Moving Beyond Incineration

Putting residues from California forest management and restoration to good use

Sierra Club California
November 2019

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1. Executive Summary

Drought, pest infestation, wildland development and wildfire – all exacerbated by climate change – have led to increasingly challenging conditions on the state's forested landscapes. The persistence and visibility of these challenges in 2018 resulted in unprecedented funding for forest interventions.

Defensible space treatments, the removal of dead trees near homes and infrastructure and community protection projects are all necessary to save home and lives during wildfires. CAL FIRE and the California Natural Resources Agency favor mechanical thinning projects for forest health projects. These activities result in significant residual material in the form of traditionally non-merchantable wood, also known as biomass.

Sierra Club California continues to advocate for less-intensive forest interventions but recognizes that there is existing and anticipated accumulation of orphan biomass. This biomass must be dealt with in a low-impact, sustainable way. The state has failed to leverage the most progressive, technologically advanced economy in the world to find and endorse low-impact uses for biomass. Instead, the state has propped up antiquated, pollution-producing biomass incinerators.

Biomass incinerators represent some of the dirtiest stationary sources of criteria pollutants in a state plagued by poor air quality. These incinerators emit more CO_2 than fracked gas and, in some cases, more than coal. Biomass incineration is an unacceptable, unimaginative solution to an important issue. This report explores how to use biomass in a low-impact, sustainable way and move California beyond biomass incineration.

This report estimates tons of biomass expected to be generated in the foreseeable future and maps the areas where the most biomass will be removed. The report outlines the high cost of state policies that propped up existing incinerators (BioRAM) and look to spur a new generation of small incinerators (BioMAT). Finally, the report analyzes a number of biomass utilization methods investigating their marketability and environmental impact.

The report does not endorse a particular product or suite of products, instead it is intended to kickstart a more intensive, more heavily funded investigation by the state. The utilization methods in this report are all preferable to incineration. However, the state must scrutinize each method before spending public dollars to incentivize them or considering policy changes.

In a period of intense public anxiety about climate change, the state imprudently chose a means of biomass utilization that emits substantial climate pollution, impacts local and regional air quality, displaces clean renewable energy and incinerates ratepayer dollars. There are better options and decision makers must move California beyond incineration.

2. Introduction

Drought, pest infestation, wildland development and wildfire – all exacerbated by climate change – have led to increasingly challenging conditions on the state's forested landscapes. These challenges are also worsened by a history of intensive logging and aggressive fire suppression. While there is a great deal of debate as to the optimal management regime for forests and other wildlands, based on plans and statements from California state agencies, there is little doubt that active thinning and fuels treatments will continue to take place in California's forestlands.

This management activity, in turn, creates an additional problem in the form of significant residual woody biomass that must be dealt with on-site. Woody residues from logging, thinning, and fire management activities in the State of California are typically left on site or burned in piles, raising concerns of fire hazard and air quality impacts. Recognizing this challenge, policymakers in Sacramento have sought to develop markets for these materials in order to facilitate their removal and even in hopes of improving the economics of the thinning treatments themselves.

Policymakers have turned to thermoelectric power generation as a key market for woody biomass, and have been pursuing subsidy mechanisms to promote its further development in California and its uptake of forest residual feedstocks. The regulated nature of electric power markets makes this a seemingly attractive sector for policy intervention. However, electricity generation via biomass incineration can lead to significant environmental harm from local air pollution to increased carbon emissions. Furthermore, there are likely more environmentally *and* economically attractive uses for these residues, but these have not been sufficiently investigated or promoted as they do not have the advantage of an incumbent industry with existing infrastructure and political influence.

This report lays out the current state of woody biomass mobilization and use in California today, and details pathway alternatives to incineration that could serve to reduce air pollution from open burning while also stopping the displacement of cleaner energy sources. We estimate the volumes of forest residues that are being created in California forests and investigate alternative economically viable pathways that could offer the greatest near-term uptake of residual biomass while minimizing criteria pollutant and greenhouse gas emissions while creating needed jobs in rural California.

2.1. Forest restoration and fire management efforts in California

The way California manages its forests and wildlands has important implications for public safety, biodiversity conservation, water resource management, air quality, climate change, and the state's economy. Because of these cross-cutting impacts, especially in the wake of two years of severe wildfires, significant political will and economic resources are now being mobilized in Sacramento to facilitate more active management of California's forests.

The California Department of Forestry and Fire Protection (CALFIRE) is slated to spend $289 million during FY 2019-20 through the California Climate Investments (CCI) program on what they call "sustainable forestry and wildfire management projects", bringing the total expenditure to $878 million since 2014 (ARB, 2019). The Forest Health Grant program is the largest of the CCI investments in this space, and is focused on projects aimed at forest restoration, watershed protection, wildfire resilience, and promoting long-term storage of carbon in forest trees and soils. CALFIRE also manages the smaller California Forest Improvement Program, which offers grants to small landowners (20-5,000 acres) for forest treatments.

These and other forest treatment efforts in California are to be coordinated through the interagency Forest Management Task Force. The Task Force was established pursuant to Governor Jerry Brown's Executive Order B-52-18 and is tasked with implementing management goals called for in the state's Forest Carbon Plan with the goal of doubling forest management treatments within 5 years to a level of 500,000 acres per year (FMTF, 2019).

2.2. Residues from forest management

Forest treatment and harvest activities in California produce a significant amount of residual woody material that must be managed in the forest. Business as usual for these residues is a combination of open pile burning and on-site decay over time either whole or chipped. Slash burning has been considered a best management practice, but it results in increased cradle-to-grave emission of GHGs per unit lumber (Ter-Mikaelian et al. 2016). The same applies to fire management thinnings; burning of slash material, while a common management practice, results in elevated GHG and criteria pollutant emissions compared to other management alternatives.

To avoid the GHG and criteria pollutant emissions associated with open pile burning of forestry residues, policymakers are increasingly focused on supporting removal of these residues from the field. However, while removal of these materials can reduce wildfire risk and impact, there is concern about the effects on forest productivity and sustainability (Vance et al. 2018). These residues represent a substantial stockpile of nutrients and carbon in the ecology of a forest, and under the most intensive harvest removal models, nutrient losses can approach 100% of critical phosphorus, potassium, calcium, and magnesium soil stocks (Achat et al. 2015). Most of these nutrients reside in the foliage, however, so management practices that leave foliage behind at harvest can reduce nutrient losses (Achat et al. 2015).

Leaving some residue onsite can mitigate compaction from equipment. It may also reduce the erosive effects of forest treatment (Binkley and Brown, 1993), and the resultant impact on watershed ecology (Vance et al. 2018). Buck (2013) recommends a minimum of between 20% and 50% of residues be retained in the forest. The precise amount depends on factors including forest type, ecology, topography, and clear best management practices should be utilized and strengthened as necessary with recognition of local factors.

While some residue should be retained in the woods, much of the biomass generated through forest management is typically removed to manage ecological and wildfire risks. However, due to the high cost of collection and transport, removal of these materials is typically a money-losing proposition (Lord et al, 2006). The California Natural Resources Agency (2017) notes that "one of the core challenges facing forest health restoration activities…is the lack of economically sustainable demand for smaller diameter trees, dead trees, and other woody biomass that may be removed during restoration…This can be especially true for forestry practices that best advance California's forest carbon and overall forest health goals, such as multi-age class management and selective removal of dead and dying trees in the Sierra."

Sierra Club California has taken issue with the CNRA's aggressive treatment-focused approach to forest management in California. However, the goal of this report is not to re-litigate California's forest management practices, but instead to discuss the current use of the residues generated by the active management that is currently being conducted.

The state of California has taken a number of executive and legislative actions aimed at addressing the economic and ecological challenges on the state's forested landscapes. A key element of this effort is California Senate Bill 859, signed in 2016. This bill established the Wood Products Working Group, an interagency effort managed by the CA Natural Resources Agency with the goal of "…expanding wood product markets that can utilize woody biomass, especially biomass that is removed from high hazard zones…" This working group then subsequently established three goals (CA Natural Resources Agency, 2017):

1. Utilize material that is removed from High Hazard Zones, particularly in ways that can substitute or complement bioenergy production;
2. Promote forest health and carbon sequestration, as described in the Draft 2017 Forest Carbon Plan and Draft 2017 Scoping Plan Update, and advance other statewide climate change goals
3. Promote rural economic development, including job creation.

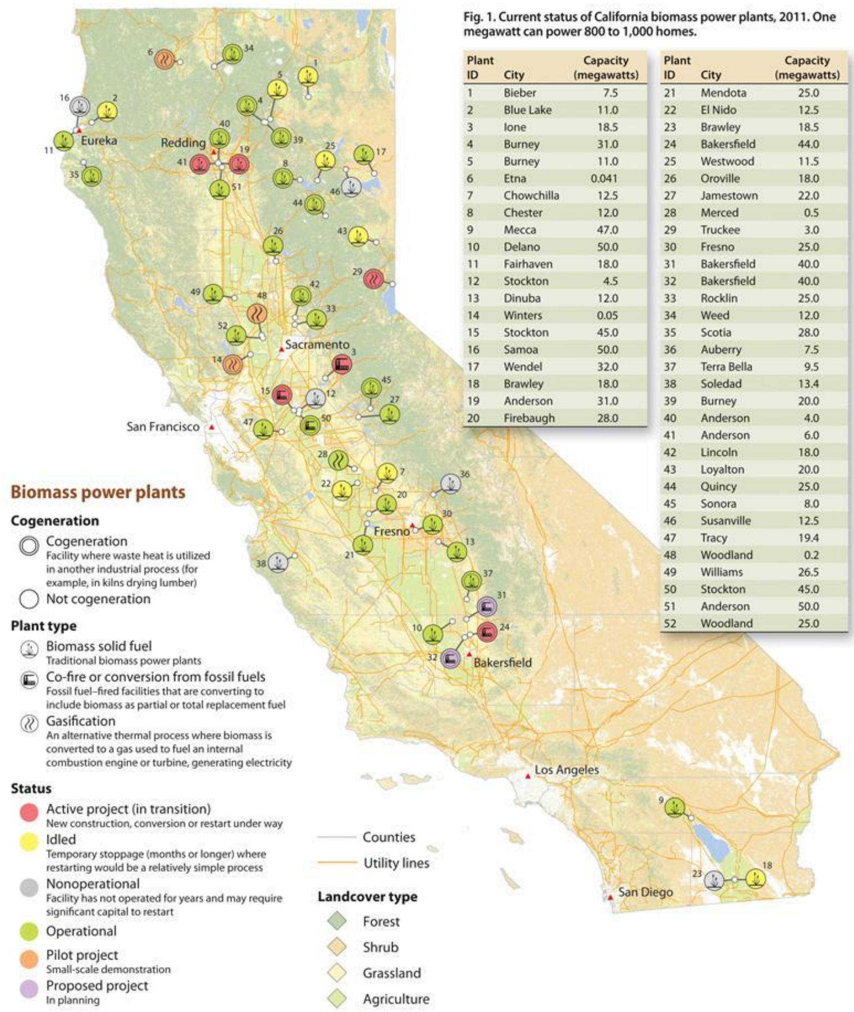
The Working Group developed a series of recommendations in 2017, and has begun implementing them through its member agencies. Some of the actions are summarized below (CA Natural Resources Agency):

- **Improve the process for redevelopment of sawmill and rural industrial sites into wood products manufacturing facilities**. An interagency team is charged with engaging regional or local permitting agencies as well as assisting in navigating liability, financial assurance, and regulatory processes associated with the cleanup and reuse of sites.
- **Accelerate the use of mass timber construction** through building code development and outreach to local planning agencies and developers and promotion of low carbon building design statewide – especially for state facilities.
- **Create a finance information clearinghouse** offering developers information about and streamlined application to private and public funding support targeted at rural development and wood products innovation.

- **Promote innovation** by funding applied research and development by business and academic institutions as well as supporting investment in any necessary fire, seismic, and other material testing to facilitate further mass timber code development and construction.
- **Invest in human capital** by strengthening career pathways in advanced wood products and innovation including support for relevant educational attainment.

Despite all of the above efforts to develop alternative markets, the vast majority of low value wood that is mobilized in California is incinerated in bioelectricity plants.

2.3. Bioelectricity in California



Plant ID	City	Capacity (megawatts)	Plant ID	City	Capacity (megawatts)
1	Bieber	7.5	21	Mendota	25.0
2	Blue Lake	11.0	22	El Nido	12.5
3	Ione	18.5	23	Brawley	18.5
4	Burney	31.0	24	Bakersfield	44.0
5	Burney	11.0	25	Westwood	11.5
6	Etna	0.041	26	Oroville	18.0
7	Chowchilla	12.5	27	Jamestown	22.0
8	Chester	12.0	28	Merced	0.5
9	Mecca	47.0	29	Truckee	3.0
10	Delano	50.0	30	Fresno	25.0
11	Fairhaven	18.0	31	Bakersfield	40.0
12	Stockton	4.5	32	Bakersfield	40.0
13	Dinuba	12.0	33	Rocklin	25.0
14	Winters	0.05	34	Weed	12.0
15	Stockton	45.0	35	Scotia	28.0
16	Samoa	50.0	36	Auberry	7.5
17	Wendel	32.0	37	Terra Bella	9.5
18	Brawley	18.0	38	Soledad	13.4
19	Anderson	31.0	39	Burney	20.0
20	Firebaugh	28.0	40	Anderson	4.0
			41	Anderson	6.0
			42	Lincoln	18.0
			43	Loyalton	20.0
			44	Quincy	25.0
			45	Sonora	8.0
			46	Susanville	12.5
			47	Tracy	19.4
			48	Woodland	0.2
			49	Williams	26.5
			50	Stockton	45.0
			51	Anderson	50.0
			52	Woodland	25.0

Figure 1: Current status of biomass power facilities in California. Map source: UC Division of Agriculture and Natural Resources. As the wood products and bioenergy landscapes in California are quite dynamic, some of the 2012 data presented here may no longer be accurate. An up-to-date wood facility database is maintained by the University of California at: https://ucanr.edu/sites/WoodyBiomass/Project/California_Biomass_Power_Plants/

In 1980, the operating capacity of biopower facilities in California was approximately 20 MW (NREL, 2000). Capacity additions occurred very rapidly in the following decade, culminating with the addition of 11 new facilities in 1990 alone, bringing total capacity to 340 MW. As of 2015 the operating capacity of California's biomass plants in commercial service was approximately 550 MW (TSS Consultants, 2015). According to CalRecycle (2017), the 25 biopower facilities operating in 2017 incinerated approximately 3.4 million bone-dry tons (BDT) of biomass annually. On average, forest residues accounted for 13% of this total, mill residues for about 34%, and the remainder derived from agricultural and urban waste streams (CalRecycle, 2017)

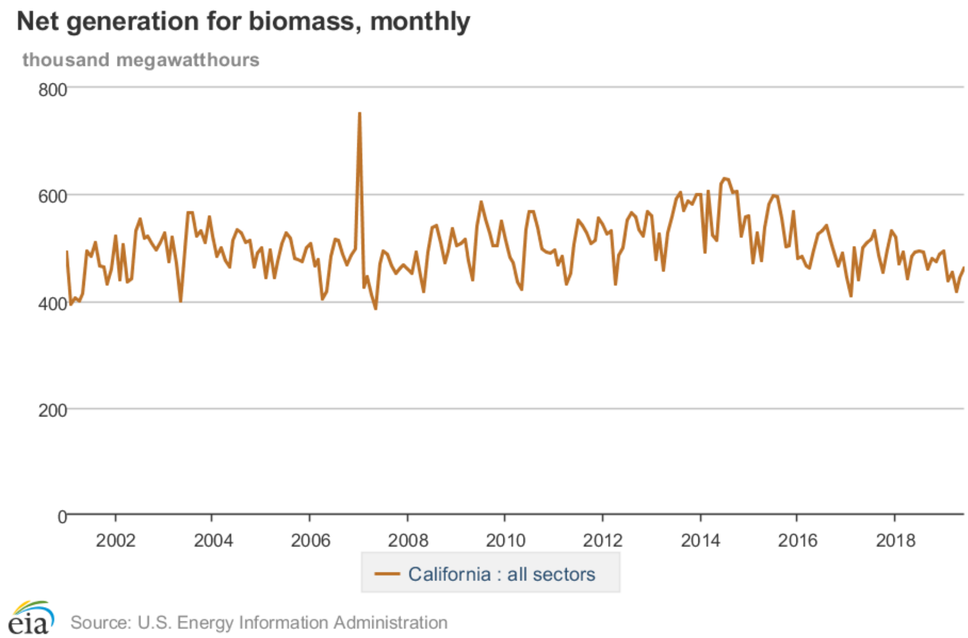


Figure 2: Historical biomass power generation from wood and wood derived sources in California (EIA, 2019).

One of the key environmental concerns surrounding bioelectricity is its contribution to air pollution and resultant contribution to human health concerns. The combustion process yields significant emissions of carbon monoxide, nitrous oxides, and particulate matter at both 10 (PM10) and 2.5 (PM2.5) micron scales, in addition to the immediate release of stored carbon as carbon dioxide at the smokestack. Typical emissions profiles for mobilization of a bone-dry ton of forest residuals and combustion in a biopower facility are reported in Table 1, below.

Table 1: Emissions from forest biomass use for bioelectricity production (data sources: Carresas-Sospedra, 2015; Cooper, 2008)

	Emissions by supply chain phase (lbs/BDT)		
	Harvest	**Transport**	**Combustion**
VOC	0.034	0.001	0.212
CO	0.242	0.001	3.0445
NO_x	0.273	0.004	4.361
PM10	0.01	0.002	0.502
PM2.5	0.009	0.002	0.251
SO_x	0.001	<.001	0.163
CH_4	0.003	<.001	0.152
N_2O	<.001	<.001	0.436
CO_2	69.13	0.05	3510

2.4. Market supports for biopower in California

Electricity generation has long been the primary outlet for low-value woody material in California – including mobilized forest residues--despite documented pollution impacts. In fact, lawmakers have overtly ignored these impacts when considering incineration. To further stimulate the market for residues in the face of the large increases in forest treatment forecast in the state, legislators passed Senate Bill 1122 in 2012, requiring the state's Investor Owned Utilities (IOUs) to purchase electricity at above-market rates from small-scale facilities generating electricity from specified priority feedstocks. This led to the establishment of the Bioenergy Market Adjusting Tariff (BioMAT) program.

Later, in response to Governor Brown's 2017 directives on wildfire risk, the BioMAT program was joined by the Bioenergy Renewable Auction Mechanism (BioRAM), requiring California IOUs to purchase power at above the prevailing price from existing biomass power facilities provided that those facilities purchase at least 50% of their feedstock from residues of forest management in wildfire high-hazard zones (HHZs)—including mill residues originating in these regions. This proportion was raised to 60% in 2018, and 80% for 2019 and beyond (Beck Group, 2019, High Hazard Fuels Assessment).

Table 2: BioRAM facilities in California, feedstock requirements by year (adapted from USDA Forest Service and UC Berkeley, 2017)

Estimated Forest Biomass Consumption (BDT/Year)				
BioRAM 1 Facilities	**2017**	**2018**	**2019-2021**	**Total for 5-year Contract Period**
Burney Forest Power	108,800	130,560	522,240	761,600
Greenleaf Honey Lake	87,500	105,000	420,000	612,500
Rio Bravo Fresno	109,200	131,040	524,160	764,400
Rio Bravo Rocklin	109,200	131,040	524,160	764,400
Pacific Ultrapower Chinese Station	77,400	92,880	371,520	541,800
Subtotal BioRAM 1	492,100	590,520	2,362,080	3,444,700
Annual HHZ feedstock requirements	50%	60%	80%	
BioRAM 2 Facilities (or similar contract)				
Wheelabrator Shasta	190,640	190,640	571,920	953,200
Loyalton	0	107,200	321,600	428,800
Subtotal BioRAM 2	190,640	363,360	1,090,080	1,644,080
Annual HHZ feedstock requirements	80%	80%	80%	
Total BDT/Year—BioRAM 1 and 2	***682,740***	***953,880***	***1,150,720***	***5,088,780***
Estimated Treated Acres at 12.5 BDT /acre	***54,619***	***76,310***	***276,174***	***407,102***

The seven BioRAM facilities in California incinerated a combined 691,000 BDT of BioRAM-qualifying fuel in 2018, or about 60% of their total feedstock demand (Beck Group, 2019). Across the state, these contracts accounted for 35% of the total biomass incinerated, 16% of the mill residue and 68% of the forestry slash. Going forward, BioRAM facilities are expected to consume around 930,000 BDT of qualifying fuel annually (Beck Group, 2019). Historically, about

65% of this material has come from forestry residuals, with the rest derived from sawmills. The average cost of BioRAM-qualifying fuel has been consistently higher than the prevailing market price for biomass because of competition between facilities for this fuel. The average price of qualifying fuel rose by about a third in 2017-2018 to about $60/BDT while non-qualifying fuel dropped in price to $23/BDT (Beck Group, 2019).

The critical element of the BioMAT program from the standpoint of this report is its Category 3, allocating 50MW of feed-in tariffs to small facilities using "byproducts of sustainable forest management" as their fuel. This has the stated aim to "promote sustainable and resilient forests, reduce the risk of high intensity wildfires, reduce the use of open pile burning as a forest management tool, and protect public safety and infrastructure (CPUC, 2018)." BioMAT is currently undergoing a review triggered by the Category 3 offer price exceeding the $197/MWh "soft cap" set out in the program design. During this process, the Public Utilities Commission put in place a price cap of $199.72/MWh[1]. The review aims to evaluate program performance to date, enable expanded participation, and ensure that the program achieves stated goals.

Table 3: Summary of BioMAT program activity as of program period 17 - Q4 2018. Source: CPUC (2018)

Category	# of Projects with Executed Contracts	Cumulative Capacity of Projects with Executed Contracts (MW)	Capacity Remaining in Category (MW)	Offer Price Accepted by Projects ($/MWh)	Current Market Depth (# of projects from unaffiliated applicants in the statewide queue)
1-Biogas	7	13.0	97.0	$127.72	< 5
2-Dairy	8	8.0	77.9	$187.72	< 5
2-Other Agriculture	4	4.0		$187.72	< 5
3-Sustainable Forest	3	7.9	42.1	$199.72	< 5

2.4.1. Cost to Californians of the BioMAT and BioRAM Programs

Although BioRAM power purchase agreements are confidential, the Beck Group (2019) estimates that their average price is about $115/MWh. The BioMAT program is more transparent, and also more expensive as the facilities it supports are newer and smaller-scale. The current Category 3 offer price in the BioMAT program ($199.72/MWh) is between the low ($148/MWh) and medium ($219/MWh) levelized cost estimates for energy generation from forest management byproducts estimated by Black and Veatch (2013). It is not possible to know the cost of facilities that have *not* been developed, so we use the current offer price in evaluating the cost of the BioMAT program. This is a very conservative approach, since only about 16% of the allocated capacity had been contracted at that price before the program

[1] For more information about the BioMAT program review, see: https://www.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

review was triggered. However, assuming technology and markets continue to mature, we use this price in projecting the cost of the fully-enrolled program.

According to the California Energy Commission (Neff, 2019), biopower facilities are the most expensive of commonly deployed energy technologies (see Figure 3), meaning these supports for biomass incineration are costing Californians money. The California grid operator reports an average wholesale price of power on the CA grid at $49/MWh (CAISO, 2018). This means that the BioRAM program is subsidizing biopower facilities at a rate of $66/MWh and the BioMAT program at a rate of $151/MWh.

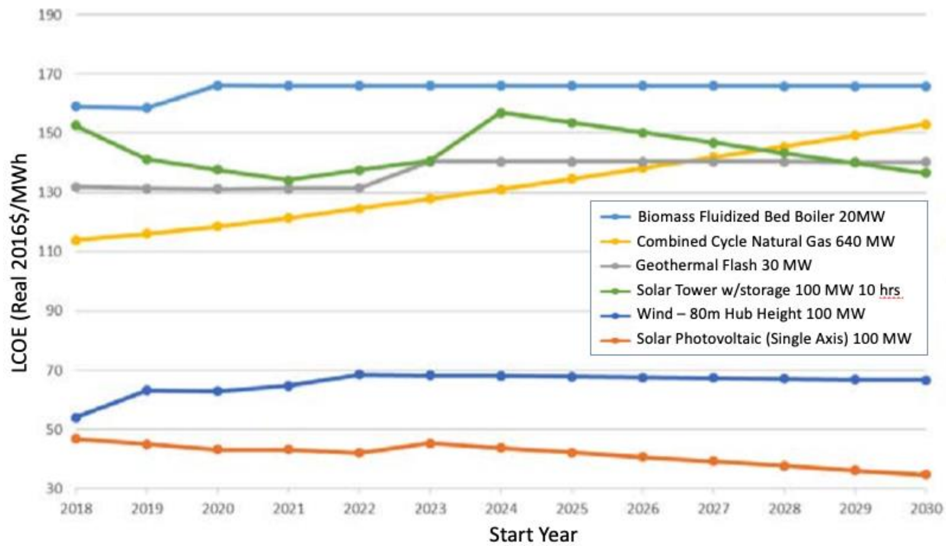


Figure 3: Levelized cost of generation estimates by technology (Real 2016 $/MWh). Source: Neff (2019)

At a capacity factor of 60%—the average for biopower facilities in California—the 50MW of plants allocated to Category 3 in BioMAT would produce 262,800 MWh at a total cost to utilities of about $52.5 million. The Beck Group (2019) projects that the seven BioRAM facilities will incinerate 930,000 BDT of qualifying fuel annually, for 80% of their total fuel needs. At a typical biopower plant efficiency of 1MWh/BDT, this amounts to 1,162,500 MWh of power generated under BioRAM contracts at a total cost of $133.7 million. Historically, only 65% of qualifying fuel has been forestry residues, meaning 605,000 BDT of residue mobilized annually.

Table 4: Calculation of the subsidy for biomass incineration created by the BioMAT and BioRAM programs in California

	BioMAT	**BioRAM**
Wholesale Price ($/MWh)	$199.72	$115
Grid average price ($/MWh)	$49	
Total power purchased (MWh)	263,000	1,163,000
Total program cost	$52.5 million	$134 million
Total net ratepayer subsidy	$39.6 million	$76.8 million
BDT of forest residues mobilized	263,000	605,000
Net Subsidy per BDT of residues removed	$150	$127
Weighted average subsidy ($/MWh)	**$82**	
Weighted average subsidy ($/BDT)	**$134**	

As shown above in Table 4, we conservatively estimate the additional cost created by the BioMAT and BioRAM programs combined to be $82/MWh and $134/BDT of biomass mobilized. These costs are not paid for from state coffers, but are instead borne by California's electric utility ratepayers. They are, nevertheless, a form of subsidy to biopower facilities, and raise the question of whether incineration is the most economic use case for subsidized residue mobilization—especially given its significant environmental impacts. Notably, biomass incinerator electricity is far more expensive than clean, renewable energy, but the forced purchase of biomass electricity effectively displaces new development of clean renewables that would otherwise be purchased by utilities.

2.5. Moving beyond incineration

Policymakers in Sacramento have chosen to use bioelectricity as the outlet for much of the residue created by CA forest management activities. This is not unexpected, because electricity generation has historically been the only real market for woody residues and because the electric power sector is much more heavily regulated than other industries, and is therefore accustomed to government intervention. However, it should not be assumed that biopower is the only option for the use of woody biomass, nor that it offers the best environmental or economic performance of all alternatives.

Incineration of woody residues means releasing the carbon stored in that biomass directly to the atmosphere. Turning them into durable wood products, on the other hand, would mean at least temporary sequestration of that carbon, with attendant climate benefit. Furthermore, several BioRAM and proposed BioMAT facilities are located in disadvantaged communities (DACs) according to the criteria set forth in Senate Bill 535. These facilities will contribute to the further degradation of already sub-standard local air and water quality (CPUC, 2018).

Bioelectricity facilities are not the only end use for residues from forest management activities. They may currently be the most stable option, because the structure of the power purchase agreements mandated by the BioMAT feed-in tariff program enables them to offer long-term contracts to landowners. However, this is due to policy, not the inherent properties of the bioelectricity sector. Creative policy could also facilitate less polluting alternate uses of these residues.

The remainder of this report lays out the state of forest residue generation in California today and some of the alternatives to incineration that should be considered in the effort to turn this byproduct of forest management into a sustainable resource for the California economy. In section 3, we estimate the size of the woody biomass residue base in California and map where it is currently being created. Section 4 then describes some of the key markets that could make use of this resource if their development and uptake of residual biomass were supported by policy. Section 4 then lays out our conclusions.

3. Forestry residues in California

To evaluate the efficacy of biopower and other alternate uses of woody biomass residues from California forest management, it is necessary to understand the scale and spatial distribution of this resource base. In doing so, we draw upon a dataset created by the Natural Resource Spatial Informatics Group at the University of Washington (Comnick and Rogers, 2018) in support of the California Biopower Impacts Project[2].

This dataset projects the residue generated from a range of treatments applied to California forestlands. Treatments are categorized into fourteen different harvest types, covering most common forestry activities as defined by California Forest Practice Rules. Drawing on tree list inventory (GNN) data produced by the Landscape Ecology, Modeling, Mapping and Analysis (LEMMA) group at Oregon State University, Comnick and Rogers (2018) modeled the total biomass residue resource base for each treatment type at 30-meter resolution across California forestlands. This residue is divided into stem, bark, branch, foliage, and root biomass based on national biomass estimators (Jenkins et al., 2003).

We apply this dataset to the actual harvests carried out in California in recent years. In particular, we estimated the amount and spatial distribution of woody residual biomass generated by all permitted commercial harvests in California in 2017 and 2018 based on the timber harvest plans on file with CALFIRE as well as those generated by the "forest health" treatments being supported as part of the California Climate Investments program.

3.1. All California forest treatments

The spatial extent of all timber harvest plans approved in the state are made publicly available by the California Department of Forestry and Fire Protection (CALFIRE, 2018) (Figure 4). We assume that only those timber harvests marked as "complete" were completed and that they were performed entirely in the year of their completion.

[2] The California Biopower Impacts Project is a research initiative based at Humboldt State University. It is supported by a 3-year, $1 million grant from the California Energy Commission. More information can be found at http://schatzcenter.org/cbip/

Table 1: Silvicultural Treatments by Total Area for 2016-2018. Only those treatment types accounting for more than 1% of total treated area are included here.

Harvest Type	*% of total*
Group Selection	*28.4%*
Selection	*23.7%*
Clear-cut	*22.2%*
Shelter wood Removal Cut	*6.5%*
Sanitation Salvage	*4.6%*
Commercial Thin	*4.1%*
Shelter wood/Commercial Thin	*1.7%*
Fuel Break	*1.3%*
Variable Retention	*1.1%*

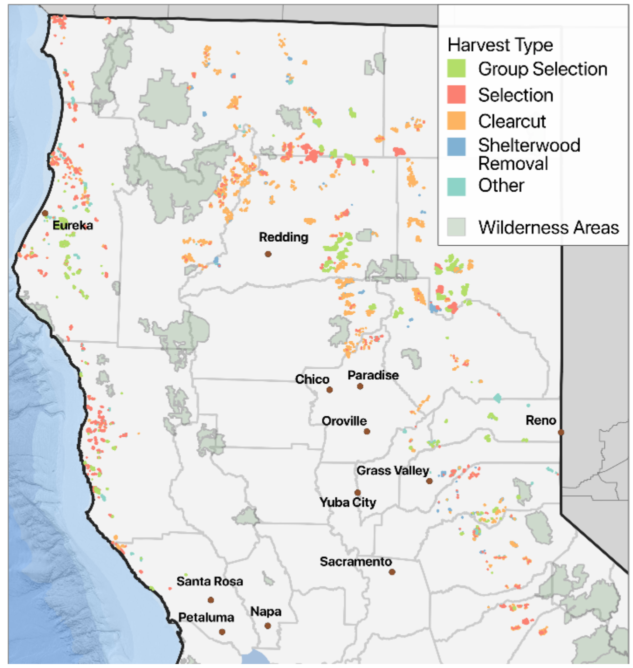


Figure 1: THPs in Northern California 2016-2018. These represent almost all of the THPs in the state for this period.

We matched the silvicultural treatment applied to a given site (Table 5) to those characterized in the University of Washington dataset (Comnick and Rogers, 2018) based on definitions from the California Forest Practice Rules (CALFIRE, 2019) to create high and low estimates of the resource base (Table 6). We assume 70% of total woody residues generated to be recoverable and 15% of stemwood cut to be broken or damaged in harvest (Kizha and Han, 2015) and therefore allocated to the residue base rather than to merchantable roundwood. This is intended to capture the possible range of residue generation rather than to predict the precise amount of residues. We assumed lodgepole pine, Douglas fir, white fir, and ponderosa pine to be the only species suitable for post-and-pole manufacture.

Table 6: Estimated amount of recoverable residue generated from commercial forest harvest in California on average over the 2017 and 2018 harvest years – reported by residue class.

Material type	**Low** estimate (tons/year)	**High** estimate (tons/year)
Residues <4"	271,712	531,967
Stemwood (non-pole)	209,690	418,081
post-and-pole species 4-6"	48,355	91,044
Foliage	79,469	158,847

These residues are not evenly distributed across the state and the potential for their utilization is transportation-dependent. Figure 5 illustrates the distribution of the residue base across California counties for our high-residue estimate over the 2016-2018 period. Low estimates exhibit a similar spatial pattern.

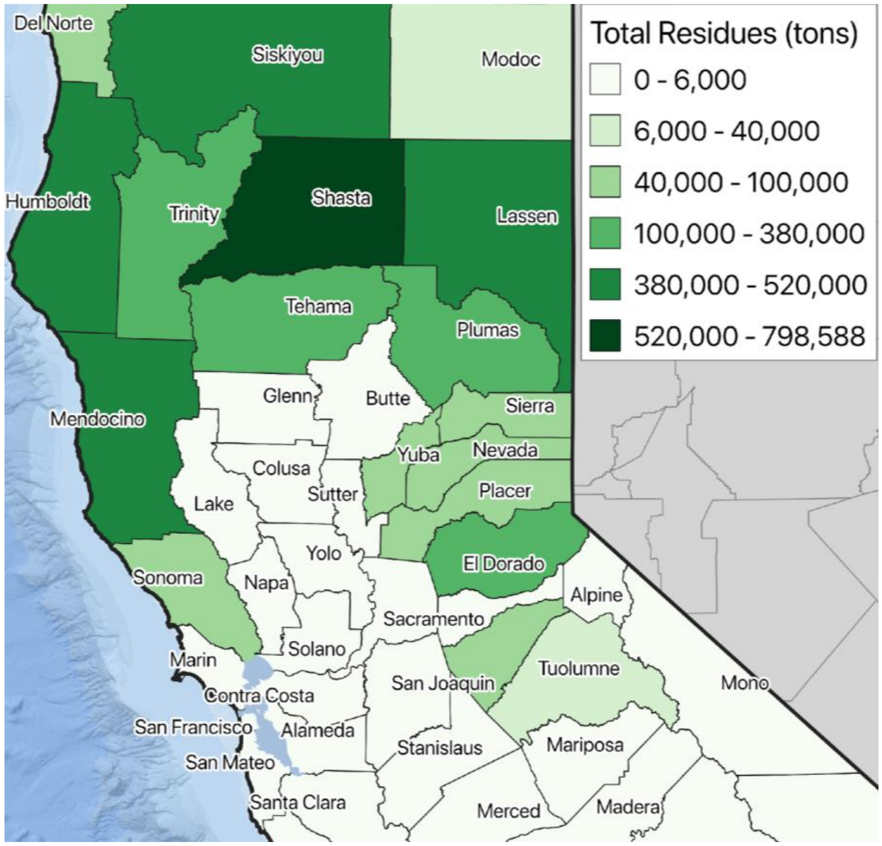


Figure 5: Spatial distribution of woody residue generation from commercial harvest in the 2016-2018 timeframe under high-end harvest assumptions.

3.2. California Climate Investment forest health projects

Because they are paid for by the state government using cap-and-trade program revenues, forest health treatments funded under the California Climate Investments program are of particular interest. We developed a database of CCI forest health projects, with location and area treated for each project funded in the 2016 through 2018 funding cycles. The information publicly available from the published project proposals does not specify harvest levels. As these are forest health treatments aimed at managing fire risk and overstocking on forestlands rather than commercial harvests, we assume they are to be carried out as thinning treatments with smaller diameter trees preferentially removed. We estimate a range of treatment intensities on the treated acreage with 20% basal area removal (light thin) as the low estimate and 40% basal area removal (moderate/heavy thin) as the high estimate. Unlike the THPs filed for approval with CALFIRE, the CCI project proposals do not establish specific treatment areas, instead providing only a single point to identify treatment location. We model the treatments using a circle with the total area of the treatment and this point as its center. Furthermore, we assume the treatment in question to be carried out in the year in which it was funded. This is inaccurate, as many of these treatments will take some time to be implemented. However, it is representative of the treatment intensity created by CCI investments over time at the current funding level. That is, if $250 million were spent annually on forest health treatments, even if those treatments are delayed and spread out over time, an average of $250 million in treatments would occur each year, generating residue at the scale we model here.

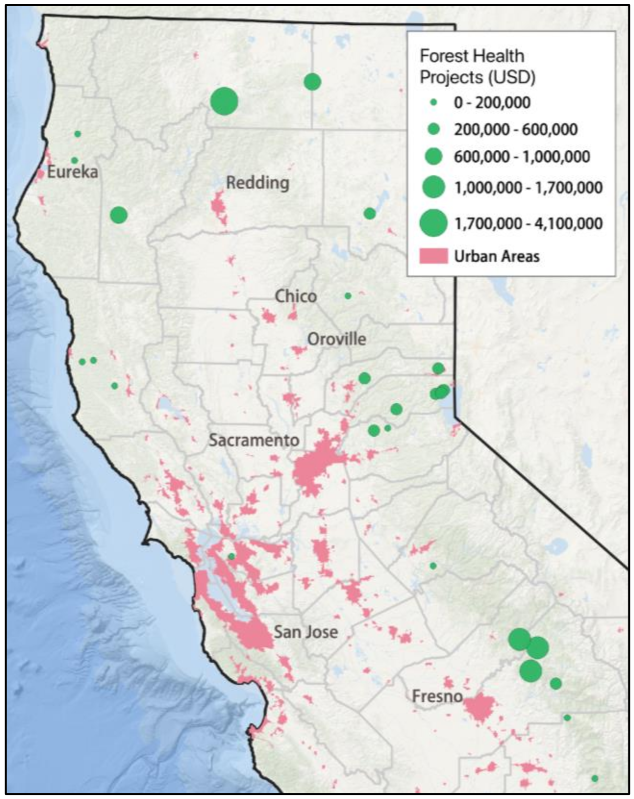


Figure 6: Forest health treatments funded under the California Climate Investment program during the 2016-2018 funding cycles. The size of the green circles represents the expenditure on the treatment, not the area treated, though the two are correlated.

Table 7: Estimated amount of recoverable residue generated from forest health treatments funded by the State of California under the California Climate Investments program. Annual average residue base from projects funded during the 2016-2018 program years.

Material type	**Low** estimate (tons/year)	**High** estimate (tons/year)
Residues <4"	80,258	164,227
Stemwood (non-pole)	43,053	74,553
post-and-pole species 4-6"	10,856	16,874
Foliage	10,861	23,607

4. Non-incineration pathways for forest residues in California

Historical uses of forest residues were varied. Short billets could be used for box veneer and paper cores. As today, fencing, small poles, and tree stakes could be sourced from small-diameter logs, as could bedding and mulch. Adapting to changing markets and location-specific circumstances has always been key to developing use cases for low-value material (Reineke, 1965). The US share of global wood product production peaked in 1998 at 28% (Prestemon et al., 2015). In recent years, technology has influenced wood product composition, with engineered wood products such as I-joists, cross-laminated timber, and particleboard allowing for a shift towards utilization of smaller trees. Housing construction is the most active source of demand for these products, but efforts to promote wood use in tall building construction could open up new markets (Prestemon et al., 2015). Life Cycle Assessment to determine carbon footprint may favor wood use in buildings over concrete and steel (Hafner and Schäfer, 2017).

According to the Employment Development Department, employment in wood products manufacturing is expected to increase in coming years, while logging jobs are expected to decrease sharply (EDD, 2019). Tables 8 and 9 below lay out expected employment and economic impacts of ongoing developments in California's forest products industries.

Table 8: Employment Projections in California Wood Products Sector 2016-2026

Industry Title	***2016 Employment Estimate***	***2026 Employment Estimate***	***Change in Employment***	***% Change in Employment***
Wood Product Manufacturing	*23,800*	*25,400*	*1,600*	***6.7%***
Other Wood Product Manufacturing	*16,800*	*18,000*	*1,200*	***7.1%***
Logging	*1,800*	*1,400*	*-400*	***-22.2%***

Table 9: Average annual employment and labor income contributions from CA forest industry, 2016 (UMT, 2019)

Sector	**Direct Employment**	**Indirect and Induced Employment**	**Total Employment Contribution[a]**	**Direct Labor Income**	**Indirect and Induced Labor Income**	**Total Labor Income Contribution[a]**
				----------thousand 2016 dollars--------		
Wood Product Manufacturing	28,685	37,534	66,219	$ 1,374,406	$ 2,061,265	$ 3,435,671
Forestry and Logging	5,266	6,824	12,090	$ 273,460	$ 251,200	$ 524,660
Forestry Support Activities	1,595	627	2,222	$ 105,093	$ 53,009	$ 158,102
Paper Manufacturing	22,345	58,573	80,918	$ 1,886,131	$ 2,834,289	$ 4,720,420
Total Forest Industry	**57,891**	a	a	**$ 3,639,090**	a	a

California's Little Hoover Commission, an independent state oversight agency, investigated the state's forest management challenges and came out with a set of recommendations aimed at addressing these challenges (Little Hoover Commission, 2018). Their recommendations include:

- Make greater use of the 2014 Farm Bill's "Good Neighbor Authority" allowing state agencies to coordinate with federal land managers to conduct forest management treatments on federal lands
- Accelerate use of mass timber construction, primarily through building code outreach to county planners
- Remove financing barriers, creating a finance information clearinghouse on resources and incentives
- Create career pathways based on an assessment of the workforce potential in growing sectors
- A statewide policy that allows for the different needs of different regions and provides grants for local communities to adapt in the way of best fit

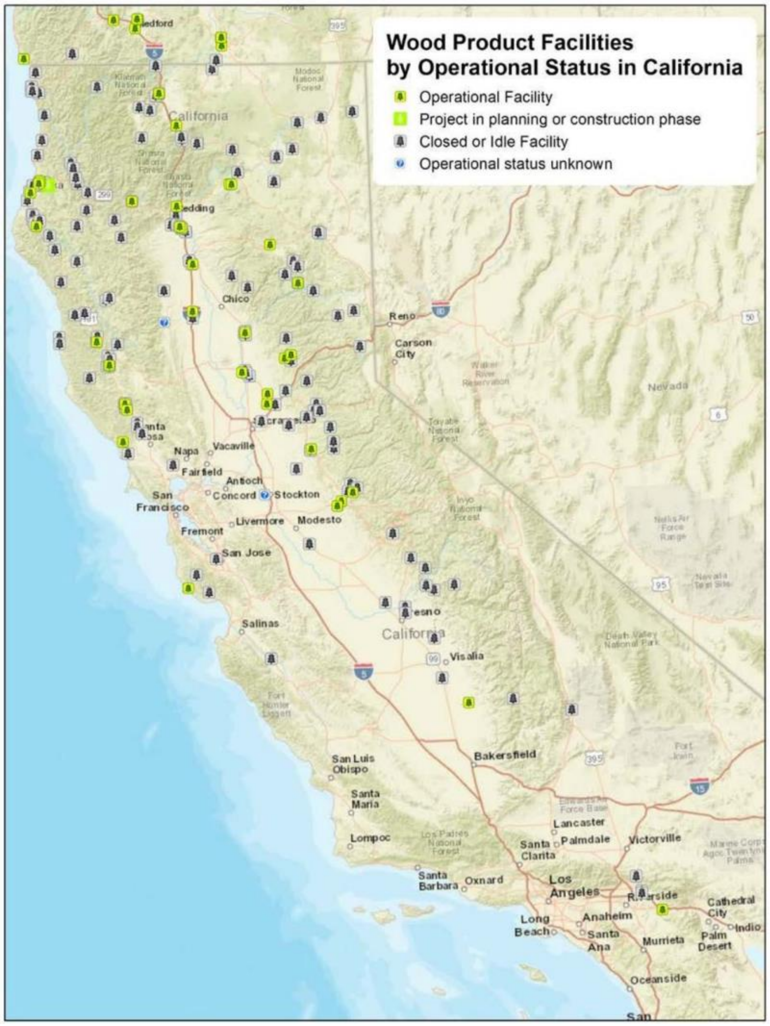


Figure 7: This map shows the location of closed or idled wood product facilities, along with operational or planned facilities (as of June 2017). Formerly active sites offer unique opportunities for redevelopment due to their proximity to abundant forest resources and existing infrastructure. Source: CA Natural Resources Agency (2017)

Recent interest in woody biomass utilization has sparked numerous actions from federal and state agencies. For instance, the USDA Forest Service recently awarded $8.9 million in grants for the Wood Innovation Program with two awards in California going to firms working on mass timber, Karazogian & Case, INC, and FactoryOS. The State of California has also been working heavily on the issue. For example, AB1668 is a bill introduced in the Assembly that would, among other things, create an inmate reentry program through the California Conservation Corps that would provide some of the needed labor if California were to mobilize the existing residue stocks out of the forest.

The vast majority of forestry residuals are left or burned in place. Mill residues, on the other hand, are almost fully utilized. The USDA Forest Service estimates that in the US, 75% of bark at mill sites is used as fuel, and about 23% is used in low-value products such as mulch (USDOE, 2016). 77% of coarse milling residues are used in the manufacture of fiber products, 13% for fuel, and 8% has other applications. 55% of fine residues are used as fuel, 25% as fiber products, and 19% in other uses. Overall under current conditions, only 1.5% of primary mill residues go unused (USDOE, 2016). This means that further development of products from low-value wood would need to draw on the forestry residue base to avoid competing for existing uses of mill residues or roundwood.

The remainder of this section describes in detail some of the many industries and products that could make use of portions of the woody residue base generated by California's forest harvest and management activities. We focus here on wood chips/shavings and mulch, post and pole, wood panel products, mass timber building materials, and finish carpentry/furniture applications. We lay out some environmental and economic characteristics of each of these alternate uses for woody biomass in California.

4.1. Wood chips, mulches, and shavings

Wood chips are a very common co-product of logging practices, being generally sourced from tops, branches, and small diameter logs (Moskalik et al. 2019), as well as being a by-product from mills. Wood chips have a defined length of 5 to 50 mm, and can often contain a number of mineral contaminants which can affect their viability for use in wood products (Moskalik et al. 2019). Chipping is generally the most space-efficient mode of transport of residues, especially from mixed sources. Wood shavings are thinner than wood chips, ranging in thickness from approximately 0.2 to 0.5 mm.

4.1.1. Market characteristics

There are a variety of markets that utilize wood chips, and these uses are restricted by the quality of the chips. Wood chips from residue of a high enough quality can be used to make panels such as Oriented Strand Board (OSB), hardboard, and fiberboard (EPA, 2002). Lower quality wood chips can often be utilized in landscaping and agricultural purposes for bedding and mulch (Chalker-Scott, 2007). Insulation can be made from a composite including wood chips (Brenci, 2016), and chips have also been used in Switzerland and Canada as an alternative to winter road salt (SWI, 2010; CBC Canada 2018) as well as in lieu of herbicides in managing roadside vegetation.

The current lack of pulp mills and suitable wood products manufacturing facilities in California has meant that the major economically attractive use of low-value wood chips has been bioelectricity (Stewart and Nakamura, 2012). The only port in California recently engaging in exports of wood chips is in Eureka, the dock being owned by Simpson Timber and exporting Douglas Fir chips and tanoak chips to Japan (SFP, 2016). In the years 2014 and 2015, this dock exported 48,500 bone-dry tons of chips. Beck Consulting Group (2015) found that chip prices are quite variable, but under some circumstances, such as for use in bio-filtration applications, chips can be sold at up to $80 per BDT.

Table 10: Suppliers of wood chips products in California listed at www.thomasnet.com (Thomas Publishing Company, 2019). Only manufacturers of chip types suitable for forestry residual feedstocks are listed here, rather than those intended for culinary use or other high-end applications.

Company	Location	Primary Markets	Employee Estimates
Mallard Creek, Inc.	Rocklin	Livestock bedding, landscape, fuel pellets, mulch, industrial fibers	unknown
Creative Recreation Systems, Inc.	Gold River, SF, LA	Engineered wood fiber for playgrounds	50-99
Sierra Pacific Industries	Anderson	Bark, chips, mulch, sawdust. Second-largest lumber distributor in the US	5000 (part in CA)
Sun Country Systems	San Jose	Virgin forest wood chips, primarily playground	1-9
Crane Mills	Corning	Bark, Chips, Wood	200-499
Redwood Products of Chino	Chino	Wood shavings and chips for landscaping and amendments	50-99
American Organics	City of Industry	Soil amendments, composite mulch, wood chips	unknown
B & B Pallet	Compton	Wood chips and fiber as a by-product of pallet-making	10-49

Employment figures at firms producing wood chips vary widely, possibly due to factors including the length of time established, market share, and diversification. For example, Sierra Pacific Industries produces a wide variety of wood products, while Creative Recreation Systems, Inc provides product for a very specific market. Where trees are killed by bark beetle infestation and have been standing dead for three years or more, chipping is typically the only viable option because the wood lacks the structure and consistency necessary for other uses (FPL, 2011). These chips have historically been used for bioelectricity and/or combined heat and power applications because of their low value. However, provided that the necessary phytosanitary measures were in place to prevent cross-contamination, they could be put to other uses.

The largest market in the Western US for wood shavings is for use as bedding for horses, demand for which is estimated at 380,000 tons per year (Beck Group, 2015). Bedding materials are considered desirable with higher water-retention capacities, and less desirable when they produce more dust and particulate matter. Relative to wheat straw and newspaper pellets, pine wood shavings were found to have higher dust levels when used as bedding for horses, but did not require as high of a frequency of addition of fresh material as wheat straw (Ward, 2001). Because of their small size and higher surface-to-volume ratio, wood shavings take less energy to refine into pulp for use in paper products than wood chips (Kang, 2010), making them an attractive feedstock for the pulp and paper industry.

4.1.2. Environmental characteristics

Using wood chips as a mulch can have a wide variety of environmental and agricultural benefits. Soil structure, aeration, water retention, erosion, and temperature can all be moderated by the addition of chips (Chalker-Scott 2007). Mulch placed around seedlings can also improve weed control in restoration areas. A key consideration is that chips should be selected from parent material that is local and ideally native to the landscape in which the mulch is applied (Chalker-Scott, 2007). Tannins, suberin, and lignin in the mulch can slow the rate of decomposition, and chip mulch can be applied to capture pollutants. Use as a landscape amendment can include taking the material out of the forest or leaving it in the forest for residue retention. Both methods should be considered for environmental and economic effects.

Manufacture of wood chips and other processed wood products affects air quality in the manufacturing facility impacting workers. This would be equally so with the chipping process in a biomass incineration system. With wood chips, the primary air pollutant produced in the chipping process is particulate matter, which has been reliably linked to pulmonary diseases in humans (Anderson, 2012). All parts of the process of making wood chips yield a degree of particulate matter emissions in the form of sawdust, bark, and mineral dust.

Wood shavings can be added as an element of the aggregate in concrete to decrease density and improve thermal conductivity (Bederina, 2008). While this does result in some lost mechanical strength, not all applications of concrete have the same structural requirements, and the lighter weight of “sawdust concrete” is attractive for many building applications (Smith, 2017). This offers the benefit of reducing the use of highly carbon intensive cement as well as the destructive mining of riverbeds for gravel (Smith, 2017).

4.2. Post and pole

Out of all residue types, small-diameter stemwood is most conducive to manufacture into posts and poles. If value-added, economical pathways can be found for this material, forest restoration costs can be offset (Livingston, 2004). Some small-diameter timber uses under the post and pole category include fencing, guard rails, signage, log homes, pilings, and certain classes of utility poles. As described in section 2 of this report, markets for post and pole primarily call for lodgepole pine, Douglas fir, white fir, and ponderosa pine. We estimate that between 48,000 and 91,000 tons of forest residues suitable in size and species for this market are currently being generated annually from commercial harvest on California forestlands. New fastening systems allow for small diameter roundwood to be utilized in the construction of small structures as poles, rather than chipped and manufactured into panels (Livingston, 2004). This has been found to provide a cost offset to thinning operations. Roundwood retains strength, resists warp, maintains stability, and minimizes processing costs. Beaudette Consulting Engineers in Montana developed detailed plans for kiosks and small structures made from roundwood (Livingston, 2004).

4.2.1. Market characteristics

The primary preferred species for post and pole manufacturing is Lodgepole pine, *Pinus contorta,* which presents an issue for California manufacturers as Lodgepole pine is not as prevalent as in other areas of the country (Beck Group, 2015). In 2001, the value of material produced by the one pole manufacturer in the state, and the three chemical treating plants, was $83 million in treated and untreated poles (Beck Group, 2015).

Table 11: Size distribution and market value for post and pole production in the Western U.S. Data source: Beck Group, 2015

Size class (inches diameter)	Percent of Production	Treated price (per lineal ft)	Unreated price (per lineal ft)
2.0 to 2.9	13%	$0.36	$0.33
3.0 to 4.9	56%	$0.60	$0.49
5.0 to 6.9	26%	$1.12	$1.02
7.0 and larger	5%	$1.84	$1.75

According to the Beck Group, capital investment in a typical post and pole plant ranges between $750,000 and $1.5 million, with lower capital investments being associated with increased labor costs. California plants would have significant transportation cost advantages over plants in producer states including Oregon, Washington, Idaho, Montana, and Canada.

4.2.2. Environmental characteristics

There are two general categories of commercially available posts and poles, treated and untreated. As with almost any milling process, particulate matter emissions must be monitored, but treated poles create other potential environmental hazards. Treated post and pole products are manufactured by applying a preservative to untreated material, with or without a pressure treatment process. Historically, the treatment process has been associated with creosote or arsenic, but newer compounds have been evaluated and found to have lower toxicity profiles, although they continue to be reviewed under the Federal Insecticide, Fungicide, and Rodenticide Act of 1910 (EPA, 2017).

Pentachlorophenol and creosote are preservatives that are currently restricted to use in utility poles and railroad ties. Guardrails, utility poles, and fences can be treated with triadimefon. Alkaline copper quaternary is a fungicide and insecticide that can treat utility poles, landscape ties, pilings, and fence posts. Copper azole is a fungicide and can treat fence posts, building and utility poles, and pilings. Copper – HDO can be used to pressure-treat rails, spindles, gazebos, fencing, and posts (EPA, 2017). Any manufacture of treated wood products in California will have to be closely regulated and monitored to ensure that use of toxic preservatives is minimized and emissions are entirely avoided.

4.3. Fiberboard, particleboard, and oriented strand board

Any woody material of suitable quality can be manufactured into fiberboard or particleboard sheet products of varying characteristics. This includes small diameter logs of the type present in forest residues (Beck Group, 2015). Particleboard or fiberboard not intended for structural applications is inexpensive and has larger tolerance for impurities in the feedstock.

Fiberboard is a non-structural panel used in interior applications and furniture. Low and medium density fiberboard can be insulators, where higher density fiberboards are utilized in applications requiring solid faces like indoor walls and furniture. Applications in repair and renovation have help fiberboard retain market share even through downswings in new construction such as during the 2008 financial crisis (Prestemon et al., 2015).

First developed in 1965, oriented strand board (OSB) is a structural panel material with applications comparable to those of plywood. It is built of 3 layers of strands of wood chips bonded by resin, with outer layers stranded perpendicular to the direction of the center layer. Testing conducted by Benetto et al. (2009) found that this structure leads to strong mechanical properties, with uses in wall sheathing, roof panels, subfloors, single-layer floors, structural insulated panels, floor joists, and rim boards. Some furniture and packaging sectors also utilize OSB as a structural base (Prestemon et al., 2015).

4.3.1. Market characteristics

Oriented strand board currently averages 45% less expensive than plywood products used for similar applications. Because it is inexpensive but structurally effective, the market for this versatile building material has grown significantly and is expected to continue growing. The global market for oriented strand board stood at an estimated USD 11.3 billion in 2017 and is expected to grow at 14.3% from 2018 to 2025 (Grand View Research, 2019). OSB use in the US has increased faster than growth in domestic production, leading to increased import of panel materials since the 1990s (Prestemon et al., 2015). OSB exports have represented less than 5% of total domestic production since the early 1990's, and imports have historically been higher than exports of particleboard products in the US (Figure 8). Creation of OSB manufacturing facilities in the western US would enable sourcing of domestic building products in place of imports.

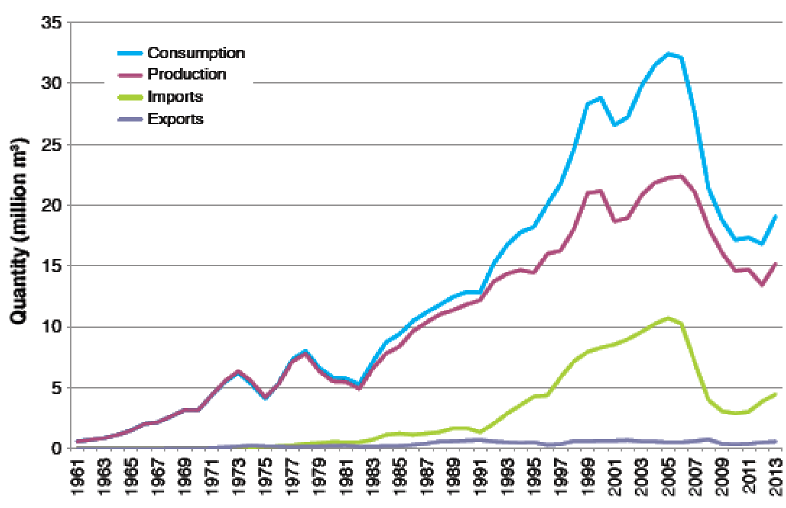


Figure 8: Consumption, Production, Imports, and Exports of Particleboard in the US from 1961-2013 (Prestemon, 2015)

As of 2015, the nearest OSB plant to California was in British Columbia. Transport costs from the British Columbia plant are estimated at $35 per thousand square feet, and upwards of $58 per thousand square feet from a Texas plant (Beck Group, 2015). A new OSB manufacturing facility would experience a clear advantage in transport costs over existing suppliers in most California building markets (Beck Group, 2015). Existing mills can be easily retrofitted to make OSB-quality strands rather than pulp-quality chips, enabling existing infrastructure to shift towards OSB production.

		Average Trucking Cost From Anderson, CA	Average Trucking Cost From TX	Average Freight Advantage Over TX	Average Trucking Cost From BC	Average Freight Advantage Over BC
Primary Market Area	Central California	10	61	**51**	45	**35**
	Northern California	5	63	**58**	40	**34**
	Southern California	20	52	**32**	54	**34**
Secondary Market Area	Arizona	31	40	**9**	62	**31**
	Nevada	14	55	**41**	45	**30**
	Southern Oregon	8	72	**64**	32	**24**
	Northern Oregon	15	75	**60**	25	**10**

Figure 9: Estimated Freight Advantage of a California OSB plant ($/thousand ft^2 3/8" basis) From Beck Group, 2015

4.3.2. Environmental characteristics

Manufactured panel products can carry significant environmental concerns, especially due to the dust and chemicals associated with their manufacture. Emission of VOCs and the use of phenols and formaldehyde in manufacture generates an odor and can impair air quality with effects including throat irritation and increased cancer risk. Chlorophenols have been shown to affect the liver, and are listed as a possible carcinogen (ATSDR, 1999). The EPA standard set in 2016 for formaldehyde limits emission at 0.09 ppm in particleboard plants (EPA, 2016). There have been innovations that improve the ability of plants to offset these pollutant emissions—for example, there is potential for an "ecodry" process to offset VOC emissions from baseline by 30% (Benetto et al. 2009). Further, California-based Noble Environmental Technologies has developed a 100% bio-based material called ECOR that they claim is manufactured without chemical additives and can be used for a variety of applications in place of OSB and particle products.

Oriented strand board, particleboard, and similar products can be manufactured with a wide array of potentially-toxic chemicals and materials including chlorophenols, arsenic, chromium, and copper – which can often accumulate at mill sites and in impacted wildlife for years after closure (Lyytikainen, 2001). This bioaccumulation process is especially prevalent with heavy metals. Any development of panel material production in California would need to be accompanied by rigorous planning and oversight to prevent contamination. The full list of pollutants that the EPA has found to have the potential to be released by composite wood manufacturing is as follows (EPA, 2003):

- acetaldehyde
- acetophenone
- acrolein
- benzene
- biphenyl
- bromomethane
- carbon disulfide
- carbon tetrachloride
- chloroform
- chloroethane
- chloromethane
- cresols
- cumene
- ethyl benzene
- formaldehyde
- hydroquinone
- methanol
- methylene chloride
- methylene diphenyl diisocyanate (MDI)
- methyl ethyl ketone (MEK)
- methyl isobutyl ketone (MIBK)
- n-hexane
- phenol
- propionaldehyde
- styrene
- toluene
- xylenes
- 1,1,1trichloroethane
- bis-(2-ethylhexyl phthalate)
- 4-methyl-2-pentanone
- di-n-butyl phthalate

4.4. Mass timber

Mass timber is defined by the Engineered Wood Association as prefabricated wood built of more than three layers of either sawn lumber or structural composite lumber, where adjacent layers are oriented perpendicular to one another, and bonded with either dowels, structural adhesives, or nails to create a complete wood panel. The mass timber category includes such products as cross-laminated timber (CLT), nail-laminated timber (NLT or Nail-lam), glued-laminated timber (glulam), dowel-laminated timber (DLT), structural composite lumber (SCL), and wood-concrete composites (Yard, 2015). Table 12 below describes these types of mass timber materials in detail and provides use categories and code environment where available.

Table 12: Adapted from American Wood Council – Mass Timber in North America

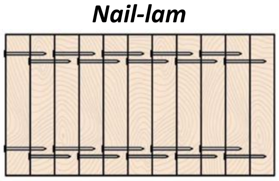
Type of Mass Timber	Manufacturing	Use Categories	Code Environment
Cross-laminated Timber  Photo: AWC	Generally made of three, five, or seven layers of dimensional lumber, with the grain of the layers oriented at right angles. Can be manufactured in custom panels.	Particularly effective for large buildings and multistory applications. CLT is suited to floors, walls, and roofs. Two-way span capabilities. Aesthetics are pleasant when left exposed.	2015 International Building Code (IBC) recognizes CLT made to the ANSI standard, for Type IV buildings. Can be used in all types of construction, where timber framing is allowed.
Nail-lam  Photo: woodworks.org	Typically made from dimensional lumber (2-by-4, 2-by-6, etc.), stacked by edges, fastened by screws or nails to create a larger panel or structural element.	Nail-lam is a century-old technology, commonly used in decks, floors, roofs, and various exposed applications. Stair and elevator shafts in mid-rise wooden-frame buildings.	IBC has recognized Nail-lam and provides guidance for fire safety and structural design. No ANSI/APA standard is required. All types of combustible construction.
Glulam	Dimensional lumber, chosen and positioned for	Strength and stiffness properties, available in	IBC accepts glulam designed according to

 *Photo: APA*	performance, bonded with moisture-resistant, durable adhesives.	many grades of appearance for architectural and structural properties. Flexible manufacturing can create unique and complex geometries.	standard in ANSI A190.1-2012.
Dowel-Laminated Timber  *Photo: StructureCraft*	Softwood dimensional lumber boards stacked like NLT and fit together by friction with dowels. Dowels generally made of hardwood lumber, offer lateral strength.	Commonly used in Europe. Acoustic strips can be integrated directly into the bottom of a panel, to improve acoustic properties.	No prescriptive code path under 2015 IBC. Authorities with jurisdiction must approve on a case-by-case basis.
Structural Composite Lumber	Built of layers of graded and dried wood veneer, flakes, or strands over moisture-resistant adhesive and sawn to size.	Laminated Veneer Lumber (LVL) and Laminated Strand Lumber (LSL), in panels up to 8 feet wide. Parallel Strand Lumber (PSL) can be used in columns.	APA product reports available to provide specifications and design capacities. ICC-ES provides evaluation reports.
Wood-Concrete Composites	Panels can be built with a layer of concrete on top of CLT.	Very long spans, wood high-rises, and other specific requirements.	Unknown.

Because they are made with cross-laminated lumber, mass timber products exhibit superior structural properties. 2016 testing conducted by the US Department of Defense in collaboration with the US Forest Service showed mass timber to exhibit “acceptable levels of damage under significant explosive loading” sufficient for its use in blast-resistant construction. This is due to the inherent flexibility of wood products, a property which also makes them ideal for many applications in California’s earthquake-prone landscape (Sierra Institute, 2019).

CLT, as a mass timber product poised to be used as replacements for steel and concrete, has been raising questions surrounding its fire safety (AWC, 2015*).* According to the American Wood Council, CLT has an “impressive ability to meet two and three hours of fire resistance,” but due to builders’ preconceptions, awareness of its actual fire performance has been “overshadowed by concerns about its combustibility.”

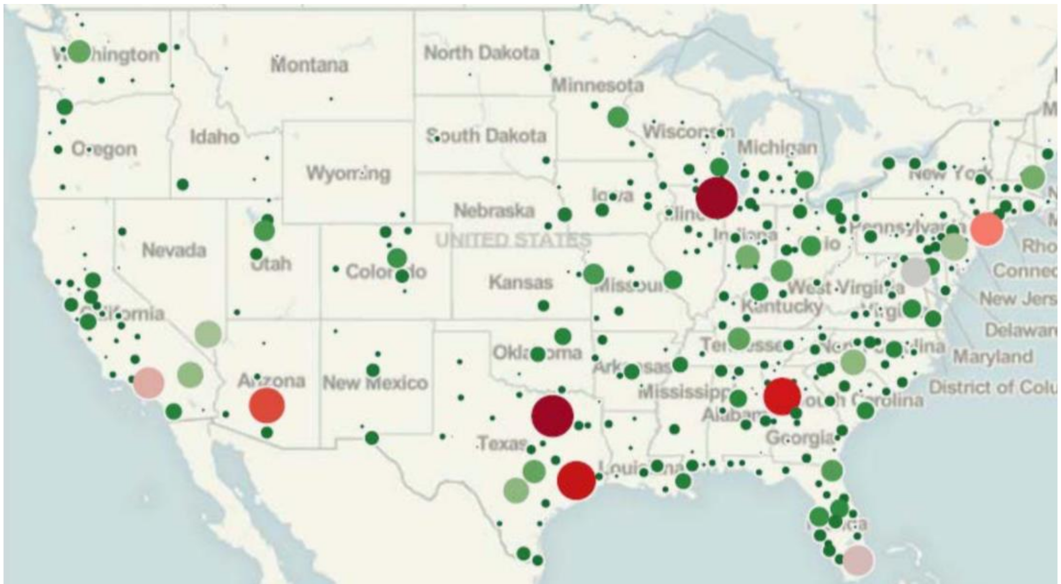


Figure 10: Key US construction markets for CLT. The size of each circle is proportional to construction market size; greener circles represent markets that are more economically conducive to CLT as a product due to transport and growth factors. Image source: FP innovations (2011)

4.4.1. Market characteristics

As of 2014, 90% of worldwide CLT production was in Europe (FAO, 2014). However, the US market has been developing rapidly. I-joists, a type of engineered wood used for structural support, were used in 31 percent of single-family construction in 1998, increasing to 50 percent in 2009 (Prestemon et al. 2015). Forest products industry leaders in California have been anticipating a growing market for CLT in the state for some time, and this market is beginning to develop as building codes are updated to respond to continuing research on the performance of this material. Several buildings with significant CLT elements have recently been completed or are underway, including the new Brentwood public library, built using prefabricated CLT wall and floor panels (Sierra Institute, 2019). Further, Microsoft recently announced plans to use CLT to construct its new Silicon Valley campus in Mountain View, which will be the largest mass timber building in the US (Microsoft, 2019).

California’s forest products industry and construction markets make it well-suited to mass timber manufacturing. Softwood-dominant forests, including small diameter and beetle-killed trees as well as limited opportunities for rural development in forested regions make mass timber manufacture an economically attractive proposition in the state (Sierra Institute, 2019). Also, California buildings need to be constructed and retrofitted to meet stringent seismic standards, making CLT a promising choice, because CLT buildings up to 7 stories tall have been found to test well for seismic resistance. Code adoption has begun in the US, and is becoming more widely specified.

Domestic production of CLT is currently limited. As of 2015, there were only 3 CLT manufacturers in North America, and only one in the US. Montana’s SmartLam corporation, plans to build a facility that will require 50 million board-feet of lumber per year. (Beck Group, 2015). However, California markets and production potential are being stimulated by policies such as SB 859, which promotes the development of advanced wood products in the state. It is notable that the Scandinavian region has seen strong development in its mass timber industry, spurred in large part by policy support and progressive building code adoption.

An example of promising economic activity in this space is the new cross-laminated timber production facility being developed in Tracy by Katerra, with associated job creation and investment. The fact that this construction technology company, headquartered in California had raised $4.1 billion in venture investments and had a $3 billion project backlog as of January, 2018 (Kolodny, 2019) is an indication of the market potential for this type of wood use in the state. Development of a new CLT facility is estimated to have a capital cost of $15-30 million (Beck Group, 2015).

One point of concern is that mass timber production currently relies primarily on dimensional lumber. While this can be drawn from smaller-diameter material than conventional sawlogs, it does raise concerns about the potential for this market to make use of many forest management residues (Sierra Institute, 2019). This use would probably need to be incorporated as part of an integrated wood-utilization campus with varying applications for residues of different size and quality.

4.4.2. Environmental characteristics

Mass timber has been seen as an alternative to conventional construction abating the toxic pollution emissions that can occur from the manufacture of other structural products (Crawford and Cadorel, 2017). Prefabrication of panels may reduce transportation-related pollution due to reducing total trucking miles for a construction project (Inverse, 2018). CLT, like glulam, utilizes polyurethane, melamine, and phenolics as adhesives (NC State, 2019). As with OSB, this would indicate that manufacture and use of these panels emits VOC's, formaldehyde, and phenols among other pollutants. However, polyurethane can also be used effectively as it does not contain formaldehyde and reduces the overall amount of adhesive needed to manufacture panels. (Messmer, 2015).

Some mass timber products can also be made from beetle-killed trees as is the case with the new Microsoft campus in Mountain View (Microsoft, 2019). While most beetle-killed trees would be infeasible and ecologically destructive to remove, some are falling hazards to homes and infrastructure. Further development of the mass timber industry would offer an economically attractive use for the beetle-killed trees that need to be removed. The BioMAT program was initially introduced to respond to this acute circumstance of tree mortality, but has struggled to stimulate facility development because of the marginal economics. Mass timber manufacture from these materials would offer an avenue for their use without relying on incineration.

4.5. Furniture and finish carpentry

Pine is a common wood for furniture mass production as it is inexpensive, lightweight, strong, and easy to process. Furniture products often also contain particleboard, OSB, High-density, or

Medium-density fiberboard (Danilova, 2016). Wood destined to become furniture is often required to be of a high aesthetic quality and uniform grain, but this does not have to be required, as tastes can change. An in-person survey of potential furniture buyers found character marks on doors to be unimportant to 73 percent of those surveyed (Jahn, 2001).

A budding market opportunity has been the utilization of beetle-killed wood, also called “blue stain” or “blue denim” wood in furniture and finish carpentry applications. Pine bark beetle infestations are accompanied by a fungus which stains the wood a blue to black to gray color (Popular Woodworking, 2015). This fungus is killed during the kiln-drying process (RMFP, 2019). Blue stain pine is considered by many an attractive option for siding and flooring, cabinetry, as well as for furniture manufacture. It gives a “distressed,” rustic appearance that furniture and finishing suppliers sometimes otherwise replicate artificially with conventional staining (Woodworking Network, 2018). This material can also be painted and sometimes stained, which could negate differences in appearance versus traditional sources of building pine material.

Policy support for the use of blue stain pine in finish carpentry and furniture applications could support significant removal of beetle-kill trees that are serious falling risks for homes and infrastructure. This would offer an efficient avenue for reducing risk without propping up incinerators.

4.6. Climate performance of alternate residue pathways

To evaluate the full climate impacts of a product or process, researchers apply the concepts of life cycle assessment (LCA). This is how “carbon footprint” or “embedded carbon” values are rigorously calculated. Using this technique, Hafner and Schäfer (2017) found that construction of single-family homes using wood for structural purposes where possible reduced total GHG footprint by 35% compared to brick and 56% compared to concrete.

As trees grow, they absorb carbon in the form of CO_2 from the atmosphere and sequester it in their biomass. 1 ton of dry wood represents over 1.8 tons of CO_2 removed from the atmosphere. The best outcome from a climate standpoint is, of course, to leave the tree growing and sequestering carbon into the future. However, this report is focused on residues from existing forest management, so the relevant question is how the carbon footprints of the alternatives discussed here compare to incineration.

When forest management residues are incinerated, the carbon they have sequestered as they grow is immediately released to the atmosphere. If the biomass is instead manufactured into durable wood products, the carbon in the wood remains sequestered for at least the lifetime of that product reducing near-term climate change. The wood products discussed in this report all carry some carbon footprint from the form of fossil carbon released in the transportation and industrial processing involved in their manufacture. However, these emissions are typically much smaller than those from incineration of the same residue. For example, Benetto et al (2009) estimated the life-cycle emissions associated with OSB manufacture at approximately 325kg CO_2e/m^3, which is about 760 kg CO_2e/ton. Since that same ton of residues would have emitted about 1.8 tons of CO_2 if combusted, this represents *a net emission reduction of over 1 ton of CO_2 per ton of residues diverted from incineration to OSB manufacture*.

All of the products discussed in this report have lower net carbon intensities if a higher percentage of the product is able to be recycled at end of life. This is of course not possible for biomass that is incinerated. For instance, at the end of the lifespan of a CLT-constructed building, a significant fraction of the CLT it contains can be recycled or reused. Liu et al. (2016) found that if 90% of CLT is recycled into the next project, carbon emissions are reduced by more than 46% from baseline. When CLT is also being used as a substitute for products with large GHG footprint and low recyclability such as concrete or brick, the net emissions abatement becomes even more significant.

5. Conclusions

Biomass incineration is not the only option for making use of the residues from forest management in California. It is hugely polluting, unnecessarily expensive, and does not effectively promote good forest management. The alternate uses for these residues discussed in this report will lead to much less air pollution and greenhouse gas emissions than biopower, while also offering more attractive economics and opportunities for rural development. It would take creative policy implementation to facilitate the development of these alternate wood product supply chains here in California, but it is a necessary step.

The implicit assumption behind policy supports for biomass incineration is that they will promote forest treatment in service of restoration, fire management, and climate objectives. There is little evidence of that happening at present, in large part because forest restoration and fire management activities cost between $500 and $2000 per acre treated (Sierra Institute, 2019) and the price offered for residue is not nearly sufficient to offset this cost. Of the $115/MWh paid for power in the BioRAM program and $200/MWh in BioMAT, about $60 at most is going to forest operators. This is barely more than the cost of residue mobilization in many cases. **These subsidies are propping up the biomass incinerators, not supporting forest management.**

In this report, we conservatively estimate that the BioRAM and BioMAT programs—once BioMAT is fully enrolled—will cost Californians an additional $116 million per year on our electricity bills. This expense is not coming directly from the state coffers, but is a cost borne by Californians nonetheless. This subsidy to the biomass incineration industry amounts to about $134 per ton of forest residues mobilized from the field. Policymakers should carefully consider whether a comparable subsidy to a higher-value or lower cost user of biomass could generate better environmental *and* economic outcomes for Californians.

The alternatives outlined in section 4 of this report are all viable options for residues from forest management given the right economic and policy environment. Furthermore, they can be combined to develop nimble, regionally appropriate, scalable wood products industries. So-called "cascading" use of residues gives priority to the most economically and environmentally beneficial use of each type of raw material. For example, beetle-killed "blue stain" pine can be used for furniture and finish carpentry, small trees or tops for post and pole and mass timber applications, and smaller-diameter residues for wood chip and panel material manufacture.

State policy should not be promoting an expensive, dirty, and outdated technology. If the goal of biopower subsidies is residue removal, then this outcome could be subsidized directly to allow the market to determine which are the most cost-effective use cases for this low-value wood resource. If the goal is GHG reduction from forest residues, the support could be targeted at this outcome, with the subsidy tied to the level of emission reduction rather than the mass of material consumed.

Any residue removal supports should also carry rules and incentives built to ensure that the environmental goals underpinning the policy are in fact being achieved. One key step would be requiring that life-cycle GHG and air pollutant impacts of any biomass utilization project be calculated and that these meet thresholds set to aid California in meeting its climate and air quality targets. Climate is not the only impact of concern, and broader environmental performance must also be ensured by establishing sourcing requirements for wood products facilities using residues. Best practice guidelines could ensure biodiversity, soil conservation, and watershed stewardship goals are met on any landscapes from which residues are sourced, and third-party certification by entities such as the Forest Stewardship Council and the Roundtable on Sustainable Biomaterials can be an effective tool for providing these assurances.

The status quo of biomass incineration is not promoting sustainable forest management or fire risk mitigation. Subsidizing the incineration of what could otherwise be a renewable resource indicates a lack of vision and creative thinking among policymakers in Sacramento. Wood products such as those discussed in this report can be developed as part of integrated, regionally appropriate systems making the best use of each residue type instead of sending them to the incinerator. These systems stand to nearly eliminate criteria pollutant emissions from residue utilization while also sequestering carbon and delivering robust, sustainable economic development to the California communities hardest hit by climate change. It is time for California to lead the world in *moving beyond incineration.*

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This report published by:

Sierra Club California
909 12th Street, Suite 202
Sacramento, CA 95814

Acknowledgements:

Based on research, commissioned by Sierra Club California, conducted by Dr. Kevin Fingerman, Dylan Anderson, and Max Blasdel.