to topics specific to BioRAM.

There are currently 24 biomass power plants in California. Seven of these biomass power plants obtained BioRAM contracts as of 2018. In 2015, CalRecycle began collecting and reporting information, (CalRecycle, 2015) about the type of biomass material used at all power plants as shown in the first block Figure 1.[3] Over the three years reported (CalRecycle, 2017), (CalRecycle, 2016), an average of 3.4 BDT[4] of biomass was consumed at an average of 25 biomass power plants.[5] On average, In-Forestry biomass fuel accounted for about 452,000 tons, about 13% of the total. Mill Residue accounted for just over 1.1 million tons, about 34% of the total. The rest of the biomass was derived from agricultural and urban waste streams.[6] [7]

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[3] The CalRecycle data is self-reported and allows biomass plants to report in both green and dry tons. CalRecycle does not convert to a common basis but notes that In-Forestry and Mill Residues are typically reported as dry tons, Ag is typically reported as wet tons, except for nut shells, and Urban is typically reported as wet. We adjusted Ag and Urban to BDT using factors of 0.6 and 0.8 respectively. Data collected for this study are expressed in BDT.

[4] BDT = Bone Dry Ton. A BDT is a measurement unit used in the biomass industry. It is derived by calculating wood's weight after subtracting the portion of the weight that is water. For example, an amount of wood (and the contained water) weighing 2,000 pounds, that is 50% moisture by weight, would contain 1,000 pounds of "bone dry" wood and is equal to 0.5 BDT.

[5] 3.4 million BDT would fill about 272,000 chip vans.

[6] For Figure 1 we use the terminology of the CalRecycle report – "In-Forestry" and "Mill Residue." Throughout the rest of this report we use the more common terms of "forest residue" and "mill residuals."

[7] Figure 1 also reports biomass consumption data collected by the USFS in the 2012 mill study (McIver, et al., 2014). The USFS researchers contacted each biomass consuming power plant to determine how much forest-based biomass was delivered directly to the mills, and how much came from mill residuals. That reports shows about 40% more biomass delivered to biomass power plants, and that more of it was from forest residue than mill residuals. We do not know if these differences are due to methodology, or changes in the biomass markets.

Figure 1. Biomass utilization in tons (BDT) by BioRAM and other biomass power plants in California, 2012-2017. USFS data from UM BBER 2012 (McIver, et al., 2014) and indicated harvested volume.

			2012	2013	2014	2015	2016	2017	2015-17 Ave
		Units	USFS			Reported by CalRecycle			
All CA Biomass Plants	# Facilities					29	22	24	25
	Ag	Estimated BDT				813,421	744,673	581,056	713,050
	In-Forestry	Reported BDT	1,629,000			552,323	298,577	503,939	451,613
	Mill Residue	Reported BDT	531,000			1,305,490	816,666	1,116,881	1,079,679
	Urban & Other	Estimated BDT				1,446,082	1,080,585	955,127	1,160,598
	Total					**4,117,316**	**2,940,500**	**3,157,003**	**3,404,940**
					Reported in this study				
BioRAM Plants	# Facilities				7	7	7	7	7
	Ag	Bone Dry Tons			383,788	337,385	352,877	330,859	340,374
	In-Forestry	Bone Dry Tons			195,711	224,431	150,366	339,810	238,202
	Mill Residue	Bone Dry Tons			175,063	156,668	193,735	175,909	175,437
	Urban & Other	Bone Dry Tons			375,813	421,821	251,984	268,360	314,055
	Total				**1,130,375**	**1,140,305**	**948,962**	**1,114,938**	**1,068,068**
						Calculated			
Other Biomass Plants	# Facilities					22	15	17	18
	Ag	Estimated BDT				476,036	391,796	250,197	372,676
	In-Forestry	Reported BDT				327,892	148,211	164,129	213,411
	Mill Residue	Reported BDT				1,148,822	622,931	940,972	904,242
	Urban & Other	Estimated BDT				1,024,261	828,601	686,767	846,543
	Total					**2,977,011**	**1,991,539**	**2,042,065**	**2,336,872**

Over the three-year period (2015-2017), the seven BioRAM plants consumed about 1.1 million BDT—about 31% of the total biomass consumption. The BioRAM contracts began in 2017, however, which is more relevant for understanding the biomass market share of the BioRAM contracts. In 2017, BioRAM contracts accounted for 35% of the total biomass consumed. The BioRAM plants took 68% of the 2017 In-Forestry biomass and 16% of the Mill Residue.

The biomass consumed by other non-BioRAM biomass plants is calculated in the third block of Figure 1**.** These plants consume a large portion of the urban and agriculture waste streams. This category includes the biomass power plants located at the sawmills, which explains their high percentage of Mill Residue consumption.

SB 1122[8] directs California Public Utilities Commission (CPUC) to procure another 50 MW of power from new smaller power plants under the BioMAT[9] program. To date, none of these plants are yet operating so there are not yet data about their fuel consumption. We estimate annual fuel consumption from the BioMAT plants could be around 394,000 BDT once they are fully operational.[10] This would be a 12% increase to the total biomass consumption. Assuming the BioMAT plants use In-Forestry and Mill Residue exclusively, the additional BioMAT demand against those resources would be 26%. In practice, however, we would expect some of the BioMAT demand would come from In-Forestry and Mill Residue

[8] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201120120SB1122

[9] BioMAT – Biomass Market Adjusting Tariff

[10] Assuming the BioMAT plants can make 1 MWH from 1 BDT of biomass. Then 24 hours/day x 365 days/year x 90% uptime x 50 MW/hour x 1 BDT/ 1 MWH = ~394,000 BDT/year

that currently goes to other biomass power plants, where the price is favorable. Ultimately, some of the additional demand from BioMAT plants could shift demand to agricultural and urban wastes.

To provide some context for Figure 1, we preview here a few relevant figures developed in following sections:

- Section 5 shows that the BioRAM plants will need about 940,000 BDT of biomass fuel going forward. This will be some combination of forest residues and mill residuals.

- Section 6 shows that the inventory of potential forest residue biomass on the 13 million acres of HHZ suitable for management is about 248 million BDT.

- Section 7 estimates that total forest residue biomass cut annually is between 745,000 BDT and 2.5 million BDT.

- Section 8 estimates that current production of forest biomass fuel is about 150,000 BDT from USFS lands and 300,000 BDT from private lands.

5 DEMAND FOR BIOMASS FUEL FROM BIORAM POWER FACILITIES

The study objectives are to provide a better understanding of the barriers to increased utilization of HHZ biomass fuel and the fuel supply chain. This section focuses specifically on the plants operating under BioRAM power sales contracts.

5.1 BIORAM PLANTS

As of August 2018, a total of seven biomass power plants have executed BioRAM contracts. They have a combined nameplate power production capacity of 206.7 MW and a BioRAM contractual power generation capacity of 171.7 MW (Figure 2). As shown in the table, five of the plants are operating under BioRAM I contracts and two are operating under BioRAM II contracts.

Figure 2. Summary of BioRAM Plants

Plant Owner/Plant Name/Location	Nameplate Plant Capacity (MW)	BioRAM Contract Capacity (MW)	BioRAM Contract Type (I or II)	BioRAM Contract Start (Date)
IHI - Rio Bravo – Fresno, CA	24.3	24.3	I	10/1/2017
IHI - Rio Bravo – Rocklin, CA	24.4	24.4	I	10/1/2017
IHI - Pacific Ultrapower - Chinese Station, CA	22	18	I	4/1/2017
Greenleaf Power - Honey Lake Power, Honey Lake, CA	30	24	I	2/1/2017
Olympus Power - Burney Forest Power – Burney, CA	31	29	I	10/1/2017
Wheelabrator Technologies Inc. – Shasta – Anderson, CA	50	34	II	12/2/2017
American Renewable Power - Loyalton Cogen LLC, Loyalton, CA	25	18	II	4/20/18
Total	**206.7**	**171.7**		

5.2 BIORAM SNAPSHOT

This BioRAM Snapshot describes the BioRAM plant's compliance with contract requirements, descriptive statistics about their overall fuel supplies and costs, and how forecasted supplies compare with contract requirements.

The BioRAM Snapshot is based on data the consulting team collected directly from BioRAM plants regarding their fuel usage and fuel costs, and from in-person interviews conducted with plant managers and plant fuel buyers. Except as noted, all information reported is from either the BioRAM plant fuel data or from interviews with BioRAM plant representatives.

5.2.1 BIORAM PLANT BIOMASS FUEL USAGE

The following report subsection provides data about biomass fuel consumption among the seven BioRAM plants. Please note, the BioRAM power plants consider their delivered fuel prices to be confidential information. Therefore, data is presented on an aggregated basis to preserve confidentiality. This allowed for collection of quarterly biomass fuel data regarding the volume, delivered costs ($/BDT), and sources (urban, ag/orchard, mill residues, forest derived, and other) consumed before and after execution of BioRAM contracts. Per terms of the NDAs, the fuel usage and fuel cost data presented in this report is aggregated so that fuel volumes and fuel prices cannot be linked to a specific BioRAM power plant. Also note the term *qualifying fuel* refers to fuel sourced from HHZs and sustainable forest management sources and *non-qualifying* fuel refers to fuel from all other sources (e.g., urban wood waste and ag/orchard wood waste).

5.2.2 HISTORICAL BIORAM PLANT BIOMASS FUEL CONSUMPTION

Based on the data provided by the BioRAM plants, Figure 3 illustrates the amount of biomass fuel consumption at the plants before BioRAM started (2014 to 2016) and under BioRAM in 2017 and 2018. As illustrated in the table, 324,000 BDT of qualifying fuel was consumed in 2017 and 691,000 BDT in 2018. The fuel usage data provided by the plants indicates that once they began operating under BioRAM contracts, they have been meeting the minimum qualifying fuel requirements in 2017 (50% for BioRAM I and 80% for BioRAM II) and 2018 (60% for BioRAM I and 80% for BioRAM II). The exception is a BioRAM I plant that opted to exercise its one-time irrevocable fuel switching option.

Figure 3. Annual Consumption (BDT) of qualifying and non-qualifying fuel among BioRAM power plants

	2014	***2015***	***2016***	***2017***	***2018[11]***
Non-BioRAM Fuel Demand *(BDT thousands)*	1,358	1,368	1,177	1,020	486
BioRAM Qualifying Fuel Demand *(BDT thousands)*				324	691
Total Fuel Demand *(BDT thousands)*	1,358	1,368	1,177	1,344	1,177

Several points about fuel consumption reported above merit further discussion:

- The fuel usage totals are aggregated in this report to avoid revealing the identity of any specific plant.
- One BioRAM plant did not report fuel usage data. Therefore, the total volume consumed was adjusted to include the estimated qualifying and non-qualifying consumption of that plant.
- Only the first and second quarters of 2018 fuel usage data were reported by the plants because the data was gathered in Q3 2018. Therefore, the 2018 consumption totals were adjusted to an annualized amount based on usage in Q1 and Q2 2018.

5.2.3 BIORAM PLANT FUEL SOURCES: BEFORE BIORAM & SINCE BIORAM

Historically, California's biomass plants have consumed fuel from a variety of sources including urban wood wastes, ag/orchard waste, forest products mill residues, forest derived fuel, and miscellaneous sources:

- *Urban Wood Waste* – this fuel source includes industrial wood wastes such as pallets and wood scraps from woodworking shops, lumber yards, etc. It also includes wood material arising from construction and demolition and land clearing activities—including sawn lumber and other wood products, and whole trees and stumps generated from land clearing activities. Finally, it also includes wood wastes recovered from the municipal solid waste stream including pruned branches and whole trees from urban tree maintenance activities.

- *Ag/Orchard* – this fuel source includes trimmed/pruned material from orchards, whole trees/stumps from orchard removals, and various ag/orchard by-products such as fruit pits and nut shells. Ag/Orchard derived fuel can be used at BioRAM plants so long as it constitutes the portion of the total fuel supply not required to come from specified sources.

- *Mill Residues* – this fuel source includes various by-products of forest products manufacturing operations including sawdust, planer mill shavings, wood chips, bark, and log yard debris. Mill residues derived from logs harvested in HHZ areas are generally considered to be BioRAM qualifying fuel.

- *Forest Derived* – this fuel source is material sourced directly from forests including whole trees removed as forest management treatments that aren't otherwise used as sawtimber, veneer logs, etc. It also includes the portions of trees not utilized by forest products manufacturers: including branches, tree tops, and the portions of a tree's main stem that are defective (e.g., crook, rot, etc.). Forest derived fuel originating from an HHZ or from a sustainable forest management activity is a BioRAM qualifying fuel.

- *Other* – this fuel source includes all forms of woody biomass not otherwise included in the preceding categories.

The intent of the BioRAM program is to increase the proportion of fuel consumed from HHZs. This typically includes the forest derived and mill residues categories. Therefore, data were collected about the proportion of fuel consumed from each source type among the BioRAM plants. The data were collected from 2014 to the present so that inferences could be drawn about how the fuel source mix has changed since the implementation of BioRAM.

Figure 4 illustrates how the sources of fuel among the plants have varied over time. Note that in Q1 2017 (denoted by the vertical black line in the figure), at least a portion of the plants first reported procurement of biomass fuel meeting the specifications of the BioRAM contracts.

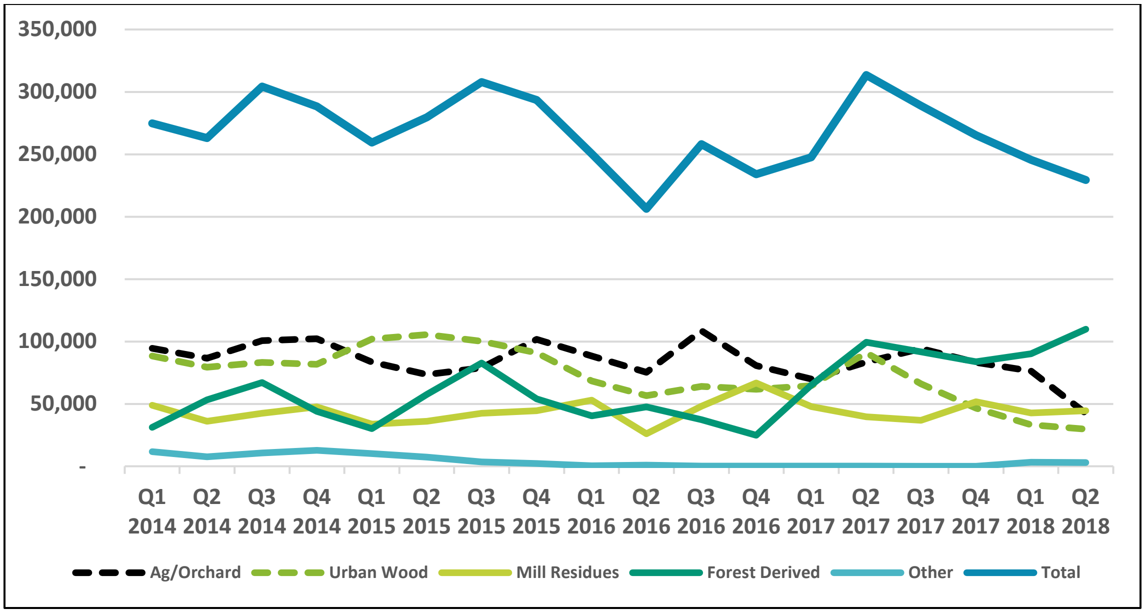

Figure 4. Composition of biomass fuel (BDT, vertical axis) by source type at BioRAM plants by quarter (horizontal axis) from 2014-2018

As the data in the figure show, since the inception of the BioRAM contracts, the mix of sources of fuel consumed at the reporting plants has changed. Specifically, utilization of urban and ag/orchard biomass fuel sources (i.e., fuel not from HHZs) has declined. During 2014 to 2016, the average quarterly consumption of ag/orchard and urban wood was 171.3 thousand bone dry tons (88.5 thousand BDT of ag/orchard plus 81.8 thousand BDT of urban). By the second quarter of 2018, the combined consumption of ag/orchard fuel and urban fuel was 72.1 thousand BDT (42.4 thousand BDT of ag/orchard plus 29.7 thousand BDT of urban); a drop of nearly 60% compared to the 2014 to 2016 average. The current disposition of ag/orchard fuel that was previously used at BioRAM facilities is a knowledge gap.

Related to the drop in utilization of ag/orchard and urban fuel, utilization of forest derived fuel has increased significantly. Between 2014 and 2016, the average quarterly consumption of forest derived fuel was 47.5 thousand BDT. By the second quarter of 2018, the quarterly consumption of forest derived fuel increased to 109.8 thousand BDT; a 230% increase in the amount of fuel consumed from forest derived sources (e.g., qualifying fuel from HHZs, sustainable forest management, etc.).

Also related to the changing fuel supply source mix, the utilization of mill residues and “other” fuel have both remained relatively unchanged since the inception of the BioRAM program. This is despite mill residues being a qualifying fuel—so long as the supplying mills can provide documentation that their logs originated in HHZs and, in the case of the BioRAM 2 contracts, from sustainable forest management activities. The BioRAM plants reported that while more mill residues are produced than are consumed by the BioRAM plants, a significant portion have a higher value for other uses. Therefore, utilization of mill residues as a qualifying fuel is essentially "capped." Those BioRAM plant-reported observations are supported by a publication by Montana's Bureau of Business and Economic Research (McIver, et al., 2014). In 2012, California's bioenergy sector consumed about a quarter of all primary mill residues produced in the state. The balance of the primary mill residues produced were consumed by a combination of landscaping, mulch, animal bedding and other products, internal energy production at mills, and by composite wood panel manufacturers (e.g., particleboard producers). Nevertheless, a more detailed examination of mill residue utilization is a gap in existing knowledge.

In summary, the data from the BioRAM plants suggests that utilization of biomass fuel at the BioRAM plants is consistent with the intent of the BioRAM program (i.e., providing a mechanism for increasing the utilization of forest derived fuel from areas designated as HHZs and from sustainable forest management sources).

5.3 BIORAM PLANT FUEL PRICES

Figure 5 illustrates the delivered fuel price over time among the reporting BioRAM power plants. Again, the black vertical line denotes when the reporting plants began procuring qualifying fuel and the data represents six of the seven BioRAM plants. One plant elected not to provide what they considered to be confidential price data. Increased utilization of fuel from forest derived sources beginning in Q1 2017 is associated with an increase in the delivered cost of fuel. During the three-year period of 2014 to 2016 (i.e., prior to BioRAM) the weighted average delivered fuel price was $35.95/BDT. Then beginning in Q1 2017 the average delivered cost of fuel begins a steady upward trend each quarter ending at an average delivered price among reporting plants of $46.22/BDT in Q2 2018. The rise in average delivered price is apparently driven by increasing prices for qualifying fuel (the light green line in the figure). Qualifying fuel starts at an average cost of $44.84 in Q1 2017 and ends at an average cost of $59.26 in Q2 2018.

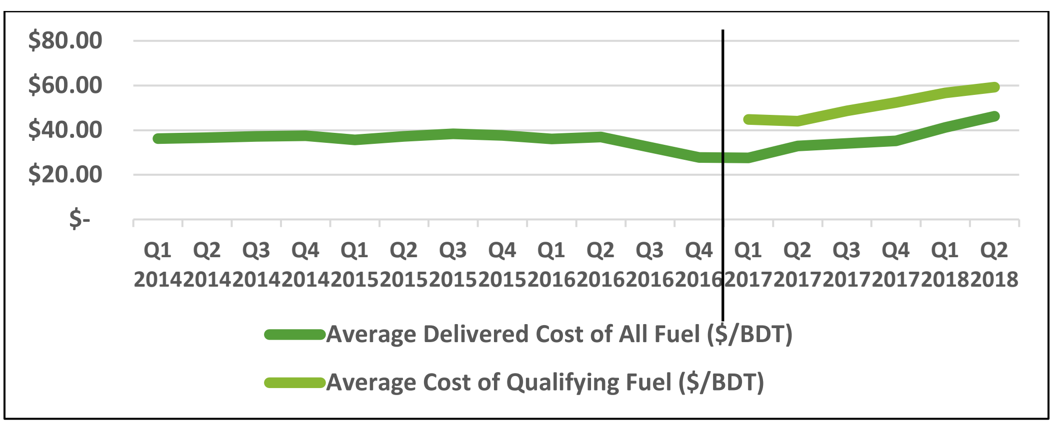

Figure 5. Delivered fuel cost history among BioRAM plants, $/BDT (vertical axis) versus quarter (horizontal axis)

Figure 6 combines the BioRAM plant fuel volume and pricing information with usage and pricing data for 2014 to 2018. Additional predictions are made about fuel usage for 2019 to 2021, based on BioRAM contract terms about qualifying fuel amounts and on biomass industry averages as reported by the BioRAM power plants, including fuel utilization rates of 1 BDT per 1 MWH (Shelly, 2007) and plants operating at 90 percent capacity (i.e., about 7,900 hours out of the 8760 hours in a year).

Figure 6. Comparison of fuel demand and price among BioRAM plants

	2014 Actual	***2015 Actual***	***2016 Actual***	***2017 Actual***	***2018 Actual***	***2019 Forecast***	***2020 Forecast***	***2021 Forecast***
Non-BioRAM Fuel Demand *(BDT thousands)*	1,358	1,368	1,177	1,020	486	233	233	233
Non-BioRAM Avg. Del. Cost *($/BDT)*	$36.88	$37.30	$33.20	$28.62	$23.22			
BioRAM Qualifying Fuel Demand *(BDT thousands)*				324	691	930[12]	930	930
BioRAM Qualifying Avg. Del. Cost ($/BDT)				$49.57	$57.97			
Total Fuel Demand *(BDT thousands)*	1,358	1,368	1,177	1,344	1,177	1,163	1,163	1,163
Total Fuel Avg. Del. Cost *($/BDT)*	$36.88	$37.30	$33.20	$33.67	$43.62			

No estimates of predicted (2019 to 2021) fuel prices were generated for the BioRAM Snapshot memo because of too much uncertainty about the availability of qualifying fuel supply in the years ahead, and the possibility that one (or more) plants may exercise their fuel switching option, which would alter the supply and demand balance and fuel pricing.

The utilization of non-qualifying fuel (i.e., urban, ag/orchard, and other) has declined significantly with the implementation of BioRAM. Conversely, qualifying fuel usage doubled from 2017 to 2018 (324,000 BDT in 2017 and 691,000 BDT in 2018). Qualifying usage is expected to further increase in 2019 by nearly 240,000 BDT to a total of 930,000 BDT, as plants continue to ramp-up qualifying fuel purchases to meet BioRAM contract terms. Note that for the predicted fuel usage, one plant was excluded since it has exercised its one-time, irrevocable fuel switching option.

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[12] This forecasted annual qualifying fuel consumption amount includes annual consumption at all BioRAM plants. Note, however, that one plant has elected to utilize the one-time fuel switching option and is therefore no longer tracking it's use of qualifying fuel

During the same period, the price for non-qualifying fuel has dropped by about one-third ($37/BDT in 2017 versus about $23/BDT in 2018). Because of the switch to qualifying fuel, there is extra non-qualifying fuel available, and that drops the price. That is a benefit to the BioRAM plants, because they can still burn some non-qualifying fuel. But it is likely a bigger benefit to the non-participating plants as their fuel becomes less expensive.

The price for qualifying fuel was about $50/BDT in 2017 and increased to about $58/BDT in 2018. The net impact on the average delivered cost of all fuel is an increase in price of about 33% from 2017 to 2018 (i.e., $33.67/BDT all fuel average delivered cost in 2017 vs. $43.62/BDT all fuel average delivered cost in 2018).

5.4 OBSERVATIONS FROM BIORAM PLANT VISITS

This section provides a summary of key observations arising from on-site visits to each of the seven BioRAM plants and interviewing plant management and plant biomass fuel procurement staff. Importantly, the information provided is a summary of what was reported by the biomass plant managers and plant fuel buyers. When possible, the information has been verified with data collected from the BioRAM plants, or from other published sources. In other cases, where observations made by the BioRAM plants cannot be independently verified, it is noted as a gap in existing information.

5.4.1 COMPETITION FOR QUALIFYING FUEL

A frequently mentioned issue during the plant visits was the unexpectedly high level of competition for qualifying fuel. Many of the plants reported that they based their BioRAM contract bids on the historically available volume and pricing of forest derived qualifying fuel. Once they began operating under the program, and as the number of BioRAM contracts increased, the plants reported that it became quickly clear that there is considerable competition for qualifying fuel among the BioRAM plants, especially among the four plants in Northern California. This observation is supported by the fuel cost data provided by the plants, which shows steadily rising prices for qualifying fuels.

As a result, several plants reported that exercising the one-time, irrevocable fuel switching option in the BioRAM I contracts is under serious consideration because they are not certain they can obtain the required amount of qualifying fuel at cost effective levels.

5.4.2 BIORAM PLANT FUEL BUYING BEHAVIOR

The following list includes specific examples of how an apparently limited supply of readily available qualifying fuel is affecting the procurement behavior of the plants.

1. *Shifts in Historical Procurement Areas*– it was reported during the plant visits that in order to procure qualifying biomass fuel, BioRAM plants have shifted from historical fuel procurement areas

to other areas where qualifying fuel is more plentiful. Based on the reports of the plants it is likely that the average fuel transportation distance has increased since the implementation of BioRAM. However, that conclusion is not definitive without additional analysis that would involve collecting fuel transportation data from the BioRAM plants.

2. *Contractor Assistance* – BioRAM plants reported that they are aiding fuel grinding and fuel trucking contractors in an attempt to maintain (and build) the required supply chain infrastructure. The aid provided has come in the form of financially assisting contractors who are encountering cash flow issues and by providing working capital to contractors to be used as bonding for purchasing biomass fuel from landowners. Additionally, the U.S. Forest Service Wood Innovation Grant program has funded 3 grants within the last 3 years to help BioRAM plants lease equipment that logging contractors were hesitant to purchase.

3. *Working Closely with Landowners* – BioRAM plants reported that they have begun to work more closely with timberland owners to be able to better utilize the available fuel. One specific example reported by the plants is that the U.S. Forest Service developed a statewide map and accompanying spreadsheet that includes a comprehensive list of planned and active U.S. Forest Service timber sales. This information was considered a helpful planning tool.

5.4.3 FACTORS AFFECTING SUPPLY AND COMPETITION FOR QUALIFYING FUEL

During the plant visit interviews, the plant managers and procurement staff also provided analysis, based on their experience participating in BioRAM, about the factors underlying and affecting the level of supply and the associated competition for fuel.

5.4.3.1 BIORAM PLANTS PERCIEVE DIFFERENCES AMONG BIORAM CONTRACTS

At the time of plant visits (early fall 2018) the BioRAM plants reported several perceived differences between BioRAM I and BioRAM II contracts. The plants held the position that these differences created an uneven playing field among BioRAM plants in the competition for procuring qualifying fuel. The differences reported by the plants included: 1) the “ramp up” over time for qualifying fuel requirement among BioRAM I plants versus an “immediate” qualifying fuel threshold for BioRAM II plants; 2) that BioRAM I contracts had a one-time fuel switching option, while BioRAM II plants did not have that option; and 3) BioRAM I plants had the option of “carrying over” fuel from reporting period to reporting period as a tool for managing compliance with contract terms, while BioRAM II plants did not have the fuel carry over option.

On September 21, 2018 SB 901 was signed into law. That legislation addressed the BioRAM I versus BioRAM II contractual issues described in the preceding paragraph. Additionally, on February 6, 2019, the CPUC issued Resolution E-4977 containing several amendments to the BioRAM program. Specifically, Resolution E-4977 offered guidance for amending BioRAM contracts to: 1) expand eligible fuel stock that can be classified as High Hazard Zone fuel; 2) offer BioRAM power plants a monthly opt-out and reporting option for annual fuel use requirements; and 3) remove missed fuel requirements as an event of default.

5.4.3.2 INFRASTRUCTURE

The BioRAM plants reported that limited infrastructure in the supply chain is a significant constraint on HHZ fuel supply. At the most basic level, the infrastructure needed to supply biomass fuel includes logging contractors, grinding/chipping contractors, trucking contractors, and labor to operate the equipment used by each type of contractor. It is the grinding and trucking contractor areas of the supply chain that the BioRAM plants reported the greatest constraints on fuel supply. Aside from what is reported by the BioRAM plants, detailed information about the capacity for trucking and fuel grinding is a gap in knowledge.

<u>Discussion about Infrastructure</u>

The following paragraphs aim to provide perspective on the infrastructure capacity needed to supply the plants. As previously described, the total annual demand for BioRAM qualifying biomass fuel is expected to reach about 1 million BDT per year.

From the data provided by the BioRAM plants, the historical average fuel moisture content is about 40%. Therefore, on average, each truckload of fuel, with a payload of 25 green tons, would deliver 15 BDT of fuel [25 green tons/truckload x (1 – 0.40) = 15 BDT/truckload]. Thus, 1 million BDT of annual fuel demand equates to roughly 67,000 truckloads per year (1,000,000 BDT divided by 15 BDT per truckload). This in turn translates to about 270 truckloads delivered per day among the BioRAM plants assuming a 250 work days per year (67,000 truckloads per year divided by 250 working days per year). Further, assuming each truck makes an average of two round trips per day, then a fleet of a minimum of 130 truck/trailers and the same number of drivers are needed to supply the BioRAM plants (270 ruckloads per day divided 2 round trips per day). It is not definitively known how many trucks, trailers, and drivers are currently operating, but trucking capacity was frequently listed as a supply constraint by the BioRAM plants.

Regarding grinding capacity, the productivity of mobile horizontal grinders can vary significantly, depending on the type of material being processed, its moisture content, the access to and handling of the material being processed, and the length of the logging season. That being said, an order of magnitude estimate of average annual grinder production capacity when processing forest derived fuel is 22,500 BDT per year per grinder (150 BDT/day x 150 days per year).

According to the data provided by the plants and from information provided during the plant visits, mill residues have historically supplied a total of about 160,000 BDT of fuel annually to the seven BioRAM plants. The mill residue volume consumed has not changed significantly for several years and according to the BioRAM plants, it is not expected to change in the future. Therefore, assuming the same level of sawtimber production (and mill production) in the future, when the total annual demand for BioRAM qualifying fuel reaches about 1 million BDT, about 840,000 BDT of that annual demand will have to be forest-derived material that will have to be processed into fuel using grinders. This, in turn, means that an estimated 35 to 40 grinders would need to be operating to supply the demand for forest-derived fuel among BioRAM plants (840,000 BDT/year divided by 22,500 BDT/year/grinder). It is not known how many grinders are currently operating, but grinding capacity was frequently listed as a supply constraint by the BioRAM plants.

Specifically Identified Infrastructure Issues

Given the preceding discussion about BioRAM qualifying fuel demand and the rough estimates of the grinding and trucking infrastructure needed to meet that demand, the following list includes specific infrastructure related fuel supply constraints reported by the BioRAM plants during the site visits.

1. *Limited Infrastructure is a Supply Constraint but Varies Regionally* - Lack of infrastructure, especially among grinding/chipping and trucking contractors in Central and Southern Sierra region, constrains the ability of BioRAM power plants to procure BioRAM qualifying biomass fuel. Limited infrastructure (grinding/chipping and trucking) was also cited as a concern by plants in the Northern Sierra region, but to a lesser degree.

2. *There is a Need for Long-Term Investment* - The power plant fuel buyers reported that their fuel supply contractors were hesitant to make the significant investments in equipment needed to build-up supply chain infrastructure (e.g., grinders/chippers, trucks, etc.). This is reportedly driven by the fact that the five-year term of the BioRAM contracts makes investing in equipment too risky because there is limited assurance the equipment can be amortized over the short term of the BioRAM contracts. Note that CPUC Resolution E-4977 addressed this issue by allowing 5-year extensions to certain BioRAM and other biomass contracts.

3. *Labor Shortages also Contribute to Lacking Infrastructure* – Even in regions where contractors have equipment and the infrastructure is more robust, the plant fuel buyers reported that it is very difficult for biomass fuel contractors to find enough dependable labor to operate equipment at full capacity.

4. *Log Supply for Sawmills is a Priority* - Related to the two previous points, the biomass plant managers and fuel buyers reported that sawmills throughout the HHZ areas are well established, have well developed supply chains, and are viewed by contractors as being relatively stable. It was reported that these factors all combine to cause contractors to prioritize logging and delivering sawtimber rather than diversifying their businesses to also produce lower-value biomass fuel.

5. *Impact of Wildfire* – The occurrence and response to wildfires strains infrastructure. The economic value of biomass fuel is among the lowest of all primary forest products (e.g., much lower than the value of sawlogs). Therefore, little biomass supply develops from forest management activities

solely focused on generating biomass fuel. Rather, biomass fuel much more commonly develops as a by-product of saw timber harvesting operations. In other words, as saw timber is harvested, the limbs and tops of those trees become what is most utilized as biomass fuel. This material is commonly referred to as logging slash.

According to the biomass plant fuel buyers interviewed, this situation means that for biomass fuel sourced directly from the forest, supply is dependent on the amount and location of saw timber harvesting activities. An example of how this circumstance can negatively impact a given plant's supply chain is when large wildfires occur. The first and relatively short-lived impact is that many contractors temporarily quit logging and trucking to assist in firefighting efforts. This disrupts biomass fuel supply.

A second and longer-lasting impact is that there is a limited time window for salvaging fire killed timber. Therefore, logging contractors quickly move to the site of a fire to carry out salvage operations and to capture the sawtimber value before trees deteriorate. This may disrupt biomass fuel supply as contractors move off non-salvage harvesting operations that are supplying biomass fuel. It may also be that the site of the fire is a great distance from biomass plants. In such cases, the biomass fuel supply can be negatively impacted if the cost of transporting fuel from a distant fire salvage operation makes the material too expensive. Finally, log markets are negatively affected by a glut of fire salvaged saw logs. Depressed log markets decrease the economic incentive for landowners to harvest timber, which in turn reduces the amount of biomass fuel available as a by-product of timber harvesting.

6. *Transition in Logging Equipment* – in the Northern Sierra region over the last several years, there appears to have been a change in the make-up of logging industry infrastructure. Specifically, it was reported by the plant fuel buyers that logging contractors have transitioned from whole-tree logging systems to cut-to-length logging systems. This distinction is important because in a whole-tree logging system, the whole tree (bole, limbs, top) is brought to a centralized landing area for processing into logs. Whatever parts of the tree that don't become logs accumulate at landings. This accumulated material is called logging slash and since it is all gathered up at a landing it can be processed into biomass fuel with relative ease. In contrast, a cut-to-length system processes a tree into logs right at the spot the tree was harvested. Then only the logs are brought to a centralized landing area. Thus, in a cut-to-length system, all of the "non-log" parts of a tree are scattered across an entire timber harvest area and gathering it all up after the logs are removed is cost prohibitive because the cost of operating the machinery to collect the material across a wide area greatly increases cost. The change in logging systems was reported by the fuel buyers to constrain the ability of BioRAM power plants to procure BioRAM qualifying biomass fuel. Note that in interviews with other stakeholders conducted as part of this study, different opinions were stated about the extent of the transition in logging equipment. Thus, there is conflicting information being reported and detailed information about the types of logging equipment in use is a gap in knowledge.

7. *Mill Residue Utilization Addresses the Seasonality of Forest Derived Fuel* – Sawmills and other primary forest products conversion facilities are also part of the industry infrastructure. Across all regions, the power plants reported that sawmills are able to document the percentage of their logs (and resulting mill residues) that come from BioRAM qualifying sources. This means that sawmill residues such as bark, sawdust, planer shavings, and chips are all being utilized as qualifying fuel. Since the sawmills operate year-round, their fuel becomes almost the only source of BioRAM qualifying fuel during the winter when nearly all logging ceases and the forest derived biomass fuel arising from logging activities is not readily available.

8. *Competition from Other Forest Products Facilities is a Factor Limiting Supply of Qualifying Fuel* – The power plant managers and fuel buyers reported that a negative aspect of the existing mill infrastructure is that some operations are competing for the same material used by BioRAM plants. This includes operations that produce composite panels, bagged shavings, landscape materials, firewood, and logs/chips for overseas export. It should be noted, however, that if there were a more robust forest products industry in California, the overall level of timber harvesting and forest products manufacturing activity would increase, which would likely result in more fuel available to BioRAM plants.

9. *Satellite Supply Yards* – A new addition to the infrastructure equation is that a number of the BioRAM plants have established remote and/or on-site satellite supply yards. What is accepted at the yards varies by plant but includes BioRAM qualifying fuel in both ground/chipped form and in the form of non-merchantable logs (i.e., logs that are too small, too decayed, or that contain other defects which render them unusable at sawmills). In the case of the non-merchantable logs, grinders are periodically brought into the yards to process the roundwood into biomass fuel. Building log inventories prior to winter at these satellite yards, allows some mitigation of seasonal issues affecting biomass fuel supply. The log yards, however, are not big enough to build inventory levels sufficient to make it through the winter.

5.4.3.3 QUALIFYING FUEL FROM PUBLIC LANDS

Timberland in California is about 61% federally owned and 39% privately owned per the U.S. Forest Service's Forest Inventory and Analysis database. More specifically, the U.S. Forest Service manages about 48% of the timberland in California. Despite the majority of the timberland in California being publicly owned, BioRAM plants reported that only about 15% to 50% (depending on the specific plant) of their fuel comes from public lands.[13] Overall, it is estimated that about 20% of all qualifying fuel comes from public lands. Note, however, this data was only provided as estimates from fuel buyers.

[13] We did not collect data from the BioRAM plants about the source of their biomass purchases. Further study would be needed to get a complete picture.

Detailed information from plant procurement records was not used. Thus, detailed information about the proportion of qualifying fuel from public versus private lands is a gap in knowledge.

1. *__Limited U.S. Forest Service Human Resources and Budget Resources__* - The plant managers and fuel buyers observed that the U.S. Forest Service's limited staffing and limited budget constrain the agency's ability to plan and deliver sales containing BioRAM qualifying biomass fuel. Per the BioRAM plant interviews, this appears to be more of a problem in the Central and Southern Sierra region where limited sawmill infrastructure has contributed to a less robust timber sale program from nearby national forests. In contrast, on national forests in the Northern Sierra region, BioRAM plants reported more experienced U.S. Forest Service staff and better lines of communication amongst U.S. Forest Service staff, contractors, and mills, which results in a more stable and predictable supply of biomass fuel from national forests in the Northern Sierra.

2. *__Focused on Wildfire__* -Related to the preceding point, BioRAM plants reported that they have observed that the increasing scale and severity of fires has shifted focus among U.S. Forest Service staff from forest management to firefighting and fire salvage. Additionally, the BioRAM plants have observed that agency funding is increasingly directed to fire-fighting rather than to adequate staffing and other agency initiatives.

3. *__Biomass Optional vs. Biomass Mandatory__* - Although the policy varies among National Forests and among Ranger Districts, a prevailing theme reported in plant visits is that U.S. Forest Service timber sales generally specify "biomass removal optional" rather than "biomass removal mandatory". When a U.S. Forest Service timber sale is "biomass removal optional" it was reported that in nearly all cases the resulting non-merchantable biomass is not utilized. Instead the material is either open-pile burned or distributed back across the harvest unit.

   The context underlying this observation from the power plants is that utilizing biomass generally results in a net cost to the landowner, whereas utilizing sawtimber generates a net revenue. Therefore, in most cases, if a landowner wants to utilize the biomass in a timber sale it will come at the cost of reduced revenue from the sale of sawlogs on that timber sale. Therefore, most landowners, including the U.S. Forest Service, elect to make biomass removal optional in order to maximize revenue from the sale of saw timber.

6 POTENTIAL SUPPLY OF BIOMASS FUEL

In this section, we focus exclusively on the forest residue component of woody biomass fuel and refer to it as "forest biomass" or "biomass." Given the relative value of wood for fuel versus other wood products, we assume that any portion of a tree that can be made into a solid wood product should not be counted as biomass. **Appendix E** shows that the value of any other wood product surpasses the value of biomass for power generation.

Forest-based biomass used for fuel comes in two forms:

- Sawmill residuals are shavings, chips, sawdust and bark that are created during the manufacture of lumber, veneer and other wood products. Sawmill residuals from timber sourced from within the HHZs constitute qualifying fuel under the BioRAM contracts, and the BioRAM facilities rely on these residuals as described in Section 5 of this report.

- Forest residue consists of the trees or portions of trees that are not used for the manufacture of higher-valued wood products. Forest residues used for biofuel are most typically ground or chipped in the woods and delivered to a woody biomass power facility in chip vans. In some cases, forest residue may be delivered to the biomass facility in log form and chipped at the facility.

For the purpose of this study, we identify three components of forest residue biomass:

1. The tops of trees that otherwise produce commercial sawlogs. This is logging waste, typically piled at the landing. See **Appendix L,** photos L-5 and L-6, for an example.

2. Trees too small to meet sawtimber merchantability specifications. These trees often constitute an understory and are sometimes considered "ladder fuels." Removal and disposal of these trees is often part of management prescriptions that seek to restore forest health and resiliency.

3. Dead trees that are unsuitable for manufacture of sawlogs due to decay, staining, or insect damage.

To assess the potential supply of forest biomass, we estimated a current forest-wide, in-place inventory for all of California's 37 million acres of forest land. An in-place inventory defines the timber volume for every acre in the study area. This inventory is unique to this study.

Using this inventory, we identified the portion of the inventory that is within the HHZs and is suitable and compatible with management activities that produce biomass. We refer to this as a comprehensive biomass inventory. We apply several operational filters (Figure 7) to identify the biomass volume from the HHZs that could be potentially available to woody biomass using power plants. We analyze the potential biomass available to each BioRAM plant and develop biomass cost curves for each. We also calculate the supply to each BioRAM plant after considering the possible influence of other, nearby biomass using powerplants.

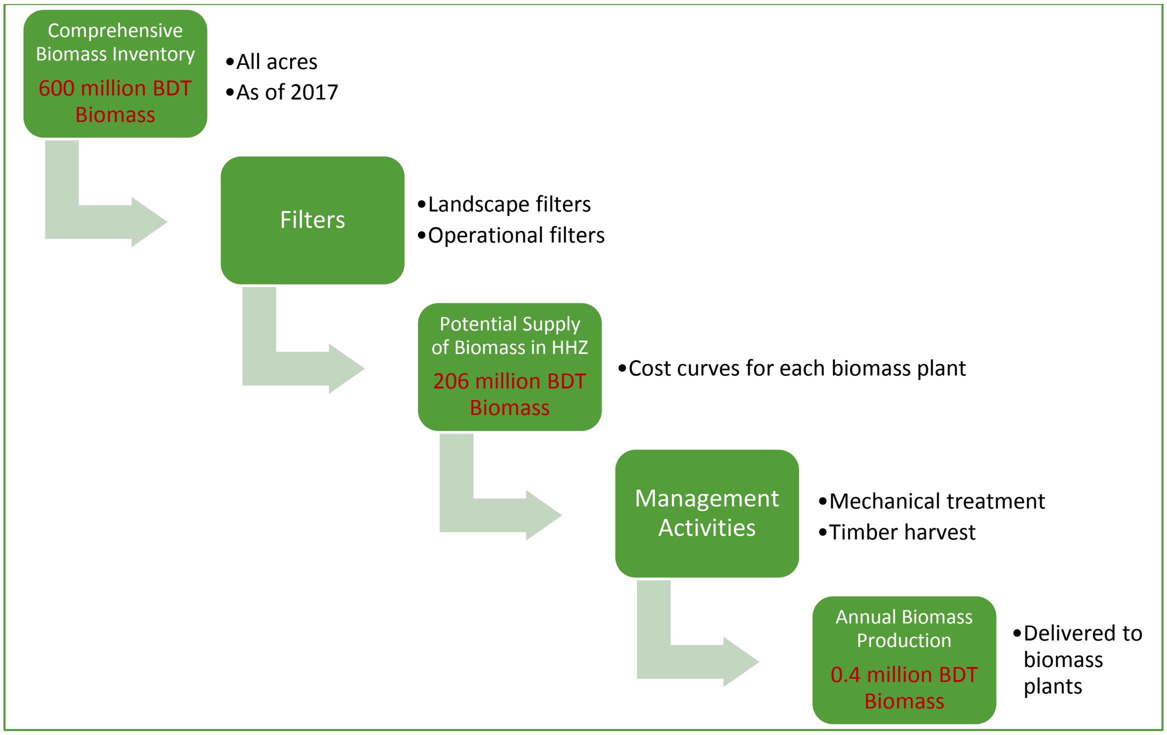


Figure 7. Relationships between Comprehensive Biomass Inventory, Potential Supply of Biomass Fuel from the HHZ and Annual Biomass Production

6.1 DEVELOPING A BIOMASS INVENTORY FOR CALIFORNIA

A wide variety of forest conditions are found across California's 37 million acres of forestlands. As forest residues consist of small trees and the tops of larger trees, an inventory of potential biomass supplies must account for the number and size of trees in each area.

For this project, we used the LEMMA[14] dataset to prepare a comprehensive biomass inventory of biomass. The LEMMA dataset provides timber inventory information for 30-meter grid cells across the state as of 2012.[15] The inventory consists of a list of trees including species, diameter and height. A complete description of methods is found in **Appendix B.**

[14] https://lemma.forestry.oregonstate.edu/

[15] A grid cell that is 30 meters by 30 meters is approximately one quarter of an acre. There are approximately 160 million grid cells in the LEMMA dataset describing California forests.

To estimate HHZ biomass potentially available over a 20-year period, we applied two sets of filters to the comprehensive state-wide inventory: (1) a set of land-based filters narrowed the focus to forest land eligible for management in the HHZs, and (2) a set of operational filters adjust the total inventory to levels that could reasonably be expected to be available for use. Figure 8 illustrates the process at a high level.

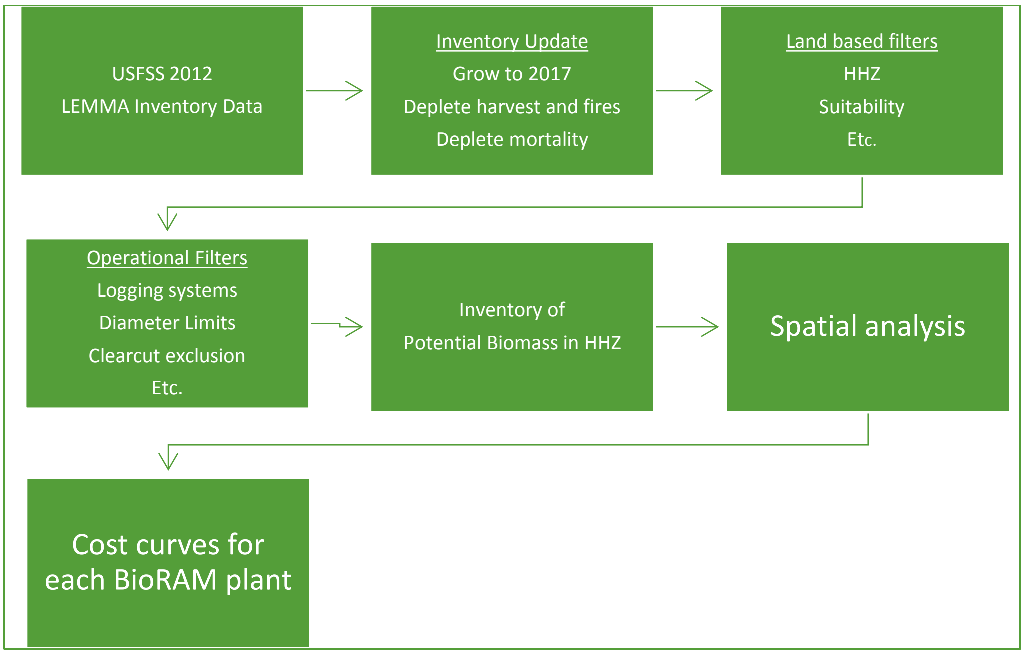


Figure 8. Processes for developing cost curves from primary inventory data

Our intent is to provide a conservative estimate of the potential inventory of biomass within the HHZs. Several assumptions and processes were required, and each has an impact on the reliability of the estimate. These are explained in detail in **Appendix C**.

Forest residue biomass is that portion of the stand volume which is not suitable for manufacture into higher-valued forest products but is available for biomass fuel. For this study we identified three components of forest biomass, as shown in Figure 9:

a. Tops of sawtimber sized trees. We considered any portion of a tree above the point at which the tree's stem diameter drops below 8" as biomass.

b. Small trees. Trees between 6 and 10" diameter at breast height (DBH) are too small to be considered sawtimber but can be chipped into biomass. Trees less than 6" DBH were included as biomass only on shallow slopes (<30%), since these small stems are not economically feasible to remove in a cable logging operation.

c. Dead trees greater than 10" DBH.

Further reductions were made based on ownership and management objectives, as described in **Appendix C.**

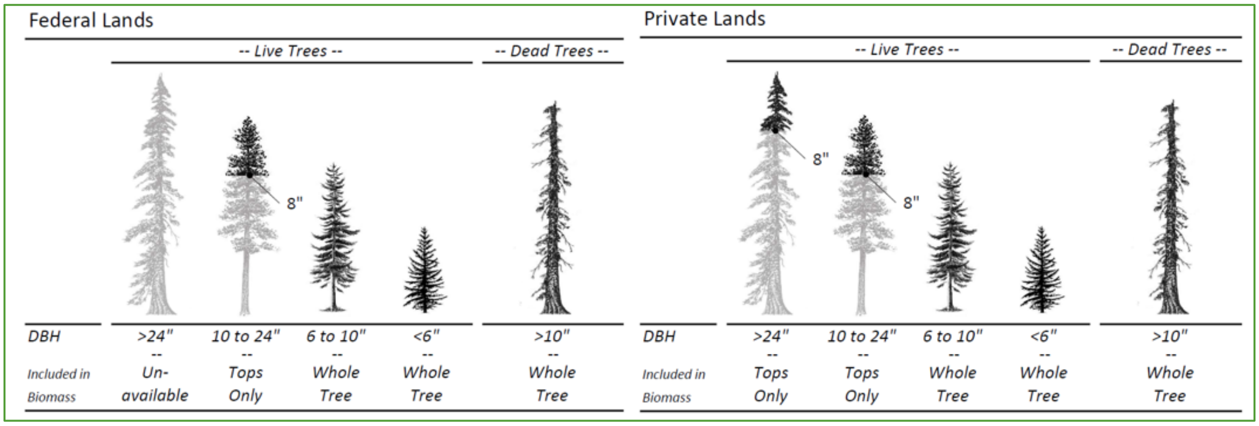


Figure 9. Volume classified as forest biomass for this study

6.2 SUMMARY OF POTENTIAL BIOMASS INVENTORY

The previous section and **Appendix C** describe the process of creating the current inventory of potential biomass. Here we summarize the results of that process and provide context for understanding the nature and scope of potential biomass in the HHZs.

Figure 10 describes the composition of the inventory in the HHZ relative to the total inventory for all California forestland. Statewide, nearly 37 million acres of forest land contain about 516 billion board feet (Bbf) of sawtimber. Biomass inventory is expressed in BDT, so we convert the total sawtimber volume to BDT for context: statewide there are about 1.7 billion BDT of live sawtimber and 165 million BDT of dead sawtimber.[16] In addition to the sawtimber, there is woody biomass in smaller trees that cannot be milled for sawtimber, as well as in tops from sawtimber-sized trees. These comprise about 570 million BDT of live material and 30 million BDT of dead material. On a BDT basis, tops and smaller trees account for 26% of the total inventory. Figure 10 also shows that dead trees constitute 10% of the sawtimber and 5% of the tops and small tree mass.

The HHZs encompass 16.7 million acres with about 263 Bbf of sawtimber and 255 million BDT of tops and small trees. As expected, the HHZ carries a disproportionate share of the dead material – the HHZ occupies 45% of land base but contains 62% of the dead volume.

[16] (BDT'000) means thousands of bone-dry tons.

We depleted the inventory for stand replacing harvest (105,000 acres), stand replacing fires (650,000 acres), USFS acres incompatible with management (2,662,000 acres), and acres unsuitable for harvest (107,000 acres).[17] The remaining 13,143,000 acres of HHZ could potentially be managed for biomass production over the next 20 years. On these acres, the timber inventory consists of 239 Bbf of sawtimber and 223 million BDT of tops from sawtimber-sized trees, and smaller trees.

Figure 10. Statewide Forest Land Acres and Tons (BDT'000) by HHZ Status and Suitable for Management, before adjustments

	Acres	Total Saw Timber (Bbf)	Bone-Dry-Tons (BDT'000)				
			Saw Timber		Tops; Smaller Trees		Total
			Live	Dead	Live	Dead	
Statewide Forest Land	36,934,686	516.49	1,504,610	164,979	569,657	30,377	2,269,623
HHZ Forest Land	16,668,328	263.70	718,179	102,360	235,796	18,654	1,074,989
Harvest 2012-2018	105,331	-	-	-	-	-	-
Burned 2012-2018	650,543	-	-	-	-	-	-
USFS Available, but Undesirable	107,297	1.66	5,037	679	2,328	168	8,212
USFS Management Incompatible	2,661,937	22.66	67,967	10,344	26,319	2,257	106,888
HHZ Suitable for Management	13,143,219	239.38	645,176	91,336	207,149	16,228	959,889
Federal	7,154,963	165.72	419,281	70,177	109,178	11,145	609,782
Local	27,681	0.10	448	23	271	4	747
NGO	2,560	0.01	62	5	36	1	104
Private	5,850,663	71.66	220,438	20,366	96,079	4,951	341,833
State	107,351	1.89	4,946	766	1,585	127	7,424

Figure 10 also summarizes by ownership the HHZ lands suitable for management. About 55% of the acreage and inventory are on public lands (federal, local government, and state). Thus, about half of the suitable HHZ acres are governed by the budgets and goals of public institutions, while the other half is governed by those of private landowners. In terms of volumes, the private lands have less sawtimber per acre than public lands, but more live biomass (smaller trees) per acre—this reflects a more aggressive harvest resulting in a larger proportion of smaller trees. Private lands, furthermore, have experienced less tree mortality than the public lands.

Appendix C describes a set of operational filters and adjustments to the inventory to translate the standing volume into an expression of material potentially available for biomass fuel, with implications for steep slopes, limits for harvesting large trees on USFS land, and eligibility of dead trees by harvest system. These adjustments did not remove any acres from consideration but reduced the potential biomass available per acre. For example, the sawtimber available on federal HHZ lands suitable for management was reduced from 165 Bbf to 58 Bbf (a 65% reduction), primarily due to the USFS diameter limits, which preclude harvest of larger trees. Since those trees are not available for harvest, there is a

[17] See **Appendix C** for details on depletions.

corresponding reduction in biomass because the corresponding tops of those trees are also not available.

Figure 11 shows the inventory adjusted by these operational filters and summarizes our definition of 248 million BDT of potential biomass in the HHZs. About 55% of this potential biomass is on federal land, and about 44% on private land. In the following section, we calculate the cost and volume of this potential biomass delivered to each of the BioRAM power plants.

Figure 11. HHZ Potential Biomass Acres and Tons (BDT'000)

		Live Saw Timber		Potential Biomass (BDT'000)			
	Acres	Board Foot (BBF)	Tons (BDT'000)	Saw-Sized	Tops; Smaller Trees		Total
				Dead	Live	Dead	
HHZ Potential	13,143,219	131.20	401,642	72,373	162,734	13,003	248,110
Federal	7,154,963	58.06	176,057	54,496	72,877	8,695	136,067
Local	27,681	0.10	444	19	249	3	271
NGO	2,560	0.01	62	5	35	1	41
Private	5,850,663	71.15	220,154	17,233	88,122	4,202	109,558
State	107,351	1.87	4,925	620	1,452	102	2,173

Appendix A provides additional summaries from the biomass inventory that give insight into the scope and nature of the potential forest biomass material. Note, for example:

- **Appendix A** Tables 1 and 2 show that about 21% of the HHZ acres are not suitable for management due to forest plan decisions or vegetation types. Those acres contain only 11% of the potential biomass.

- **Appendix A** Table 7 shows the number of dead trees and Table 8 the volume of dead trees in the HHZ land base that is suitable for management. These tables show that the HHZ encompasses most of the forest land mortality, and that federal land has a disproportionately large share of the mortality.

- **Appendix A** Table 9 shows the distribution of potential biomass in the HHZ by source. About 40% of the total is from tops, another 40% from small trees 6"-10" DBH and 20% from small trees less than 6" DBH.

  This table also highlights the role of federal lands in supplying qualifying fuel -- about 61% of the biomass on federal lands falls within the HHZ, while the corresponding fraction for private lands is about 36%.

6.3 DEVELOPING COST CURVES FOR POTENTIAL BIOMASS

With an in-place inventory of potential biomass, we can develop curves showing the relationship between potential biomass supply and delivery cost to each BioRAM and biomass power plant. These curves help to determine whether there is enough biomass to service each BioRAM contract at an affordable price. In this section, we explain the methodology. Section 6.4 displays the results.

The cost curves consider the costs described below:

- Cutting and skidding costs. These are the costs of falling the tree and skidding it to the landing. Cutting and skidding costs used for this analysis are based on data collected during our interviews and are shown in Figure 12.

Figure 12. Biomass cutting and skidding cost assumptions

Biomass Component	Live Tree Biomass	Dead Tree Biomass
Sawtimber tops	$0/BDT	$0/BDT
Small trees 6-10” DBH	$27.50/BDT	NA
Dead sawtimber	NA	$25.00/BDT

Most harvest in California is whole tree logging[18]. As a result, the tops of sawtimber trees come to the landing with the sawlog. Cutting and skidding this material, therefore, does not include any incremental cost incurred against sawtimber. These costs assume a reasonable profit to the logger.

- Chipping Costs. Most biomass in California is chipped on site with mobile chippers or grinders. Based on our interviews, we use an average chipping cost of $20/BDT. This includes the cost of loading the chips into a chip van. These costs assume a reasonable profit to the chipping operation.

- Haul Costs. Haul costs include the time and cost of loading and unloading the chip van, and the time travelling from the harvest area to the biomass plant. We estimated travel time for each 10-mile increment (“shell”) using a cost of $88/hour for a chip van, an estimated 65 minutes for loading and unloading, and a typical load mass of 25 green tons per load. As shown in Figure 13, we assumed that long hauls would include more time on paved roads than shorter times. These costs assume a reasonable profit to the biomass hauler.

Figure 13. Biomass haul cost assumptions

	Travel Distance										
	5	15	25	35	45	55	65	75	85	95	105
MPH	36.9	39.9	41.3	42.2	42.8	43.4	43.8	44.2	44.5	44.8	45.1
Green $/BDT	$9.53	$12.92	$16.16	$19.32	$22.42	$25.48	$28.52	$31.52	$34.50	$37.47	$40.41
Dead $/BDT	$9.21	$12.04	$14.74	$17.37	$19.96	$22.51	$25.03	$27.54	$30.02	$32.49	$34.95

[18] Note that in the Sierra Nevada region, approximately six logging contractors have converted their operations to cut-to-length systems. It remains accurate to state that “most” harvest in California is conducted as whole-tree. These few Sierra Nevada contractors constitute a minor fraction of statewide harvest.

- Forwarding and Road Improvement Costs: Interviews with land managers estimated that there are substantial acreages inaccessible to chip vans due to road design, but the specific location of these areas and the road remediation costs are unknown (see **Appendix I**).

  Accessing the biomass in these areas is a matter of making road improvements or forwarding the biomass material from the landing to a remote chipping site. We estimate that forwarding would typically cost between $5-15/BDT.

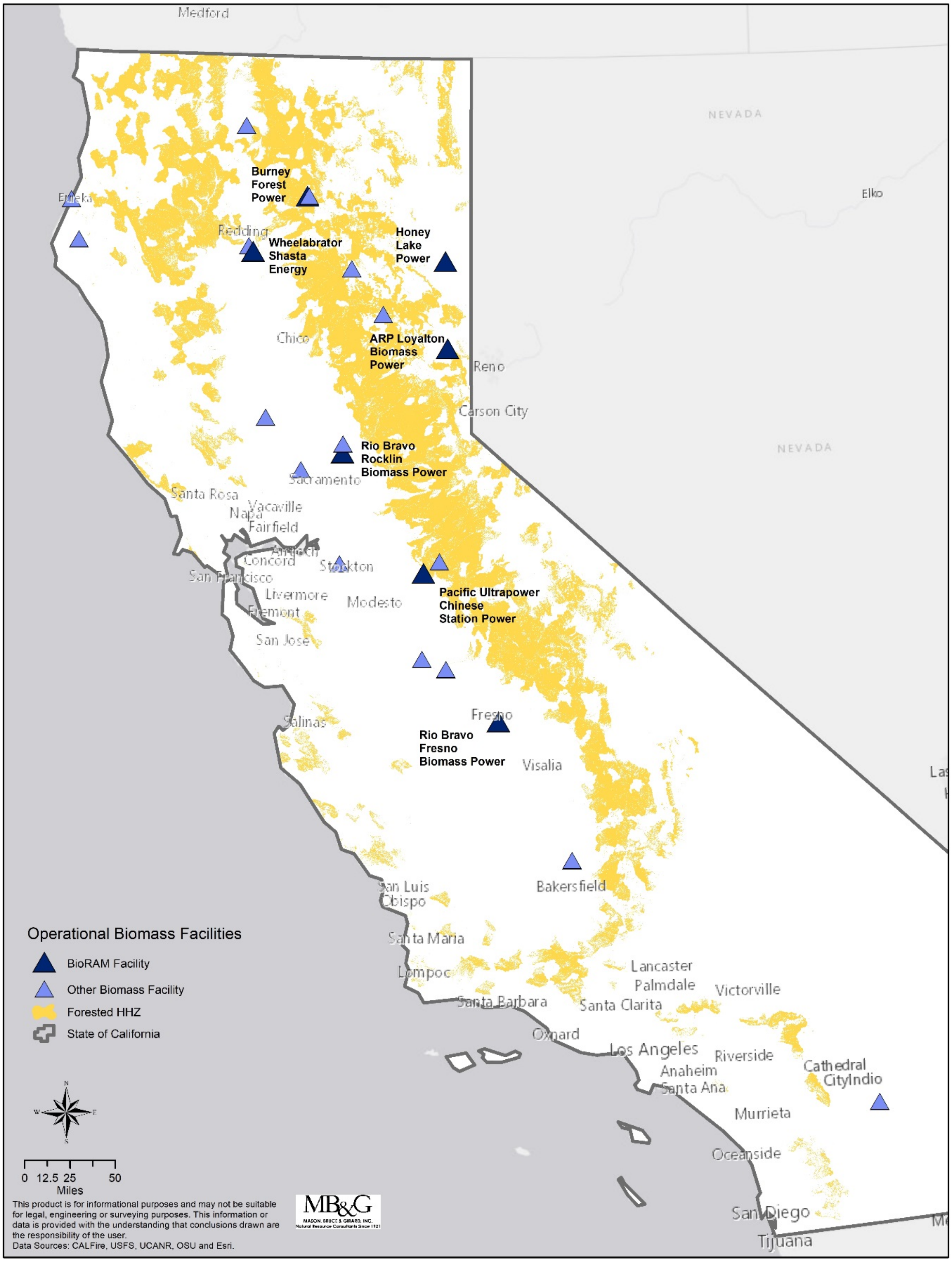
  Since the location of these areas is unknown, however, we do not include any of these potential costs in our cost curve analysis.

  Stumpage Return to the Landowner: The difference between the value of the wood products delivered to the mill and the cost of extraction is referred to as stumpage. From our interviews with land managers, it is our understanding that private land managers do not expect to receive any stumpage payment for biomass production. Often the biomass is given to the logger free and clear in exchange for removal. USFS timber sale contracts require a stumpage payment of $0.10/green ton for biomass. That is equivalent to $2.50/van load and we did not include it in our calculation.

This analysis estimates biomass delivery costs for each of the 23 biomass power plants currently operating (Figure 14), mapped locations shown in Figure 15 with BioRAM plants marked by dark blue symbols and HHZ areas shaded yellow.

Figure 14. Operational BioRAM and non-BioRAM power plants in California as of first-quarter 2019.

Name	Owner	Cogen	City	County	Contracts
ARP Loyalton Biomass Power	American Renewable Power	No	Loyalton	Sierra	BioRAM
DG Fairhaven	EWP Corp	No	Fairhaven	Humboldt	Other
Humboldt Redwood Company Scotia Power	Humboldt Redwood Company	Yes	Scotia	Humboldt	Other
Burney Forest Power	Burney Forest Products	Yes	Burney	Shasta	BioRAM
Chowchilla Biomass Power	Akeida Capital	No	Chowchilla	Madera	Other
Collins Pine Biomass Power	Collins Companies	Yes	Chester	Plumas	Other
Greenleaf Desert View Power	Greenleaf Power (Recycled En. Dev.)	No	Mecca	Riverside	Other
Honey Lake Power	Greenleaf Power Inc	No	Wendel	Lassen	BioRAM
Merced Power	Akeida Capital	No	El Nido	Merced	Other
Pacific Ultrapower Chinese Station Power	IHI Power Services	No	Jamestown	Tuolumne	BioRAM
Rio Bravo Fresno Biomass Power	IHI Power / N. Am. Power Group	No	Fresno	Fresno	BioRAM
Rio Bravo Rocklin Biomass Power	IHI Power / N. Am. Power Group	No	Rocklin	Placer	BioRAM
Roseburg Forest Products Biomass Power	Roseburg	Yes	Weed	Siskiyou	Other
SPI Burney Biomass Power	SPI	Yes	Burney	Shasta	Other
SPI Anderson Biomass Power II	SPI	Yes	Anderson	Shasta	Other
SPI Lincoln Biomass Power	SPI	Yes	Lincoln	Placer	Other
SPI Quincy Biomass Power	SPI	Yes	Quincy	Plumas	Other
SPI Sonora Standard Biomass Power	SPI	Yes	Sonora	Tuolumne	Other
Wadham Biomass Power	Wadham Energy LP	No	Williams	Colusa	Other
Wheelabrator Shasta Energy	Wheelabrator Shasta Energy Company	No	Anderson	Shasta	BioRAM
DTE Woodland Biomass Power	DTE Energy Services	No	Woodland	Yolo	Other
DTE Stockton Biomass Power	DTE Energy Services	Yes	Stockton	San Joaquin	Other
DTE Mt. Poso Cogen	DTE Energy Services	Yes	Bakersfield	Kern	Other



Medford
NEVADA
Elko
Eureka
Burney
Forest
Power
Redding
Wheelabrator
Shasta
Energy
Honey
Lake
Power
Chico
ARP Loyalton
Biomass
Power
Reno
Carson City
NEVADA
Rio Bravo
Rocklin
Biomass Power
Sacramento
Santa Rosa
Vacaville
Napa
Fairfield
Antioch
Concord
Stockton
San Francisco
Livermore
Fremont
Modesto
Pacific Ultrapower
Chinese
Station Power
San Jose
Salinas
Fresno
Rio Bravo
Fresno
Biomass Power
Visalia
Bakersfield
San Luis
Obispo
Santa Maria
Lompoc
Lancaster
Palmdale
Victorville
Santa Barbara
Santa Clarita
Oxnard
Los Angeles
Riverside
Anaheim
Santa Ana
Cathedral
City
Indio
Murrieta
Oceanside
San Diego
Tijuana
Operational Biomass Facilities
BioRAM Facility
Other Biomass Facility
Forested HHZ
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Miles
This product is for informational purposes and may not be suitable for legal, engineering or surveying purposes. This information or data is provided with the understanding that conclusions drawn are the responsibility of the user.
Data Sources: CALFire, USFS, UCANR, OSU and Esri.
MB&G

Figure 15. Currently operating biomass power plants. BioRAM plants are dark blue.

As transportation costs account for a significant portion of the total delivered cost of biomass, we developed 10-mile travel shells around each biomass power plant.[19] Figure 16 shows the travel shells around Burney Forest Power, for example. In this figure, the HHZs are shown in dark pink underneath the travel shells.

[19] Time-based transportation cost shells are preferred to distance-based shells. A statewide road layer with travel speeds was not available, however, leaving distance-based shells the only option for this report.

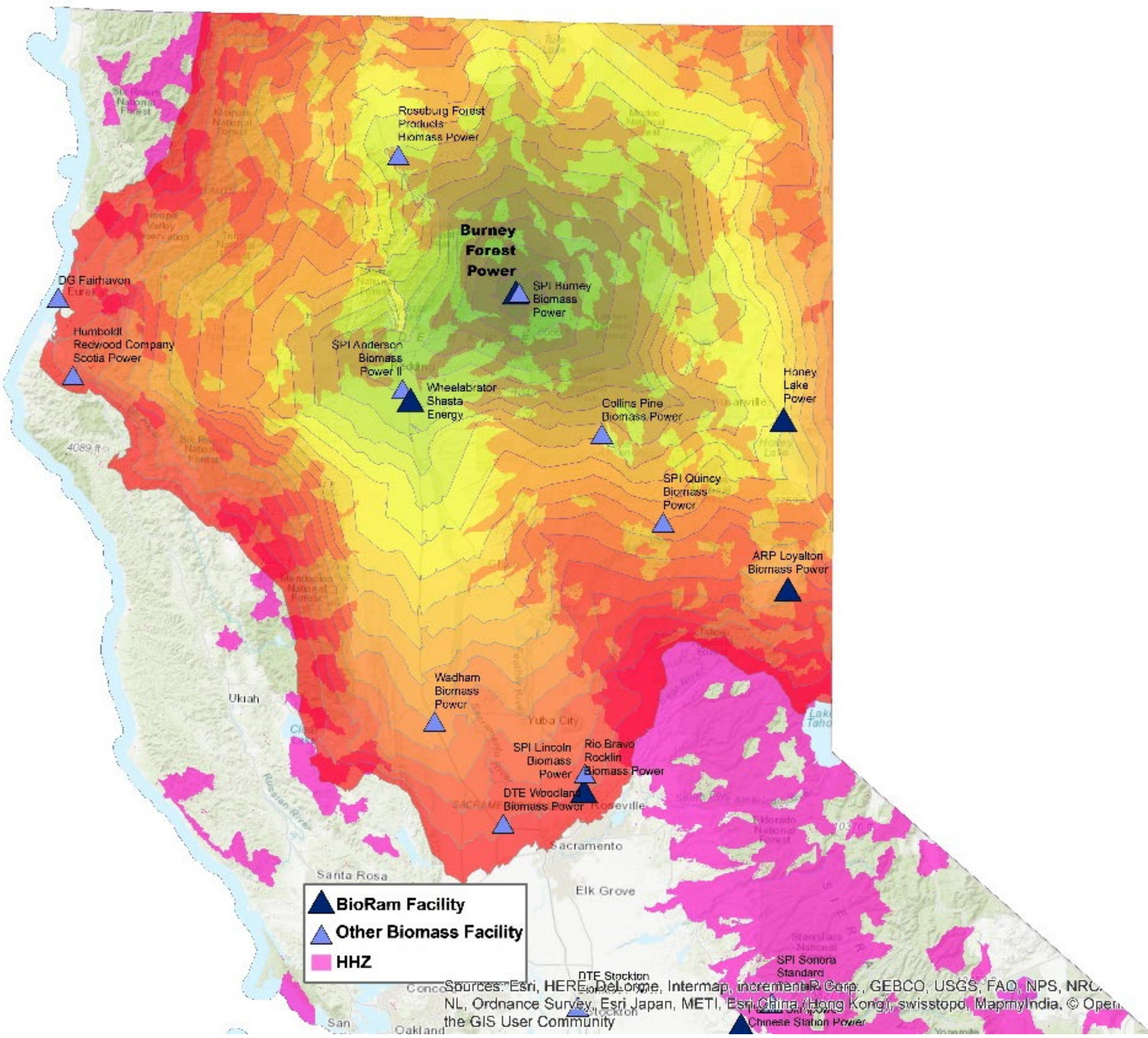

Figure 16. Ten-mile travel shells around Burney Forest Power

The cost curves presume there is enough biomass production capacity (loggers, chippers, haulers) to process all the material. That presumption is supported by our interviews with land managers and loggers. Nearly all indicated that there is sufficient biomass production capacity to process current levels of biomass, and perhaps some level of increase. Firm estimates of how much more could be processed were not available, however. At some level of production, however, new production capacity would certainly be needed. This would require new equipment and additional employees, both of which could be expected to have higher marginal costs. We have not estimated those additional costs here.

Overlaying the travel cost shells with the inventory of potential biomass, we represent the relationship between volume and price with a cost curve. Figure 17 (on the following page) is an example cost curve for federal land biomass available around the for the Burney Forest Products biomass power plant, and serves to illustrate the interpretation of the cost curve:

- The x-axis is the potential biomass volume available expressed in million BDT. This is an accumulated total. The first step, for example, shows the volume available in the first 10-mile travel shell. The second step shows the total volume in the first 10-mile shell plus the second 10-mile shell, etc.

  We project that the seven BioRAM plants will annually consume about 930,000 BDT per year of qualifying forest biomass in the future, or an average of 132,000 BDT per mill (Figure 6). While the BioRAM plants currently get some forest biomass in the form of mill residuals, we use 132,000 BDT per facility/year here as a conservative upper limit to judge the sufficiency of the inventory of potential biomass. A 20-year supply would be about 2.6 million BDT for an average BioRAM facility. In Figure 17 we add a vertical line at 2.5 million BDT to benchmark the location of a 20-year supply.

- The y-axis is the delivery cost in terms of $/BDT. This is the average accumulated cost including logging, chipping and hauling. The first step, for example, shows the cost of the biomass in the first 10-mile travel shell. The second step shows the average cost of the biomass in the first 10-mile shell and the second 10-mile shell, etc.

- A cost curve is frequently represented by a continuous ascending line representing the increased cost of acquiring successively greater share of some resource based on important barriers to its acquisition. In the base of biomass, this study is interested in the additional cost of biomass as a function of increasing distance from biomass power facilities. The real cost of forest biomass increases as a continuous function of distance but calculating the precise distance of all forest biomass sources to every biomass facility is prohibitive. We simplify the problem by calculating the distance to each facility in 10-mile increments. This simplification alters the form of the cost curve from the typical continuous function, instead resulting in a step function with discrete shifts at the boundary of each simplified travel shell increment. For example, the cost of forest biomass transported 12 miles is lower than the cost for comparable biomass transported 17 miles, but both of sources are transported between 10 and 20 miles, so under the travel shell simplification each source costs the same amount. The impact of transport cost registers only at the transition between travel shells at 10-mile increments, causing the stepped appearance of this cost curve. The reader may envision a continuous cost curve connecting points, but to faithfully represent the simplifying assumptions in the transportation model, we retain the step function and apply the mid-point travel cost across each shell. Biomass within the 10-to-20-mile shell is assigned a transport cost corresponding to 15 miles.

Note that the horizontal increment in this cost curve is not distance, but rather accumulated biomass. Continuously increasing transport distance from destination facilities leads to accumulating biomass along the horizontal axis, but the amount of biomass accumulated in a given step—representing a 10-mile travel shell—depends on the amount of forested area encountered in that shell. We would interpret each incremental movement to the right of the cost curve as additional biomass accumulated by incorporating one additional 10-mile travel shell. The additional cost of acquiring the mass in the travel shell is represented by the vertical increment, expressed as cost to deliver biomass to a facility in $/BDT units.

In the example cost curve, the green line is the cost curve for the tops of sawtimber trees, the blue line is dead sawtimber trees, and the red line is the small trees. All cost curves show the biomass volume and delivery cost within 100 miles of each biomass plant.

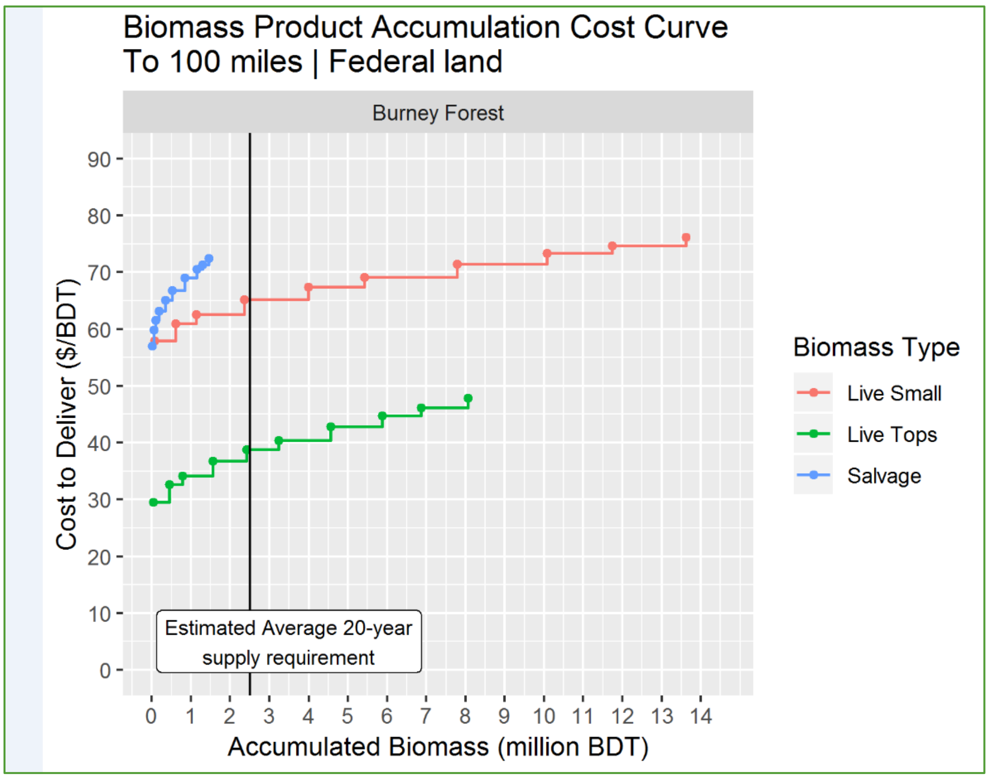

Figure 17. Example cost curve, Burney Forest Products, Federal Land

In this example, Figure 17 shows the tops of live trees have the lowest delivery cost – the cost of harvesting and yarding the tops is borne by the sawlog portion of the tree. Therefore, the green tops (green line) only incur the cost of chipping and transportation. The salvage logs (blue line) and the small green trees less than 10" DBH (red line) incur a felling and skidding cost, in addition to the cost of chipping and transportation. The cost of salvage logging is lower because the trees are generally larger which improves logging productivity. We also assume that the dead trees will be drier at harvest and therefore more BDT can be loaded into a chip van.

For each cost curve, the horizontal axis illustrates the amount of biomass available within each 10-mile travel shell, expressed in BDT. These are additive in this graph – from federal lands within 100 miles of the Burney biomass plant, there is about 15 million BDT of small tree biomass, 6 million BDT of salvage biomass, and 8 million BDT of biomass from tops of live trees – a total of 29 million BDT across all components.

As these are accumulated cost curves, the cost of delivering any volume is the least-cost method of delivering that volume. The actual price of delivery will be determined by the nature and location of the forest biomass actually offered for sale.

Section 6.4 contains cost curves summarized in several ways. Each of those cost curves can be interpreted as described above.

6.4 POTENTIAL BIOMASS COST CURVES

Figure 18 contains cost curves for the components of biomass on federal lands within 100 miles of each BioRAM plant. These curves do not account for competition between biomass plants. These cost curves are analogous to the Burney Forest Products example in Section 6.3.

Note that there are significant differences in the amount of volume available within 100 miles of each BioRAM plant. This is due to location and the nature of the timber resource. Rio Bravo Fresno, for example, is located at some distance from the federal forest land, while Wheelabrator Shasta Energy is more favorably located. For most of the plants, there is more biomass from small trees than from any other source. Recall, however, that we adjusted the potential biomass from dead trees down by 75% based on our salvage assumptions (**Appendix C**).

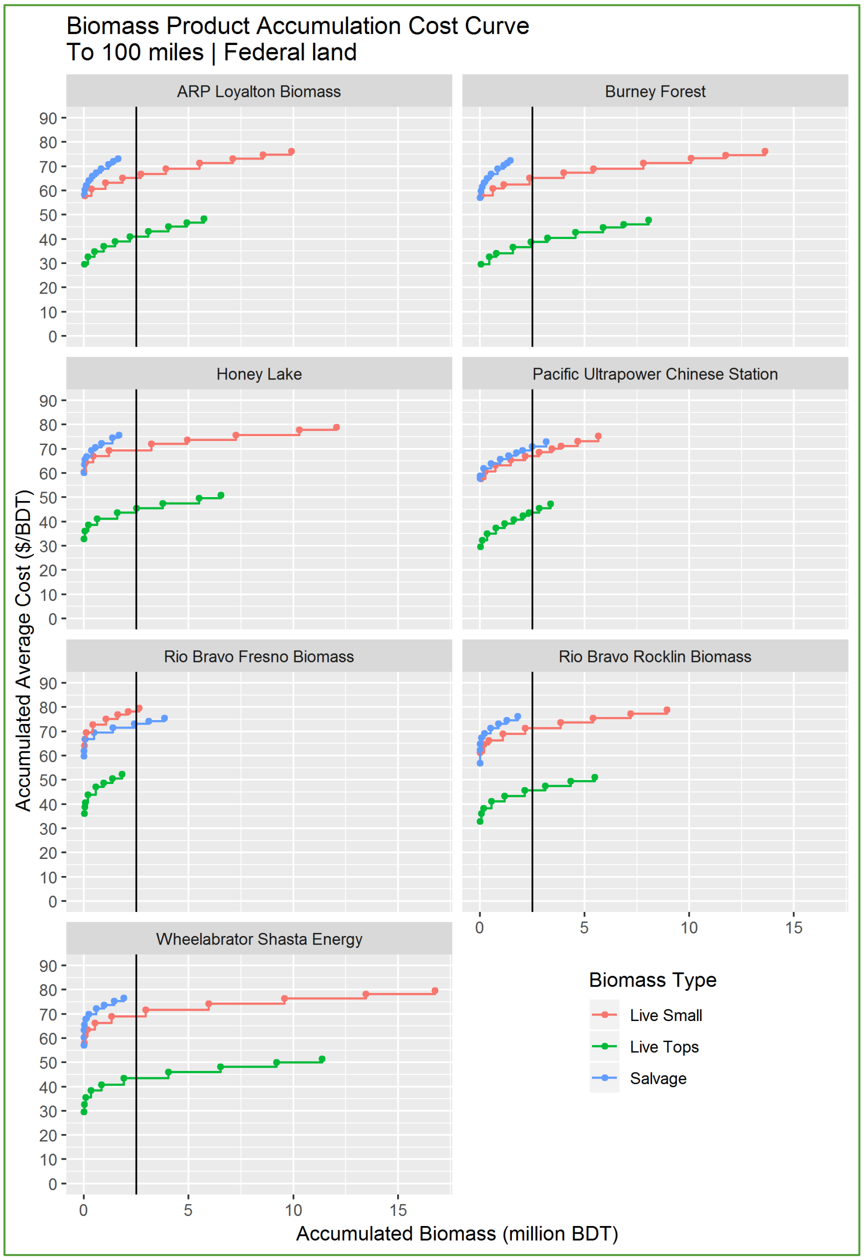

Figure 18. Cost curve: Biomass components, Federal land

Figure 19 shows cost curves for biomass from private lands. Note the change in the x-axis scale – there is less potential biomass on private lands than from federal lands. Salvage volumes are lower as the large-scale mortality from 2010-2019 occurred primarily on federal lands.

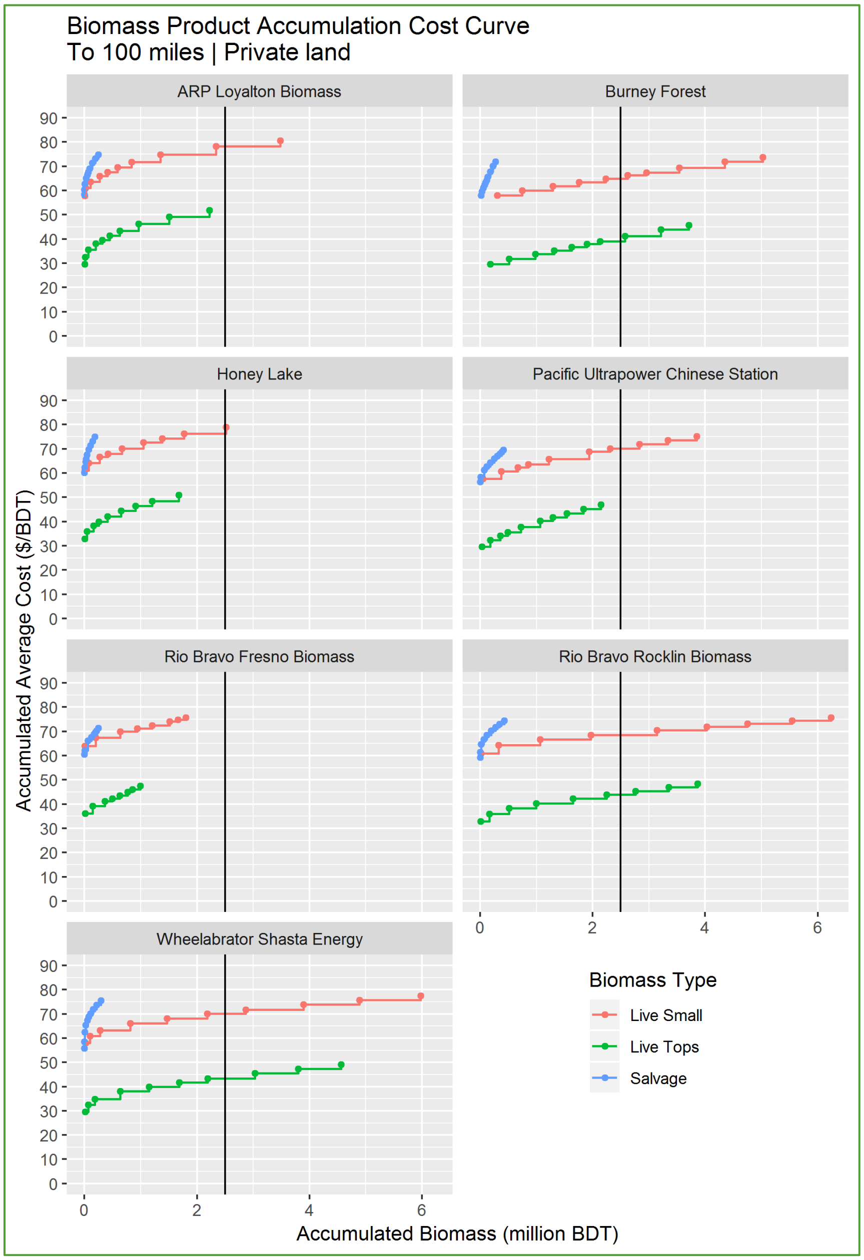

Figure 19. Cost Curves: Biomass components from private lands

Figure 20 plots the biomass components within 100 miles of each BioRAM plant by component and owner. This provides a good picture about the relative volumes and costs by component. Note, for example, that the small tree component accounts for a substantial portion of the potential biomass, and the federal lands have about twice as much of that as the private lands. Also notice that potential biomass from salvage on federal lands is greater than on private lands.

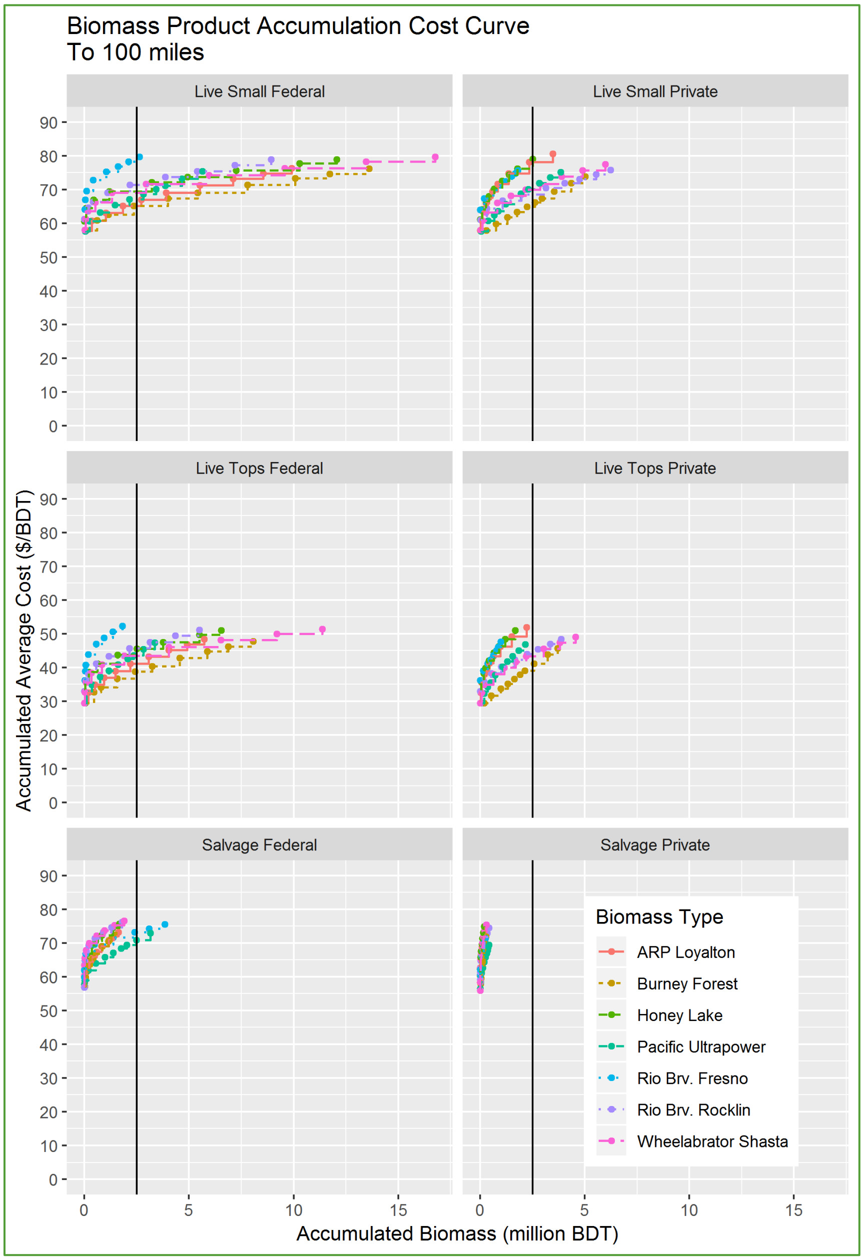

Figure 20. Cost Curves: Comparison by biomass component by ownership

Since the biomass plants do not control the nature or composition of the timber sales from either public or private land, they do not have the ability to specify or control the source of the biomass. They cannot request, for example, biomass consisting solely of sawtimber tops because that is the least expensive fraction. Rather, they are more likely to acquire a mixture of biomass products, depending in part on the landowners' silvicultural objectives. In Figure 21 we plot the cost curve averaged across the available components by ownership. Again, this assumes no competition for the biomass. These total volumes far exceed the 2.5 million BDT average 20-year consumption benchmark.

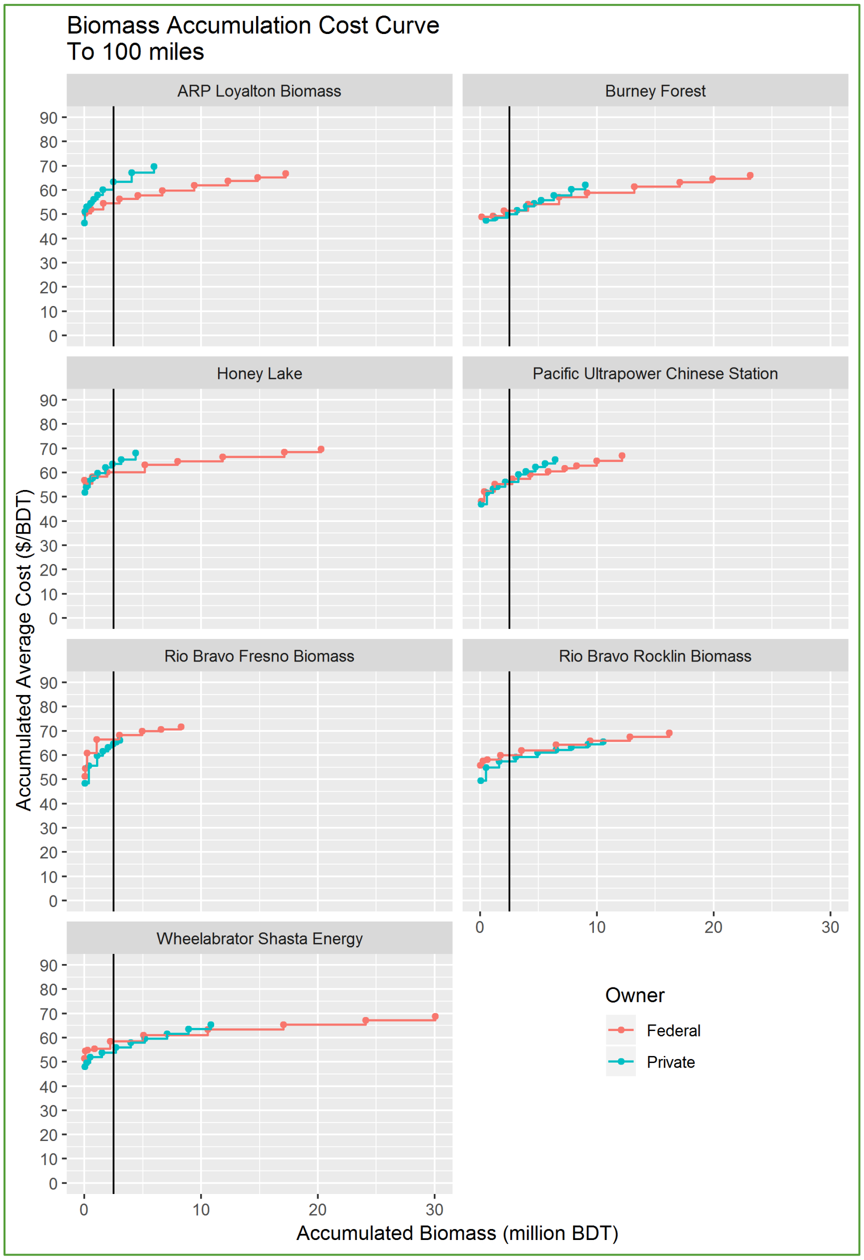

Figure 21. Cost Curve: Accumulation of components, by ownership

The BioRAM plants are not evenly distributed throughout the HHZ. The figures above have not accounted for competition between the BioRAM plants. In Figure 22, we allocated the potential biomass on each acre to the closest BioRAM plant, and made a new set of cost curves limited to the volume for which each BioRAM plant had the lowest delivery cost.

The change in the x-axis suggests that there is only about half as much potential biomass available to each plant after accounting for competition between BioRAM plants. There is still more than enough potential biomass to source the BioRAM plants for 20 years, however.

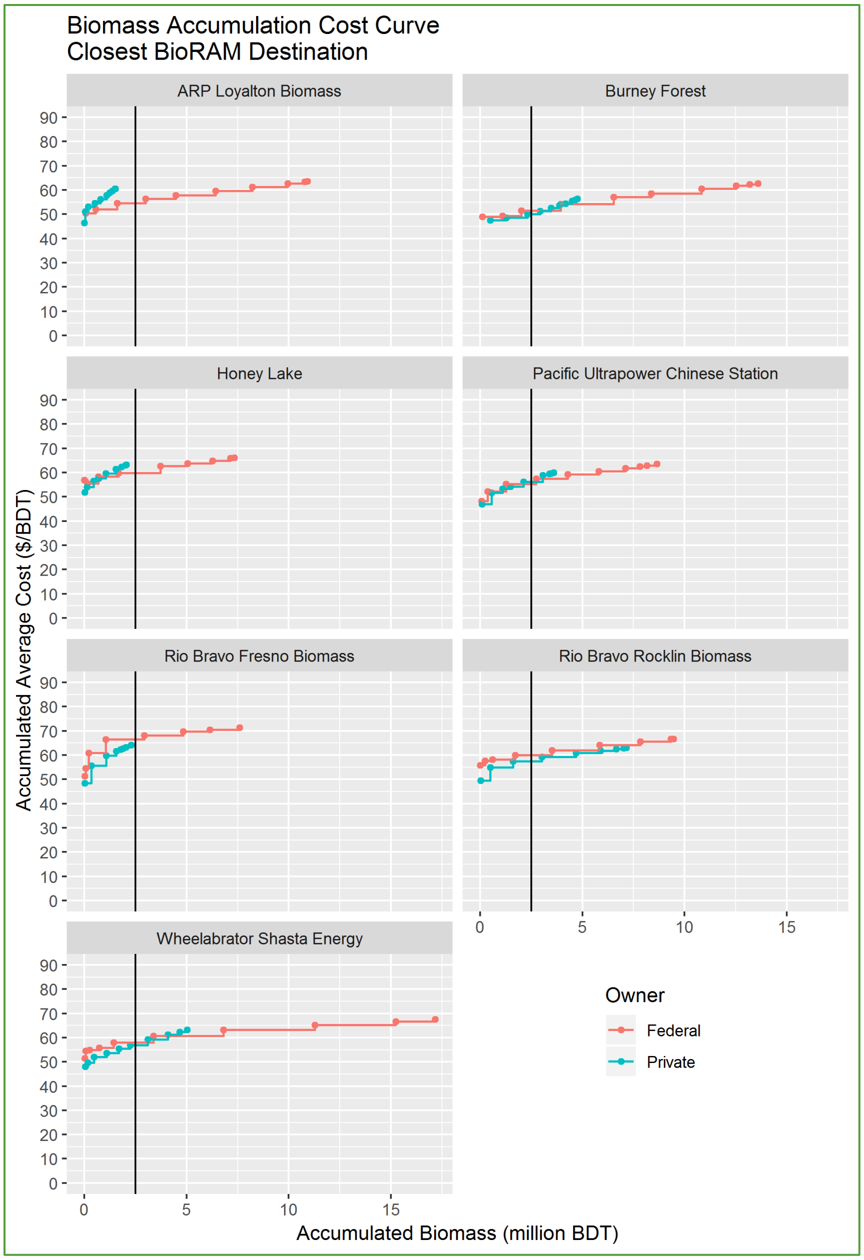

Figure 22. Cost Curves accounting for competition between BioRAM plants

Figure 23 is analogous to Figure 22 except that potential biomass is allocated to the closest of any of the 24 operating biomass power plants. Clearly this is a worst-case from the viewpoint of the BioRAM plants, and it is an unlikely worst case. Given that the BioRAM plants have favorable power contract rates, it is unlikely that the non-BioRAM plants could bid much of the potential biomass away from the BioRAM plants, nor would they be incentivized to forego other biomass sources.

Note here, however, that even in this worst-case scenario, the 20-year consumption benchmark could still be met, except perhaps for Honey Lake.

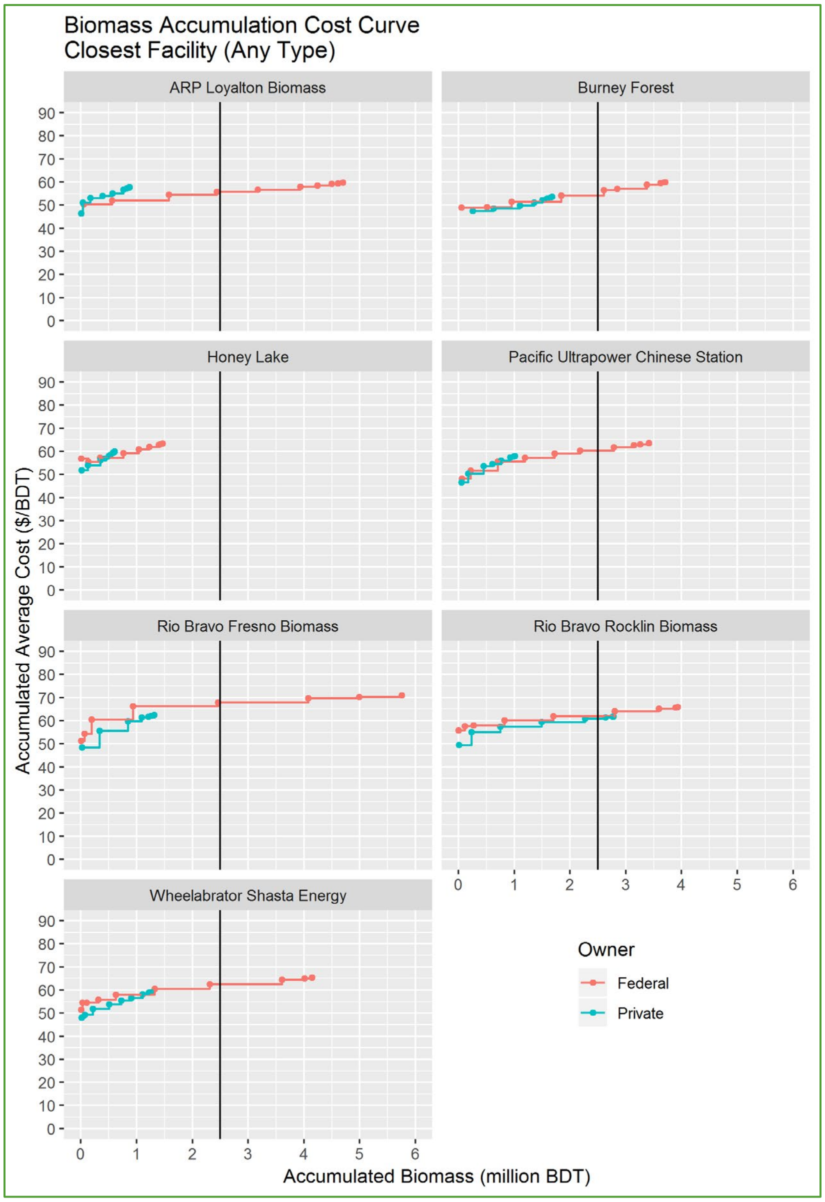

Figure 23. Cost Curves assuming equitable competition between all biomass power plants

6.5 DISTRIBUTION OF POTENTIAL BIOMASS

With the data from Figure 24, we can look at the distribution of potential biomass volume in the HHZ with respect to distance from a BioRAM plant. Figure 24 shows, for example, that only about

1 million BDT are within the first travel shell of 0-10 miles of a BioRAM plant (note that the 0-10 mile is labeled here with the midpoint of the range -- 5 miles). Another 4 million BDT is in the 10-20-mile shell (shown with the midpoint of 15 miles), etc.

Interviews with land managers indicated that they think that biomass within 40-60 miles of a BioRAM plant can usually be sold. There is about 42 million BDT of HHZ eligible biomass within 50 miles of a BioRAM plant.

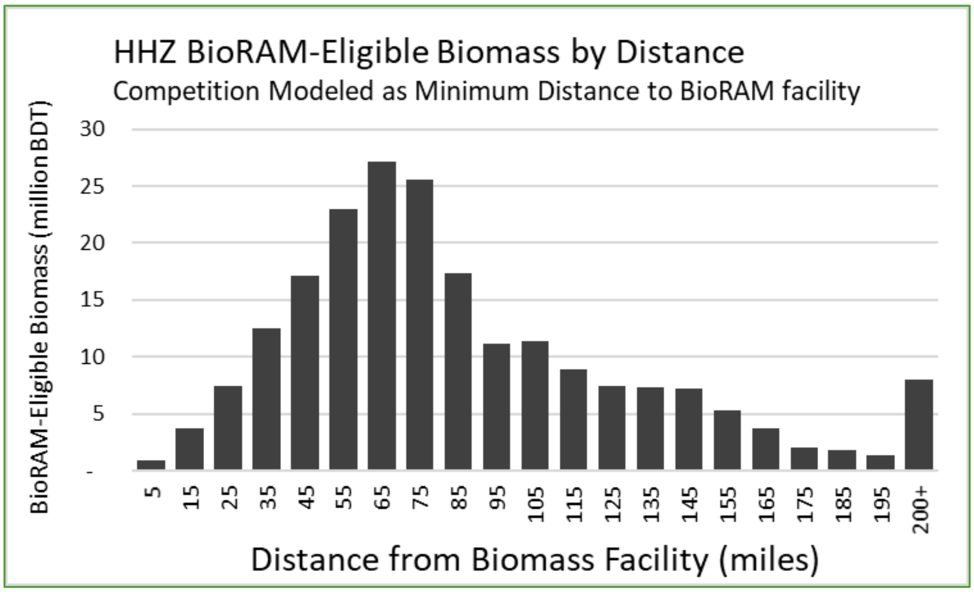

Figure 24. Distribution of potential biomass, distance from nearest BioRAM facility

Figure 25 is a cumulative distribution of the same data. It suggests that if all the biomass could be harvested from the acres closest to BioRAM plants, the facilities could be supplied for 20-years from biomass that was no further than 40 miles from a BioRAM plant. While that might be considered ideal from the standpoint of the BioRAM plants, it is unlikely to happen, and does not address broader HHZ forest management objectives that prompted SB 901 and similar legislation.

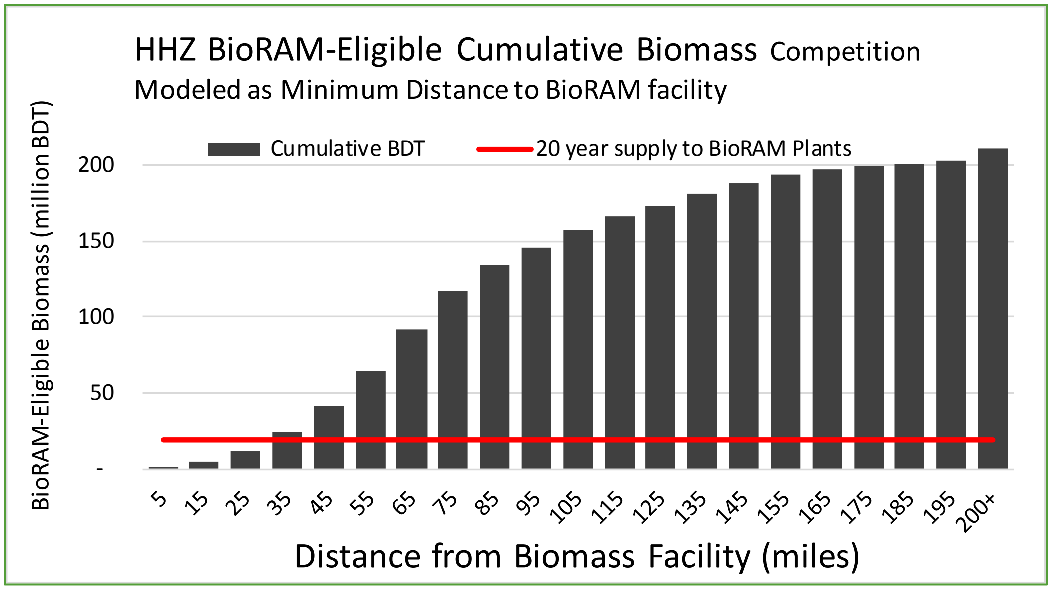

Figure 25. Accumulated distribution of potential biomass, distance from any BioRAM facility.

Figure 26 shows the potential biomass volume by distance to the closest biomass power plant. Notice that the volume shifts to the left as some biomass that is distant from a BioRAM plant is closer to non-BioRAM facilities. If those plants were incentivized to seek forest biomass, their demand for biomass could facilitate harvest treatments across a substantial portion of the potential biomass in the HHZ. There is about 77 million BDT of HHZ eligible biomass within 50 miles of any biomass power plant.

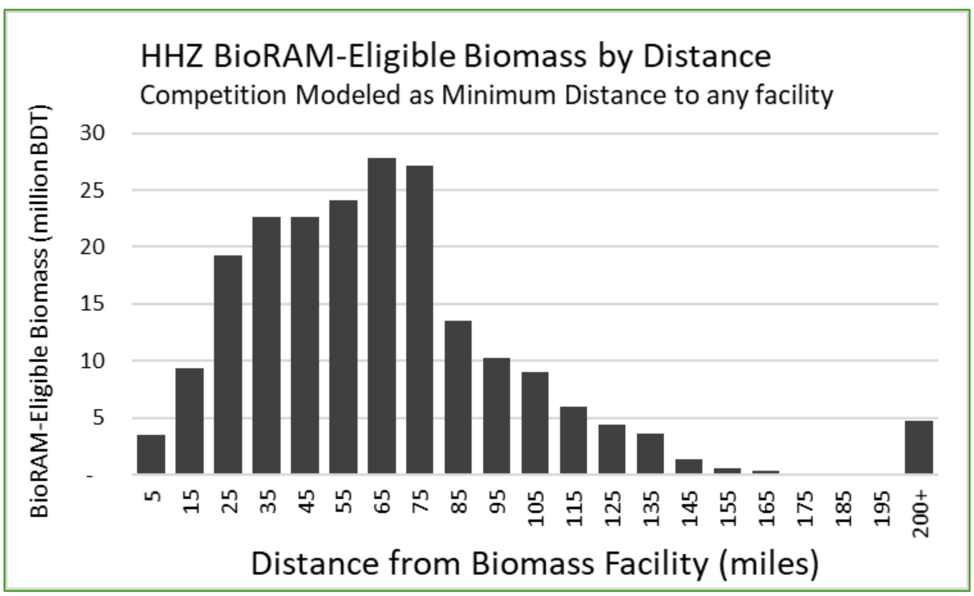

Figure 26. Distribution of potential biomass, distance from nearest biomass power plant of any type

Figure 27 shows the cumulative volume associated with Figure 26. The horizontal line corresponds to a 20-year supply requirement of forest residue biomass, assuming the 24 biomass power plants substituted forest residue biomass from the HHZs for their current consumption of about 1.5 million BDT of forest-based biomass (mill residuals and forest biomass residues).

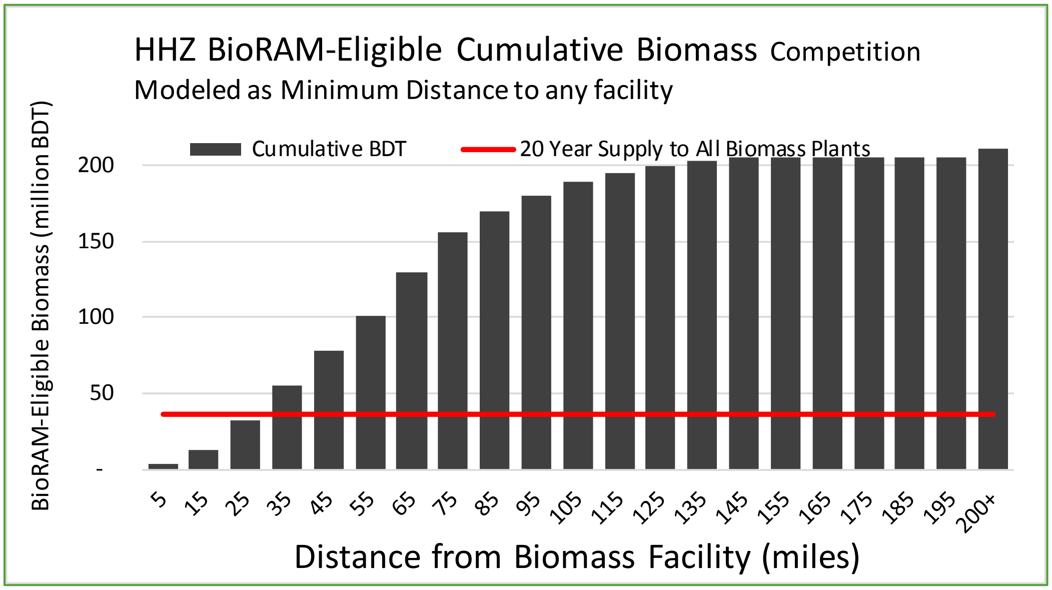

Figure 27. Accumulated distribution of potential biomass, distance from any biomass power plant.

Figure 25 and Figure 27 show that there is currently more than enough potential biomass in the HHZ to supply the BioRAM plants, and in fact all biomass plants, for decades to come.

Conversely, these figures could be interpreted to suggest that current biomass plant capacity is insufficient to address the forest health objectives – they simply cannot consume all of the potential biomass in the woods.

We urge readers to be cautious in drawing such conclusions. While reducing ladder fuels and removing dead trees would render many stands more resilient and reduce fire hazard, "forest restoration" does not mean that all the potential biomass inventory must be removed (see Section 8.4). Some of the small trees, for example, must be retained to grow future forests. Some of the dead trees might be retained for wildlife. An integrated forest restoration strategy, furthermore, will require a set of silvicultural regimes designed to bring forests into a desired condition. Some of the forest restoration treatment will be accomplished through prescribed burning, especially on USFS lands. This will remove forest fuels without producing biomass fuel (Section 8.2).

7 PRODUCTION OF BIOMASS FUEL

In Section 6 we defined “potential biomass” as forest material that is best suited for use as fuel because it is unsuitable for use in a higher valued product. The “potential biomass” includes tops of trees that produce sawtimber, trees too small to be used for sawtimber, and dead trees no longer suitable for sawtimber. The “potential biomass” is still uncut, in the woods.

In this section we turn our attention to the biomass associated with the annual harvest. Another distinction becomes useful. In this report:

- “Biomass cut” means the forest biomass material that is cut as part of a timber harvest and/or forest restoration treatment. Statewide estimates of biomass cut range from about 740,000 BDT to 2.5 million BDT, as discussed in Section 7.1.

- "Biomass fuel produced” means that portion of the biomass cut that is actually delivered to a biomass power plant to be burned to make electricity. The remainder is typically left in the woods unutilized. From Figure 1, forest biomass fuel production averages about 450,000 BDT annually.

The BioRAM plants and the biomass in the HHZs comprise only a part of California’s commercial timber economy. While a comprehensive description of California’s timber economy is beyond the scope of this report, there are several topics that will help the reader to better evaluate barriers and recommendations regarding biomass production and utilization. This section addresses the following questions:

- How much biomass is cut? (Section 7.1)
- How much biomass fuel is produced? (Section 7.2)
- How much biomass fuel has the Tier 1 HHZ provided? (Section 7.3)
- How much of the biomass from timber harvest goes unutilized? (Section 7.4)
- How much logging slash is unutilized? (Section 7.5)
- How much of current timber harvest is within a reasonable haul distance of the BioRAM plants? (Section 7.6)
- What are the economics behind biomass fuel production? (Section 7.7)

To the extent possible, we minimize replicating the narrative found in other studies, doing so only where it serves to provides context to the narrative of this report.

7.1 ESTIMATES OF FOREST BIOMASS CUT

Finding: Available data are inadequate to develop a robust accounting of forest biomass cut. Estimates developed for this report range from 750,000 BDT to 2,500,000 BDT.

Implication for biomass production: The biomass cut each year is sizable, relative to the 450,000 BDT of biomass fuel used by the biomass power plants.

Forest material suitable for use as biomass fuel is created on every timber harvest and on every forest restoration project that relies on mechanical treatment. The amount of material that is eventually delivered to a biomass power plant is measured and recorded as part of the sale transaction. The portion of the biomass that is cut but not removed, however, is neither measured, nor recorded.

The total amount of forest biomass cut every year can only be estimated using some rules of thumb. We describe here three rough estimates.

Our in-place inventory of potential biomass suggests there is about 0.16 BDT of top wood associated with each BDT of sawtimber. Total sawtimber harvest in California has been averaging about 1.5 Bbf/year which is equivalent to about 4.61 million BDT. That suggests that there might have been 740,000 BDT of top wood associated with the annual harvest. This is a conservative estimate since it does not account for biomass from branches, small trees, and dead trees. Nor does it take into account the fact that land managers design forest restoration projects specifically targeting small trees.

Another approach relies on a field estimate of 0.9 BDT of biomass created per Mbf of sawtimber harvest.[20] That suggests the annual sawtimber harvest produces as much as 1.35 million BDT of biomass. Again, this estimate may not take into account projects that specifically target small trees.

A third approach is based on an observation that an acre of timber harvest generally creates about a half of chip van load of biomass fuel or about 12.5 BDT/acre. Assuming that is the case even if the biomass is not removed, we can apply that estimate to estimates of annual harvest acreage. In Section 8.2 we estimate that about 110,000 acres of USFS lands are thinned each year – nearly all thinning treatments– which would yield about 1.375 million BDT of biomass cut. In Section 8.3 we estimate that total harvest on private lands is about 110,000 acres per year of partial cutting and clear cutting, yielding an additional 1.375 million BDT of biomass cut. Combining USFS with private biomass cut, this estimate yields 2.8 million BDT, which round down to 2.5 million BDT.

The preceding estimates apply statewide; there is no basis for refining the estimate to BioRAM qualfying fuel from the HHZ. We refrain from estimating biomass cut in proportion to acreage because HHZ harvests in areas with extreme tree mortality may yield more biomass cut than the observations on which these estimates are based.

[20] Larry Swan, USFS (*personal communication).*

7.2 ESTIMATES OF FOREST BIOMASS FUEL PRODUCTION

Finding: Statewide annual USFS timber harvest yields about 213 MMbf of sawtimber and 150,000 BDT of forest biomass fuel production.

Finding: Statewide annual private timber harvest yields about 1,300 MMbf of sawtimber and 300,000 BDT of forest biomass fuel production.

Implications for biomass production: The USFS provides about one third of the biomass delivered to the biomass power plants. This is an over-sized portion considering that the agency provides just 9% of the total harvest and reflects the agency's focus on forest restoration. Much of the recent tree mortality, furthermore, is concentrated on USFS lands.

In Section 6, we calculated the biomass inventory available on USFS land within the HHZ and found there was sufficient inventory to supply the BioRAM contracts for decades.

In this section, we look at actual production of forest biomass fuel. Records for USFS lands are more complete and available, and we examine those first. Then we take up biomass fuel production from private lands.

7.2.1 BIOMASS FUEL PRODUCTION FROM USFS LAND

Our interviews with USFS land managers indicate that most of the biomass delivered to biomass plants from USFS lands is produced in conjunction with the sawtimber harvest. Nearly all told us that by itself, biomass will not pay its way out of the woods.

Our interviews with the BioRAM plant managers revealed some frustration that the USFS does not typically require biomass removal from the timber sales, and as a result, the timber sale purchasers have not incentive to remove the biomass. We asked USFS land managers about whether and when they make biomass removal optional versus mandatory.[21] Most responded that they currently make biomass removal optional because timber sale purchasers view biomass removal as a net cost rather than a net benefit. Several mentioned that they had experience where they made biomass removal mandatory and then the sale did not receive any bids. When some of these sales were re-offered with biomass removal optional, they did receive bids.

Figure 28 summarizes the volume sold from USFS lands FY 2012-17. When a timber sale is advertised, the agency estimates the volume available in one or more product types. Logs that meet certain minimum specifications for manufacture into lumber or veneer, for example, are merchandized as sawtimber

[21] Appendix G provides some background on the types of USFS timber sale contracts and under which types of contracts biomass removal can be optional or mandatory.

		Annual Average FY 2012-17	
Code	***Product***	**Mbf**	**Ccf**
01	**Sawtimber**	233,154	409,387
02	Pulpwood	-	-
03	Poles	208	416
06	Posts	68	136
07	Fuelwood	39,483	78,813
08	Non-sawtimber	10,596	26,523
14	Misc convertible	1,450	3,103
18	Cull	4,654	8,343
19	Small Roundwood	1,038	2,075
20	Green Biomass	22,769	69,160
21	Dry Biomass	930	2,385
	Subtotal "Possible Biomass"	81,195	190,953
	Total Convertible . .	314,348	600,340
	"Possible Biomass" in BDT		**124,119**

Figure 28. Summary of timber sold from USFS lands

For reporting purposes, the agency converts all products to thousand board feet (Mbf) and hundred cubic feet (Ccf), even though some products are more typically sold under different units of measure (cords, tons, etc.) Sawtimber is the primary product from USFS timber sales accounting for about 74% of the total volume. Biomass accounts for about 7% of the total volume sold. Note that 13% of the volume is sold as “Fuelwood” – this code is typically used for personal use firewood, not suitable for the biomass plants. Most other product types are less well-defined, and the final disposition and delivery of those products may not line up with the product type. USFS timber sales with “Biomass” in the sale name, for example, may have volumes for product types other than the “Green Biomass” or the “Dry Biomass” product types. For that reason, we summed all the product types that are not sawtimber and not firewood and labeled that “possible biomass.” We converted the “possible biomass” subtotal into BDT at the bottom of the table. That calculation shows that on average, the USFS annually sold an average of about 124,000 BDT of biomass over the previous six years. Since this is volume paid for, we count it as forest biomass fuel delivered to biomass power plants.

During a timber sale, however, the volume removed may differ from the volume sold. The contract administrator, for example, may add or subtract contract volume to account for changed conditions which make more volume available for harvest (fire, windthrow, etc.). Or the timber sale purchaser, for example, may request authorization to haul off additional biomass volume, or ask to be relieved from removing biomass. This additional volume is called “optional volume,” and is in addition to or a subtraction from the sold volume reported in Figure 28**.**

USFS timber sale contracts usually cover a three-year period which means that the volume sold each year may not line up with the volume removed each year. Figure 29 shows rolling annual average of non-sawtimber harvested from all USFS lands in California. Here, non-sawtimber includes all products other than sawtimber or fuelwood. Note the trend – current levels of non-sawtimber harvest have fallen to less than half of the levels during the 1980s and early 1990s.

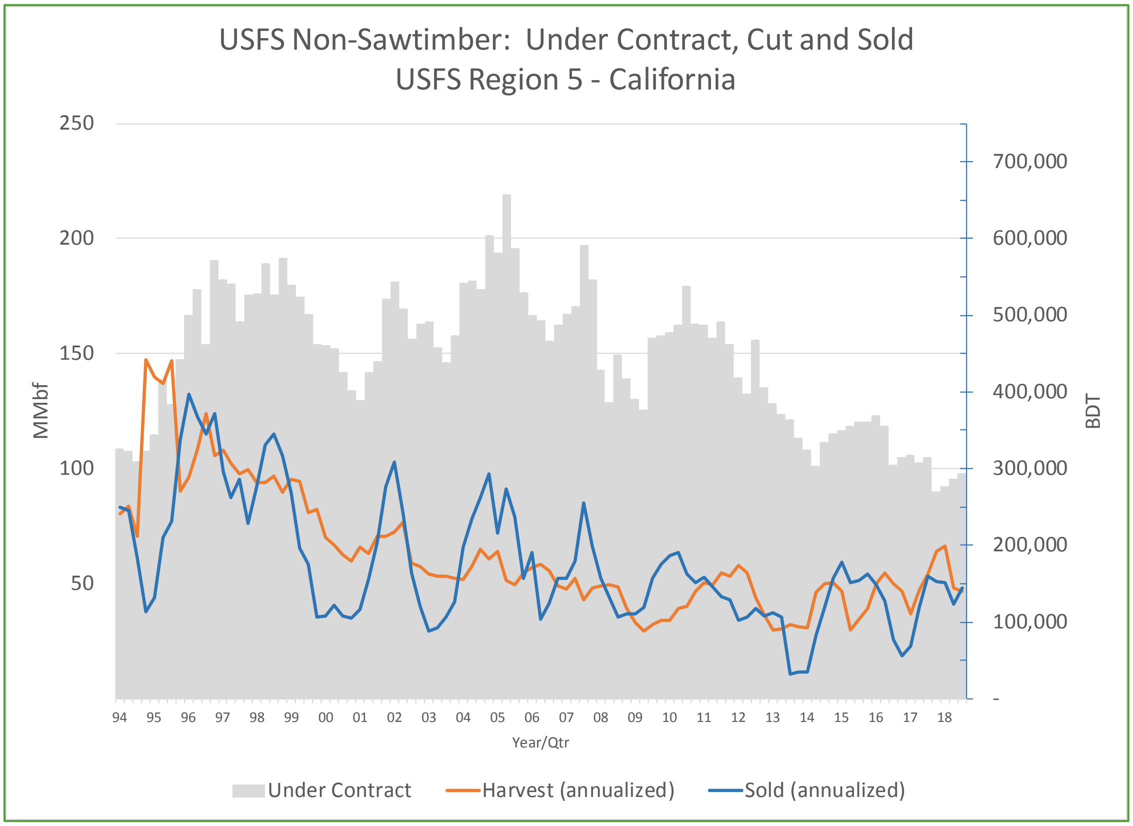

Figure 29. Summary of non-sawtimber sold, cut and remaining under contract, USFS.

7.2.2 BIOMASS FUEL PRODUCTION FROM PRIVATE LANDS

Typically, we rely on data collected by the State Board of Equalization (SBE) for statistics about timber harvest by ownership in California. In collecting the timber harvest tax, SBE collects and compiles information about sawtimber harvested in the State. The SBE publishes annual statistics about timber harvest by owner group in each county. This historic data series is considered reliable within the industry. SBE also reports sawtimber values by species and size classes for each of nine Timber Value Areas.

The tax rate on forest biomass is zero, however, and SBE does not require that all biomass be reported. SBE does not routinely publish the biomass data. We requested annual totals from SBE and received the data shown in Figure 30. The 2015-17 volume is only 45% of the total In-Forestry volume reported by CalRecycle (Figure 1). As a result, we conclude that the SBE data are under-reported and cannot be used for this analysis.

Figure 30. Biomass production recorded by State Board of Equalization

Year	BDT Woods Produced Fuel Chips
2009	256,919
2010	266,487
2011	297,263
2012	225,544
2013	162,411
2014	241,594
2015	273,353
2016	143,924
2017	199,116

Given the under-reporting of the SBE data, our best estimate of forest biomass from private lands is calculated as the difference between the totals from the CalRecycle data and the non-sawtimber reported by the USFS -- about 300,000 BDT per year.

7.3 HHZ TIER 1 HARVESTS

Finding: CalTrans has removed about 217,000 BDT of forest biomass fuel in its efforts to remove hazardous trees from rights of way over a three-year period. CalTrans hazard tree removal cost averages $850/tree.[22]

Finding: PG&E has removed about 125,000 BDT from its line clearing activities through the end of 2018.

Implications for biomass production: Hazardous tree removal from Tier 1 HHZ provided a substantial amount of biomass in the recent past. Going forward, there will be less biomass produced from these activities.

[22] Biomass removed by CalTrans and PG&E from USFS land will be reported by the USFS as biomass harvest. The figures reported in this section, therefore cannot be added the figures reported by the USFS as that would double count biomass production.

About 1% of the HHZ is designated as Tier 1 -- areas near critical infrastructure including roads, utilities and public schools and the primary focus is on removing trees that present a hazard to public safety. Early efforts to address tree mortality were directed at Tier 1 areas, and substantial volumes of biomass were produced from these efforts. We report here on two.

7.3.1 CALTRANS HAZARD TREE REMOVAL ALONG STATE HIGHWAYS

CalTrans is responsible for maintaining safety along state highways. The recent mortality in the central Sierra forests created hazard trees along roads, requiring a focused effort by CalTrans to remove the hazard trees.[23] This was a new and difficult kind of effort for CalTrans. The agency has 20,000 employees, most of the professional staff are engineers, there are 150 landscape architects, but no foresters. CalFire and the USFS provided some assistance, but CalTrans was faced with the task designing hazardous tree removal projects, engaging logging contractors, and navigating the regulatory environment. Contractors were responsible for disposing of the material and CalTrans encouraged the contractors to haul the material to biomass power plants.

Between 2016 and 2018, CalTrans initiated 37 hazardous tree removal projects along highways covering 4,625 miles. A total of 179,800 trees were removed at a cost $153 million -- an average cost of $850/tree. The effort generated about 217,000 BDT of biomass, about 63% of which was hauled to biomass power plants. Some of the material was chipped and scattered in place, some went for mulch.[24]

There is still much work to do even if mortality trends reverse. Going forward, CalTrans is evaluating what needs to be done going forward to maintain desirable forested conditions in rights of way. Plans are to develop “shaded fuel breaks” that will require periodic maintenance going forward. At this time there are no estimates about how much biomass fuel that might produce.

7.3.2 PG&E POWERLINE CLEARING

In summer of 2018 PG&E began an Accelerated Wildfire Risk Reduction program (AWRR). The goal of AWRR was to clear hazardous trees from over 7,000 miles of power lines in less than one year. The AWRR line clearing effort represented a substantial effort for PG&E. It is estimated that over 1,000 employees and contractors were involved in the effort, including many from out of state.

By the end of 2018 about 125,000 BDT was removed and delivered to biomass power plants by PG&E contractors. Additional material was delivered to sawmills or was retained by the landowners, but an estimate is not available from PG&E.

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[23] HHZ acres along state highways is considered Tier 1.
[24] Personal Communication, Lisa Worthington, CalTrans.

Learning from the AWRR program, PG&E has made some operational improvements and has launched the Enhanced Vegetation Management program (EVM). Updated targets and goals for the EVM program were not available at the time of this report deadline.

7.4 UNUTILZED BIOMASS

Finding: While there are no statistics available about unutilized biomass, we estimate that between 40% and 80% of the forest biomass cut each year is unutilized by the biomass power plants. Estimates for unutilized qualifying fuel are not available.

Implication for biomass production: A substantial amount of forest biomass that is cut is left behind in the forest.

During our interviews with land managers, all noted that biomass that could be utilized is often left in the woods because the cost of producing and delivering biomass to the power plants is greater than the value of the biomass at the power plant. The unutilized biomass is typically: (1) left behind in piles; (2) piled and burned; (3) scattered back throughout the harvest unit; or (4) chipped and scattered in the harvest unit.

Since the amount of unutilized biomass is not measured nor estimated in any comprehensive fashion, we can only make a rough estimate of unutilized biomass.

We start with the CalRecycle data indicating that the biomass power plants burned on average about 450,000 BDT of forest residues over the last three years. In Section 7.1 we estimate that the total biomass cut each year is between 750,000 BDT and 2.5 million BDT. As a result, utilization is between 18% and 60%. Stated conversely, between 40% and 82% of the biomass cut is unutilized.

The estimates cannot be refined further for the HHZ or qualifying fuel.

7.5 UNUTILIZED SLASH

Finding: Unutilized slash is generally in the range of 5-10 green tons per acre. Many factors affect this estimate.

Implication for biomass production: On harvest units where biomass is produced, the unutilized slash might be equivalent in weight to about 20% biomass removed. Increasing efforts to remove this material would not be cost-effective.

After sawlogs are removed from a logging site, the material left behind is referred to as "slash." In this report, the portion of the slash that is processed into chips and hauled to a biomass power plant is called "biomass." The biomass typically consists of the tops of trees, smaller pre-merchantable trees skidded to the landing, and portions of larger trees not suitable for lumber manufacture due to breakage, defect, or species.

After biomass is removed and shipped to the biomass plant, there is still some material consisting of branches, stray logs, etc. Picking up all this material typically costs more than it is worth. For the purpose of this discussion, this unutilized portion of the slash is called "unutilized slash." Unutilized slash is sometimes pushed into a pile and burned. Where burning is difficult or risky, it is sometimes left in piles or scattered back into the harvest unit to decompose.

Forest land managers know the volume of merchantable sawtimber and biomass removed because these quantities are measured at the destination and these measurements are the basis for payment. The unutilized slash is never measured, however. In our interviews, we found that forest managers could make some general estimates of the amount of unutilized slash, but there was not great confidence in the estimates.

Several land managers offered estimates in the range of 5-10 green tons/acre. Most respondents fell on the lower end of the range when biomass is being removed aggressively.

Unutilized slash is typically higher in the Coast Range (trees limbs are larger and there is more brush), on clearcuts (smaller pre-merchantable trees might be cut but not hauled), and on fire salvage (dead trees too damaged to send to a sawmill, and dead trees too small to skid to a landing.)

Where biomass is not removed, it shares the fate of the unutilized slash – it is piled and burned, it is piled and not burned, or it is distributed back throughout the sale.

Where biomass is being hauled, land managers estimate that they produce about 1-2 chip van loads -- about 25-50 green tons per acre. In that case, the unutilized slash would be equivalent to about 20% of the material removed. Given the nature of this material the additional handling costs will exceed the value of the material.

7.6 HOW MUCH HARVEST IS WITHIN STRIKING DISTANCE OF BIOMASS POWER PLANTS?

Finding: The forest acres now designated as HHZ account for about 42% of the forest land base, and have accounted for about 62% of the historic harvest.

Finding: About 23% of the HHZ falls with an economically viable 50-mile haul of the BioRAM plants. Historically, this area has accounted for about 45% of the acres harvested within the HHZ.

Implication: Historically, harvest has been located favorably for the BioRAM plants. Future forest restoration efforts will likely be directed at more distant acres which will incur higher haul costs.

Because most of the biomass power plants are located at some distance from forestland, only a portion of the forested area lies within the economically viable haul distance. We asked land managers and loggers how far they could afford to haul biomass without incurring a loss. Most indicated that the breakeven point was somewhere between 40 and 60 miles.

In Figure 31 we delineated 50 miles haul distances around the BioRAM plants and in Figure 32 we added the same delineation around all 23 biomass power plants (see Figure 15 for currently operational facilities).

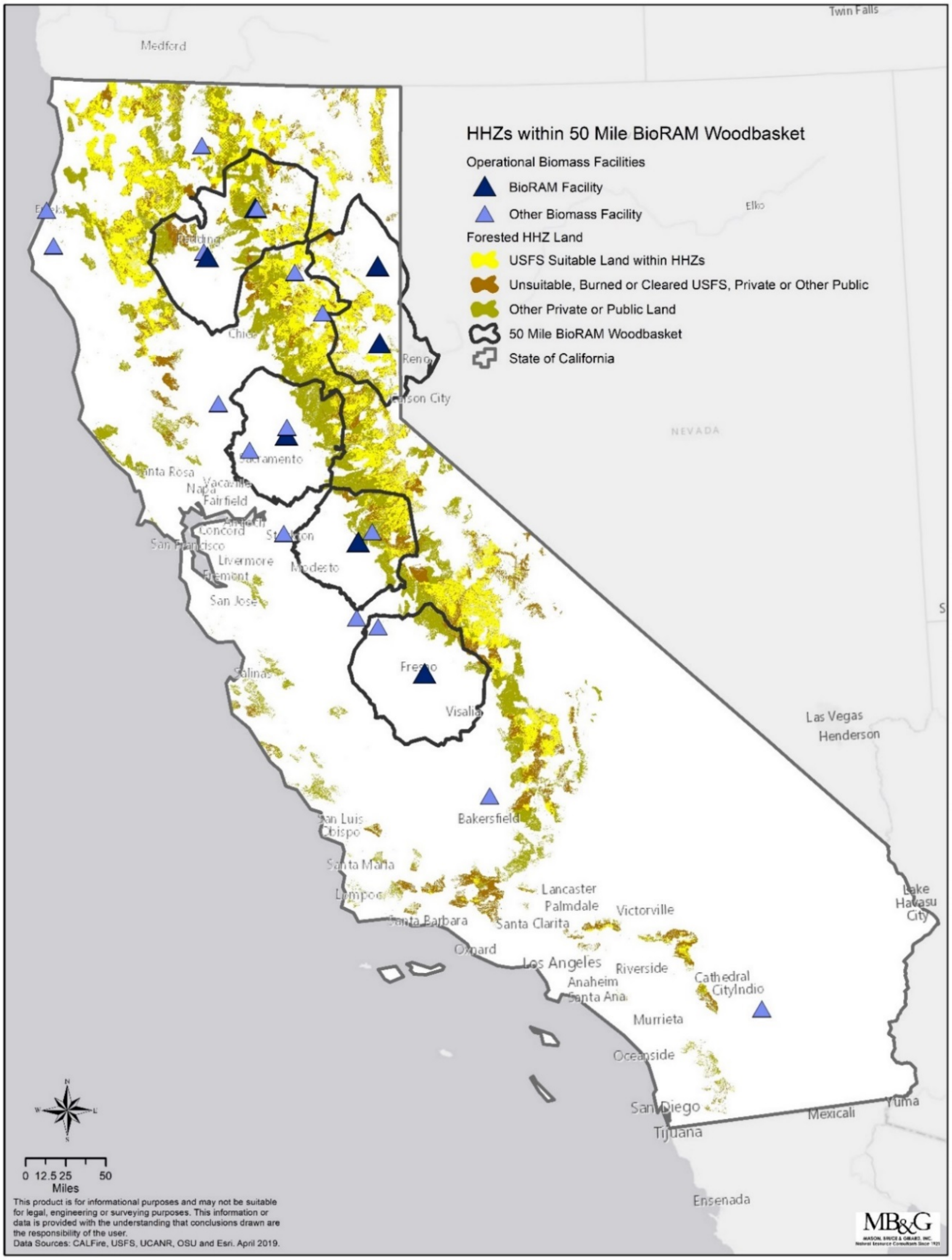

Figure 31. HHZs within 50 miles of BioRAM plants

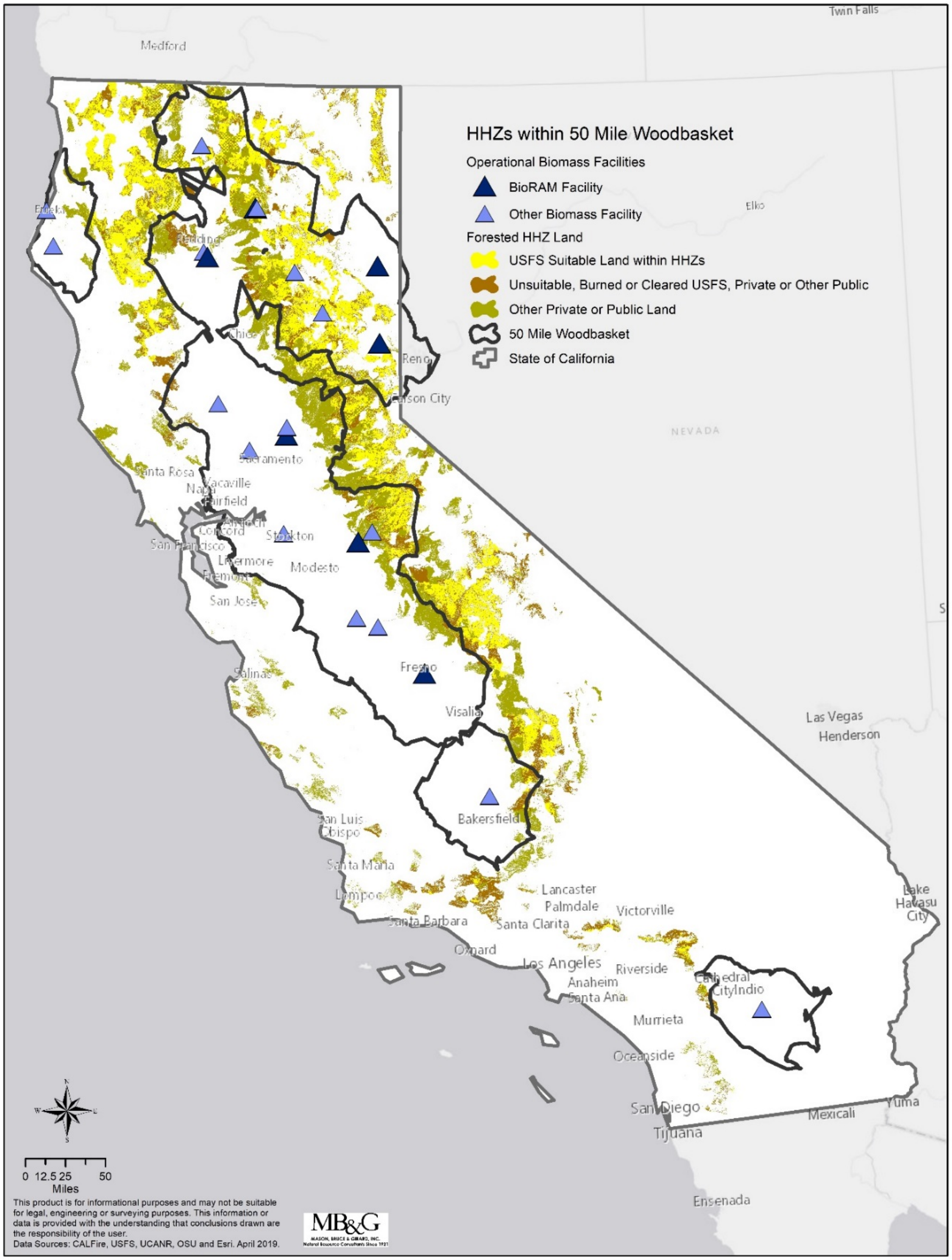

Figure 32. HHZs Within 50 Miles of BioRAM Plants and All Biomass Plants

We used the USFS GIS layer of timber sale activities and the CalFire GIS layers of timber harvest permit requests (THP and NTOS) to calculate how much harvest activity fell within the 50-mile haul zones.

Figure 33 summarizes the result.[25] Key findings include:

- The HHZ includes about 42% of California forestland, but about 62% of the annual harvest acres.

- Only 3.6 million acres of the HHZ (23% of the HHZ) fall within 50 miles of a BioRAM plant, but that area accounts for 45% of the historic harvest acres in the HHZ.[26]

- About 6.4 million acres of the HHZ (41% of the HHZ) fall with 50 miles of any biomass power plant. That area accounts for 86% of historic harvest acres in the HHZ.

	All California Forestland	**HHZ Acres**		
	State totals	**All HHZ**	**50 miles of BioRAM Plants**	**50 miles of all Biomass Plants**
Acres of Forestland	36,934,686	15,563,961	3,626,979	6,357,063
USFS timber harvest acres (2012-2017)	452,759	332,876	112,596	194,830
Private timber harvest (2012-2018)	728,866	394,277	219,533	443,787
Total of harvest above	1,181,626	727,153	332,129	638,616
Annual average	179,584	111,805	50,128	95,870

Figure 33. HHZ timber harvest within 50 miles of BioRAM plants and all biomass plants.

In summary, the forest now designated as HHZ has historically had a disproportionate share of timber harvest activity. Similarly, the HHZ within 50 miles of the biomass plants has had a disproportionate share of the HHZ harvest.

Whether future harvests can be similarly concentrated in areas favorable for haul to the BioRAM plans remains to be seen. Future efforts to increase the pace of forest restoration will undoubtedly need to be directed to acres more distant from the BioRAM plants. The result will be higher haul costs.

7.7 ECONOMICS OF BIOMASS PRODUCTION

Finding: Producing forest residue biomass for power has an unfavorable economic return and generally requires financial incentives to encourage biomass production.

[25] HHZ acres do not match those shown in Section 6 due to GIS processing differences.
[26] Note that the HHZ was not delineated as such for most of the historic period shown.

Implications for biomass production: If returns are unfavorable, forest biomass will not be fully utilized, and forest management objectives that depend on biomass removal will not be met.

Here we explore the economics of biomass production, first from the perspective of the power plant operator, then from the perspective of the land manager seeking to achieve some forest management objectives through biomass production. Finally, we review roles of various participants in the biomass economy and discuss incentives to increase biomass production.

Our interviews with land managers, loggers and others revealed that delivery of forest residue biomass to a biomass power plant seldom pays for itself. Even with the favorable power price received by the BioRAM contracts, biomass production costs often exceed delivered prices.[27]

Land managers typically view biomass production as a favorable outcome for several reasons:

- Removing small trees as part of a silvicultural prescription reduces competition for water and nutrients, improves forest health and resiliency, and reduces risk of unnatural wildfire.

- Removing concentrations of dead trees reduces risk to the public, firefighters, and private and public employees who work in the woods, reduces risk of high-intensity burns once the trees begin to break and fall down, provides openings for natural regeneration or replanting, and can increase vegetative diversity for wildlife.

- Using forest thinnings and slash as fuel for biomass power plants reduces carbon impacts, and greatly reduces the emission of carbon and other pollutants compared to open-burning, prescribed burns and wildfire.

- Hauling away the logging waste (tops and branches) as biomass eliminates or reduces the need for burning slash. Slash burning is sometimes difficult due to air quality regulations and is sometimes seen as a liability.

- Biomass removal requires less of a subsidy than simply felling the trees and burning them on site.

Section 6 of this report estimates the volume of forest residue biomass as a function of the type of material (tops, small trees, dead trees) and the haul distance to the nearest biomass plant. We found that biomass costs range from $60/BDT to $70/BDT and that there exists within 50 miles of each BioRAM plant sufficient forest biomass to supply each plant for 40-50 years at current consumption rates.

7.7.1 ECONOMICS OF BIOMASS: BIOMASS POWER PLANT PERSPECTIVE

[27] Some of our interviews revealed that the economics are better for the BioRAM 2 contracts.

A simple model of biomass power plant economics computes profitability by subtracting operating and fuel costs from the power price, where units are $/MWH. In our experience a $45/MWH operating cost for a 25 MW biomass power plant is a reasonable estimate.[28] Using $45/MWH as a constant operating cost, we calculate potential profit on a $/MWH basis as the difference between the price of power and the cost of fuel (Figure 34**).** This expression of potential profit is over and above the expected rate of return included in the operating cost.[29]

Figure 34: Estimated profit ($/MWH) at a biomass power plant at a given power sales price and a delivered fuel cost

		Power Price $/MWH													
		$ 70	**$ 80**	**$ 90**	**$ 100**	**$ 110**	**$ 120**	**$ 130**	**$ 140**	**$ 150**	**$ 160**	**$ 170**	**$ 180**	**$ 190**	**$ 200**
Fuel Cost $/BDT	$ 30	$ (5)	$5	$15	$25	$35	$45	$55	$65	$75	$85	$95	$105	$115	$125
	$ 40	($15)	($5)	$5	$15	$25	$35	$45	$55	$65	$75	$85	$95	$105	$115
	$ 50	($25)	($15)	($5)	$5	$15	$25	$35	$45	$55	$65	$75	$85	$95	$105
	$ 60	($35)	($25)	($15)	($5)	$5	$15	$25	$35	$45	$55	$65	$75	$85	$95
	$ 70	($45)	($35)	($25)	($15)	($5)	$5	$15	$25	$35	$45	$55	$65	$75	$85
	$ 80	($55)	($45)	($35)	($25)	($15)	($5)	$5	$15	$25	$35	$45	$55	$65	$75
	$ 90	($65)	($55)	($45)	($35)	($25)	($15)	($5)	$5	$15	$25	$35	$45	$55	$65
	$ 100	($75)	($65)	($55)	($45)	($35)	($25)	($15)	($5)	$5	$15	$25	$35	$45	$55
	$ 110	($85)	($75)	($65)	($55)	($45)	($35)	($25)	($15)	($5)	$5	$15	$25	$35	$45
	$ 120	($95)	($85)	($75)	($65)	($55)	($45)	($35)	($25)	($15)	($5)	$5	$15	$25	$35
	$ 130	($105)	($95)	($85)	($75)	($65)	($55)	($45)	($35)	($25)	($15)	($5)	$5	$15	$25
	$ 140	($115)	($105)	($95)	($85)	($75)	($65)	($55)	($45)	($35)	($25)	($15)	($5)	$5	$15
	$ 150	($125)	($115)	($105)	($95)	($85)	($75)	($65)	($55)	($45)	($35)	($25)	($15)	($5)	$5

While the BioRAM contract prices are confidential, we understand that the average price is about $115/MWH.[30] At that rate, a power plant should be able to pay on average fuel cost of around $65-$70/MWH and achieve the expected rate of return.

Note that this is the average fuel cost. Higher costs on some portion of the fuel can be offset by lower cost on another portion. For example, Figure 35 shows that prices for mill residuals are substantially less expensive than forest biomass. If the biomass power plant can obtain less expensive qualifying fuel like mill residuals, or if operating costs are lower, then additional profits are possible.

Section 6 of this report shows that the least expensive forest residue biomass comes from tops and waste from commercial sawtimber harvest. Biomass derived from small trees or dead trees is more expensive as it must be cut and hauled to the landing. Mil residuals are generally less expensive than forest residues, as are ag and urban waste (see Section 7.6.2). Mixing these less expensive fuels into its

[28] https://biomass.ucdavis.edu/files/2013/09/10-31-2013-energy-cost-calculator-generic-power-only.xls

[29] In this example, operating costs include capital replacement, capital recovery, depreciation and an allowance for normal profit.

[30] http://cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Electric_Power_Procurement_and_Generation/Renewable_Energy/BioMAT%20Program%20Review%20and%20Staff%20Proposal.pdf

source allows a BioRAM plant pay more for forest residues while keeping average costs within the profitable range.

Section 4 indicates that the BioRAM plants currently account for about two-thirds of the forest biomass consumed by all of the power plants in California and Figure 34 can help explain that. We believe that the power price for other biomass power plants ranges from $70-85/MWH. At that rate, there is little forest biomass that can be utilized at a profit. The cost of the forest biomass must be averaged with less expensive mill residuals, ag and urban waste.

The first BioMAT contract was reportedly let for $192/MHW (Harper, 2019). We understand that operating costs for the smaller BioMAT plants are likely higher than for the larger BioRAM plants, but do not have any specific data.

7.7.2 FOREST RESIDUES V. MILL RESIDUALS

Finding: Historically, biomass from forest residue has cost about 50% more than mill residuals. Since the initiation of the BioRAM contracts, that difference has increased substantially.

Finding: Mill residuals offer some operational advantages over forest residue in terms of meeting BioRAM contract thresholds.

Finding: For 2017, the BioRAM mills used about twice as much forest residue as mill residuals.

Implication for biomass production: To the extent that increased forest restoration results in increased sawtimber production, and those residuals can qualify under the BioRAM contracts, the increase in mill residuals will offset some of the demand for forest residue biomass as the price is much more favorable.

Mill residuals are a less expensive fuel source for a couple of reasons. Mill residuals is the material left over after manufacturing the sawtimber into solid wood products – lumber and veneer. The cost of cutting and skidding the sawtimber to the landing, loading and hauling the sawtimber to the mills out of the mountains into the valleys is covered by the revenue from producing the lumber and veneer – essentially, the mill residuals are a by-product of the solid wood products production. In addition, much of "chipping" the wood into small pieces for the biomass plant has already been performed by the lumber or veneer mill as well. The biomass power plant need only pay the cost of transportation from the mill to the biomass plant (which are all highway miles) plus enough to bid the source away from the alternative uses – MDF, particleboard, pellets, etc.

The mill residuals have another advantage to the BioRAM plants, they help meet the qualifying fuel thresholds during the winter quarters when forest residue biomass is less plentiful. Sawmills build up large log decks in the fall to operate during the winter and early spring when access to the woods is limited. Since the mills operate year-round, mill residuals serve as the qualifying fuel available during the winter.

In this report, we focus primarily on the portion of woody biomass fuel that is either the residue of logging or the objective of forest restoration treatments. Figure 1 shows that in 2017, the BioRAM plants used 340,000 BDT of forest residue and 176,000 BDT of mill residuals. The biomass consumption profile of the non-BioRAM power plants is inverted – they used 164,000 BDT of forest biomass and 941,000 BDT of mill residuals. Why the difference in sourcing?

Figure 35 shows California woody biomass price trends as published by North American Wood Fibre Review. Note here that forest residue biomass historically cost more than biomass from any other source. We assume that the abrupt price increase in 2017 reflects the onset of the requirements of the BioRAM contracts, which allows the BioRAM plants to pay more for forest biomass.

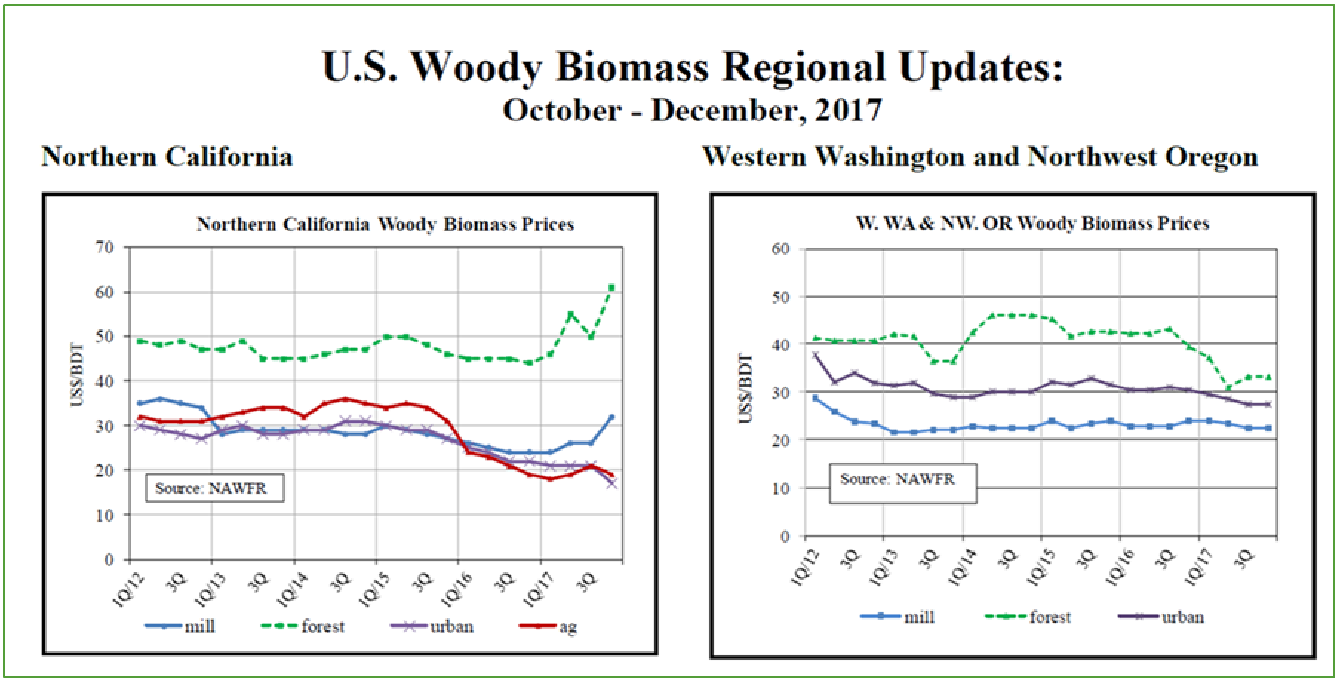

Figure 35. Biomass price trends, North American Wood Fibre Review

Despite the advantage of mill residuals, at least for 2017, the BioRAM plants used half as much mill residuals as forest residue biomass. We can only speculate about the reasons:

1. A sizeable portion of the 2017 forest biomass was from Tier 1 harvests, which had very favorable economics due to hazardous tree removal subsidies (see Section 7.2).

2. BioRAM plants may have difficulty sourcing qualifying fuel from mill residuals – the logs need to come from the HHZs and cannot come from clearcuts for the BioRAM 2 contracts. In our interviews, we spoke to private land managers that do not consider selling forest biomass or mill residuals to BioRAM plants for this reason.

3. Some of the sawmills use biomass for fuel and may not make as much mill residual available to the BioRAM plants.

7.7.3 RETURN TO LOG CALCULATIONS

Finding: The use of forest biomass for fuel provides the least return to log value of any wood product.

Implications for biomass production: The forest biomass used for fuel is either the by-product of producing some higher-valued wood product, or the result of some forest subsidized improvement activity.

Historically, biomass has been a by-product of producing higher valued wood products. An understanding of the relative values of forest products will help illustrate and demonstrate to what extent the value of biomass can affect or change production decisions.

In a 2015 report, The Beck Group developed pro forma income statements for several different potential small wood-using business opportunities in Northern California. A high-level Return to Log (RTL) or Return to Fiber (RTF) analysis of each business helps illustrate the relative values of different wood products.

RTL and RTF are forest industry terms used to describe the value a conversion facility will yield after accounting for the cost of converting the material from its original form into a finished product. RTL refers to processes where the incoming feedstock is logs. RTF refers to processes where the incoming feedstock is wood fiber in the form of chips, sawdust, shavings, etc. To illustrate, an RTL example for sawmills is calculated by:

1. Estimating the total revenue that can be generated from sawing a log (i.e., the combined value of the lumber, chips, sawdust, shavings and bark all expressed on a $/MBF basis).

2. Subtracting the total cost of converting the log into lumber and byproducts from the total revenue (again expressed on a $/MBF basis).

3. The result is referred to as the RTL Value, the Maximum Allowable Delivered Log Cost, or the “break-even log cost”.

The result of an RTL or RTF calculation is the value generated by the log or fiber after accounting for the cost of converting it into a set of products.

BECK completed RTL/RTF analyses for seven products. Since the various technologies use different units of measure for the raw materials and finished products, BECK converted all units to a dollar per BDT basis. This allows for a direct comparison of the economics underlying each technology and identification of technologies capable of generating the greatest value from the wood raw material.

BECK's analysis was conducted at a relatively high level using a combination of data from its work on prior projects. Several assumptions were made about the scale and operating costs of the various technologies. The results should not be viewed as precise cost and revenue estimates. Rather, the focus should be on the relative difference between the values generated by each conversion technology.

Figure 36 reproduces Table 4.6 from that report showing the estimated RTF/RTL values and key metrics associated with each wood producing technology.

Lumber manufacturing is the technology creates the highest RTL value, at $97/BDT. Shavings, and post and pole manufacturing are in a second tier providing RTL/RTF values around $50/BDT. The third tier of technologies includes briquettes, pellets, and firewood that each create roughly equal value around $40/BDT. Finally, fuel chips have the lowest return at $6/BDT.[31] A more complete discussion of this analysis is found in **Appendix D**.

Figure 36. Estimated Return to Fiber/Log Values for Seven Technologies

	Lumber	Shavings	Post and Pole	Briquettes	Pellets	Firewood	Fuel Chips
Sales Value f.o.b. plant, ($/BDT)	206	178	195	167	160	95	25
Conversion Cost Inc. dep. and owner return @ 15% ($/BDT)	109	126	144	126	122	60	19
RTL/RTF Value ($/BDT)	**97**	**52**	**51**	**41**	**38**	**35**	**6**

The RTL/RTF figures shown above represent the value of the log/fiber at the processing facility. To underwrite forest management activities without subsidy, these values must cover the costs of harvest, transportation, contract administration and an acceptable stumpage return to the landowner. In the Biomass Financial Model (Section 8.6) we show that those costs can be considerable; common practice for biomass is to allocate the harvest and contracting cost to the sawtimber and pay little or nothing to the landowner for the biomass. Even with that arrangement, biomass transportation costs may overshadow the RTL.

[31] This calculation was based on an 18 MW plant selling power on a 20-year contract with the first-year price starting at $70/MWH and then escalating 2% annually. The BioRAM plants start at a more favorable rate and should therefore have a more favorable RTL.

Given the substantial difference between the value of timber for manufacture of lumber and for the production of bioenergy, production of biomass fuel is almost always the by-product of production of sawlogs, or the result of a forest restoration effort with additional funding.

The magnitude of the difference suggests that biomass values are unlikely to be sufficient to make much of a difference in the pace and scale of forest restoration efforts.

Finally, the difference also suggests that to loggers and haulers looking to invest in employees and equipment, sawlog production offers a more attractive investment opportunity than does biomass production – the margins are better.

7.7.4 ROLES AND RESPONSIBILITIES

A simplified model of biomass power economics includes the power plant, the land manager and the timber producer, but in practice, the transaction is accomplished by several overlapping or related entities and requires many different activities. Figure 37 illustrates the roles and responsibilities for one typical arrangement. Others typical arrangements are shown in **Appendix D.**

In this example, the biomass harvester gets the biomass material at no cost – earning income by removing and delivering biomass and being paid directly by the biomass power plant. If the costs of removing and delivering biomass exceed the value of the delivered material, then the biomass harvester will require additional payment from the landowner.[32]

Note that in the example in Figure 37, the landowner does not receive any revenue from the biomass, but does benefit by having the biomass removed – future risks are reduced as discussed in Section 7.6.

Finally, note that in the current situation, the financial incentive to utilize biomass comes from the power plant in the form of a more favorable power price. The power plant has every incentive to keep fuel costs as low as possible, however, which means that the power plant will prefer fuel found close by and sourced from logging waste – tops and branches. There is no financial incentive for the power plant to seek biomass from more expensive sources, whether from small trees or dead trees or from more distant forests.

To incentivize forest restoration, additional funding might be paid directly to landowners to finance biomass removal or paid to biomass harvesters and haulers to cut and haul higher priority biomass that might be more distant and/or more expensive.

[32] On a USFS contract, the sawtimber purchaser will cover the additional cost of removing the biomass, if biomass removal is required in the contract. If biomass removal is not mandatory and the biomass is not profitable, the purchaser often leaves the biomass behind in the sale unit.

Figure 37. Roles and responsibilities for a typical timber harvest operation on private land that contracts with a professional forester.

Case 1: Private landowner contracts with forester to prepare and sell timber

Actor	Role	Cash flows	Notes
Landowner	Decide to harvest timber Engage forester	Receives net cash from Forester contractor	Retains title to logs until delivered to mill
Forester (RPF)	Layout timber sale Road design Permitting (THP) Get log price contracts with sawmills Get road contract Get logging contract Get biomass contract Get slash disposal contract Get site prep contract Get reforestation contract Arrange for seedlings, if needed Administer all contracts Invoice sawmill for logs Pay contractors Accounting and reporting to landowner	Contract with landowner	Logs are sold to different mills based on species and size
Road contractor	Road construction Road reconstruction Road maintenance during the operation Road repair after the sale	Paid hourly rate by landowner as work is performed	
Logging contractor	Get log hauling contractor Cut, skid and buck logs Load sawlogs on to log truck	Paid by landowner per Mbf as work is performed	
Log hauling contractor	Haul logs to the sawmill	Paid per Mbf by landowner as work is performed	Most loggers have some log trucks
Biomass contractor	Chip biomass and load chip vans Get chip van hauling contract	Gets the biomass for free. Paid by the power plant for delivery of biomass	May be employees of the logging contractor. Or might be a separate company. Owns the chipper/grinder.
Chip hauling contractor	Deliver chips to biomass plant	Paid by the biomass contractor as work is performed	Often is employee of biomass contractor. Sometimes a third party.
Slash disposal	Pile and burn logging slash	Paid per acre by the landowner	Often a separate contractor
Site prep contractor	Apply herbicide Brush control	Paid per acre by the landowner	May not be needed for partial cut
Reforestation	Plant seedlings	Paid per tree by the landowner	Not needed for partial cut
Sawmill	Receive sawlogs Make lumber	Pay per Mbf to the landowner	
Biomass plant	Receive chips Make power	Pay per BDT to biomass contractor	Some facilities may receive logs and perform the chipping.

8 FOREST RESTORATION AND BIOMASS PRODUCTION

California forests are in a condition widely recognized as "unhealthy," especially with a changing climate. Many timber stands are overly dense and as a result trees are less likely to survive drought, insect attack, and disease. Many uneven-aged stands have too many small trees which stress more desirable large trees and serve as a ladder for fire to move from the ground to the crown.

Broad scale tree mortality between 2012-2018 in the Central Sierras and large, devasting wildfires offer clear evidence that a concerted effort is needed to shift California's forest back into a more resilient condition. State, local and federal governments, along with many NGOs, are engaged in a variety of efforts to address these problems.

A few figures illustrate the key challenges facing forest restoration strategies:

- The USFS manages about 12 million acres of unreserved forest land and intends to treat 9 million acres over a 20-year period. We estimate that will be 500,000 acres per year.
- Private forest land owners have about 12.5 million acres. CalFire hopes that annual forest treatments will increase to 250,000 acres by 2020 and 500,000 acres by 2030.
- The HHZ designation currently encompasses about 13 million acres of public and private forest land. This is about one third of California's total forest land.

Forest restoration treatments will take several forms. Over the last four years, the USFS has done prescribed burning on about 45,000 acres per year, and some form of mechanical treatment on 122,000 acres per year (see Section 8.2). Similar statistics are not available for private land, but we are unaware of any large-scale burning on private lands due to liability issues. In Section 8.3 we estimate that harvest on private lands totals about 110,000 acres per year.

While reducing ladder fuels and removing dead trees will help many stands become more resilient and reduce fire hazard, "forest restoration" does not mean that all the potential biomass inventory must or should be removed. An integrated forest restoration strategy will require a set of silvicultural regimes designed to bring forests back into a desired condition. Applying those regimes to the inventory should provide an estimate of biomass production from the HHZs.

Designing a forest restoration strategy to meet public objectives is beyond the scope of this study. Our objective is more modest: show how producing forest-based biomass contribute to the forest restoration effort. In this section, we review historic harvest levels, provide insight about the range of forest conditions in the HHZ, and show how biomass can help pay for forest restoration treatments.

8.1 HISTORIC HARVEST LEVELS

Finding: Current timber harvest levels are well below historic levels.

Finding: Current harvest levels on private lands are equivalent to 52% of the annual growth. Current harvest levels on USFS lands are equivalent to just 5% of the annual growth.

Implications for biomass production: Forest restoration efforts could increase timber harvest substantially without causing any concern about exceeding sustainable harvest levels.

Figure 11 indicates that on the HHZ lands suitable for management, 248 million BDT of biomass is associated with 131 Bbf of sawtimber. Given that most biomass production is a by-product of commercial timber harvest, it is important to understand past and current timber harvest levels to evaluate the likelihood of capturing the potential biomass. A broad understanding of the dynamics of California's forests, furthermore, provides perspective about how the scope and scale of current and planned harvest levels, as well as an idea about sustainable levels of production.

For this section, we rely on the 2016 USFS Forest Inventory Analysis Report (Christensen G. , Waddell, Stanton, & Kuegler, 2015).[33] The USFS FIA Report provides insights into growth, harvest and mortality between 2001 and 2010, and breaks private land into two ownership categories – two functions that our in-place biomass inventory cannot perform.

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[33] Specific figures differ somewhat from the in-place biomass inventory that we prepared due to differences in processing the data, time period, and the recent mortality event.

		Cubic feet (millions)	Annual average 2000-2010, cubic feet (millions)			
	Acres (thousands)	Net standing inventory	Growth	Removals	Mortality	Net Change
USFS unreserved	12,086	41,763	759	35	484	241
USFS reserved	3,500	12,784	169	1	232	(64)
Other federal government	3,279	8,525	13	1	3	10
State and local government	1,126	5,270	6	-	0	6
Corporate Private	4,542	13,772	392	285	70	37
Noncorporate Private	8,280	17,661	300	78	76	146
Totals	32,813	99,775	1,640	400	864	375

Figure 38. USFS Forest Inventory Analysis statistics, California forestlands, 2000-2010.

Figure 38 summarizes the FIA inventory by ownership group. According to the FIA data, private timberland owners manage about 12.8 million acres (39%) and 31.4 billion cubic feet (32%) of California's forestland.[34] The FIA report reports on two classes of private ownerships. Corporate forestland is owned by a company, corporation, legal partnership, or financial investors. Non-corporate forest land is owned by individuals or families, non-governmental conservation organizations, unincorporated partnerships, associations, clubs, or Native Americans (Christensen G. , Waddell, Stanton, & Kuegler, 2015).

Past studies show that corporate forestlands are typically managed more intensively than non-corporate forestlands. Figure 38 shows that to be the case in California. Annual removals (mostly harvest) constitutes 73% of annual growth on corporate forestlands, but just 26% of growth on private forestlands. Note, however, that for both classes of private land owners, annual growth exceeded removals and mortality, so there was a net increase in inventory. This demonstrates that current harvests are well within the sustainable harvest level.

Figure 38 shows that on the unreserved USFS lands (lands available for harvest), removals are only 5% of annual growth – harvests could be increased substantially before issues of long-term sustainability would come into play. Mortality on the USFS lands is 64% of growth and nearly 14 times greater than harvest. Again, harvests are far below the sustainable levels. In fact, harvests do not keep pace with mortality.

[34] The FIA Report summarizes volumes in terms of cubic feet, and we maintain that convention here. An approximate conversion factor is 5 bf/cf.

According to the FIA report, average annual harvest is 400 million cubic feet. The USFS accounts for about 9% of the total, private corporate is 71% of the total, and noncorporate private is 20% of the total. The 4.5 million acres of corporate private lands contributes the bulk of the annual harvest.

Finally, note that across all owners, total harvest is only about 25% of annual growth. The current forest health crisis is due in part to this annual accumulation of inventory, and the concentration of that inventory in smaller trees.

Figure 39 shows that recent harvest levels are far below historic harvest levels. Timber harvest on both public and private land accelerated to meet rising housing demand after World War II. USFS harvests fell off substantially in the 1990s as the USFS re-evaluated its forest management objectives in light of social and political pressures. Those same social and political pressures resulted in more regulation on private land, further reducing timber harvest by increasing administration and permitting costs. (McIver, et al., 2014).

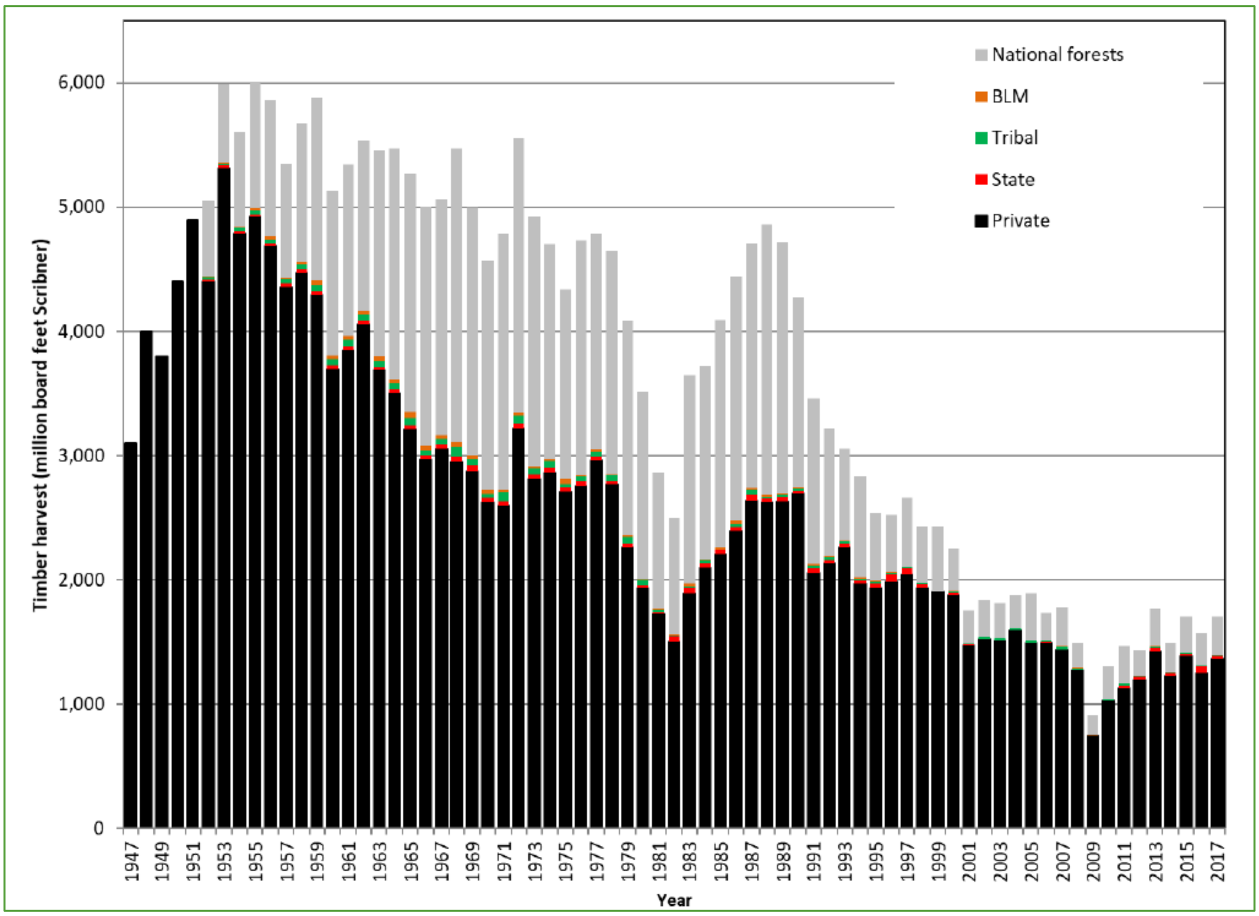


Figure 39. California timber harvest by owner. Source: (Marcille & Morgan, 2019)

Markets also affect annual timber harvest, and there have been several recessions during the time period shown above. Most notably the 1981-82 recession and the 2008-2009 recession had substantial impact on timber harvest levels as demand for housing, and therefore lumber, fell off substantially.

Since the 2008-2009 recession, California harvests have stabilized around 1.5 Bbf, about two thirds lower than the 5 Bbf annual harvest during the 1950s-70s. The FIA Report shows total growth at 1,640 billion cubic feet or roughly 8.2 Bbf, suggesting that current growth levels exceed both current and historic harvest levels. Changes in harvest policies, harvest levels, and market trends have had an impact on California's forest products manufacturing sector as reported by (McIver, et al., 2014). Figure 40 shows, for example, that the number of sawmills has declined from 216 in 1968 to 30 in 2012. (Note that the 2012 count of 26 bioenergy facilities in Figure 40 differs from the UC Berkeley[35] current count of 27 operational facilities and 12 active projects, which further differs from our 23 operational plants (Figure 15) due to four plants being currently non-operational but not updated in the UC Berkeley database.)

Table 13—Active California primary wood products facilities by sector, 1968–2012

Industry sector	1968	1972	1976	1982	1985	1988	1992	1994	2000	2006	2012
Sawmills	216	176	142	101	89	93	56	53	47	33	30
Veneer and plywood	26	25	21	10	6	6	3	4	2	2	2
Pulp and board	17	18	7	10	11	11	9	12	7	4	1
Bioenergy	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	25	25	26
Decorative bark	*b*	*b*	*b*	*b*	*b*	*b*	*b*	*b*	10	10	11
Other[a]	3	13	13	9	9	9	5	6	2	3	7
Total	262	232	183	130	115	119	73	75	93	77	77

[a] Other includes log home accent producers, shake and shingle manufacturers, fuel pellet producers, as well as post, pole, and piling manufacturers.
[b] Data unavailable for bioenergy and decorative bark sectors for 1968–1994.
Source: Barrette et al. 1970; Hiserote and Howard 1978; Howard 1974, 1984; Howard and Ward 1988, 1991; Morgan et al. 2004, 2012; Ward 1995, 1997.

Figure 40. Number of California wood processing facilities 1968-2012

Assessing the capacity of California wood processing facilities to absorb additional harvest that might come from increased forest restoration efforts is outside the scope of this study. We do know, however, that today's sawmills are larger and more efficient at converting logs to lumber than historic mills. Figure 41 shows that California's lumber production is not yet back to pre-recession levels, suggesting that existing mills may have some unutilized capacity. Further research may be needed on this point.

[35] UC Berkeley Woody Biomass Utilization Group. 2019. https://ucanr.edu/sites/WoodyBiomass/Project/California_Biomass_Power_Plants/#table

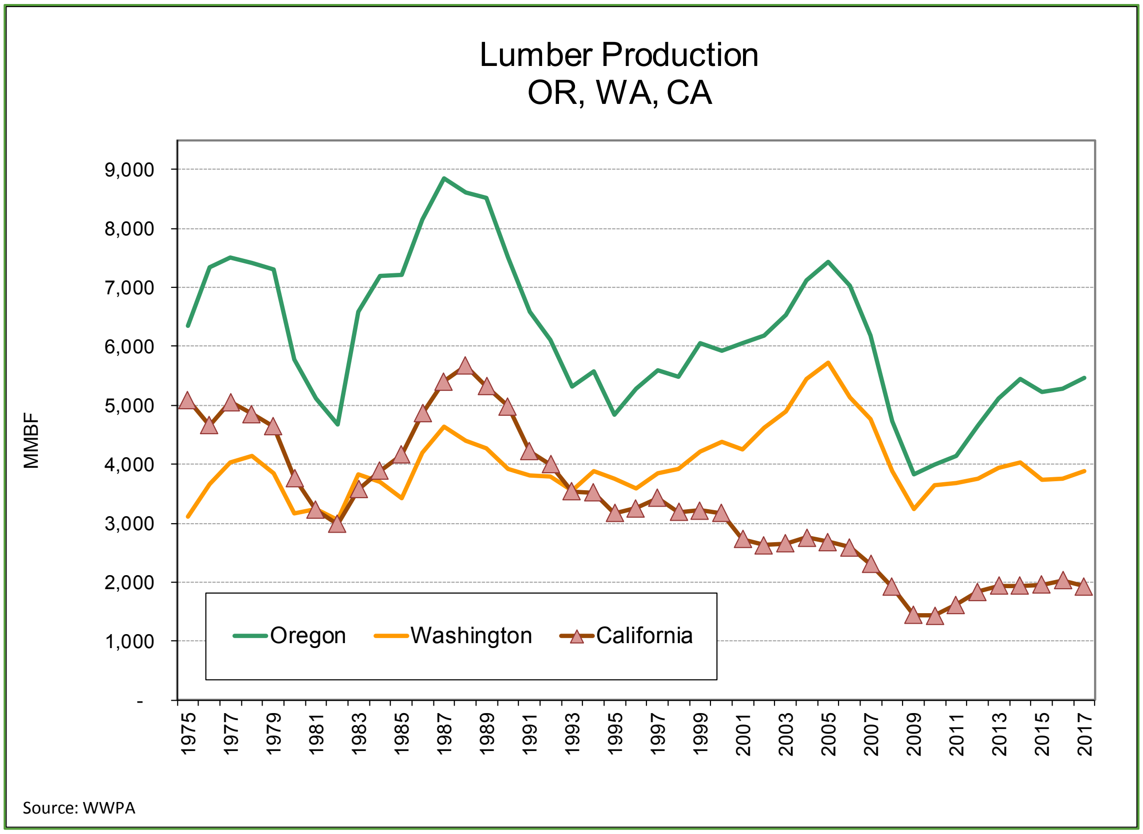


Figure 41: Lumber Production, Oregon, Washington, California

In our interviews of land managers, we asked whether they currently experience logging capacity issues. Almost all told us that the current logging force can handle the current level of harvest but were reluctant to estimate how much additional timber could be cut by the existing workforce. Most pointed out, however, that the logging force is aging, and loggers find it difficult to recruit new employees. These observations reflect national trends and suggest that California's logging workforce may limit the ability to make large increases in harvest. To the extent that the workforce is a limiting factor, we would expect that those scarce resources will be allocated more toward producing higher-valued sawlogs than to biomass.

According to the Associated California Loggers (ACL), there are currently about 6,000 loggers in California. ACL does not keep statistics on the number of log trucks, chippers, grinders, chip vans, mechanical harvesters, skidders, loaders, etc. If there were a substantial increase in harvest as part of a large-scale forest restoration effort, the logging industry would face substantial capital investment requirements.

8.2 FOREST RESTORATION: USFS

Finding: The USFS intends to treat about 500,000 acres per year, or about 9 million acres between 2015 and 2035.

Finding: Currently the USFS reports an average of about 287,000 acres of treatments per year (1.1 million acres during 2015-2018). Treatment includes mechanical treatment, prescribed burning and wildfire acres burned with low intensity.

Finding: About 110,000 acres treated annually might product produce biomass fuel. We estimate that current USFS biomass fuel production is about 150,000 BDT/year.

Implication for biomass production: More biomass will be cut as the agency moves toward meeting its management objects. How much of that could be delivered to the biomass plants is unknown. For this report, we estimate that USFS production of forest residue biomass fuel might increase to as much as 300,000 BDT.

The USFS forest restoration objective is found in a 2015 leadership statement of intent with respect ecological restoration (USFS, 2015). That document states:

> "With Ecological Restoration as the driving force behind the Region's work, and with a pace and scale sufficient to reverse current trends, it our out intent to accomplish the following in the next 15-20 years: … Increase forest resilience through treatments (including prescribed fire and thinning) and wildfire, resulting in resource benefits to approximately 9 million acres on national forest system lands."

To treat 9 million acres in 15-20 years would require treatment of between 500,000 to 600,000 acres per year. We use the 500,000 level to evaluate current levels.

Figure 42 summarizes the USFS fuel reduction report for FY 2018. About 316,000 acres were counted as treated in FY 2018 – about 63% of the 500,000 per year target. There are forest management activities that are categorized as "forest restoration treatments" and/or "fuel reduction treatments" which may not produce forest biomass for use as fuel. These treatments include prescribed burning, piling slash, burning slash piles, mastication, etc. In addition, 90,711 acres are in a "fire use" category – our understanding is that these are acres burned by wildfire with a low intensity, resulting in fuel reductions similar to that which might have been accomplished through some other management action.

Of the 316,000 acres of fuel reduction treatment, about 110,000 acres received treatments that potentially produced some biomass for use as fuel, namely "biomass removal," "chipping," and "thinning."

Figure 42. USFS report on fuel treatments for FY 2018.

R5 FP-FUELS-ALL Accomplishment FY18 yearend as of November 5, 2018 0350 hr PDT Version (excludes preparation for treatment; includes naturally ignited wildfire acres with fire effects meeting desired condition)	
Activity	Total acres
Fire subtotal	153,569
Broadcast Burn	24,477
Fire Use	90,711
Jackpot Burn	3,769
Machine Pile Burn	34,613
Mechanical subtotal	158,119
Biomass Removal	18,740
Chipping	4,789
Crushing	1,727
Lop and Scatter	10,925
Machine Pile	30,621
Mastication/Mowing	89
Thinning	91,229
Other subtotal	773
Chemical	658
Grazing	115
Preparation for Treatment subtotal	3,422
Preparation	3,422
Grand Total	315,884
Low intensity fires	(94,133)
Total with wildfire low intensity removed	221,751

Some acres might receive several treatments. For example, a commercial thinning and lopping and scattering the slash, or machine piling the slash and then burning the piles. While there is a potential for double counting treatments, especially when activities straddle reporting periods, it is our understanding that the USFS takes measures to minimize double counting – we therefore consider the acres from this report to be the footprint of the acres treated.

Figure 43 offers a longer-term view summarizing USFS hazardous fuels reduction accomplishments between 2001-2018.[36] Similar to Figure 42, forest biomass fuel might be expected to be produced on the subset of acres reported as "mechanical treatment." From 2015-2018, an average of about

[36] Until 2018, the acres of wildfire with a low intensity burn were reported as part of the USFS accomplishments under the "Other" column. About 685,000 acres of "Other," which includes wildfire, accounts for about 22% of the 2001-2018 hazardous fuels reduction accomplishments on USFS lands.

122,000 acres per year received a mechanical treatment. As shown, 2018 was the year with the highest number of acres of mechanical treatment at nearly 159,000 acres.

Figure 43. Summary of USFS fuel reduction treatments 2001-2018

Pacific Southwest Region (R5) Hazardous Fuels Reduction Accomplishments (acres) (18 years FY 2001 - 2018)

Fiscal Year	National Forest System (NFS) lands				Non-NFS Lands	ALL Lands Total
	Mechanical	Prescribed Fire	Other* (Note #1 for 2018)	NFS Total	(SFA and other)**	Total (See footnote #2 for 2018)
2018	158,884	62,858	90,710	312,452	5,900	318,352
2017	95,842	43,775	129,914	269,531	40,968	310,499
2016	134,327	35,936	246,929	417,192	17,001	434,193
2015	99,945	36,695	11,739	148,379	48,713	197,092
2014	96,192	24,314	18,167	138,673	60,936	199,609
2013	86,027	20,200	372	106,599	21,354	127,953
2012	89,922	33,033	1,073	124,028	28,377	152,405
2011	99,582	33,777	21,503	154,862	31,686	186,548
2010	123,845	40,891	15,019	179,755	103,697	283,452
2009	157,957	44,218	54,893	257,068	69,784	326,852
2008	99,056	36,557	19,429	155,042	166,122	321,164
2007	115,920	60,749	18,967	195,636	12,803	208,439
2006	44,526	36,322	17,212	98,060	31,819	129,879
2005	58,685	41,565	2,689	102,939	14,491	117,430
2004	67,077	46,014	11,069	124,160	2,710	126,870
2003	52,039	57,468	24,479	133,986	1,650	135,636
2002	37,732	44,647	515	82,894	-	82,894
2001	77,293	37,737	371	115,401	-	115,401
Total 2001-2018	1,694,851	736,756	685,050	3,116,657	658,011	3,774,668
Average 2015-2018	122,250	44,816	119,823	286,889	28,146	315,034

(Source is the NFPORS database) (Fiscal Year 2018 data updated as of 11/1/2018)

* Differs from NFPORS category by the same name; WFU is included in this category in this table.

** Includes leveraged acres

WUI = Wildland Urban Intermix/Interface

Footnote 1 = In 2018 counts only towards national not regional FP-FUELS-ALL target

SFA = State Fire Assistance

Footnote 2 = Includes "Other" (see footnote #1)

Achieving USFS forest restoration treatments to 500,000 acres per year will require a substantial increase in activity. In addition, we understand that the agency will no longer report acres of wildfire as "accomplishments" suggesting directed treatments will increase to compensate. While we can observe the current ratio between mechanical treatments and prescribed burning, we are unaware of any specific commitments about how that will look in the future.

If the USFS can achieve its stated goal, more forest biomass will be cut. The amount of increase depends on the proportion of acres of mechanical treatment relative to fire-based treatments. Further confounding the matter is how much of the forest biomass that will be cut will also be delivered to the biomass power plants. To date, the difference has primarily been a matter of economics, which is influenced by project location and design. As the USFS expands the acres treated, more projects will undoubtedly occur within areas with chip van accessibility problems which will increase costs (**Appendix C**). In addition, we note that USFS treatments that target removal of small trees have higher costs, which tends to limit the biomass that is delivered to the power plants.

For this report, we estimate that if the USFS can meet its forest restoration targets, biomass fuel production from USFS lands could double from the current 150,000 BDT/year to 300,000 BDT/year. With no other changes, however, this may be an optimistic estimate.

8.3 FOREST RESTORATION: PRIVATE LANDS

Finding: Private landowners conduct harvest on about 110,000 acres per year, which is about 0.85% of the private timberland base. There are no data available about how much of this activity might be considered as forest restoration.

Finding: Perhaps as little of 25% of the biomass cut from private lands makes its way to the biomass power plants as fuel.

Finding: The 2018 California Forest Carbon Plan establishes goals to increase treatments to 250,000 acres of private forestland by 2020 and 500,000 acres by 2030.

Implications for biomass production: A fourfold increase in harvest on private lands could potentially create much more biomass fuel than could be consumed by current biomass power plants, if it were fully utilized.

More than 86,000 private timberland owners in California own and manage over 12.5 million acres of forestland—about 39% of the total forestland in the state (Butler, et al., 2016).

Timber harvests on private lands reflect land management decisions made by individual private forest landowners. Forest management and harvest decisions are made based on landowners' management objectives and needs, markets, incentives and regulation. While the State has established ambitious goals for treating private forestland (discussed below) the State has limited mechanisms available to accelerate or conduct forest restoration treatments on private lands.

We can observe past behavior to better understand the scope and scale of forest management activities on private lands.

Private landowners are required to file a Timber Harvest Plan (THP), a Notice of Timber Operations (NTO), or an exemption or emergency notice with CalFire prior to conducting timber harvest activities. We obtained GIS data from CalFire showing the acres harvested by treatment type.

Figure 44 summarizes harvest from large private landowners filing THPs. These landowners manage about 4.7 million acres in California. Over the last six years, these landowners had harvest activity on about 90,000 acres per year – or about 2% of the ownership per year. Nearly all the treatments listed in Figure 44 could conceivably result in biomass fuel production. Our interviews with larger private landowners, however, revealed that biomass fuel is usually not removed from private timberland harvests unless it is profitable, or at a very low cost.

Figure 44. Acres by treatment type from THPs

	2012	2013	2014	2015	2016	2017	Grand Total
Aspen/Meadow/Wet Area Restoration	-	-	3	41	37	23	104
Commercial Thin	6,671	5,553	2,990	3,507	931	3,667	23,318
Conversion	1,255	636	128	87	61	72	2,239
Fuelbreak/Defensible Space	1,098	1,322	965	285	84	879	4,632
Group Selection	13,461	36,889	20,618	36,260	18,701	25,739	151,668
Non Standard Practice	162	12	4	-	-	-	177
Rehabilitation of Understocked	947	1,262	424	337	257	1,346	4,573
Road Right-of-Way	81	163	26	90	35	39	434
Seed Tree Rem/Commercial Thin	-	16	-	-	-	-	16
Seed Tree Removal Step	2,313	2,385	1,160	2,467	225	157	8,707
Seed Tree Seed Step	144	253	100	265	14	73	849
Selection	42,853	23,750	11,287	22,818	28,034	10,797	139,540
Shelterwood Prep Step	136	-	142	-	71	-	349
Shelterwood Seed Step	4	5	46	-	25	93	174
Substantially Damaged Timberland	932	3,928	2,450	4,992	174	211	12,688
Transition	1,755	4,232	2,990	4,304	155	1,137	14,573
Variable Retention	1,671	1,688	1,525	2,658	655	782	8,980
Clearcut	22,242	26,407	13,568	11,402	9,009	11,802	94,429
Shelterwood Rem/Commercial Thin	86	-	-	-	-	-	86
Shelterwood Removal Step	4,541	7,151	1,749	1,850	578	2,963	18,831
Alternative Prescription	18,236	11,492	4,352	10,856	4,561	8,474	57,972
Totals	**120,600**	**129,157**	**66,541**	**104,234**	**65,624**	**70,271**	**544,340**

Figure 45 summarizes harvest from small private landowners filing NTOSs. These landowners own about 6.9 million acres of forestland in California, and conduct harvest on about 16,000 acres per year, only about 0.2% of their land base. Again, most of these treatments would conceivably produce biomass fuel, but actual production is limited by economics.

Figure 45. Acres by treatment type from NTOs filed by smaller private landowners

	2012	2013	2014	2015	2016	2017	Grand Total
Aspen/Meadow/Wet Area Restoration	-	-	38	-	18	-	56
Commercial Thin	117	66	156	25	-	-	364
Fuelbreak/Defensible Space	-	43	245	-	260	-	549
Group Selection	2,587	1,693	2,291	2,285	5,089	2,638	16,583
No Harvest Area	17	8	54	93	-	-	173
Rehabilitation of Understocked	280	72	139	126	128	398	1,143
Road Right-of-Way	10	19	5	19	-	6	59
Sanitation Salvage	3,397	1,154	16	37	705	326	5,635
Selection	17,295	5,178	12,938	10,365	10,537	5,008	61,321
Shelterwood Prep Step	-	-	-	-	-	112	112
Special Treatment Area	-	17	39	33	0	-	89
Substantially Damaged Timberland	-	-	-	-	54	-	54
Transition	275	120	441	421	707	-	1,964
Alternative Prescription	612	52	75	33	4,243	230	5,245
Grand Total	**24,590**	**8,422**	**16,438**	**13,436**	**21,742**	**8,718**	**93,346**

Overall, private timberland owners conduct harvest on about 106,000 acres per year. Using an estimate of 12 BDT of biomass per acre suggests that biomass harvest from private lands could have been as much as 1.3 million BDT of biomass material. In Section 7.1, however, we estimated that the private land share of current biomass fuel production is only about 300,000 BDT. This would suggest that only about 25% of the potentially available biomass from private harvest is making it to the biomass power plants.

The 2018 California Forest Carbon Plan establishes goals to increase treatments on private land to 250,000 acres by 2020 and 500,000 acres by 2030. If "treatment" means timber harvest, that would constitute a doubling of treatment by 2020 and a quadrupling by 2030. If private harvest levels were doubled or quadrupled, that could potentially create large supplies of biomass – far beyond the capacity of current forest biomass using power plants. As shown in Figure 1, the operating biomass using power plants currently consume 3 million BDT from all sources.

The Carbon Plan, however, discusses use fire as an important treatment method for private lands, and to the extent that fire is traded for harvest, there will be a reduction in potential biomass supplies.

8.4 DISTRIBUTION OF FOREST CONDITIONS

Finding: With respect to forest biomass, there is a wide variety of forest conditions across the HHZs.

Implications for biomass production: The HHZ biomass inventory reported in Section 6 could be used to help create strategic plans to guide HHZ forest restoration treatments.

Section 6 reports that the HHZ spans about 16.7 million acres of California forestland. About 13.1 million of those acres are in areas that are available for, and compatible with, active forest management. While all these acres have been identified as high hazard zones, they are by no means homogenous. Different acres require different treatment and should have different priorities. We made a few simple queries from our database to illustrate the point.

Figure 46 shows the distribution of dead tree volume within the HHZs in 5 BDT/acre classes. Note that a chip van hauls about 12.5 BDT of chips. About 70% the acres have less 10 BDT/acre of dead trees per acre. The mortality event is concentrated on a portion of the HHZ.

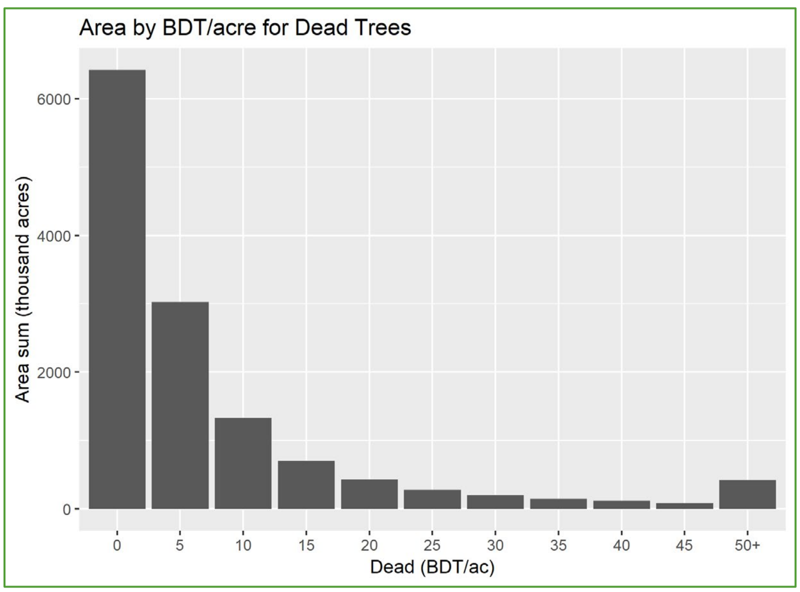


Figure 46. Distribution of HHZ acres by biomass in dead tree volume per acre.

On some stands, small trees are considered part of the ladder fuels that turn ground fires into crown fires. Trees less than 10" DBH are not suitable for sawtimber and are chipped for biomass. On other stands, however, these small trees may constitute the future crop trees. Figure 47 shows that about 65% of the acres in the HHZ have 10 BDT or less per acre. Many of these stands likely do not require immediate treatment because they are young stands with a healthy structure. The distribution might suggest where prescribed burning would be preferred over mechanical treatment.

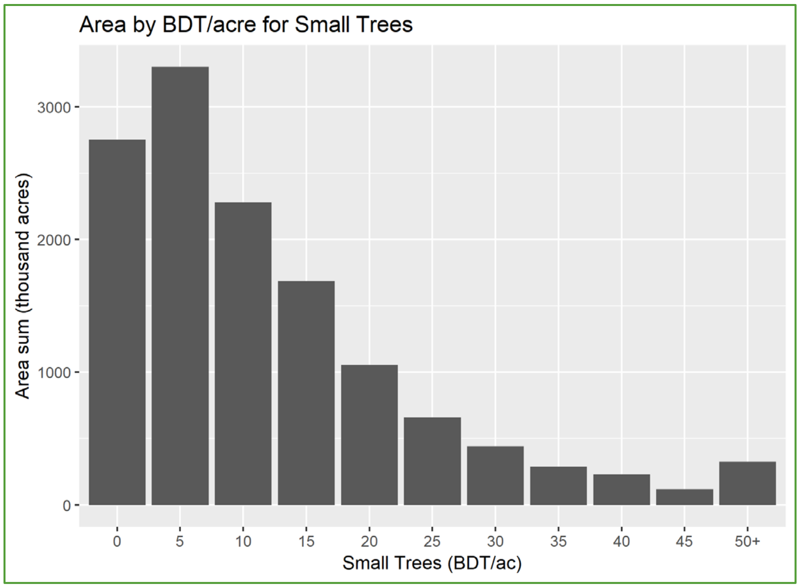


Figure 47. Distribution of HHZ acres by BDT/acre in small trees.

Figure 48 shows the distribution of trees >24” in the HHZ. The large trees are typically hardier than the small trees, able to better withstand drought and insect and disease, if they are not crowded by smaller trees. Stands with large trees may be targeted for restoration as they provide valuable habitat and other services. Note, however, that over half the HHZ acres have few if any large trees. Again, knowledge of the distribution might suggest which acres should be burned, and which should receive mechanical treatment.

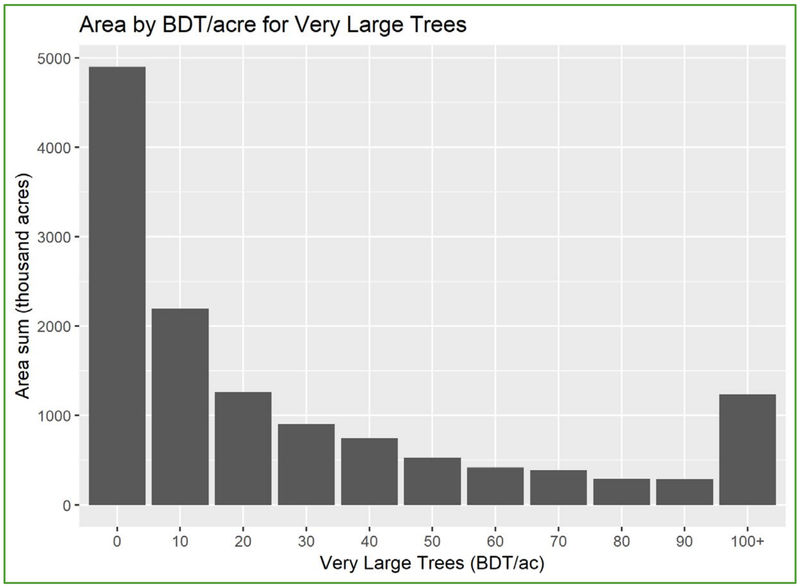


Figure 48. Distribution of HHZ acres by trees >24" DBH/acre.

Across the HHZs there are a variety of forest conditions, and not all 13.1 million acres in the HHZ are suitable for biomass production. Not all acres need immediate treatment, nor do all acres require the same treatment. An increased forest restoration effort should set priorities about which kinds of conditions should have priority for treatments, and what those treatments should be.

8.5 ECONOMICS OF BIOMASS: PERSPECTIVE OF A LAND MANAGER

We asked land managers what kinds of forest management treatments they apply when biomass production is not possible and what the alternative costs would be. There were a wide variety of responses.

- Logging waste is typically piled and burned, although some land managers now favor scattering the tops and branches back throughout the logging unit. This reduces risk of fire from slash piles, but increases fuel loading, at least for a few years until the material begins to decompose. Another approach is to grind or chip the biomass and spread the chips around the harvest unit.

- Removing small trees to improve forest health can be a costly endeavor. The smaller trees can be hand piled and burned. Alternatively, a masticator can grind up smaller trees in place, leaving the chips in the unit. Chips pose less of a fire hazard than unprocessed slash piles.

- Ideally, dead trees can be removed and used for sawtimber, leaving the land manager with just the problem of the logging waste. As the dead trees age, however, they lose sawtimber value and only have value as biomass. Given the fuel loading, burning in place is not favored.

Land managers typically quoted the cost of alternative treatments in the range of $500 - $1200/acre. How does that compare to the cost of biomass production?

Assume post-harvest biomass of about 25 green tons per acre (or 12.5 BDT/acre). This is typical of a partial cut that also removes some smaller, non-sawtimber trees. Assume the alternative cost is $750/acre. That is equivalent to a cost of $60/BDT ($750/acre / 12.5 BDT/acre). If the biomass could be gathered, processed, delivered and paid for at $60/BDT, then the timber sale purchaser would effectively accomplish the desired silvicultural work with no out-of-pocket costs to the landowner.

Suppose now that the biomass production cost totaled $80/BDT, but the value of the biomass delivered to the mills is only $60/BDT – the biomass production economically unfavorable by $20/BDT. When this occurs on a USFS timber sale, there are three possible arrangements, depending on how the timber is sold (see **Appendix G** for a discussion of the USFS timber sale program):

- For a regular timber sale, the purchaser is not required to remove material with a negative value. Removal of biomass is said to be "optional." It is likely in this case that the biomass will be left behind for the USFS to dispose of, typically by burning the piled biomass and slash.

- In a stewardship timber sale contract (IRTC), the USFS could specify that the biomass must be removed as part of the sale. In this case, the purchaser of the stewardship contract will subtract the cost of removing the biomass from positive revenue associated with the commercial sawtimber. The USFS gets the work done, effectively at the cost of $20/BDT or $250/acre. That is a $500/acre benefit, given that the alternative cost of treatment is $750/acre.

- In a stewardship service contract (IRSC), the costs of services (removing the biomass) is greater than the revenue from the commercial timber sale. In this case, the USFS would pay the contract holder to cover the cost of the biomass, less the cost of the commercial sawtimber. These sales are less common as they require funding.

When biomass removal is a primary objective, the land manager is faced with designing a timber sale that has enough positive value in sawtimber to offset the cost of the biomass removal. Land managers told us that this is a difficult balancing act: if there too much negative value, potential timber sale purchasers may decide to not bid on the sale, and all the presale work will have been in vain.

Land managers told us that in the 1990s, they could sell a sale with 50% biomass anywhere on the forest. Now, as a rule, they think that a sale having 30% biomass within 50 miles of a biomass plant will likely work out.

8.6 BIOMASS FINANCIAL MODEL

To illustrate the impact of biomass fuel on the financial returns from a commercial timber sale, we developed a Biomass Financial Model (BFM). The BFM can also be used to understand how sensitive the economic returns are to different assumptions. The BFM is described in detail in **Appendix H**.

Figure 49 illustrates an example of a USFS timber sale planner evaluating the impact of requiring biomass removal on a normal timber sale. All figures are on a per acre basis. The essential assumptions are that this is a partial cut, removing about 5 Mbf/acre of sawtimber and 13 BDT/acre of biomass. Both the sawtimber and the biomass are appraised to facilities 50 miles from the timber sale. Lumber sells for $400/Mbf lumber tally and power sells for $89/MWH—we understand this to be the BioRAM fallback price.

Under this scenario, the sawtimber will provide $844/acre in net value, or $169/Mbf. Net return from removing the biomass and delivering it to the power plant is negative: $-212/acre or $-17/BDT. The negative biomass value will be borne by the timber sale purchaser, and as a result the sale should sell for $632/acre or $152/Mbf.

Suppose that the alternative cost of cutting, piling and burning the biomass in place was $750/acre. In this case, the USFS forest manager would have achieved the same effect at the cost of just $212/acre. This difference illustrates the contribution that production of biomass fuel can make to forest restoration.

Sawtimber			Biomass

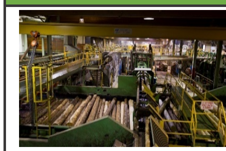
Resource in the Woods

Sawtimber			Biomass
Volume of Timber per Acre			Volume of Biomass per Acre
Cubic Foot (CCF/Acre)	10	25	Green Tons (GT/Acre)
Brd Ft (MBF/Acre (Log Scale [LS])	5	13	Bone Dry Tons (BDT/Acre)
Mill Residuals (BDT/MBF [LS])	0.85		

End Product

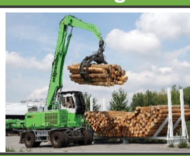
Sawtimber			Biomass
MBF (Lumber Tally [LT])	10	13	Power (Megawatt Hrs [MWH])
Lumber Price $/MBF (LT)	400	89	Power Price ($/MWH)
Mill Residuals Price ($/BDT)	30		
Lumber & Chip Value	$ 3,928	$ 1,113	**Power Value**

Conversion to Products



Sawtimber			Biomass
Lumber Production ($/MBF [LT])	145	45	Power Production ($/MWH)
Profit and Risk	10%	10%	Proft and Risk
Total Costs	$ 1,515	$ 619	**Total Costs**

Delivered Log Value



Sawtimber			Biomass
$/Mbf (LS)	482	40	$/BDT
Total Dollars	$ 2,412	$ 494	**Total Dollars**

Delivery Costs

Sawtimber			Biomass
Miles to Saw Mill	50	50	Miles to Power Plant
Haul Rate ($/Hr)	88	88	Haul Rate ($/Hr)
Haul Time (Round Trip Hrs)	3.4	3.4	Haul Time (Round Trip Hrs)
Transport Cost ($/MBF)	67	24	Transport Cost ($/BDT)
Total Delivery Cost	$ 333	$ 300	**Total Delivery Cost**

Extraction Costs

Sawtimber			Biomass
Cut, Skid & Load ($/MBF)	163	-	Cut & Skid Tree Tops ($/BDT)
Sale Administration ($/MBF)	72	13	Cut & Skid Small Trees ($/BDT)
Road Construction ($/MBF)	12	20	Chipping & Loading ($/BDT)
Total Extraction Cost	$ 1,235	$ 406	**Total Extraction Cost**

Net Stumpage Value

Sawtimber			Biomass
Sawtimber ($/Acre)	$ 844	$ (212)	**Biomass ($/Acre)**
$/MBF	$ 169	$ (17)	**$/BDT**

Figure 49. Biomass financial model, USFS Scenario 1

8.7 ECONOMIC IMPACTS OF FOREST RESTORATION

Much attention is rightly given to the cost of increasing forest restoration efforts in California. We are unaware, however of any studies of the economic benefits of those efforts.

In 2012 we prepared a study commissioned by then Oregon Governor Kitzhaber (Rasmussen, et al., 2012). The Governor wanted to know what it would take to double the pace of forest restoration on Eastern Oregon National Forests, and what the economic impacts would be. While this is out of the scope of this project, we offer below the summary table for consideration (Figure 50).

In short, the USFS annually spent about $40.8 million to treat 129,000 acres ($316/acre). That level of effort generated about 141 MMbf of sawtimber and 225,000 green tons (112,500 BDT) of biomass. The effort supported about 2,310 jobs, created $231 million of economic output, $90 million of income and $3.6 million of state tax revenue.

We cannot know whether California's forest restoration effort would have similar ratios, but it may be worth investigating, given the level of investment being made.

Figure 50. Economic impacts of forest restoration in Eastern Oregon

Summary data of National Forest health economic assessment

Summary Data	Northeast	Southeast	Interior Central	Interior South	Total Eastern Oregon
Total Acres (1,000)	2,646	2,905	2,016	3,801	**11,368**
Available Acres (1,000)	1,879	2,556	1,451	3,307	**9,193**
Footprint Acres (1,000)*	33	22	37	37	**129**
Cost ($1,000)*	$ 6,687	$ 5,171	$ 10,474	$ 18,452	**$ 40,784**
Sawlogs (MMBF)*	18	25	32	66	**141**
Non-saw/Biomass (1,000 GT)*	73	38	57	57	**225**
Jobs (#)*	397	329	319	1,265	**2,310**
Output ($1,000)*	$ 36,898	$ 35,186	$ 25,106	$ 134,322	**$ 231,512**
Income ($1,000)*	$ 16,102	$ 14,019	$ 12,875	$ 47,521	**$ 90,517**
State Tax Revenue ($1,000)*	$ 778	$ 518	$ 1,125	$ 1,191	**$ 3,612**

*On an average annual basis

9 BARRIERS

Earlier sections of this report describe the economic, fiscal, biological, physical and political systems that affect biomass fuel production from the HHZs.

A few key statistics summarize the demand and supply of forest biomass.

- Seven BioRAM plants consumed an estimated 1.12 million Bone Dry Tons (BDT) of fuel in 2018. Of that, 691,000 BDT (60%) was qualifying fuel. The HHZ qualifying fuel requirements have increased from 40% to 80% of total feedstock supply needs. Going forward, the seven BioRAM plants are expected to consume about 930,000 BDT of qualifying fuel annually. This will be some mix of forest residues and mill residuals.

- To date, the implementation of BioRAM at the seven plants has increased the proportion of forest derived fuel (i.e., HHZ) utilized by 230% relative to the amount of forest derived fuel consumed prior to implementation of BioRAM at the plants.

- The cost of qualifying fuel is greater than the cost of non-qualifying fuel. The average cost of qualifying fuel increased 33% to about $60/BDT from 1Q17 to 2Q18. During the same period, the price of non-qualifying fuel at the BioRAM plants dropped 33% to $23/BDT.

- Increasing fuel cost is due to: (1) competition for qualifying fuel between BioRAM contract holders; and (2) higher production cost of fuel from forest residues relative to fuels from other sources like agricultural and urban wastes.

- A current in-place inventory developed for this project identifies potentially 248 million BDT of biomass on 13.1 million acres suitable for management in the HHZ.

- There are 3.6 million acres of HHZ within a 50-mile haul distance of the BioRAM plants, and those acres contain about 42 million BDT of potential biomass. Given that the BioRAM plants will need about 930,000 BDT per year, there is no shortage of potential biomass material in the HHZ.

- Statewide, somewhere between 750,000 BDT and 2.5 million BDT of forest biomass are cut each year. However, only about 450,000 BDT of this biomass has been delivered to biomass power plants. Most of the biomass cut each year is left in the woods to be burned or scattered back through the cutting units.

- In 2017, the BioRAM plants burned 340,000 BDT of forest biomass and 176,000 BDT of mill residuals, this was 68% and 16% of the statewide biomass consumption, respectively.

Now we turn attention to barriers that limit production and utilization of forest biomass fuel that qualifies under the BioRAM contracts.

In conducting this research, we heard many good recommendations about improving the condition of California's forests – everyone we spoke with expressed passion for the forest and frustration with the current situation. We note however that California's state, local, Tribal, federal governments, NGOs and private companies are engaged in a variety of ongoing programs, studies, and collaborative efforts. Funding for forest restoration work is coming from many sources. Many projects are underway, and progress is being made. It is not our intent to critique that work, or to replicate the many good recommendations found in other studies. While we heard many good ideas about how to make things better,[37] we narrow our focus here to barriers affecting the utilization and production of BioRAM qualifying biomass fuel.

9.1 THE ECONOMICS OF BIOMASS PRODUCTION ARE GENERALLY UNFAVORABLE

Biomass extraction and delivery costs are often greater than the value for biomass power generation. Biomass fuel typically does not generate a positive return to private landowners or to the purchaser of a public timber sale. We estimate that only 20-60% of the forest biomass cut each year is delivered to the power plants. Biomass not used for fuel is often burned in the woods or scattered back through the harvest area.

Forest biomass fuel is most likely to generate a positive return (or an acceptable loss) when it is close to the biomass plant. Biomass fuel production is therefore more likely to facilitate forest restoration close to the biomass plants, and less likely to contribute to forest restoration projects distant from the BioRAM plants.

Biomass production costs are lowest for fuel derived from tops and branches from commercial timber harvest. Costs are highest for treatments that are more focused on forest restoration and/or salvage.

The BioRAM contracts provide a more favorable power price for electricity generated from qualifying biomass fuel, but even that price may not be enough to overcome haul costs beyond 40-60 miles.

9.2 THE DEFINITION OF QUALIFYING BIOMASS FUEL, COUPLED WITH THE COST OF HAULING BIOMASS FUEL, LIMITS THE PRODUCTION OF FUEL FOR THE BIORAM PLANTS.

Under the BioRAM contracts, qualifying fuel must come from the HHZ. Of the 36 million acres of forestland in California, about 16 million acres are in the HHZ. Only about 3.6 million HHZ acres, however, are within 50 miles of the seven BioRAM plants – generally considered an economically viable haul.

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[37] See **Appendix J** for some ideas and insights about larger forest management issues.

Over the last eight years, those 3.6 million acres have accounted for less than 30% of the timber harvest activity in the state. Furthermore, some not insignificant portion of past and future harvest in the HHZ is associated with clearcutting on private lands, thereby disqualifying that fuel for the BioRAM 2 contracts and the BioRAM 1 contracts modified under SB 901. Thus, the qualifying fuel that falls within an economically viable 50-mile haul distance of a BioRAM plant falls below 30%.

The supply of qualifying fuel could be expanded by expanding the HHZ, focusing forest treatments on the HHZ acres within an economically viable haul distance, subsidizing additional haul, and/or relaxing the qualifying fuel standard to include biomass from clearcuts.

9.3 SOME FOREST RAODS WILL NOT ACCOMMODATE BIOMASS CHIP VANS

Biomass chip vans cannot negotiate some legacy roads that were designed for logging trucks. Several strategies exist ranging from realigning roads to trucking biomass around the difficult segments to an accessible chipping location. Every work around, however, adds costs to an already marginal effort.

Land managers provide estimates of inaccessibility ranging from 10% to 75% of the forests they manage, most are in 30-50% range. This is substantial enough to raise concerns about the contribution of biomass production toward larger forest restoration objectives.

The first step to address this barrier is to develop a comprehensive view of which forested acres are inaccessible to chip vans and the costs of removing the physical barriers.

9.4 SHORT TERM CONTRACTS LIMIT INVESTMENT AND PLANNING

Nearly everyone that we interviewed noted that the five-year BioRAM contract length is viewed as an impediment to increasing biomass production and utilization throughout the supply chain:

- The BioRAM plants need continuous investment to maintain and/or improve the power facilities. The uncertainty around a five-year contract hinders such investment.

- To increase biomass fuel production, biomass producers need to invest in equipment and personnel. These can be major investments and will require substantial financing. These businesses are reluctant to make the financing commitments when the BioRAM contracts are only let five-year increments.

- USFS timber sales typically require at least a two-year planning process before a sale is ready to sell. Most USFS timber sale contracts have a three-year contract length. As a result, the USFS land managers are planning timber sales without any assurance that a favorable biomass market will exist by the time the timber is harvested. If biomass removal is required by the contract and the biomass market disappears (e.g. the closest biomass power plant closes), contracts must be renegotiated, and purchasers normally will have to make up for the discounted price paid for timber because of the cost of biomass removal.

9.5 THE STRUCTURE OF THE BIORAM CONTRACTS HINDERS THE ABILITY TO SOURCE REQUIRED LEVELS OF QUALIFYING FUEL

Each BioRAM plant submitted a bid to their respective utility, which included a power sales pricing structure. The bids and resulting BioRAM contracts resulted in differing power sales prices among the BioRAM plants. Additionally, BioRAM plant managers perceived that there were differences between BioRAM I and BioRAM II contracts with regard to the ability for carrying over qualifying fuel across reporting periods; the amount of qualifying fuel needed in a given period, the types of fuel that qualify (e.g., HHZ, Sustainable Forest Management, etc.), and a stricter penalty for BioRAM 2 plants if they do not meet fuel requirements. Finally, as evidenced by the increase in the cost of qualifying fuel at the BioRAM plants, the unexpected competition for the available qualifying fuel created friction in the biomass economy, which resulted in some plants having a competitive advantage over others. It appears that passage of SB 901 and the issuance of Resolution E-9477 has eased these observed tensions. Still, the BioMAT plants, when developed, will have contracts with yet even higher power sales prices, potentially exacerbating this problem.

9.6 THE STRUCTURE OF THE BIORAM CONTRACTS MAY NOT FACILITATE BROADER FOREST RESTORATION OBJECTIVES

The BioRAM contracts offer contract holders a favorable power price to utilize forest biomass fuel from the HHZ. Power plants have a financial incentive to minimize wood costs to increase profits. They can do this by focusing on the lowest cost qualifying fuel. This will generally be biomass located closer to the plant, and biomass from logging waste.

The BioRAM plants least-cost strategy, however, may not line up with forest restoration priorities. Stands distant from the biomass plants may benefit from treatment more than stands close to the plant. Removal of small trees and dead trees may be the primary silvicultural interest on some projects but producing fuel from this biomass is more expensive than biomass from logging waste. The financial incentives in the current BioRAM contracts - a more favorable power price – may not necessarily facilitate forest-based priorities for biomass removal.

An additional incentive system that pays biomass fuel producers for additional haul and/or for the cost of taking smaller trees or dead trees may be more effective in targeting forest restoration priorities.

9.7 THE RESTRICTION ON BIOMASS FROM CLEARCUTTING LIMITS BIOMASS FUEL PRODUCTION

Biomass fuel from clearcutting is not considered qualifying fuel under the BioRAM2 contracts nor under the BioRAM1 contracts to be modified under SB901. This limits potential biomass that could be delivered to the BioRAM plants. It means that HHZ biomass from clearcutting is either left in the woods adding to future fire hazard, or is burned in the woods, with negative impacts on air quality.

Given the marginal economics of biomass fuel production, the impact of the policy is not enough to change management behavior or private landowner policy. The policy, furthermore, creates additional accounting issues at sawmills that deliver mill residuals to the BioRAM plants.

9.8 SOME ORGANIZATIONS HAVE LIMITED CAPACITY FOR ADDRESSING LARGE SCALE MORTALITY

The recent forest mortality crisis has challenged entities that have not traditionally been involved in managing forest resources (e.g. CalTrans, utilities and local governments). These entities were faced with the need to remove hazard trees from many miles of roads and powerlines, with limited internal forestry contract and staff experience or capacity. They needed and will continue to need to develop policies, procedures and operational expertise while implementing new large-scale efforts.

Access to established expertise would make these kinds of efforts more efficient and effective.

9.9 INCREASING FOREST BIOMASS FUEL PRODUCTION WILL REQUIRE NEW INVESTMENTS THROUGHOUT THE SUPPLY CHAIN

Biomass is ultimately produced by loggers, haulers, and foresters and the equipment they have to work with.

The current logging capacity is built around the current harvest level – about 1.5 Bbf of timber harvest and 450 BDT of biomass. Any substantial increase to the pace and scale of mechanical forest restoration treatments will require expanded capacity in the logging and hauling sectors. Additional Registered Professional Foresters will be needed to help develop forest management projects on private forest lands.

Logging contractors and hauling contractors face several hurdles to expanding their operations. Both will need to hire more employees and buy more equipment. Both require a long-term assurance of future work and substantial capital investment. Attracting new employees requires investment in recruitment, training and workforce retention.

In the past, both federal and state agencies have provided financial assistance to fill in gaps in infrastructure. More might be needed in the future.

Similarly, efforts are underway to envelope strategies to develop more capacity in the logging and hauling work force, and to attract and train more Registered Professional Foresters.

9.10 POLICIES MAY OVERLOOK KEY DIFFERENCES BETWEEN TYPES OF FOREST BIOMASS

At a high level, it is tempting to think about producing "forest-based biomass" as a singular effort. Policies that do not recognize and consider differences in the strategies for supplying different kinds of biomass, however, will be less effective than hoped.

At the biomass power facility, forest-based biomass comes in three forms

- Residual chips from sawmills and veneer mills.
- Biomass logs arriving on a log truck
- Forest residues arriving in chip vans;

Forest residues, furthermore, can be classified into three general categories:

- The tops and branches from sawtimber trees. This is a waste product of a commercial timber harvest. If it is not used for biomass it is either burned as slash or scattered back throughout the sale.
- Small trees that are not large enough to make sawtimber. Forest restoration treatments often focus on removing these trees as they often constitute ladder-fuels or to reduce the density of stands to make the remaining stand more resilient.
- Larger dead trees that no longer have sawtimber value, or cull trees. Fires, insects and disease create substantial amounts of timber that has deteriorated to the point where the only remaining value is for fuel.

The forested land base can be split many ways, each division faces a different set of challenges:

- Public land managers face a much different permitting and decision-making process than private land managers.

- Small private landowners typically face different financing and cash flow issues than large corporate landowners.

- Some USFS HHZ land is located within areas that are available for streamlined NEPA processes, others are not.

- Some HHZ land poses a greater threat to infrastructure than other HHZ land.

Throughout the biomass supply chain, biomass producers face a variety of challenges specific to each project. While the BioRAM contracts allow biomass producers to pay more money for biomass fuel, additional resources may be required to overcome more specific barriers. It is likely that any additional resources dedicated to biomass fuel production could be more efficiently deployed by identifying specific challenges and focusing solutions on those specific challenges.

10 DATA GAPS

During our investigation, we ran up against a few questions that could not be answered from existing data sources. Here we identify areas that merit further investigation.

10.1 THE CURRENT DISPOSITION OF AG/ORCHARD FUEL THAT WAS PREVIOUSLY USED AT BIORAM FACILITIES.

Prior to BioRAM, several of the biomass plants relied on ag/orchard waste for a significant percentage of their fuel. Since operating under BioRAM and the associated requirements for utilizing certain forest-based fuels, the plants reported that their use of ag/orchard fuel has dropped significantly. The consulting team is not aware of any data showing how the ag/orchard fuel that used to be consumed at the BioRAM plants is now being disposed.

A better understanding of the disposition of potential biomass fuel from all sources would help policy makers evaluate the current biomass power capacity relative to the waste stream.

10.2 A MORE DETAILED EXAMINATION OF MILL RESIDUE UTILIZATION.

California’s primary wood processing plants (e.g., sawmills) produce a variety of mill residues including bark, shavings, sawdust, and chips. While the University of Montana conducts periodic studies of how the wood harvested in California is utilized including the disposition of mill residues, in the consulting team’s judgment, a detailed understanding of the volumes, market values, and market dynamics affecting this sector is not well understood.

Policy makers should understand the extent to which mill residuals are considered waste that requires disposal beyond current systems.

10.3 EXTENT OF AREAS INACCESSIBLE TO CHIP VANS, AND COST OF REMEDIATION.

Land managers estimate that significant acres of most forests are not accessible to chip vans. Most land managers, however, had not made a formal assessment of the acres affected or the cost of remediation.

A comprehensive inventory effort would provide planners and policy makers with an idea about the extent of the issue, the impacts on biomass production, and the cost of remediation.

10.4 TOTAL PRODUCTION OF BIOMASS

The State Board of Equalization collects comprehensive information about commercial sawtimber harvested and reports summary volumes by county and ownership class. Since biomass harvest is not taxed, however, it appears that SBE does not collect complete information about forest biomass removed from the woods. More comprehensive data would help policy makers and analysts better understand production of forest biomass.

10.5 AMOUNT OF BIOMASS THAT IS CUT AND LEFT IN THE WOODS

All the land managers that we interviewed are aware of forest biomass that is cut but left in the woods for burning or decomposition. In this report, we estimate that perhaps as much as 40-80% of the biomass that is cut is left in the woods unutilized. This is a wide range based on some simple assumptions.

A more reliable estimate of biomass utilization would help policy makers and land managers better understand utilization of forest biomass, and perhaps develop policies and procedures for improving utilization.

By its very nature, it is difficult to measure and report the amount of biomass that is unutilized. Requiring land managers to report unutilized biomass, furthermore, might be expensive. There might be some useful rules of thumb that could be used instead.

10.6 CURRENT BIOMASS LOGGING CAPACITY AND EQUIPMENT

Land managers believe that there is sufficient biomass logging capacity to serve current levels of biomass fuel production but are uncertain how much additional capacity exists. Understanding the current capacity would help policy makers anticipate the need for additional investment needed to service planned levels of forest restoration treatment.

Evaluating biomass production capacity is difficult given that there is a great deal of overlap in terms of equipment and personnel between biomass logging/hauling and sawtimber logging/hauling. Nevertheless, biomass fuel production requires some specialized equipment, namely chippers/grinders and chip vans. A census of this specialized machinery would go a long way towards evaluating the need for future investments.

11 GLOSSARY

BDT – Bone Dry Ton (one short ton, 2000 pounds)

BioRAM – Biomass Renewable Auction Mechanism. A CPUC approved power supply contract offering favorable power rates in exchange for agreement to source with qualifying fuels.

BioMAT – Biomass Market Adjusting Tariff. A CPUC approved power supply contract offering favorable power rates to new small power plants in exchange for agreement to source with qualifying fuels.

Biomass – In this report, forest-based woody biomass used for fuel. A broader sense includes mill residuals.

Ccf – Hundred cubic feet

CPUC – California Public Utilities Commission

DBH – diameter of a tree (inches) at breast height (4.5 feet above the ground)

Forestland - Land that has at least 10% crown coverage of live trees or had so in the past based on the presence of stumps or snags, as defined by USFS Forest Inventory Analysis[38].

HHZ – High Hazard Zones

Mbf – Thousand board feet. In this report Mbf is always short log scale. MMbf is million board feet. Bbf is billion board feet. A log truck typically has about 4 Mbf of logs

MWH – Megawatt Hour. A measure of production of electricity. One MWH can provide energy for 750 homes.

NTO – Notice of Operations

Sawtimber – The portion of a tree suitable for manufacturing solid wood products. For this study, a minimum top diameter of 6 inches and a minimum DBH of 10 inches."

Stumpage – The value of the tree standing on the stump, prior to harvest.

THP – Timber Harvest Plan

[38] https://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/

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APPENDICES

APPENDIX A: CURRENT HHZ FOREST INVENTORY

Table 1: Acres by Ownership and Management Suitability for HHZ Forest Land

	HHZ 1			HHZ 2			Total
	Suit.	Unsuit.	Subtotal	Suit.	Unsuit.	Subtotal	
Federal	40,013	11,354	51,366	7,114,950	3,231,381	10,346,332	10,397,698
Private	74,970	2,933	77,903	5,775,693	274,386	6,050,079	6,127,982
State	1,004	3	1,007	106,346	4,510	110,856	111,863
Local	489	-	489	27,193	543	27,735	28,224
NGO	1	-	1	2,560	-	2,560	2,560
Total	116,477	14,289	130,766	13,026,742	3,510,820	16,537,562	16,668,328

Suit. *Suitable for Management*

Unsuit. *Unsuitable for Management*

Table 2: Tons (BDT'000) by Ownership and Management Suitability for HHZ Forest Land

	HHZ 1			HHZ 2			Total
	Suit.	Unsuit.	Subtotal	Suit.	Unsuit.	Subtotal	
Federal	3,313	434	3,747	606,469	114,665	721,134	724,882
Private	4,678	-	4,678	337,155	-	337,155	341,833
State	121	-	121	7,302	-	7,302	7,424
Local	41	-	41	705	-	705	747
NGO	0	-	0	104	-	104	104
Total	8,153	434	8,588	951,736	114,665	1,066,401	1,074,989

Suit. *Suitable for Management*

Unsuit. *Unsuitable for Management*

Table 3: Biomass Tons (BDT'000) by Ownership and Management Suitability for HHZ Forest Land

	HHZ 1			HHZ 2			Total
	Suit.	Unsuit.	Subtotal	Suit.	Unsuit.	Subtotal	
Federal	666	121	787	119,658	30,951	150,609	151,396
Private	1,345	-	1,345	99,684	-	99,684	101,030
State	26	-	26	1,685	-	1,685	1,711
Local	12	-	12	264	-	264	276
NGO	0	-	0	37	-	37	37
Total	2,050	121	2,171	221,328	30,951	252,279	254,450

Suit. *Suitable for Management*

Unsuit. *Unsuitable for Management*

Table 4: Dead Biomass Tons (BDT'000) by Ownership and Management Suitability for HHZ Forest Land

	HHZ 1			HHZ 2			Total
	Suit.	Unsuit.	Subtotal	Suit.	Unsuit.	Subtotal	
Federal	95	22	117	11,050	2,403	13,453	13,570
Private	107	-	107	4,844	-	4,844	4,951
State	2	-	2	125	-	125	127
Local	1	-	1	4	-	4	4
NGO	0	-	0	1	-	1	1
Total	205	22	227	16,024	2,403	18,427	18,654

Suit. *Suitable for Management*

Unsuit. *Unsuitable for Management*

Table 5: Number of Dead Trees by Owner and HHZ Status on HHZ Suitable for Management

	HHZ			Non HHZ	Total
	HHZ 1	HHZ 2	Subtotal		
Federal	1,259,813	103,576,443	104,836,255	23,901,019	128,737,274
Private	1,522,538	43,728,332	45,250,870	8,946,353	54,197,223
State	6,160	1,195,849	1,202,009	327,901	1,529,910
Local	6,643	5,541	12,184	67,824	80,008
NGO	5	4,197	4,202	1,138	5,340
Total	2,795,159	148,510,362	151,305,520	33,244,235	184,549,755

Table 6: Dead Tree Tons (BDT'000) by Owner and HHZ Status (Saplings Included) on HHZ Suitable for Management

	HHZ			Non HHZ	Total
	HHZ 1	HHZ 2	Subtotal		
Federal	652	82,646	83,297	37,236	120,533
Private	508	26,229	26,737	26,437	53,175
State	10	908	918	4,686	5,604
Local	3	25	28	670	698
NGO	0	6	6	54	60
Total	1,173	109,814	110,987	69,082	180,070

Table 7: Dead vs. Live Forest Product Tons (BDT'000) by Owner and HHZ Status on HHZ Suitable for Management

	HHZ								
	Saw Logs		Saw Tops		Poles		Saplings		Subtotal
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	
Federal	419,281	70,177	58,715	6,044	50,464	5,101	23,378	1,975	635,135
Private	220,438	20,366	45,826	2,013	50,252	2,938	24,653	1,420	367,906
State	4,946	766	844	64	741	62	338	26	7,787
Local	448	23	156	1	115	3	41	1	790
NGO	62	5	25	0	11	0	3	0	108
Total	645,176	91,336	105,565	8,124	101,584	8,105	48,414	3,423	1,011,726

	Non HHZ								
	Saw Logs		Saw Tops		Poles		Saplings		Subtotal
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	
Federal	273,319	31,283	44,258	2,181	39,859	2,701	18,341	1,071	413,013
Private	394,863	20,314	101,398	1,403	99,750	3,244	44,942	1,477	667,391
State	43,562	3,897	7,965	348	5,814	306	2,615	134	64,643
Local	8,383	548	2,148	51	1,155	50	469	21	12,825
NGO	1,012	41	402	3	315	8	114	3	1,897
Total	721,140	56,083	156,171	3,985	146,893	6,309	66,483	2,705	1,159,768

	Total
Federal	1,048,148
Private	1,035,297
State	72,430
Local	13,615
NGO	2,005
Total	2,171,494

APPENDIX B: INVENTORY METHODS

B.1. Forest Inventory Background

The FMTF seeks a clearer understanding of limitations to increased supply of biomass from High Hazard Zone (HHZ) forests across the State of California. We calculated an in-place timber inventory for California that is classified with quantities relevant to understanding BioRAM contract biomass sources, including amount (volume, mass), status (live, dead, product type), removal eligibility (ownership, operational restrictions), and current rates of removal (harvest and planned harvest) of relevant biomass from forest trees as defined in Appendix C. Preceding components were formulated first as an assessment of the current total supply, and second as the potentially available supply for individual facilities in contracts administered under California's Bioenergy Renewable Auction Mechanism (BioRAM). This Appendix is intended to address aspects of the BioRAM / HHZ biofuel assessment project that pertain to questions regarding forest inventory and biofuel supply. This Appendix does not address methods concerning computation of historic harvest, timber product disposition, or forecasting future biofuel supply availability. Please refer to Appendix C suitable and unsuitable USFS lands (Appendix C items 7 and 8), and adjustments to inventory based on ownership categories (Appendix C item 5).

B.2 Forest Inventory in BioRAM Project Context

A forest inventory that can resolve questions across multiple scales, from individual facilities to the entire State, must retain a degree of spatial specificity—an organizational structure that permits summary operations on the minimum scale of anticipated assessments. For this project, the smallest single analysis unit will be the timber fuel supply availability for individual BioRAM facilities; the forest inventory must enable construction of a supply curve and must retain enough resolution to meaningfully interact with factors that influence supply—notably, transportation distances and harvest costs. An inventory that functions for this smallest scale purpose must also have the capacity to summarize timber and forest biomass availability Statewide. The inventory has the following capabilities:

1. To assess HHZ vegetation [i.e. woody biomass that qualifies as potential fuel for BioRAM facilities] availability and removal [historic and planned].
    - i. Distinguish between green (live) and dead trees. From a materials handling perspective, dead trees can be safely harvested for approximately five years beyond a mortality event, after which breakage makes mechanical handling untenable. By 10 years post-mortality, most woody material is from a biofuel standpoint.
    - ii. Contrast the amount of biomass that *has been removed* from California HHZ forests [during the mortality event ca. 2012 through 2017] to volumes that are planned for removal, classified by owner [SOW verbatim 'by whom', but indicating class of owner or forest planner, e.g. United States Forest Service (USFS), private landowners, etc.].
    - iii. Investigate and quantify the *disposition* of the woody biomass harvested annually in California via review of California wood products industry summaries, and extension of

historic dispositions to the future, in contrast with published CalRecycle disposition data.

Removals, (planned and historic) and dispositions were compiled from non-inventory data and are almost entirely decoupled from the inventory. In other words, the historic harvest is uncorrelated with historic inventory because actively managed forests constitute a small fraction of the total regional forest cover. Similarly, the disposition of harvested material depends on an interplay of operational facilities, facility location, relative price of final products, and regulations imposed on forest management activity. Annual harvest in California (approximately 1.5 billion board feet (Bbf)) is mere 0.3% of inventory, and the composition of harvest can only impact disposition to a limited extent[39], so knowledge of in-place inventory composition at any spatial scale cannot be translated to knowledge about the disposition of harvest. In the aggregate, forest inventory information is *necessary* to determine supply, but not *sufficient* to infer any facts about either harvest or disposition.

2. To assess the overall market potential for HHZ fuel in California [using the in-place inventory assembled for HHZ areas during Task 2 Subtask 1].
    i. Determine the proportion of HHZ forest biomass available for bioenergy fuel stock, and the proximity to current and planned bioenergy facilities, defining availability from several perspectives:
        A. As the fraction of inventory in HHZ vs. non-HHZ classification.
        B. As a supply curve [individually for each BioRAM plant, in the aggregate for all biomass-consuming facilities] of forest biofuel feedstocks.
        C. (A) and (B) in map form.
    ii. Account for effects of the 2012-2017 mortality event on forest-derived biofuels from HHZ areas through 2038.
        A. Fraction of dead trees in HHZ vs. dead trees in non-HHZ areas.
        B. Conversion of dead tree biomass to megawatt hours (MW) and bone-dry tons (BDT).
3. To assess potential [future] HHZ fuel supply for each current BioRAM contract period [using the current inventory as a basis for project, from which future supplies are forecasted].
    i. Develop a five-year fuel supply assessment from HHZ areas for each BioRAM contract.
    ii. Characterize the degree of competition for shared adjacent HHZ feedstocks among facilities with BioRAM contracts.

While elements of item (3) are derived in part from in-place inventory, other crucial aspects of individual contract supply include the “competitive environment” around each facility (the extent of competition among bioenergy facilities for adjacent biomass), the volume of annual timber harvest already allocated to other uses (timber, veneer, etc.), loss to mortality, and assorted economic considerations including transport cost, State and Federal regulations, infrastructure, lack of capital investment or existing

[39] For example, if inventory preceding harvest consists of small trees e.g. less than 10 inches diameter, it is possible that the disposition would exclude veneer products or certain dimensional lumber and might increase the likelihood that the harvested volume would be destined for bioenergy production.

California Public Utilities (CPUC) programs. This report/section addresses the components of supply assessment subject to determination by the in-place forest inventory.

B.3. Inventory Data

The basis dataset for our computation of California's forest inventory was acquired from the Landscape Ecology, Modeling, Mapping & Analysis (LEMMA) group at Oregon State University. These data consist of tree lists (live vs. dead trees as of 2012, species, diameter, height) assigned to a raster of 30 m by 30 m grid cells covering all the forested areas in California, Oregon, and Washington. For this project, we have extracted only the raster extent in California, which contains around 11,000 unique Forest Class Identification (FCID) numbers, each corresponding to a distinct original tree list. The publicly available LEMMA dataset includes only summaries of measured components of these tree lists, e.g. total gross volume, or volume within certain size classes of trees, results of the Gradient Nearest Neighbors (GNN) analysis. These summary classes do not align with the species groupings or log size classes specified in R4.b and are reported in metric diameter groupings and cubic metric volumes.

For an in-place inventory, we required the original tree lists underwriting each FCID in order to apply a biomass fractionation scheme relevant to the concerns of BioRAM contracts and granting the capability of summarizing biomass in English units according to 'product' classifications of sawtimber, biomass, and micro-sized material. We acquired tree list data for California from the LEMMA group (Pers. Comm. Matt Gregory[40]). These data were received in metric units, diameter of centimeters and height of meters; we converted all tree measurements to English units of inches for diameter and feet for height.

Tree lists for LEMMA were sourced from Forest Inventory and Analysis (FIA) Periodic and Annual plots, USFS Region 5 Current Vegetation Survey (R6-CVS), USFS Region 5 Inventory (R5), Bureau of Land Management Current Vegetation Survey (BLM-CVS), and Bureau of Land Management Fire Effects Monitoring and Inventory Protocol (FIREMON) plots. The LEMMA group has standardized the tree lists to control for differences in plot size and sampling procedures among the data sources.

B.4. GIS Data

We acquired GIS data from several sources, including the USFS, CalFIRE, CPUC, University of California Division of Agriculture and Natural Resources (UCANR), USGS, LEMMA, and ESRI. Most datasets were publicly available and downloaded from agency websites. Certain datasets were acquired by FTP, or similar route, or emailed directly to us.

- Datasets acquired from USFS included National Forest District Boundaries, wilderness / regulatory status operability, historic silvicultural treatments and harvests, and Aerial Detection and Monitoring[41] data (ADM, constituting tree mortality assessments from 2012 through 2017), Land Suitability data sets for each forest in the Region

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[40] Matt.gregory@oregonstate.edu (https://lemma.forestry.oregonstate.edu/about/matthew-gregory)
[41] https://www.fs.usda.gov/detail/r5/forest-grasslandhealth/?cid=fsbdev3_046696

- Data from CalFIRE included HHZ Type 1 (utilities and municipal rights of way) and Type 2 (forest), historic Timber Harvest Plan (THP) polygons, and estimated tree mortality, Public and Private Ownership,
- CPUC and UCANR provided locations of current and planned bioenergy production facilities.
- USGS provided 10 m DEM for calculating slope.
- See CalFIRE
- The LEMMA group makes publicly available the 30m raster grid[42] with FCID for connecting tree list data to spatial locations across forested areas of California.
- ESRI provided the street network used in the travel distance analysis for haul costs.

Certain areas were removed from consideration before any processing: all non-forest areas were effectively ignored because the LEMMA GNN raster encompasses only forested areas. The LEMMA data also include only forested areas known to support unburned tree cover through 2012. Therefore, areas affected by severe wildfire (fires that would replace entire stands and leave no trees alive) between 2012 and August 2018 were removed from further consideration. This decision produces a conservative estimate of forested acres and standing inventory because some wildfire areas designated severe may not be completely burned across the entire high-severity polygon, but higher-resolution data at the State level do not exist in a standardized format. The inventory *does not account for losses to wildfires that occurred in 2018 well after initiation of the contract*.

B.5. Tree List Processing

A dynamic inventory is necessary to estimate current biofuel feedstocks and to project future supply; we generated a dynamic inventory with the USFS Forest Vegetation Simulator (FVS) software. FVS is the national-standard forest simulation framework and the most comprehensive national growth model set available for regional forest growth projections. The accuracy of FVS growth projections is under constant review by the FVS Validation Subcommittee[43]. In this study, we do not propagate sampling error or bias derived from tree list composition or FVS.

The issue of sampling error and bias is complex and beyond the scope of this study. Published inventory error from LEMMA (Ohmann and Gregory, 2002[44]) is quantified under a different set of allometric equations than represented by processing LEMMA tree lists via FVS. The range standard errors from FVS volume computations are presented in the literature for individual species (implemented in the FVS progenitor model Prognosis, e.g. Froese and Robinson 2007[45]). Volume projection error over one projection cycle (five years for CA variants) may be less than 15% on the low end (e.g. 13% for Douglas-fir (*Pseudotsuga menziesii*) or 12% for grand fir (*Abies grandis*)), ranging to more than 75% for

[42] https://lemma.forestry.oregonstate.edu/data/structure-maps
[43] https://www.fs.fed.us/fvs/documents/validation.shtml
[44] https://lemma.forestry.oregonstate.edu/export/pubs/ohmann_gregory_2002_CJFR.pdf
[45] https://doi.org/10.1139/X07-002

hardwoods or e.g. *Pinus monticola* (102%). A rigorous error propagation method would require imposing a measured projection error from suitable model validation efforts (if they exist) as a function of tree size, species, and stand composition for all combinations of tree lists.

Most common tree lists for California forests should contain species with likely volume errors not less than 12% or 13%, implying a monotypic stand of *A. grandis* or *P. menziesii*, respectively. The upper bound on volume projection error is difficult to establish and is drive more by stand structure than by allometry, so we suggest that readers interpret FVS volume output with at minimum a 12% error.

To use FVS for growth projection, first, we adapted LEMMA tree lists to suitable FVS *variants*. Forest growth along the northwest coastal strip is best described by the North Coast (NC) variant, while the inland northeastern region is described by the Southern Oregon (SO) variant. The Central Valley through the Mt. Shasta region is covered by the California (CA) variant, and the Sierras through Southern California by the Western Sierras (WS) variant (Figure B-1). The FVS variant map was overlaid on the LEMMA FCID raster to determine which FCID should be defined for each variant.

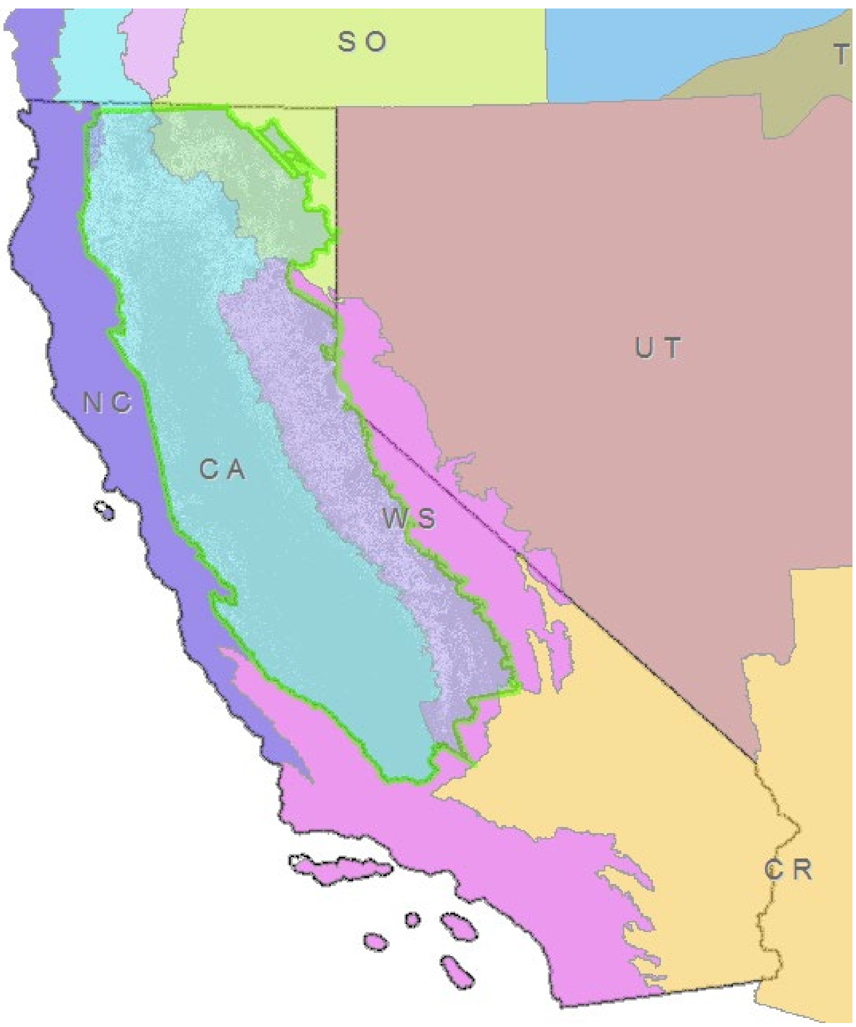


Figure B-1. Four FVS variants operate in California, NC in the northwest, SO in the northeast, CA centrally, and WS in the Sierras and southern CA. The CR variant is unused because those areas of the state are not forested

The four FVS variants that we used for this inventory each require slightly different defaults and inputs. Data from the LEMMA tree lists were prepared for FVS input according to the defaults and expectations outlined in FVS variant user guides[46]. All LEMMA tree lists share a common terminal year of 2012: any forest management activities (harvest, silviculture, prescribed burning) that occurred after 2012 are not captured in the LEMMA grid cell assignment. We account for inventory reductions due to harvest by removing areas harvested either under California's THP program (data from CalFIRE) or from USFS operations through the present, or areas subject to wildfire of high severity.

We grew LEMMA tree lists from their 2012 common date to the present (defined as 2017 for this report), then we calculated annual growth rates by FCID to facilitate the future inventory projection. Base FVS reports some general stand metrics but does not distinguish among tree size classes or product types in which we are interested for BioRAM inventory assessment. We defined five custom DBH classes (Figure B-2) in FVS using the SpMcDBH() function to apportion timber volume to product classes that correspond to typical California operations. These include unusable small trees, small trees eligible for biomass harvests, and larger sawtimber trees. Example for 10"-24" sawtimber board feet (BdFt):

$$\boldsymbol{MBF102L} = \boldsymbol{SPMCDBH}(\mathbf{4, 0, 0, 10, 24, 0, 999, 0, 0}) \qquad \textbf{Equation 1}$$

Among the sawtimber classes, we further differentiate among three diameter classes for use with USFS restrictions, see below; top sections of sawtimber trees count toward biomass. For all diameter classes, and for all the mass and volume divisions described below, we report both the live and dead fraction.

Figure B-2. Custom Tree Size Categories Defined in FVS to Correspond to Small Trees, Biomass, and Sawtimber Classes as Typically Implemented in California Timber Harvest Operations.

DBH class	Size range	Product	Qualifications
LTE6	DBH ≤ 6"	Small trees	Too small; not counted toward biomass
B610	6" < DBH ≤ 10"	Biomass	Primary biomass fraction, all owners
B1024	10" < DBH ≤ 24"	Sawtimber	Top segments biomass, all owners
B2430	24" < DBH ≤ 30"	Sawtimber	USFS not counted; top segments biomass
GT30	DBH > 30"	Sawtimber	USFS not counted; top segments biomass

Merchantable saw volume is computed by FVS either as BdFt or merchantable cubic feet (MCuFt), and not directly as tons of biomass. The growth simulator computes merchantable volume for any sufficiently large trees, which includes those less than our sawtimber size threshold of diameter (DBH) 10". Although this means that some trees <10" have merchantable volumes according to FVS, we compute sawtimber inventory only as MCuFt or BdFt for the >10" class and classify top log volume from sawtimber trees as biomass. The difference between total cubic foot volume (TCuFt) and MCuFt yields that CuFt top volume.

A straightforward output of tons of biomass can be produced by FVS for custom size class variables *for live and dead trees that FVS has internally assigned to each life status category*. We define a further set

[46] https://www.fs.fed.us/fvs/documents/guides.shtml

of outputs in units of Dry Tons (interchangeably Bone-Dry Tons, BDT) for each size class using the TREEBIO() function in FVS, setting its argument to dry tons of stem mass and dry tons of canopy mass

$$\boldsymbol{DT102LS = TREEBIO(-1, 0, -1, 0, 10, 24, 0, 999)} \quad \textbf{Equation 2}$$

(corresponding to tree tops). Example for 10”-24” sawtimber stem:

We cannot directly use these BDT quantities to compute live and dead tons per acre, however, because the number of dead trees simulated by FVS corresponds to background mortality from stand dynamics and does not assimilate mortality that occurred during the 2012 through 2017 mortality event in California.

At this step, we introduce mortality data from the Aerial Detection and Monitoring (ADM) program, which after GIS processing corresponds to the total number of trees that died across all five years of the mortality event. Published aerial survey methodology suggests[47], and discussion with USFS personnel (Pers. Comm. Jeff Moore) confirms, that detection of small dead trees is less likely than detection of larger dead trees. Mortality in the canopy dominant and subdominant[48] classes is therefore likely to be represented, while suppressed or sapling mortality may go undetected. We limit ADM mortality to trees exceeding 6” DBH. We allow the FVS background mortality rate to proceed concurrently with the

$$\boldsymbol{Dead\ TPA_{Total} = Dead\ TPA_{FVS} + Dead\ TPA_{ADM}} \quad \textbf{Equation 3}$$

anomalous mortality event, subtracting the number of dead trees simulated by FVS from the number of dead trees expected from ADM layers. In this computation, TPA indicates Trees Per Acre.

$$\boldsymbol{Dead\ BdFt_{Total} = BdFt_{FVS_{Dead}} + BdFt_{ADM_{Dead}}} \quad \textbf{Equation 4}$$

The remaining number of dead trees from ADM is then subtracted from the number of live trees simulated by FVS, and the volume and biomass transferred out of live status into dead status.

Because these trees are very recently dead, we retain their live volume and mass upon initial conversion to dead status. Total dead volume or mass is therefore the sum of recently dead quantity (deducted

$$\boldsymbol{Live\ BdFt_{Total} = BdFt_{FVS_{Live}} - BdFt_{ADM_{Dead}}} \quad \textbf{Equation 5}$$

from live) and the dead quantity simulated by FVS. Using BdFt of 10”-24” sawtimber trees as an example:

47 https://www.fs.usda.gov/detail/r5/forest-grasslandhealth/?cid=fseprd550891
48 Readers may be unfamiliar with the term ‘subdominant’, for usage see (https://definitions.uslegal.com/s/subdominant-trees/) or (https://doi.org/10.1109/IGARSS.2017.8127569)

Similarly, total live volume or mass is the difference of the live quantity simulated by FVS and the recently dead quantity. In this formulation, total volume per acre simulated by FVS is conserved, but the allocation of that volume among dead versus live status is shifted according to the ADM mortality survey data.

We make the economically-justifiable assumption that trees of eligible size to be sold as sawtimber will be sold in that way—sawtimber is more valuable than biomass by a factor of 10 or more, so rational economic actors will not use sawtimber as biofuel. Certain conditions may violate this assumption, such as when a sawtimber-sized tree has been dead for more than seven or eight years, in which case it may no longer meet structural integrity requirements for sawtimber and could be redirected to a biofuel use. We acknowledge that certain causes of mortality may violate this assumption, for example mortality due to a combination of drought and bark beetles could result in unsound timber immediately after mortality. For the current in-place inventory, we are carrying dead trees as old as six years, but still within the time window for sawtimber viability. Mortality is applied without knowledge of cause because the aerial detection survey cannot be mapped onto tree lists at an individual level. Ascribing mortality cause in this inventory is unjustified, so we supply the caveat here that some fraction of dead sawtimber-sized volume may be best suited for bioenergy production. Beyond six years, for the projected future inventory, we allow for the aging fraction of dead large trees to count toward BioRAM eligible mass rather than toward the sawtimber fraction. Thus, the caveat of under-estimated biomass from sawtimber sized trees only impacts the first six years of the 20-year study period.

Typically, on USFS land in California silvicultural prescriptions effectively preclude cutting trees that exceed 24” diameter. We defined the size classes to allow these larger trees to participate the HHZ-available inventory on non-USFS land, but to exclude them from availability on USFS land. We include the greater than 30” category for the possibility of sensitivity analysis should certain USFS areas indicate harvest may extend to 24” to 30” trees. Please refer to Figure 9 for inclusion and exclusion criteria of these large trees, and their destination as biomass material.

All output values from FVS are expressed in units of quantity per acre and distinguished by a unique combination of LEMMA FCID and FVS variant ID (CA, NC, SO, or WS). To extend these per-acre values to an area-based inventory, areas sharing FCID and FVS variant matching the FVS output are multiplied by the number of constituent LEMMA grid cells (0.22 acres) to return units of volume, tons, trees, basal area, etc. In the next section, we review steps followed to summarize standing inventory by land classification.

B.6. Statewide Forestland Raster

Beginning with the LEMMA GNN raster we used ArcGIS Spatial Analyst to code the raster by the following:

- FVS Variant,
- HHZ,

- Dead Trees Per Acre,
- Ownership,
- National Forest,
- Suitability (USFS),
- Burned,
- Slopes GE 30% and GE > 50%

The resulting statewide raster was then used to determine the 2018 forest inventory for the state of California.

B.7. Haul Costs Analysis Input

HHZ Lands

The Haul Cost Analysis only focused on the HHZ lands. An HHZ raster was extracted from the statewide raster generated in 4.1 above. The HHZ lands raster was then converted to a vector feature for the remaining analysis.

BioRAM and Biomass facilities

With the help of Julee Malinowski-Ball, from PPALLC, we identified the 23 Biomass facilities currently operating in the State of California. Of these 23, seven are part of the BioRAM program and are the primary focus of our study.

Using ArcGIS Network Analyst, we generated 200-mile services areas for each mill in 10-mile increments.

Travel Distance Overlay

We combined the HHZ feature with the 200-mile service area travel shells and assigned the distance from each facility based on the service area for each facility.

The resulting feature contained HHZ polygons and an attribute for each facility with distance to the facility from the HHZ polygon. The results were exported to a table and used to develop supply and costs curves for each BioRAM and biomass facility.

B.8. Inventory by Land Areas

Standing inventory is computed over several steps, from a total in-place inventory reflecting the current state of standing forests, through a final HHZ-only inventory incorporating reductions or removals to accommodate losses to wildfire, reductions from THP and USFS harvests and silviculture, areas ineligible for harvest based on USFS wilderness and other reserve area designation, and areas with steep slopes on which logging practices preclude harvesting certain classes of trees.

This model is fundamentally spatial, ***not inventory-based***, and its basic unit is the concatenation of FCID from LEMMA, and FVS variant, and a sequence of land classifications, including

Forestland (LEMMA default)

HHZ or Non-HHZ

- If HHZ:
- Cleared due to wildfire or harvest

Owner

- IF USFS:
- National forest name
- Suitability
  - Slope
  - If >30%, only large trees count to volume
    - County
    - Distance to BioRAM facilities A-W
- Unsuited lands
  - Roadless areas; wilderness areas
  - Not available (for mechanical operations)
  - Un-productive (not meeting FIA forestland standards)
  - Incompatible current inventory (no existing biomass material present)
  - Subject to any assorted other rules or factors that may exclude from eligibility

The foundational unit for processing data into supply curves is therefore the concatenation of:

FCID X FVS_LOC X HHZ X Owner (w/NF if USFS) X Suitability X Slope X County

All combinations of volume (or biomass) are computed for all possible sets of above combinations, resulting in a dataset with (14.6 million rows and Z columns).

B.9. Suitable-eligible-available inventory

We apply a reduction to biomass on private land based on the rationale outlined in (B-3). We expect that HHZ vs Non-HHZ private land will be managed in similar ways. Across both HHZ types, on private land, we expect that a fraction of industrial lands will be managed on even-aged rotations, approximately 1.1 million acres. Therefore around 3.4 million acres of industrial land will be managed as uneven-aged. Beyond that, approximately 12.1 million private non-industrial acres have the potential to be managed as uneven-aged. Of the 15.6 million acres likely managed as uneven-aged, we expect that over a 60-year period there would likely be three entries, so that over the 20 years of the BioRAM study, only 1/3 of the acres, and approximately 1/3 of the biomass, would be removed by selection harvests.

Figure B-3. Total private land acreage with reductions to account for differential in uneven aged vs. even aged management practices.

Private	TOTAL	16,690,262
Private	INDUSTRIAL CC	1,100,000
Private	INDUSTRIAL Uneven	3,400,000
Private	NON-INDUSTRIAL Uneven	12,190,261.60
Private	Uneven	15,590,262
Private	Uneven entry in 20 years	5,196,753.87
Private	Fraction BioRAM eligible	31.1%

Because the 1.1 million acres of even-aged management is ineligible for BioRAM contracts[49], we must not include biomass from those forests. Thus, the fraction of biomass available in the 20-year period of the study is roughly in proportion to 1/3 of the uneven-aged acres (5.2 million acres) as a fraction of the total private land (industrial and non, even and uneven, which is 16.7 million acres), or 31.1%. Thus, we apply a reduction factor of 0.31 to the biomass on private land.

B.10. Biomass Cost Curve Processor

We report the amount of forest biomass inventory as ***available*** to BioRAM facilities under three alternative competition environments. In Alternative 1, we allow the unrealistic assumption that each BioRAM plant has unfettered access to biomass within a 200-mile travel distance of the facility point location, subject to the reductions and ineligibility criteria stated previously and stipulated by USFS. As Alternative 2, we assume parity in competition among BioRAM plants only, such that all of the forest biomass within 200 miles of a BioRAM facility is available to that facility, except where there is overlap between facilities, in which case the biomass at such locations is split evenly among the facilities that overlap. That is, if the overlap is only between two facilities, each facility is granted access to 50% of the biomass in that location.

Finally, as Alternative 3, we assume uniform competition, defined as previously, among any biomass burning facility, whether BioRAM or non-BioRAM, apportioning biomass equally across any facility. We view Alternative 1 as a broad assessment of inventory, and Alternative 3 as a simplistic model of competition. For biomass sources located within 40 to 50 miles (the 'economically viable' haul distance) of a single bioenergy facility, Alternative 3 effectively directs biomass to the closest plant and precludes sending biomass to more distant facilities. When multiple facilities are within 40 to 50 miles of a biomass source, distance becomes less relevant for determining the destination. More realistic models of

[49] BioRAM 1 contracts may allow some clearcut volume, but BioRAM 2 contracts and BioMAT contracts will not allow clearcut material. This study does not apply a harvest method to particular land units or track specific volume to its contract destination (whether BioRAM 1, BioRAM 2, or BioMAT); some additional biomass volume may be available under BioRAM 1 contract from even-aged management.

competition are beyond the capacity of this study because relative competitiveness of each facility changes in relation to sawtimber price, transportation costs, and the rapidly-evolving biomass power incentives regulatory landscape. The real effects of inter-facility competition must depend on an array of factors that are beyond the scope of this work to incorporate, including the nature of biomass contracts, ratio of forest biomass vs. urban wastes or other sources, relative size of facility and economies of scale in relation to securing contracts but also relative to prices paid for power, and likely many others.

We assemble cost curves in the form of cost per ton of delivered biomass ($/BDT) as a function of biomass accumulation (BDT), see e.g. Figure 17. Cost curves are presented by product, by owner, by facility, and in the aggregate. We also calculate the sum of biomass available to all facilities, and solely to BioRAM facilities, under Alternatives 1, 2, and 3 in each 10-mile travel shell.

ShellMiles	mph
5	36.9
15	39.9
25	41.3
35	42.2
45	42.8
55	43.4
65	43.8
75	44.2
85	44.5
95	44.8
105	45.1
115	45.3
125	45.6
135	45.8
145	46.0
155	46.1
165	46.3
175	46.5
185	46.6
195	46.8

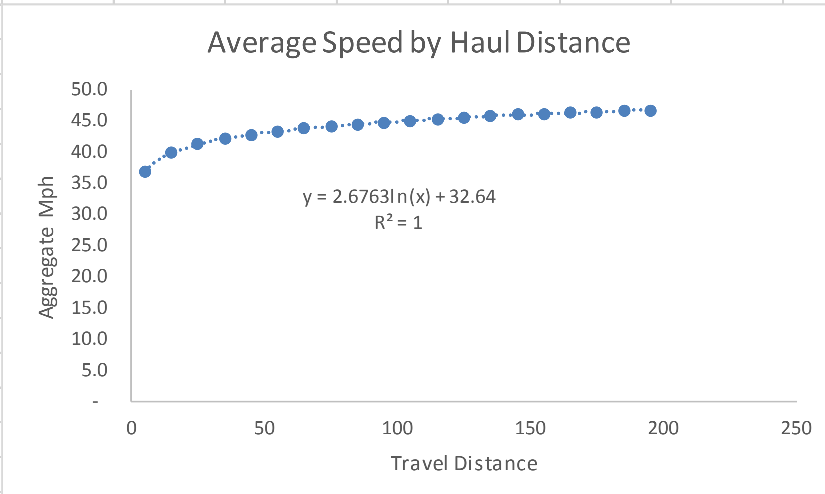


Figure B-4. Haul cost component, average speed by haul distance.

APPENDIX C: ASSUMPTIONS AFFECTING THE DEVELOPMENT OF AN INVENTORY OF POTENTIAL BIOMASS

Appendix B describes methods to develop a state-wide in-place inventory from the LEMMA dataset. This Appendix describes assumptions used to derive a conservative estimate of potential biomass available from the HHZ to be used to develop biomass cost curves.

To estimate biomass potentially available over a 20-year period, we applied two sets of filters to the comprehensive state-wide inventory: (1) a set of land-based filters narrowed the focus to forest land eligible for management in the HHZs, and (2) a set of operational filters adjust the total inventory to levels that could reasonably be expected to be available for use. Figure 8 illustrates the process at a high level.

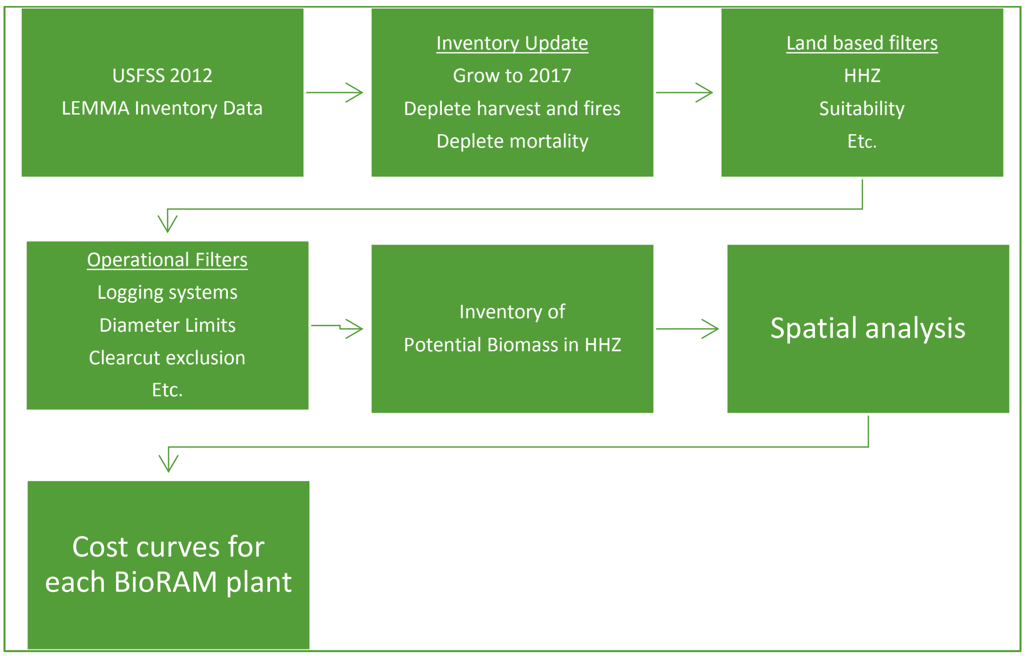


Figure C-1. Processes for developing cost curves from primary inventory data

Our intent is to provide a conservative estimate of the potential inventory of biomass within the HHZs. Several assumptions and processes were required, and each has an impact on the reliability of the estimate. Below we describe the rationale behind each assumption/process/decision.

Inventory update

2. Adjust for growth. We used computer growth modeling to grow the 2012 tree lists to 2017, using the region-appropriate FVS growth model.[50] While we evaluate the current biomass against a 20-year usage, we did not project future growth or stochastic regional mortality. As a

[50] FVS: Forest Vegetation Simulator, a tree growth model created and maintained by the US Forest Service.

result, our estimates are conservative.

3. Adjust for mortality. Portions of California's forests have recently experienced high levels of tree mortality. It is estimated that over the last 7 years, approximately 129,000,000 trees died as a result of drought, insect or disease (Tree Mortality: Facts and Figures, 2017), (Tree Mortality: Facts and Figures, 2018), with potentially another 18 million trees lost in 2018 due to wildfire[51]. We used the annual USFS Aerial Detection Survey (ADS) data[52] to apply observed mortality to the grown inventory. The ADS mortality is factored in addition to the background mortality calculated by the FVS growth model (McConnel, Johnson, & Burns, 2000). We converted these trees from live to dead categories and reduced dead volume by a marginal fraction to account for decomposition. We did not include any projections for further mortality that would become biomass. As a result, our estimates are conservative. Appendix J summarizes the ADS mortality adjustments by National Forest and County.

4. Adjust for wildfire. About 1.4 million acres of forestland statewide were burned by wildfire since the LEMMA data were finalized in 2012.[53] We depleted the inventory corresponding to the 650,000 acres of HHZ that were burned with high and medium severity from 2012-2017. This is a conservative assumption in that salvage from some of the more recent fires may make its way to the biomass power plants and would be considered qualifying fuel at the BioRAM plants.

   We did not make any inventory adjustments to acres burned by low severity wildfire. We did not project any future fire loss.

   To the extent that future fire consumes biomass, our estimates will overstate biomass availability, although that will be partially offset to the extent that salvage from those future fires can produce qualifying biomass fuel.

5. Adjust for harvest. We depleted the inventory for about 105,000 acres in the HHZ that had stand-clearing harvests between 2012 and 2017, based on spatial data from the USFS and CalFire.

6. Merchandizing to biomass. Forest residue biomass is that portion of the stand volume which is not suitable for manufacture into higher-valued forest products. For this study we identified three components of forest biomass, as shown in Figure 9:

   a. Tops of sawtimber sized trees. We considered any portion of a tree above the point at which the tree's stem diameter drops below 8" as biomass.

[51] https://www.sdentertainer.com/news/california-lost-18-million-trees-in-2018/
[52] https://www.fs.usda.gov/detail/r5/forest-grasslandhealth/?cid=fsbdev3_046696
[53] We understand that CalFire recently revised the HHZ to include all acres burned since 2012. This report was prepared before that action.

b. Small trees. Trees between 6 and 10” diameter at breast height (DBH) are too small to be considered sawtimber but are often chipped into biomass. Trees less than 6” DBH were included as biomass only on shallow slopes (<30%), since these small stems are not economically feasible to remove in a cable logging operation.

c. Dead trees greater than 10” DBH.

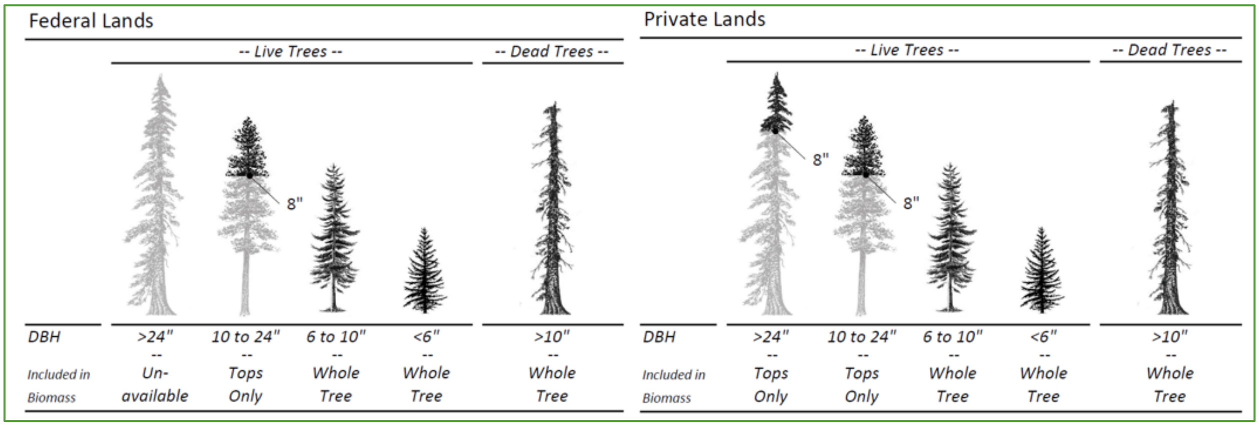


Figure C-2. Volume classified as forest biomass for this study

Our estimate of timber volume uses the FVS growth model components that include only the bole of the tree, inside the bark. Bark and branches, however, are chipped and delivered as biomass. Our biomass estimates, therefore, understate the material that is available. This could be an underestimation on the order of 15% (for larger trees) to 25% (for smaller trees).

Land-based Filters

7. Acres in the HHZ – This analysis of biomass availability is limited to the 13.1 million acres in the HHZ, as described above.

   These reductions include 105,000 acres that were recently harvested and would not be treated within a 20-year period; 650,000 acres burned by severe wildfire that would not be salvaged; 107,000 acres on USFS property that are harvestable but operationally challenging (e.g. excessively steep slopes); 2.67 million acres of USFS land that is administratively removed from consideration for biomass production (e.g. wilderness, roadless areas). In total, 3.52 million acres in the HHZ were removed, resulting in the figure of 13.1 million acres considered for the potential biomass estimation.

   The 23.8 million acres of California forest not in the HHZ contains another 352 million BDT of biomass and some of those acres will undoubtedly be harvested over the next 20 years. That will increase the biomass available for fuel beyond what we show in this report, although that volume would not be considered qualifying fuel to the BioRAM plants.

For this analysis, we assume that the HHZ designation will not change over a 20-year period. To the extent that additional lands are designated HHZ, our estimates of qualifying biomass are conservative.

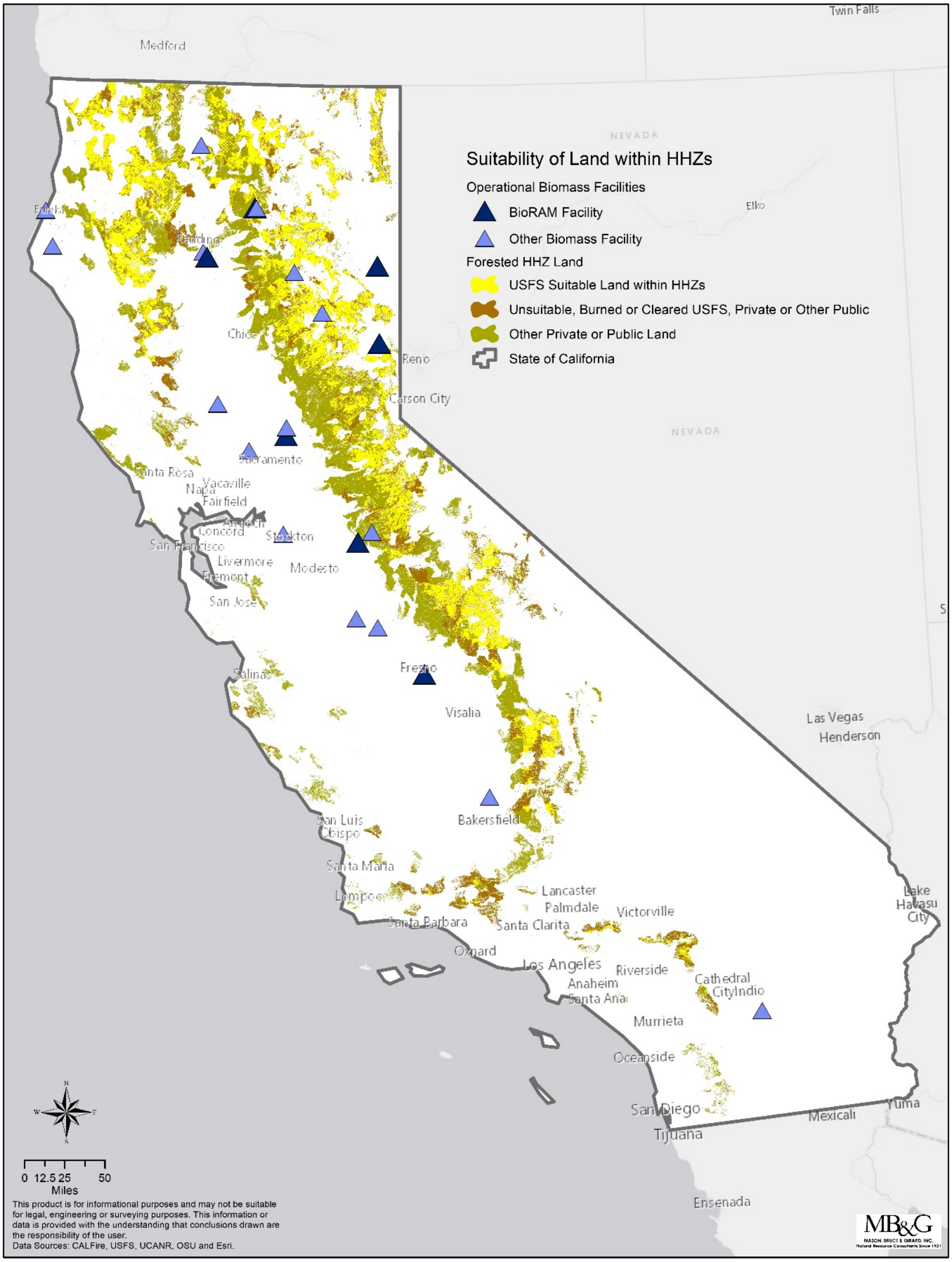
8. USFS suitability – Management on the National Forests is guided by Forest Plans prepared under the authority of the National Forest Management Act of 1976. These plans allocate lands to various uses and specify standards and guidelines under which management will occur. Some land allocations are incompatible with forest management actions that would produce biomass, and we worked with the USFS to identify and remove from consideration 2.7 million acres in the HHZ that are not compatible with harvest treatments. Another 107,300 HHZ acres were removed because the timber on those acres is unsuitable for harvest.[54] Figure C-3 shows the forested HHZ lands by ownership and suitability for management.

   Suitability determination was developed in collaboration with USFS (Pers. Comm. Joe Sherlock, Regional Silviculturist). To be considered eligible for potential biomass production, land under USFS ownership conformed to several criteria:

   - Available (for mechanical operations)
   - Productive (designated forest land by USFS, equivalent to FIA forestland standards)
   - Compatible current inventory (existing biomass material present)
   - Not subject to assorted other rules or factors that may exclude from eligibility

   Exhaustive definitions of each point may not be possible to elaborate in this study, as the definitions supplied by USFS are constructed internally, or may not be available in any published material, or may be approximate.

[54] Based on advice from the USFS, we did not exclude Protected Activity Centers. The widespread removal of small trees would make a significant reduction in the likelihood that fire behavior would continue to trend toward stand-replacement outcomes. The number of PACs affected by stand-replacing fires increases every year, with some fires affecting several at a time. Treatments designed to reduce fire risk to PACs would focus on the smaller biomass-sized trees.



Suitability of Land within HHZs
Operational Biomass Facilities
BioRAM Facility
Other Biomass Facility
Forested HHZ Land
USFS Suitable Land within HHZs
Unsuitable, Burned or Cleared USFS, Private or Other Public
Other Private or Public Land
State of California
0 12.5 25 50
Miles
This product is for informational purposes and may not be suitable for legal, engineering or surveying purposes. This information or data is provided with the understanding that conclusions drawn are the responsibility of the user.
Data Sources: CALFire, USFS, UCANR, OSU and Esri.

Figure C-3. Forested High Hazard Zone lands

Operational filters and adjustments

9. Clearcut acres – Biomass from clearcuts counts as qualifying fuel under the BioRAM 1 contracts but not under the BioRAM 2 contracts. It is our understanding that biomass from clearcuts will not count as qualifying fuel for contracts modified under SB 901. Biomass from clearcuts will be considered qualifying fuel under the BioMAT contracts.

   For this analysis, we made a downward adjustment to potential biomass for acres clearcut. There is about 12.5 million acres of private forestland in California. According to California Forestry Association, about 1 million acres are managed by industrial landowners under even-aged management regimes that will rely on clearcutting. A map of those acres is not available, necessitating a more general adjustment.

   We removed from consideration any biomass from final harvest on clearcut acres as it does not qualify as fuel under the BioRAM 2 contracts or under contracts that will be modified under SB901. We understand that about 1 million acres of private land are managed under even-aged regimes. On the rest of the private land, we assume that uneven-aged management on a 20-year entry cycle that removes 33% of the volume. Combined, we assumed that 31% of the biomass on private lands could be removed during a 20-year period.

   This adjustment may overstate the impact of disqualification of biomass from clearcutting. Biomass that might be available from intermediate thinning of even-aged stands is considered qualifying fuel under any of the contracts.

10. Riparian areas – Timber harvest in riparian areas is limited, but not precluded on both private and public lands. A state-wide map of riparian buffer areas was not available, and we believe that the LEMMA inventory data are not specific enough to distinguish between riparian and upland areas. As a result, we did not adjust the potential biomass inventory for impacts of riparian management regulations.

    Estimating the impact is difficult as the acreage in riparian areas varies by ownership and region. On past projects, we observed that riparian acres on private land in California average about 15% of the forest land base. If harvest were completely precluded from riparian areas and if biomass were evenly distributed between upland and riparian areas, an adjustment to eliminate biomass from riparian areas could be on the order of 15%.

11. Biomass from dead trees – Large trees harvested within a year or two of death have value as sawtimber. After that, the economic value declines rapidly due to checking, staining and insect

damage[55]. These lower valued trees have biomass value, but like green biomass, the dead biomass typically must be packaged with live sawtimber to help create an economically viable timber sale. Our interviews with loggers and land managers indicated that within three to five years, dead trees begin to fall and deteriorate rapidly. They noted that felling and skidding dead trees becomes problematical as the standing dead trees become more likely to break into pieces. Once down, dead trees no longer can be considered biomass fuel.

To estimate the potential biomass from dead trees, we reduced the volume of sawtimber-sized dead trees by 75% and entirely removed pole-sized and sapling trees.

12. Breakage and defect – During a timber harvest operation, there is typically some breakage that makes some logs unsuitable for sawtimber. In addition, some trees will have defect that makes the log unsuitable for manufacturing solid wood products. Finally, the logger may clip off some portion of a tree to manufacture a more valuable sawlog. Breakage and defect typically vary based on species, terrain, logging systems and stand age and is often in the range of 10-25%. The breakage and defect can be and is chipped along with the biomass. On USFS sales, some portion of the broken and defective trees are left behind on the logging site as down woody debris for habitat and sometime erosion control. We did not include breakage and defect volume in our biomass estimate. As a result, our estimates of logging waste biomass may be conservative. To some extent, this offsets the effect of other estimates.

13. USFS Diameter Limits – USFS forest management decisions in the Sierra Nevada Ecosystem Project (SNEP) preclude harvest of trees greater than 30" DBH and require at least 40% residual crown cover. The USFS estimates that as a result of these requirements, trees greater than 24" DBH will not be harvested. On USFS lands, we did not include biomass from trees greater than 24" DBH.

14. Chip van accessibility – Forest roads were originally designed to accommodate log trucks which are more maneuverable than chip vans. Most of the public and private land managers we interviewed noted that some portion of their forest was inaccessible to chip vans, making biomass production more difficult and more expensive (see **Appendix I**). When we asked land managers to estimate how much of their forests were inaccessible to chip vans, none referenced any formal studies, but all provided an estimate. In some cases, they estimated that a substantial portion of the forest was inaccessible.

    Five strategies are available for overcoming the accessibility problem:

    - Focus biomass production on accessible acres. Given a supply of biomass far in excess of required capacity, and with limited resources for planning and managing timber sales, this is

[55] Cluck, D.R., Smith, S.L. 2007. Fall Rates of Snags. Forest Health Protection. USFS. NE-SPR-07-01. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_046037.pdf

the strategy most often used right now.

- Focus biomass production on trees that can be hauled to biomass plants in log form on log trucks. Forests with large mortality salvage programs have tried this with limited success. This strategy requires chipping at the biomass plant or at some kind of intermediate chipping location. Most plants do not have chippers/grinders, relying instead on mobile chippers to come in when needed. At some locations, stockpiling logs until the chipper comes in may be difficult.

- Modify road alignments to make them work for chip vans. We have heard of a few such modifications where there were a limited number of curves that needed to be widened. In some areas, however, the problem is too pervasive to fix, especially given the low value of biomass.

- Haul unchipped biomass to the biomass power plants on a modified log truck, or on a short trailer behind a log truck. We talked to one logger that does this occasionally. The difficulty is that unprocessed biomass is bulky resulting in an under-weight load, which increases haul costs per BDT.

- Forwarding biomass to a nearby, centralized chipping station. In theory, this strategy could overcome any accessibility problem, but it could be costly as the biomass requires extra handling and additional equipment. We estimate that forwarding within a 10-15-mile range would cost between $15-25/BDT – a significant increment to the delivered cost of biomass.

Because we lacked spatial data about accessibility issues, we did not make a reduction to potential biomass for chip van accessibility. Neither did we increase the biomass production costs. As a result, our cost estimates may be understated, perhaps by as much as $5-15/BDT.

15. <u>Steep slopes</u> – On steep slopes, timber is yarded to a landing using a cable yarding system and that typically costs 75 to 90% more than ground skid logging. Given that incremental cost, it is unlikely that anyone would choose to harvest pole-sized and sapling trees for biomass on steep slopes. Since whole trees are brought to the landing, we count the tops of those trees as potential biomass.

16. <u>Partial cutting assumptions</u> – We assume that over the next 20 years, private landowners managing under partial cutting management regimes will remove one third of the volume from their timberland. This is a gross generalization of partial cutting regimes across a broad spectrum of forest conditions. Historic harvest rates on non-industrial forest lands, furthermore, are less than 1% per year (Section 8.1). This assumption may overestimate the volume of biomass available from private lands.

17. Hazardous tree removal and fire breaks – Hazardous trees have been and are being removed along power lines and roads. Forest managers are proactively building fire breaks. This activity reduces the inventory of biomass available and we have not accounted for those depletions in our analysis. While these efforts have required considerable efforts and expense and have had great visibility, they have had little impact on the total biomass on the forests. Section 7.2 describes the scope of some of these efforts more completely.

APPENDIX D: TIMBER HARVEST ROLES AND RESPONSIBILITIES

A timber harvest activity requires work from several different people and several different entities. An understanding of the roles and responsibilities of each entity and the economic relationship between entities helps identify where additional resources, personnel and investments are needed to increase the pace and scale of forest restoration. Understanding the contractual arrangements between entities, furthermore, provides insight into where the economic incentives lie.

In this appendix, we illustrate three different kinds of timber harvest arrangements:

- **Case 1**: A private timberland owner contracts with a forester to prepare, offer and administer a timber harvest. This is typical of work for small private landowners that are in the timber market infrequently.
- **Case 2**: A private timberland owner's employees prepare, offer and administer a timber harvest. This is more typical for larger private timberland owners that have internal staff to conduct the work.
- **Case 3**: A US Forest timber sale. Here the agency staff prepare, offer and administer the timber sale. The timber sale purchaser is responsible for operating the sale.

For each case, we show the work that each entity performs, who they contract with and who pays them. Obviously, there are many variations – some loggers also do the biomass work, some landowners may choose to do the road work, most loggers have some trucks but many also contract out at least part of the trucking, etc. Regardless of the variations, these exhibits illustrate that there are several different entities involved in conducting a timber harvest.

Three biomass-related items should be noted:

- In all examples here, we show that the biomass material itself is given to the biomass contractor for free. Our interviews with the loggers and landowners indicated that this is the more typical case. The biomass is seen as a waste-product with little or no value and the biomass contractor is seen as providing a service by disposing of the waste. Even so, a private landowner may incur the cost of setting up a contract with the biomass contractor transferring title of the biomass.
- The biomass contractor may be a stand-alone company or may be a special crew that works for the sawtimber logger. The biomass removal might be done concurrently with the sawtimber removal, but often the biomass contractor comes in after the sawtimber harvest is complete to process the waste piled by the logging contractor. Of special interest is the fact that the chipping/grinding equipment belongs to the biomass contractor, not the landowner, not the biomass plant.[56] The $500,000 to $1,000,000 investment in this equipment is borne by the biomass contractor. The biomass contractor views the $20-25/BDT for chipping as a significant part of their income.

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[56] We use the term "chipping" to refer to either chipping or grinding.

- Most of the biomass power plants are set up to receive chips, not whole logs. Some of the plants will pile unchipped material and periodically hire a mobile chipper to process the unchipped material.

Case 1: Private landowner contracts with forester to prepare and sell timber

Actor	Role	Cash flows	Notes
Landowner	Decide to harvest timber Engage forester	Receives net cash from Forester contractor	Retains title to logs until delivered to mill
Forester (RPF)	Layout timber sale Road design Permitting (THP) Arrange log price contracts with sawmills Arrange road contract Arrange logging contract Arrange biomass contract Arrange slash disposal contract Arrange site prep contract Arrange reforestation contract Arrange for seedlings, if needed Administer all contracts Invoice sawmill for logs Pay contractors Accounting and reporting to landowner	Contract with landowner	Logs are sold to different mills based on species and size
Road contractor	Road construction Road reconstruction Road maintenance during the operation Road repair after the sale	Paid hourly rate by landowner as work is performed	
Logging contractor	Arrange log hauling contractor Cut, skid and buck logs Load sawlogs on to log truck	Paid by landowner per Mbf as work is performed	
Log hauling contractor	Haul logs to the sawmill	Paid per Mbf by landowner as work is performed	Most loggers have some log trucks
Biomass contractor	Chip biomass and load chip vans Arrange chip van hauling contract	Gets the biomass for free. Paid by the power plant for delivery of biomass	May be employees of the logging contractor. Or might be a separate company. Owns the chipper/grinder.
Chip hauling contractor	Deliver chips to biomass plant	Paid by the biomass contractor as work is performed	Often is employee of biomass contractor. Sometimes a third party.
Slash disposal	Pile and burn logging slash	Paid per acre by the landowner	Often a separate contractor
Site prep contractor	Apply herbicide Brush control	Paid per acre by the landowner	May not be needed for partial cut
Reforestation	Plant seedlings	Paid per tree by the landowner	Not needed for partial cut
Sawmill	Receive sawlogs Make lumber	Pay per Mbf to the landowner	
Biomass plant	Receive chips Make power	Pay per BDT to biomass contractor	Some facilities may receive logs and perform the chipping.

Case 2: Private landowner's employee prepares and sells timber

Actor	Role	Cash flows	Notes
Landowner	Decide to harvest timber Engage forester	Receives cash from sawmill	Retains title to logs until delivered to mill
Forester (RPF)	Layout timber sale Road design Permitting (THP) Arrange log price contracts with sawmills Arrange road contract Arrange logging contract Arrange biomass contract Arrange slash disposal contract Arrange site prep contract Arrange reforestation contract Arrange for seedlings, if needed Administer all contracts Invoice sawmill for logs Pay contractors Accounting and reporting to landowner	Landowner's employee	Logs are sold to different mills based on species and size
Road contractor	Road construction Road reconstruction Road maintenance during the operation Road repair after the sale	Paid hourly rate by landowner as work is performed	May be landowner's employee
Logging contractor	Arrange log hauling contractor Cut, skid and buck logs Load sawlogs on to log truck	Paid by landowner per Mbf as work is performed	
Log hauling contractor	Haul logs to the sawmill	Paid per Mbf by landowner as work is performed	Most loggers have some log trucks
Biomass contractor	Chip biomass and load chip vans Arrange chip van hauling contract	Gets the biomass for free. Paid by the power plant for delivery of biomass	May be employees of the logging contractor. Or might be a separate company. Owns the chipper/grinder
Chip hauling contractor	Deliver chips to biomass plant	Paid by the biomass contractor as work is performed	Often is employee of biomass contractor. Sometimes a third party
Slash disposal	Pile and burn logging slash	Paid per acre by the landowner	Often a separate contractor
Site prep contractor	Apply herbicide Brush control	Paid per acre by the landowner	May not be needed for partial cut
Reforestation	Plant seedlings	Paid per tree by the landowner	Not needed for partial cut
Sawmill	Receive sawlogs Make lumber	Pay per Mbf to the landowner	
Biomass plant	Receive chips Make power	Pay per BDT to biomass contractor	Some facilities may receive logs and perform the chipping.

Case 3: USFS Timber Sale

Actor	Role	Cash flows	Notes
USFS	Decide to prepare timber sale Layout timber sale Prepare tentative silvicultural prescriptions. Road location and design Required surveys for T&E animals and plants; archaeological surveys. Permitting (NEPA) Perform logging feasibility Locate and mark harvest unit boundaries. Mark and cruise timber. Appraise timber. Prepare timber sale contract, prospectus, advertisement and bid. Conduct auction and award contract Administer timber sale or stewardship contract Arrange for post sale slash disposal either by Forest Service or contract if needed. Arrange site prep contract Arrange reforestation contract Arrange for seedlings, if needed Administer all contracts Invoice Purchaser for sawlogs and other forest products Accounting and reporting	Receives stumpage payment from purchaser	Retains title to logs until delivered to mill, scaled and paid for
Timber Sale Purchaser	Arrange log price contracts with sawmills if not a sawmill Arrange road contract Arrange logging contract Arrange biomass contract Pay contractors	Paid by sawmills	Often the timber sale purchaser is a sawmill
Road contractor	Road construction Road reconstruction Road repair after the sale	Paid hourly rate (or by the job) by timber sale purchaser as work is performed and accepted by the Forest Service	May be employee of timber sale purchaser
Logging contractor	Load sawlogs on to log truck Cut, skid and buck logs Load sawlogs on to log truck Road maintenance including blading and dust abatement. Perform other contractual obligations such as slash disposal, erosion control and other work required under the contract.	Paid by timber sale purchaser per Mbf as work is performed	
Log hauling contractor	Haul logs to the sawmill	Paid per Mbf by timber sale purchaser as work is performed	Most loggers have some log trucks
Biomass contractor	Chip biomass and load chip vans Arrange chip van hauling contract	Gets the biomass for free or Purchaser pays nominal amount if federal timber. Paid by the power plant for delivery of biomass	May be employees of the logging contractor. Or might be a separate company. Owns the chipper/grinder
Chip hauling contractor	Deliver chips to biomass plant	Paid by the biomass contractor as work is performed	Often is employee of biomass contractor. Sometimes a third party
Slash disposal contractor	Pile and burn logging slash	Paid per acre by the USFS	Often a separate contractor
Site prep contractor	Apply herbicide Brush control	Paid per acre by the USFS	May not be needed for partial cut
Reforestation contractor	Plant seedlings	Paid per tree by the USFS	Not needed for partial cut
Sawmill	Receive sawlogs Make lumber	Pay per Mbf to the landowner	
Biomass plant	Receive chips Make power	Pay per BDT to biomass contractor	Some facilities may receive logs and perform the chipping.

APPENDIX E: RETURN TO LOG CALCULATIONS

An excerpt from the document below provides more background on the Return to Log Calculation methodology.

The Beck Group, 2015, California Assessment of Wood Business Innovation Opportunities and Markets (CAWBIOM) Phase II Report: Feasibility Assessment of Potential Business Opportunities, completed for The National Forest Foundation, 196 pages

RTL and RTF Analysis – developing pro forma income statements for all of the potential co-located businesses is beyond the scope of this study. However, BECK has completed a high-level Return to Log (RTL) or Return to Fiber (RTF) analysis of each business. RTL and RTF are forest industry terms used to describe the value the products produced from a conversion facility will yield after accounting for the cost of converting the material from its original form into a finished product. RTL refers to processes where the incoming feedstock is logs (or roundwood). RTF refers to processes where the incoming feedstock is wood fiber in the form of chips, sawdust, shavings, etc. Thus, while the analysis does not provide what would typically be seen in a pro forma income statement, it does still give a high-level indication of the economics of each co-located business.

To illustrate, an RTL example for sawmills is calculated by:

1. Estimating the total revenue that can be generated from sawing a log (i.e., the combined value of the lumber, chips, sawdust, shavings and bark all expressed on a $/MBF basis).
2. Subtracting the total cost of converting the log into lumber and byproducts from the total revenue (again expressed on a $/MBF basis).
3. The result is referred to as the RTL Value, the Maximum Allowable Delivered Log Cost, or the "break-even log cost".

In other words, the result of RTL and RTF calculations is the value generated by the log/fiber after accounting for the cost of converting it into a product.

BECK has completed RTL/RTF analyses for seven co-located business technologies. Since the various technologies use different units of measure for the raw materials and finished products, *BECK has converted all units to a dollar per bone dry ton basis*. This allows for a direct comparison of the economics underlying each technology and the identification of the co-located technologies capable of generating the greatest value from the wood raw material.

The analysis has been conducted at a relatively high level using a combination of data from BECK's work on prior projects and data generated as part of this study. As a result, a number of assumptions have been made about the scale (and operating costs) of the various technologies. Therefore, the results should not be viewed as precise cost and revenue estimates. Rather, the focus should be on the relative difference between the values generated by each conversion technology.

Table 4.6 shows the estimated RTF/RTL values and key metrics associated with each technology. A list of the key assumptions associated with each technology is included in the sections following the table. Note that the capital cost estimate for each technology is a rough order of magnitude estimate and is considered an “all inclusive” cost estimate (i.e., includes equipment, installation, engineering, project management, etc.)

As shown, lumber manufacturing is by far the technology that creates the highest value (light green). Then shavings, and post and pole manufacturing are in a second tier group that provides similar RTL/RTF values (light orange). There is a third tier group of technologies that includes briquettes, pellets, and firewood that all create roughly equal value (light blue). However, unlike the other technologies just mentioned, using small diameter roundwood as a feedstock for these businesses is marginal at best when costly small diameter trees are the sole supply source. Finally, fuel chips were by far the conversion technology providing the lowest return (light red).

The table also shows the amount of material each conversion facility was assumed to consume annually and an order of magnitude capital cost estimate for developing such a facility. For all technologies it was assumed that the owner/developer requires a 15 percent return (calculated on the entire capital expense, not just on the owner’s equity). That cost was added to the conversion cost estimate. A more detailed description of the assumptions used in the analysis is provided following the table.

Table 4.6 – Estimated Return to Fiber/Log Values for Seven Technologies

	Lumber	Shavings	Post and Pole	Briquettes	Pellets	Firewood	Fuel Chips
Sales Value f.o.b. plant, ($/BDT)	206	178	195	167	160	95	25
Conversion Cost Inc. dep. and owner return @ 15% ($/BDT)	109	126	144	126	122	60	19
RTL/RTF Value ($/BDT)	**97**	**52**	**51**	**41**	**38**	**35**	**6**
Volume/Year (BDT)	137,000	10,200	5,000	9,900	47,000	9,400	84,000
Cap EX ($ millions)	40	2.5	1.5	2.0	10	0.5	2.0
Volume to be dried (BDT)	68,500	9,200	n/a	9,900	47,00	7,050	n/a
Avg. Incoming MC (%)	50	50	n/a	50	50	50	n/a
Volume to be dried (GT)	137,000	18,400	n/a	19,800	94,000	14,100	n/a
Tons of Water Removed	54,470	8,178	n/a	8,800	41,778	5,288	n/a
BTU needed/pound of water removed	2,300	2,300	n/a	2,300	2,300	2,300	n/a
BTU needed/year (trillions)	250	38	n/a	40	192	24	n/a
Operating Hours per year	8,400	4,000	n/a	6,000	8,400	6,300	n/a
BTU/hour (millions)	29.8	9.4	n/a	6.7	22.8	3.9	n/a

APPENDIX F: OVERVIEW OF LOGGING OPERATIONS

Biomass harvesting systems

Whole tree harvesting methods

In California the predominant method for harvesting biomass is the mechanical whole tree logging. Using this system trees are mechanically felled and piled using a feller-buncher. Whole trees are then skidded to a landing using a grapple skidder. In most cases, biomass is being harvested concurrently with a sawtimber harvest operation covering the same area. In such a case, saw logs are cut out of the whole tree using a processer, and decked at the landing. Tops and limbs from sawtimber trees are placed in a separate biomass pile along with whole trees which were too small to contain a saw log. Biomass material is then fed into a chipper using a loader, and chips are fed directly from the chipper into a chip van for hauling. The hauling of chips can occur concurrently with the loading and hauling of saw logs or may be done following the loading and hauling of saw logs from the units. In cases where sawtimber sized trees are not being removed concurrently with small non-sawtimber trees, the process would be the same with the exception that there would not be a need for a processor.

Using the whole tree method, biomass can be utilized mostly with the same equipment which would be used for a mechanical sawtimber harvest with the addition of a chipper and chip vans. The dis-advantage whole tree method is that it requires large landing sizes to accommodate the related equipment (chipper, loader, processer) and the biomass piles and log decks.

In some contexts, biomass can be hauled in log form using this system and ground off site. This is typically done when larger trees are utilized for biomass rather than sawtimber due to decay or being a non-commercial species. It is also possible for small biomass logs to be created by the processor specialized short log trailers. Under this scenario, the chipping is completed offsite precluding the need for a chipper at the landing.

Figure F-1: feller-buncher operating in a biomass and sawtimber harvest unit.

Cut to length harvesting methods

Biomass harvesting using the cut to length method could be utilized in California but use of this system is uncommon. The cut to length system involves use of a harvester in conjunction with a forwarder. Using this system, a harvester will fell, limb, cut log lengths, and pile material in the unit. The harvester is followed by a forwarder which loads cut logs onto an integrated trailer, and then transports the processed logs to the landing. Logs are then loaded from the landing onto a log truck suitable for transporting small logs. Using this system, biomass material is typically chipped offsite, although onsite chipping is still an option.

The primary advantage of the cut to length system is that yarding distances (distance from cut material to the landing) can be increased over the whole tree method. This can reduce the amount of road and landing construction required to harvest a unit. Landing sizes can also be decreased as there is no need for a processor at the landing. The primary dis-advantage of this system is that it requires purchase of specialized equipment with is not utilized for most sawtimber harvests. If sawtimber is harvested concurrently with biomass the maximum tree size which can be cut with a harvester is smaller than what can be cut with a feller-buncher. An additional dis advantage is that in processing logs in the unit limbs and tops are not brought into the landing and thus not utilized for biomass. In a fuel reduction context this may necessitate additional treatment by mastication or burning.

Conventional Logging Methods

Conventional logging involves hand felling and processing trees into logs, and thin skidding the logs into a landing to be loaded onto trucks. Using this method, the only required equipment is a log skidder and loader.

This method has the advantage of smaller landing sizes and relatively low move in and out costs. The disadvantage is that on larger units, costs are generally higher, and it is far less economically feasible to remove smaller diameter material. In the biomass context, this method is typically reserved for removal of larger trees which would otherwise be utilized for sawtimber but are unsuitable due to decay or species.

Other logging systems

Both mechanical and cut to length systems are ground based, and their use is dependent on slopes which are not excessively steep. On steeper slopes cable logging can be utilized. This involves hand or mechanical felling of trees, and then transporting cut material to the landing via a cable run along the extent of the unit. Traditionally this system is used for sawtimber harvest on steep slopes, and logs are processed in the unit resulting in the biomass component, (tops, limbs, and small trees) being left in the unit. It is possible to yard such material to the landing using the cable method, but this is seldom done due to the higher yarding cost associated with this system.

The primary advantage of this system is that it allows for operations on steeper slopes. It is also in stands with high tree morality as the machines offer some protection to the workers. The primary dis advantage is the cost, which is typically two times that of ground-based systems.

Limitations of logging systems

Ground based system are typically used on slopes less than 40% with some exceptions in situations where cable logging is not feasible. The ground-based system requires soils within the unit to be in a generally dry condition and is therefore seldom used during wet times of the year. The system requires a road network of enough density so that yarding distances generally do not exceed 2,000 feet, and of a configuration that material is yarded downhill to the landing in order to operate efficiently. Density of harvested material also plays a role in harvest efficiency in that if harvest volume per acre is two low, yarding costs increase. In general, when forest product volume falls below 1 load per acre (4mbf of sawlogs or 13bdt of chips) harvest efficiency begins to diminish rapidly. Cable logging does not have the slope restrictions of ground-based logging and can occur in the winter months if surfaced roads are available for hauling. The primary constraint with the use of cable logging is the cost, as it is difficult to for small diameter material to pay its way out of a cable unit. Cable logging costs are also more sensitive to low volumes per acre when compared to ground-based systems due to setup times. Throughout most of California, the past harvest entry's even on steep ground were ground based operations. Because cable logging requires material be yarded uphill rather than downhill, it often requires new road construction as much of the steeper ground that is cable logged today was ground based logged in the past with existing roads at the bottom of the unit.

Biomass Hauling

Onsite chipping vs offsite chipping

The biomass hauling options are driven by if material is chipped onsite or offsite. Onsite chipping is the most common scenario in California utilizing chip vans to transport material. Advantages of this system are:

1) A product is generated which does not require additional processing at the biomass plant.
2) Transport of woody material which would otherwise be too small to process into log form such as limbs can be utilized.

The primary disadvantages are:

1) Loading and unloading times are generally longer compared to transporting logs.
2) It is often not feasible to get chip vans up to the maximum haulable weight due to volume limitations trailers.
3) Conventional chip vans do not have articulated steering and therefore cannot operate on some roads with tight turns.
4) Chippers and grinders maybe underutilized during transport, set up, etc.

Conversely, operations utilizing offsite chipping and hauling material in log form can get up to the legal weight, traverse most roads, and be loaded and unloaded quickly. The disadvantages are less utilization of very small material and the need for biomass facilities to have the capacity for chipping.

Figure F-2: example of an onsite chipping operation

Road network factors effecting biomass transport

Road design

The forest road network in California in most areas was developed to facilitate hauling of forest products in log form on articulated trailers and therefore contain curves which cannot be cleared with a standard-length tractor trailer. This is particularly prominent in the Sierra and Cost ranges were topography is steep and bisected by canyons, and less of a factor in the Cascade region where topography is comparatively gentle. In such cases shorter than standard chip vans must be utilized which increases haul costs. The problem of road curvature is not unique to lower grade forest roads, it is also often found on surfaced county roads and state highways in mountainous regions.

Road surfacing

Road surfacing effects the ability to haul biomass in the following areas:

1) Travel speed – paved roads generally support higher travel speeds and relates to haul times and costs
2) Seasonality of use – paved or rocked roads can be used year-round verses dirt roads which can only be used in the dry season.

3) Maximum adverse gradient of haul – Dirt or rocked roads will not support hauling on as steep of a gradient as paved roads.

Other factors

In some rural areas of California, it is common to encounter bridges which cannot support the maximum weight of a tractor trailer. Occasionally road surfacing can work against forest product hauling where surfacing was not completed to a high enough construction standard to support a standard loaded tractor trailer. This condition mostly occurs in wildland/urban interface areas of the state where small private landowners funded road surfacing on shared private roads.

APPENDIX G: USFS TIMBER SALE PROGRAM

The majority of USFS timber is sold under three kinds of contracts.

- The standard timber sale contract (sometimes called a "regular sale" (contract forms 2400-6, 2400-3, and 2400-2) is a sale of a commercial products. The contract is awarded to the highest bidder, or in a direct sale if there is determined to be no competition. Under a standard timber sale contract, the agency can offer the biomass as a product, and the purchaser must pay for the product, usually at minimum rates ($0.10/ton).

- An Integrated Resource Timber Contract (IRTC) is a stewardship contract that allows the agency to trade some of the value of the commercial timber value for services. Those services may include cutting and yarding of the biomass. Removal of the biomass can be required, or it can be optional "Timber Subject to Agreement". In that case, utilization specifications and rates are set in the contract prior to bid. Both parties must agree to include the "Timber Subject to Agreement" product.

- An Integrated Resource Services Contract is a stewardship contract used where the cost of the services required exceeds the commercial value of the timber available for harvest. Removal of the biomass under this contract can be required as that is the service being contracted.

APPENDIX H: BIOMASS FINANCIAL MODEL

Here we describe the financial model developed to illustrate the economics of biomass fuel production and compare it to the economics of saw timber production. We begin by describing the model and the assumptions used. This is followed by results for several scenarios and conclusions drawn from the analysis.

H.1 Model Description

The Biomass Financial Model (BFM) illustrates the economics of harvesting a single acre of forest land. It assumes two main products, lumber and forest biomass-derived power. For each product we estimate the quantity and value of end-product (lumber and power) that can be produced from a single acre of forest land within the HHZ. We show the various conversion steps involved, as well as the outputs and economics associated with each step. The purpose of the model is to compare the economics of lumber production with that of forest-based biomass power.

The output from the BFM is shown in Figure H-1. The model is divided into two main columns, sawtimber (blue heading) and biomass (orange heading). The sawtimber column shows all the inputs and outputs associated with converting sawlogs into lumber for a single acre of forest land. Conversely, the biomass column shows all the inputs and outputs associated with converting forest biomass from a single acres into power.

Figure H-1 also contains a series of rows (green heading) showing the various steps in the conversion process. The steps are arranged as follows:

- **Resource in the Woods:** Shows the volume of timber and biomass that can be obtained from an acre of forest land. The volume is shown in hundreds of cubic feet (CCF) and thousands of board feet (MBF in log scale) for timber, and green tons (GT) and bone-dry tons (BDT) for biomass. The timber side also includes the mill residuals that are produced when converting logs into lumber, in BDT/MBF (log scale). This row represents the input of raw products into the conversion process.

- **End Product:** Shows the amount and value of end product (lumber and biomass power) that can be obtained from a single acre of forest land, using the volume of timber and biomass from the Resource in the Woods row. For sawtimber we show the volume of lumber in thousands of board feet (MBF lumber tally), the average lumber price in $/MBF, and the average mill residuals price in $/BDT. We calculate the value of lumber and mill residuals per acre. Similarly, we show the amount of power that could be generated in megawatt-hours (MWH), and the assumed price obtained by the power plant in $/MWH. We calculate the value of biomass power per acre. These values represent the gross revenue obtained by the lumber and power producers. The rows that follow illustrate the cost of each conversion step, and we use these to calculate the net revenue for each product on a per acre basis.

- **Conversion to Products:** Shows the manufacturing cost associated with each product. For sawtimber we show the cost of sawmilling in $/MBF (lumber tally), as well as a profit and risk margin. By multiplying these numbers with the volume of End Product we obtain the cost of converting saw logs into lumber. Similarly, for biomass we show the cost of power generation in $/MWH, as well as a profit and risk margin. By multiplying these numbers, we obtain the cost of converting biomass into power.

- **Delivered Log Value:** Shows the value of the delivered raw product (saw logs and biomass) at the respective conversion facilities (sawmill and power plant). It is obtained by subtracting the conversion cost (Conversion to Products) from the gross revenue (End Product). For sawtimber we show the total value on a per acre basis, as well as $/MBF (log scale). For biomass we show the total value per acre, as well as $/BDT. These values represent the gross revenue that could be obtained by a logger delivering saw logs or biomass at the respective facilities.

- **Delivery Cost:** Shows the cost of hauling the raw product (saw logs and biomass) from the forest to the respective conversion facilities (sawmill and power plant). For both sawtimber and biomass we show the key inputs into the delivery cost, miles to the facility, hourly cost of transport ($/Hour) and duration of haul in hours. All of this is combined to calculate the total delivery cost per acre, as well as $/MBF for sawtimber and $/BDT for biomass.

- **Extraction Cost:** Shows the cost of extracting the harvested trees to a centralized location where they can be accessed by log trucks and chip vans. The calculation steps for this cost is different for sawtimber vs. biomass. For sawtimber this cost includes cutting the standing trees, moving them from the stump to the landing (skid), and loading them onto a log truck. These three steps are expressed in a single harvesting cost ($/MBF). In addition, the sawtimber extraction cost also accounts for the cost of administering the timber sale and road construction to allow for log truck access. Both are expressed in $/MBF.

  Biomass is extracted to the landing in the form of tree tops originating from harvested saw log trees, and small or dead whole trees that cannot be sold as saw logs, and breakage. The tree tops and breakage do not incur a skidding cost, since they are brought to the road side along with the sawlog trees. The small or dead trees are extracted separately, and therefore incur an extraction cost. These two costs are accounted for separately in the model. All biomass (tree tops, small or dead tress) is chipped and loaded into chip vans, and the model uses single cost to account for this step.

  All of these costs are combined to derive a cost of extraction per acre for sawtimber and biomass respectively.

- **Net Stumpage Value:** Shows the net value of harvested trees and biomass. This is expressed in terms of total value per acre, as well as $/MBF for sawtimber and $/BDT for biomass. These values represent the value returned to the landowner resulting from the sale of trees and biomass. It does not account for other costs associated with landownership, such as land preparation, tree establishment, silvicultural treatments, general road maintenance, and administration.

In order to facilitate the use of the model results we provide the following formulas to show the relationship between inputs, outputs and conversion steps:

$$End\ Product = Resource\ in\ the\ Woods \times Conversion\ Ratio$$
$$Delivered\ Log\ Value = End\ Product - Conversion\ to\ Products$$
$$Net\ Stumpage\ Value = Delivered\ Log\ Value - DeliverCost - Extraction\ Cost$$

H.2 Model Results

H.2.1 USFS Base Scenario

The first scenario compares the economics of selling sawtimber vs. biomass from a US Forest Service (USFS) timber sale within the HHZ. The inputs and outputs in this scenario therefore assume the administrative rules and costs associated with a timber sale from USFS land. The results are shown in Figure H-1.

In terms of **Resource in the Woods** we assumed that such a sale would yield 5 MBF/Acre [57](10 CCF/Acre) of logs, and 13 BDT/Acre [58](25 GT/Acre) of biomass. We also assumed a mill residual yield of 0.85 BDT/MBF.

In terms of **End Product,** the sawtimber and biomass from this acre can be converted to 10 MBF (lumber tally) of lumber, and 13 MWH of power. This assumes a conversion ratio of 1.90 MBF (lumber tally)/MBF (log scale)[59] for the sawtimber, and 1.00 MWH/BDT [60]for the power. These outputs would result in $3,928/Acre of revenue from sawtimber, and $1,113/Acre from power. This assumes a lumber price of $400/MBF [61], a mill residual price of $30/BDT, and power price of $89/MWH[62]. In this case the sawtimber accounted for 78% of the End Product value.

The **Conversion to Products** section shows that the cost of converting the sawtimber to lumber and biomass to power is $1,515/Acre and $619/Acre respectively. This assumes a lumber production cost of

[57] Personal communication with the USFS suggested a value between 3 and 5 MBF/Acre.
[58] Our interviews suggest that an acre of land typically yields about 12.5 BDT/Acre (one chip van load)
[59] 1.90 MBF (lumber tally)/MBF (log scale) sourced through personal communication with the Beck Group
[60] Standard conversion of bone-dry biomass to power
[61] Lumber prices have seen large fluctuations over the last few years (2017/18). We elected to exclude these fluctuations from the analysis and used a lumber price that is more consistent with long-term trends.
[62] Power prices are not publicly available. We used the “Opt-Out” price under BioRAM 1 for this analysis.

$145/MBF [63](lumber tally), power production cost of $45/MWH[64], and 10% profit and risk. This shows that the production cost for lumber is about 39% of the gross revenue, and for power it is about 56%.

This results in a **Delivered Log Value** of $2,412/Acre for sawtimber and $494/Acre for biomass. These values correspond to $482/MBF for sawtimber, and $40/BDT for biomass. These prices reflect the revenue that a logger would hope to gain by delivering sawtimber and biomass to these facilities. Sawtimber represents 83% of the total value to the logger, while biomass represents 17%. This is driven in part by the fact that there is more sawtimber per acre than biomass. It is also driven by the fact that the conversion cost of biomass is substantially more than that of sawtimber (on a per unit basis), resulting in a lower delivered value to the timber sale purchaser.

The **Delivery Cost** of sawtimber was $333/Acre vs. $300/Acre for biomass. This is based on a haul distance of 50 miles[65], haul cost of $88/Hour[66], and haul time of 3.4 hours[67]. The delivery cost of biomass was 61% of the delivered value, vs. 14% for sawtimber. This is primarily driven by the fact that the delivered value for biomass is low relative to sawtimber, since the delivery cost assumptions for sawtimber and biomass were almost the same.

The **Extraction Cost** for sawtimber was $1,235/Acre, assuming a cut, skid, and load cost of $163/MBF[68], administration cost of $72/MBF[69], and road construction cost of $12/MBF[70]. For biomass the extraction cost was $406/Acre, assuming no cost for cutting and skidding tree tops, $13/BDT[71] for cutting and skidding small/dead trees, and $20/BDT[72] for chipping. In comparison, the biomass extraction cost was 82% of the delivered value, vs. 51% for sawtimber. This is driven largely by the low value of biomass, but also by the fact that it is more expensive to harvest and extract smaller piece sizes such as biomass.

The **Net Stumpage Value** for sawtimber was $844/Acre for sawtimber, and $-212/Acre for biomass. These values correspond to $169/MBF for sawtimber, and $-17/BDT for biomass. Under these

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[63] Sourced through personal communication with the Beck Group

[64] Sourced through personal communication with the Beck Group

[65] Sawtimber and biomass is typically distributed over a wide geographic area around the conversion facilities. Picking a haul distance of 50 miles is therefore somewhat arbitrary, but it is considered a marginal distance by many loggers and buyers that we interviewed.

[66] We used the USFS HaulCost application to derive a haul rate, as well as interviews with loggers.

[67] Haul time was estimated with USFS HaulCost application, assuming 1 mile of dirt road, 9 miles of gravel road, 10 miles of paved road, and 30 miles of highway/interstate. Loading and unloading was estimated at 65 minutes per trip. Log truck capacity was assumed to be 4.5 MBF, and 12.5 BDT for biomass chip van.

[68] For the sawtimber harvest cost we developed a regression equation based on observed costs. The regression predicted the harvesting cost on the available sawtimber volume.

[69] Based on a sample of administration and overhead costs published in USFS sale appraisals.

[70] Based on a sample of administration and overhead costs published in USFS sale appraisals.

[71] This harvest cost was prorated by the amount of biomass volume that was classified as small/dead. We used a base harvest rate of $25/BDT, which was based on a literature review of similar work. Our own inventory analysis showed that about 50% of the biomass volume is in the form of small/dead trees. By prorating the $25/BDT by 50% we obtained $13/BDT.

[72] Based on USGS LogCost application and interviews with local loggers.

assumptions a profit-incented landowner would have no economic incentive to pursue a biomass market, since a loss would be incurred. There is an economic incentive to pursue sawtimber, since it results in positive cashflows.

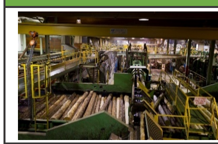
Sawtimber			Biomass
Resource in the Woods 			
Volume of Timber per Acre			Volume of Biomass per Acre
Cubic Foot (CCF/Acre)	10	25	Green Tons (GT/Acre)
Brd Ft (MBF/Acre (Log Scale [LS])	5	13	Bone Dry Tons (BDT/Acre)
Mill Residuals (BDT/MBF [LS])	0.85		
End Product 			
MBF (Lumber Tally [LT])	10	13	Power (Megawatt Hrs [MWH])
Lumber Price $/MBF (LT)	400	89	Power Price ($/MWH)
Mill Residuals Price ($/BDT)	30		
Lumber & Chip Value	$ 3,928	$ 1,113	Power Value
Conversion to Products 			
Lumber Production ($/MBF [LT])	145	45	Power Production ($/MWH)
Profit and Risk	10%	10%	Proft and Risk
Total Costs	$ 1,515	$ 619	Total Costs
Delivered Log Value 			
$/Mbf (LS)	482	40	$/BDT
Total Dollars	$ 2,412	$ 494	Total Dollars
Delivery Costs 			
Miles to Saw Mill	50	50	Miles to Power Plant
Haul Rate ($/Hr)	88	88	Haul Rate ($/Hr)
Haul Time (Round Trip Hrs)	3.4	3.4	Haul Time (Round Trip Hrs)
Transport Cost ($/MBF)	67	24	Transport Cost ($/BDT)
Total Delivery Cost	$ 333	$ 300	Total Delivery Cost
Extraction Costs 			
Cut, Skid & Load ($/MBF)	163	-	Cut & Skid Tree Tops ($/BDT)
Sale Administration ($/MBF)	72	13	Cut & Skid Small Trees ($/BDT)
Road Construction ($/MBF)	12	20	Chipping & Loading ($/BDT)
Total Extraction Cost	$ 1,235	$ 406	Total Extraction Cost
Net Stumpage Value 			
Sawtimber ($/Acre)	$ 844	$ (212)	Biomass ($/Acre)
$/MBF	$ 169	$ (17)	$/BDT

Figure H-1: Biomass Financial Model – USFS Base Scenario

H.2.2 Sensitivity Analysis: Increased Power Prices

In the following two sections we conduct sensitivity analyses on two influential model parameters: power price and haul distance. We do this by finding the power price that results in a breakeven return for biomass, first by assuming the existing parameters, and second by increasing haul distance. With this analysis we show the importance of power price and haul distance, and the sensitivity of the economics to these parameters. We are not suggesting that these prices or distances should be used to drive policy. A more rigorous analysis would be required that goes beyond the single example sale we analyze here.

One solution to improving the economic viability of biomass is to increase the price of power. Here we calculate the power price required to reach a breakeven point on a $/acre basis for biomass. Given the example sale described above, a power price of $106/MWH is required for the biomass fuel to breakeven on an acre basis, as shown in Figure H-2. These results are specific to this example.

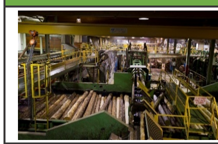
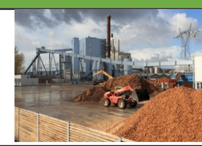
Sawtimber			Biomass		
Resource in the Woods					
	Volume of Timber per Acre			Volume of Biomass per Acre	
	Cubic Foot (CCF/Acre)	10	25	Green Tons (GT/Acre)	
	Brd Ft (MBF/Acre (Log Scale [LS])	5	13	Bone Dry Tons (BDT/Acre)	
	Mill Residuals (BDT/MBF [LS])	0.85			
End Product					
	MBF (Lumber Tally [LT])	10	13	Power (Megawatt Hrs [MWH])	
	Lumber Price $/MBF (LT)	400	106	Power Price ($/MWH)	
	Mill Residuals Price ($/BDT)	30			
	Lumber & Chip Value	$ 3,928	$ 1,325	**Power Value**	
Conversion to Products					
	Lumber Production ($/MBF [LT])	145	45	Power Production ($/MWH)	
	Profit and Risk	10%	10%	Proft and Risk	
	Total Costs	$ 1,515	$ 619	**Total Costs**	
Delivered Log Value					
	$/Mbf (LS)	482	56	$/BDT	
	Total Dollars	$ 2,412	$ 706	**Total Dollars**	
Delivery Costs					
	Miles to Saw Mill	50	50	Miles to Power Plant	
	Haul Rate ($/Hr)	88	88	Haul Rate ($/Hr)	
	Haul Time (Round Trip Hrs)	3.4	3.4	Haul Time (Round Trip Hrs)	
	Transport Cost ($/MBF)	67	24	Transport Cost ($/BDT)	
	Total Delivery Cost	$ 333	$ 300	**Total Delivery Cost**	
Extraction Costs					
	Cut, Skid & Load ($/MBF)	163	-	Cut & Skid Tree Tops ($/BDT)	
	Sale Administration ($/MBF)	72	13	Cut & Skid Small Trees ($/BDT)	
	Road Construction ($/MBF)	12	20	Chipping & Loading ($/BDT)	
	Total Extraction Cost	$ 1,235	$ 406	**Total Extraction Cost**	
Net Stumpage Value					
	**Sawtimber ($/Acre)**	$ 844	$ 0	**Biomass ($/Acre)**	
	$/MBF	$ 169	$ 0	**$/BDT**	

Figure H-2: Biomass Financial Model – Increased Power Price

H.2.3 Sensitivity Analysis: Increased Haul Distance

In the base scenario we assumed a haul distance of 50 miles, an economic threshold distance widely accepted within the industry. Much of the available biomass is between 50 to 100 miles from the closest power plant. This scenario uses the same power price as above ($106/MWH), but increases the haul distance to 75 miles. This resulted in a travel time of 4.5 hours, resulting in a biomass return of

$-95/Acre for this example sale. A power price of $114/MWH is needed to get back to breakeven. These results are shown in Figure H-3. Again, these results are specific to this example.

The Biomass Financial Model can be used to understand how any factor affects the economic viability of biomass fuel production within the context of commercial timber sales and forest restoration treatments.

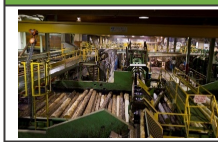
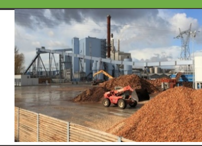
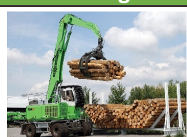
	Sawtimber		Biomass		
Resource in the Woods					
	Volume of Timber per Acre			Volume of Biomass per Acre	
	Cubic Foot (CCF/Acre)	10	25	Green Tons (GT/Acre)	
	Brd Ft (MBF/Acre (Log Scale [LS])	5	13	Bone Dry Tons (BDT/Acre)	
	Mill Residuals (BDT/MBF [LS])	0.85			
End Product					
	MBF (Lumber Tally [LT])	10	13	Power (Megawatt Hrs [MWH])	
	Lumber Price $/MBF (LT)	400	114	Power Price ($/MWH)	
	Mill Residuals Price ($/BDT)	30			
	Lumber & Chip Value	$ 3,928	$ 1,420	**Power Value**	
Conversion to Products					
	Lumber Production ($/MBF [LT])	145	45	Power Production ($/MWH)	
	Profit and Risk	10%	10%	Proft and Risk	
	Total Costs	$ 1,515	$ 619	**Total Costs**	
Delivered Log Value					
	$/Mbf (LS)	482	64	$/BDT	
	Total Dollars	$ 2,412	$ 801	**Total Dollars**	
Delivery Costs					
	Miles to Saw Mill	75	75	Miles to Power Plant	
	Haul Rate ($/Hr)	88	88	Haul Rate ($/Hr)	
	Haul Time (Round Trip Hrs)	4.5	4.5	Haul Time (Round Trip Hrs)	
	Transport Cost ($/MBF)	88	32	Transport Cost ($/BDT)	
	Total Delivery Cost	$ 439	$ 395	**Total Delivery Cost**	
Extraction Costs					
	Cut, Skid & Load ($/MBF)	163	-	Cut & Skid Tree Tops ($/BDT)	
	Sale Administration ($/MBF)	72	13	Cut & Skid Small Trees ($/BDT)	
	Road Construction ($/MBF)	12	20	Chipping & Loading ($/BDT)	
	Total Extraction Cost	$ 1,235	$ 406	**Total Extraction Cost**	
Net Stumpage Value					
	**Sawtimber ($/Acre)**	$ 738	$ -	**Biomass ($/Acre)**	
	$/MBF	$ 148	$ -	**$/BDT**	

Figure H-3. Biomass Financial Model – Increased Haul Distance

APPENDIX I: CHIP VAN ACCESSIBILITY

During our interview of land managers, many noted that one problem affecting using biomass to facilitate forest restoration is that some acres are currently inaccessible to chip vans. We asked land managers to estimate how much of their forest was inaccessible to chip vans and received the answers below. It was clear, however, that these were on-the-spot estimates. We understand that site-specific analysis has been done in some locations, but as of yet, there has not been a comprehensive analysis. Given the potential scope of the issue, it merits further study.

National Forest	% timberland inaccessible to Chip Vans
Eldorado	50%
Klamath NF	75%
Lassen NF	25%
Mendocino NF	50%
Modoc NF	10%
Plumas NF	50%
Sequoia NF	75%
Sierra NF	30%
Six Rivers NF	75%
Stanislaus NF	20%
Tahoe NF	67%
Private Forest	
Sierras	10%
Sierras	15%
Coast	30%
North CA	35%
North CA	25%

Legacy forest roads were built to facilitate log hauling on log trucks. Chip vans have a larger turning radius and cannot make it around some corners. An empty chip van, furthermore, has less traction on the drive axles which may create some additional problems.

Five strategies are available for overcoming the accessibility problem:

1. Focus biomass production on accessible acres. Given a supply of biomass far in excess of required capacity, and with limited resources for planning and managing timber sales, this is the strategy most often used right now.

2. Focus biomass production on trees that can be hauled to biomass plants in log form on log trucks. Forests with large mortality salvage programs have tried this with limited success. This strategy requires chipping at the biomass plant or at some kind of intermediate chipping location. Most plants do not have chippers/grinders, relying instead on mobile chippers to come in when needed. At some locations, stockpiling logs until the chipper comes in may be difficult.

3. Modify road alignments to make them work for chip vans. We have heard of a few such modifications where there were a limited number of curves that needed to be widened. In some areas, however, the problem is too pervasive to fix, especially given the low value of biomass.

4. Haul unchipped biomass to the biomass power plants on a modified log truck, or on a short trailer behind a log truck. We talked to one logger that does this occasionally. The difficulty is that unprocessed biomass is bulky resulting in an under-weight load, which increases haul costs per BDT.

5. Forwarding biomass to a nearby, centralized chipping station. In theory, this strategy could overcome any accessibility problem, but it could be costly as the biomass requires extra handling and additional equipment. We estimate that forwarding within a 10-15-mile range would cost between $15-25/BDT – a significant increment to the delivered cost of biomass.

APPENDIX J: SUMMARY OF MORTALITY ADJUSTMENTS

Table J.1 Relative fraction of dead versus live trees, in units of tons, for each California National Forest, comparing HHZ to Non-HHZ. Forests are ordered roughly north to south; non-USFS lands presented at the bottom of this table. National Forests particularly affected by the mortality events (Sierra, Inyo) show elevated dead tree percentages in HHZ relative to Non-HHZ areas in the same forests. National Forests in the Sierra Nevada show higher overall mortality in both HHZ and Non-HHZ land designations.

National Forest	Area (acres)		HHZ				Non-HHZ			
			Dead Tree		Live Tree		Dead Tree		Live Tree	
	HHZ	Non-HHZ	Tons	% Tot.	Tons	% Tot.	Tons	% Tot.	Tons	% Tot.
Siskiyou	92	36,043	2,126	15%	12,527	85%	350,458	8%	3,909,244	92%
Rogue River	17,496	39,874	401,099	15%	2,288,364	85%	686,906	15%	3,938,301	85%
Klamath	880,609	664,982	5,947,305	7%	75,633,221	93%	5,253,499	8%	63,914,584	92%
Six Rivers	290,550	626,940	2,607,814	6%	39,326,438	94%	5,235,713	7%	73,410,217	93%
Shasta-Trinity	1,135,766	793,180	6,988,682	6%	103,619,374	94%	4,072,926	5%	70,091,323	95%
Mendocino	327,431	418,153	1,519,845	5%	26,499,005	95%	1,822,631	5%	32,379,199	95%
Modoc	544,745	370,738	2,763,876	11%	22,866,091	89%	713,794	7%	9,887,915	93%
Lassen	859,315	193,979	4,516,729	8%	55,090,313	92%	708,995	6%	10,392,138	94%
Plumas	847,541	287,553	5,475,265	8%	65,157,329	92%	1,242,925	8%	14,619,704	92%
Tahoe	574,791	183,837	3,749,313	8%	44,983,317	92%	1,034,413	8%	11,678,522	92%
Lake Tahoe Basin Unit	82,667	14,124	706,135	11%	6,011,384	89%	195,875	14%	1,209,147	86%
Eldorado	390,922	120,900	3,631,471	10%	33,075,282	90%	1,087,274	10%	10,306,422	90%
Stanislaus	607,415	146,505	7,789,105	14%	46,737,462	86%	1,053,037	11%	8,441,073	89%
Sierra	887,539	160,313	21,743,576	29%	53,873,819	71%	2,912,666	24%	9,059,766	76%
Sequoia	609,125	280,487	11,148,393	29%	27,366,619	71%	4,562,051	27%	12,459,600	73%
Toiyabe	117,434	334,849	451,843	9%	4,709,401	91%	1,306,950	9%	13,736,822	91%
Inyo	349,648	556,865	1,379,295	11%	11,392,708	89%	1,501,437	8%	16,440,684	92%
Los Padres	367,232	752,190	936,566	9%	9,786,707	91%	1,836,761	7%	24,818,468	93%
Angeles	73,550	200,711	197,440	8%	2,379,261	92%	501,618	9%	5,125,700	91%
San Bernardino	161,477	256,460	574,747	8%	6,310,736	92%	758,468	8%	8,611,422	92%
Cleveland	26,599	55,316	55,191	7%	748,300	93%	104,946	6%	1,760,047	94%
Not USFS	7,536,125	13,868,071	40,081,326	8%	444,017,768	92%	44,656,303	5%	858,650,055	95%
NF Non-admin	5,930	141	17,959	7%	255,447	93%	80	2%	4,546	98%
Total or Avg%:	**16,693,997**	**20,362,213**	**122,685,099**	**14%**	**1,082,140,874**	**90%**	**81,599,727**	**8%**	**1,264,844,899**	**94%**

Table J.2. Count of dead trees by owner and HHZ versus Non-HHZ, inventory assessed at the end of 2017. HHZ lands (Tier 1, Tier 2, and areas of overlap where the inventory GIS encompasses both Tiers) typically show higher percentages of dead trees than Non-HHZ lands. Mortality has affected public lands (State, Federal) to a greater extent than private lands. Note the total count of dead trees, at 122 million, comes in slightly under the 129 million count of trees that have died between 2010 and 2017. The value presented here counts standing dead trees. The disparity occurs for at least two reasons: (1) some of the dead trees will have fallen over by the 2017 inventory point; (2) the level of uncertainty around each estimate is undefined.

Owner	HHZ	Acres	Mbf/ acre	Dead Trees	2017 CA inventory CuFt: after mortality event			
					Live	Dead	Live%	Dead%
Local	Tier 1	490	17.1	3,460	2,038,095	73,256	96.5%	3.5%
	Tier 2	27,631	3.5	2,740	32,566,546	218,289	99.3%	0.7%
	T1-T2 Overlap	113	10.6	683	296,053	15,954	94.9%	5.1%
	Non-HHZ	136,936	20.4	25,387	614,479,463	20,243,727	96.8%	3.2%
State	Tier 1	1,037	31.8	2,398	6,481,565	363,711	94.7%	5.3%
	Tier 2	99,910	16.7	415,933	363,429,997	23,735,411	93.9%	6.1%
	T1-T2 Overlap	11,270	24.9	163,724	53,301,627	6,506,882	89.1%	10.9%
	Non-HHZ	625,226	28.0	137,990	3,382,672,860	177,308,435	95.0%	5.0%
Federal	Tier 1	51,701	20.0	985,575	200,650,345	31,135,540	86.6%	13.4%
	Tier 2	10,016,449	19.2	69,494,354	39,919,096,699	3,126,221,903	92.7%	7.3%
	T1-T2 Overlap	346,609	22.5	7,753,140	1,472,257,473	243,197,380	85.8%	14.2%
	Non-HHZ	8,998,766	13.7	17,807,451	28,014,258,039	1,123,843,770	96.1%	3.9%
NGO	Tier 1	1	13.3	2	2,271	37	98.4%	1.6%
	Tier 2	2,535	4.7	1,329	4,288,785	68,934	98.4%	1.6%
	T1-T2 Overlap	26	5.9	4	55,225	347	99.4%	0.6%
	Non-HHZ	49,180	5.1	478	82,754,467	966,803	98.8%	1.2%
Private	Tier 1	78,388	13.3	704,347	256,926,305	16,181,459	94.1%	5.9%
	Tier 2	5,576,674	12.0	13,114,266	17,434,830,682	503,253,955	97.2%	2.8%
	T1-T2 Overlap	483,265	15.6	8,349,631	1,634,957,580	204,975,374	88.9%	11.1%
	Non-HHZ	10,552,967	11.7	3,825,661	33,248,869,531	507,858,594	98.5%	1.5%
	Total	37,059,174	14.8	122,788,553	126,724,213,606	5,986,169,760	95.5%	4.5%

APPENDIX K: INTERVIEWS

Our charge was to describe the biomass production process, to identify issues in that process and to offer suggestions to address the issues. To that end, we interviewed the BioRAM plant operators, public and private forest land managers, loggers, government agencies and others involved in the biomass economy.

Our interviews followed a general outline but were conducted as open-ended discussion. We also asked interviewees for any recommendations that they might make and found their suggestions insightful and constructive. We appreciate the time they spent with us in frank discussion.

Org	Person	Organization
BioRAM	Jim Turner	ARP Loyalton
Plants	Kraig Strauch	Burney Forest Power
	Gordon Bauer	Honey Lake Power
	Mark Shaffer	Honey Lake Power
	Rick Carter	Pacific Ultrapower
	Dennis Serpa	Pacific Ultrapower
	Hector Lara	Rio Bravo Fresno
	Scott Pedersen	Rio Bravo Rocklin
	Bryan Booth	Wheelabrator
	Chris Trott	Wheelabrator
	Alan Jacobson	Wheelabrator
USFS Staff	Dan Smith	Eldorado NF
	Ben Haupt	Klamath NF
	Ron Perry	Lassen NF
	Tony Saba	Mendocino NF
	Bill Moore	Modoc NF
	Ryan Tompkins	Plumas NF
	Dan Smith	Sequoia NF
	Mike Price	Sierra NF
	Jeff Jones	Six Rivers NF
	Brain McCrory	Stanislaus NF
	Brad Seaberg	Tahoe NF
	Larry Swan	Regional Office
	Joe Sherlock	Regional Office

Org	Person	Organization
Private	Steve Ziegler	MB&G
Land	Ed Murphy	Sierra Pacific Industries
Managers	John Anderson	Humboldt Redwood
	Rich Klug	Landvest
	Jeff Pudlicki	Beatty
	Ken Cummings	Hancock
	Dee Sanders	Trinity River
	Paul Chapman	Campbell Global
Loggers,	Dee Sanders	Trinity River Lumber
Foresters	Frank Dial	Frank Dial Logging
	Mike Albrecht	Sierra Resource Management
	Chris Trott	CT Bioenergy Consulting
	Joe Griggs Jr.	Robinson Logging
	Zane Peterson	Peterson Timber Service
	Jeff Holland	CTL Logging
Others	Tom Hobby	Mooretown Rancheria
	Debbie Franco	Office of Planning and Research
	Lisa Worthington	CalTrans
	Tim Robards	CalFire
	Matthew Reishman	CalFire
	Jason Thompson	PG&E
	Steve Brink	California Forestry Association
	Eric Carleson	California Loggers Association

Interviewees provided a wide range of data, observations, opinions and recommendations. Below, we include a representative sample of comments to provide an idea about the kind of insights provided by the interviews. As policy makers contemplate new program or approaches, we recommend that they seek similar input about specific proposals.

Comments from interviews:

- For the most part, forest-based biomass is a by-product and/or a waste product of sawtimber harvest and/or forest improvement projects.
- Proclamation directs State to use market to treat forests. Benefit of renewable energy, base load. Safety and health. Many respondents understand the health and safety aspects and are convinced of the external benefits of biomass production.
- This is early in the experiment, so market frictions are most evident – qualifying biomass from Tier 2 HHZ is proving scarce. Subsidy doesn't appear to be enough to increase supply quickly.
- Market participants point to difficulties – power contract is too short, no guarantees, hard to invest. Margins are still too thin to make this an attractive investment for biomass suppliers.
- USFS has much of the qualifying biomass, but management is hampered by budgets, personnel, forest plan land allocations and diameter limits. NEPA is still problematic.
- Efforts to salvage fire-killed timber often override efforts for more prescriptive, preventative management.
- Most of the forest-based biomass is currently provided by harvest on private lands, primarily forest industry lands.
- Mill residuals constitute and an important source to BioRAM mills. These are produced as a result of manufacturing wood products from sawlogs.
- BioRAM plants do not represent new capacity, just redirecting sourcing. This disrupts other sources (ag waste and urban waste) to other plants.
- No evidence yet that the BioRAM contracts have made much of a difference in the pace and scale of forest restoration. Lassen is the exception. Selling about 95,000 green tons/year. This is 45,000 BDT, or about 4% of the BioRAM plant requirements.
- The sustainability requirement (no clearcut volume) takes final harvest on 1 million acres out of the source. The increment from biomass is too small to be a financial incentive to change management approach.
- Reporting requirements for qualifying fuel adds an accounting burden at the mill. Margins on mill residuals are already thin. Given that qualifying and non-qualifying wood is mixed in the log decks, any precise accounting is impossible.
- Differences in contract prices means some plants are at a disadvantage. Creates more friction in biomass markets.
- No strategic coordination of forest restoration is evident, other than delineating HHZs. And that's half the forest. No emphasis on preventative measures on other forests.

- HHZ designation does not drive management on most private land.
- The Farm Bill offers Categorical Exclusion (streamlined NEPA process) on specific types of acres. Some of those acres line up with the HHZs, but others don't. This creates confusion and/or lost opportunities.
- USFS diameter limits will mean that on the next entry there will be no sawtimber removal to help finance biomass removal.
- Current harvest levels are substantially less than in the past. Capacity to increase production is limited and will require new manufacturing capacity. Barriers to investment in California are high, however. Lots of Canadian and European investment in new mill capacity in US South. Not much in the West. None in California.
- Lack of chipping at mill facilities at the BioRAM plants is a problem. The bug-killed wood can be moved on log trucks, more efficient than chip vans – gets everywhere. But one of the logical BioRAM plants will not accept logs.
- Other agreements MSA, GNA, are being explored, mostly by local governments and NGOs. CalFire does not have forest management capacity like other state forest management agencies.
- Large log sized biomass material is a recent thing. Biomass industry grew up chipping smaller wood. New problems require new approaches.
- Cost of treatment without biomass removal $400-$1200/acre. @ $500/acre, treating half the HHZ would cost $3 billion.
- Tahoe NF is experimenting with selling decks directly to BioRAM plants. They can then perform what log buyers don't want to do.
- USFS timber sales with mandatory biomass removal do not sell. Purchasers prefer regular timber sales that gives them the option of removing or leaving behind the biomass material.
- Should encourage higher value products from small wood – poles, grape stakes, animal bedding, landscaping, etc. Problem here is limited demand.
- Seasonal logging restrictions puts the loggers out of the woods for extended periods of time. The existing workforce could do more if they could have year-round access.
- When loggers are out of the woods, the contractors need to find other chipping work to keep the chippers busy, to amortize the cost. Sometimes this creates scheduling issues and conflicts.
- USFS biomass stumpage = $0.10/green ton. Private land = $0/ton.
- A few land managers mentioned hauling biomass as logs. But most goes out in chip vans.
- USFS sometimes tries to sell biomass decks, after the sale if the original purchaser did not want the biomass. Second purchaser faces road costs and other sale costs, however, which might be

too much for the biomass to carry.

- Partnerships between USFS and other groups is becoming more common. Still working through early problems.
- In Central Sierras, haul costs are still too high to service BioRAM plants.
- Biomass removal from USFS is most often done with IRTC. On regular sales, biomass is often left behind by the purchaser. Some forests using IRSC to get the work done, but that is more difficult to attract bidders.
- Some interest from mulching contractors for salvage of dead wood. Not implemented yet. Shavings plants take some wood, but not much.
- Sierra and Sequoia NFs have maxed out capacity for local mill and local contractors.
- Salvage from large fires has a big impact on regular timber sale program – all resources are diverted to salvage. As a result, green stands that need treatment are not harvested. Some have burned up before they could be harvested.
- Tier 1 harvest could not be chipped on site due to accessibility. Removed everything on a log truck. Lots of breakage. Smaller material piled for burning. Trees with sawtimber value went out as sawtimber.
- Biomass removal is considered a service, not a product under IRTC, so it earns a credit, applied against sawtimber.
- USFS land managers see the BioRAM contracts help the financial picture, but do not solve it completely. Biomass production still costs more than it is worth at the plants.
- Most USFS forests see near term future harvest levels similar to recent past – no discussion of a large effort to ramp up. A few see an increase. Some of that is due to fire salvage. One NF Supervisor is pushing to double acreage or better.
- Turnover of key staff members is a problem.
- Some private land managers: Only removing biomass where there is an economic benefit. Rarely occurs. Biomass sometimes chipped on site. Sometimes burned.
- Biomass delivered at $50/green ton is maybe break-even. Need $60/green ton to make a difference. Need $55-65/BDT for a long time to get interested. If there was $2-3/ton over operating costs, that would increase production. Need $90/BDT, at $65-75/BDT, it doesn't work.
- Need longer term commitments to develop the infrastructure to make a difference.
- In the near future, there will be a lot of work creating fuel breaks. Is that "qualifying fuel" even if it looks like a clearcut? It should.

- Companies concerned that loggers are not reinvesting in equipment.
- More than 15 miles of off-highway haul makes biomass uneconomic.
- Estimates of break-even haul distance range from 40-60 miles. Three-hour round trip is rule of thumb.
- Study shows a net benefit to society of using biomass fuel rather than burning in the woods. The net benefit is equivalent to $114/MWH. This should be the basis for setting a biomass power price.
- Private landowners: Some have questions about the "clearcut" disqualification. What about fuel breaks, what about Conservation Easements, what about silvicultural options.
- Some private landowners unaware of BioRAM contracts. Others very aware.
- Trucking is the limiting factor in some places. Not enough log trucks, not enough chip vans. Better to haul sawlogs when transportation is limited. Air quality upgrade requirements took trucks out of the fleet.
- HHZ delineation misses acres that should be treated.
- "Biomass doesn't drive the train, but we need to get rid of it to get the forests back in balance."
- Observation that many large fires are outside the HHZ. Should be qualifying fuel.
- Biomass production could be improved if it could be moved off the site at the same time as logging. Need to move logs – mule trains? – and leave behind branches and needles.
- Private landowner – contracting with biomass producer to come in after the sale. Needs contracting, insurance, administration. Big hassle for zero return.
- Loggers like to chip in the summer – the logs are drier, and you can get more BDT into a chip van. Best to let logs sit for a few weeks before chipping. Means chipping after logging.
- Logger: Unloading delays at power plant are costly. He needs a steady stream of chip vans to keep the chipper operating at full capacity all day. If there is a delay at the plant, then the vans are backed up and he's not working the chipper, losing money.
- Hourly operating costs $350-450 for grinder/chipper. $180/hr heel boom. Used chipper $600K.

APPENDIX L: PHOTOS

Photo L-1. USFS Forest Restoration Treatment at Mosquito Ridge. Notice untreated stand in the background, and down woody material left in the woods. Unutilized slash in foreground.

Photo L-2. USFS Forest Restoration Treatment at Mosquito Ridge. All small trees removed.

Photo L-3. Trees removed from Tier 1 HHZ hazardous tree removal along powerline.

Photo L-4. USFS Forest Restoration Treatment at Mosquito Ridge. Note untreated stand in background.

Photo L-5. Logging residue: Tops and branches decked for chipping or burning. Note forester in foreground for perspective.

Photo L-6: Logging Residue: Tops and branches decked for chipping or burning.

Photo L-7: Chipping tops, branches and unmerchantable lodgepole pine logs.

Photo L-8: Forest restoration treatment, Mosquito Ridge. Note lack of small trees post harvest.

Photo L-9: Biomass fuel chips

APPENDIX M: COMPANY BIOS

MB&G

Mason, Bruce & Girard, Inc. is a natural resource consulting firm headquartered in Portland, Oregon with field offices in Medford, Oregon and Auburn, California. Founded in 1921, our firm is recognized as a leader in planning for long-term sustainable management of natural resources. Our 45 professional employees take on all manner of timber-focused projects including property management, supply studies, inventory and biometrics, resource planning, policy analysis and expert witness work. Our Geospatial Group has a broad set of skills ranging from image acquisition and interpretation, to land classification and software design. Our Environmental Services Group provides a comprehensive range of regulatory compliance and environmental permitting to a wide variety of clients. MG&G's clients include federal, state, Tribal and private land owners and managers as well as regulators, investors, financial institutions, and attorneys.

THE BECK GROUP

Founded in 1981, The Beck Group is a leading, full-service forest product consulting firm based in Portland, Oregon. The Beck Group offers a range of services to private, public, tribal, and non-profit clients in North America and around the world. Our goal is to provide practical and cost-effective solutions that improve the performance of forest products firms, as well as those organizations affiliated with or supporting the forest products industry. The Beck Group's experienced staff and associates provide clients with the information and innovative solutions their organizations need to meet the challenges of today's highly competitive environment. The firm is well known in the forestry and forest products industry in the areas of project planning, management training, feasibility studies, mill modernizations, competitive assessments, due diligence, fiber supply, and timber procurement planning.

APPENDIX N: HHZ FUEL STUDY COMMITTEE

We wish to thank members of the High Hazard Zone Fuel Study Committee for the guidance, questions and review they provided to this study. Their insight and diligence contributed significantly to this report.

Rizaldo Aldas	California Energy Commission
Cheryl Cox	California Public Utilities Commission
Joanne Drummond	Pacific Gas & Electric
April Kennedy	Pacific Gas & Electric
Angela Lottes	CalFire
Julee Malinowski-Ball	Public Policy Advocates, LLC
James McGarry	California Public Utilities Commission
Kristen Merrill	CalFire
Matthew Plummer	Pacific Gas & Electric
Joe Sherlock	US Forest Service
Larry Swan	US Forest Service