Energy Use and Emissions by the California Sawmill Sector, 2016

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California legislation aims to cut greenhouse gas (GHG) emissions while continuing to grow the economy. The California Global Warming Solutions Act of 2006 (AB 32) requires that the State make sharp cuts in emissions so that by 2020 GHG emissions are what they were in 1990 (CARB 2014). California's GHG emissions in 1990 were 431 million metric tonnes (MMT) of carbon dioxide equivalent (CO2e); emissions peaked in 2004 at 486 MMT of CO2e (CARB 2007, 2018). California's emissions in 2016 were 429 MMT of CO2e, nearly 6.6 percent of the total US GHG emissions (US EPA 2019). This analysis takes a closer look at how the California sawmill industry's on-site energy consumption contributed to emissions during 2016 by quantifying the emissions of selected GHGs and criteria pollutants and by quantifying the quantities and types of energy used on-site at sawmills.

Methods

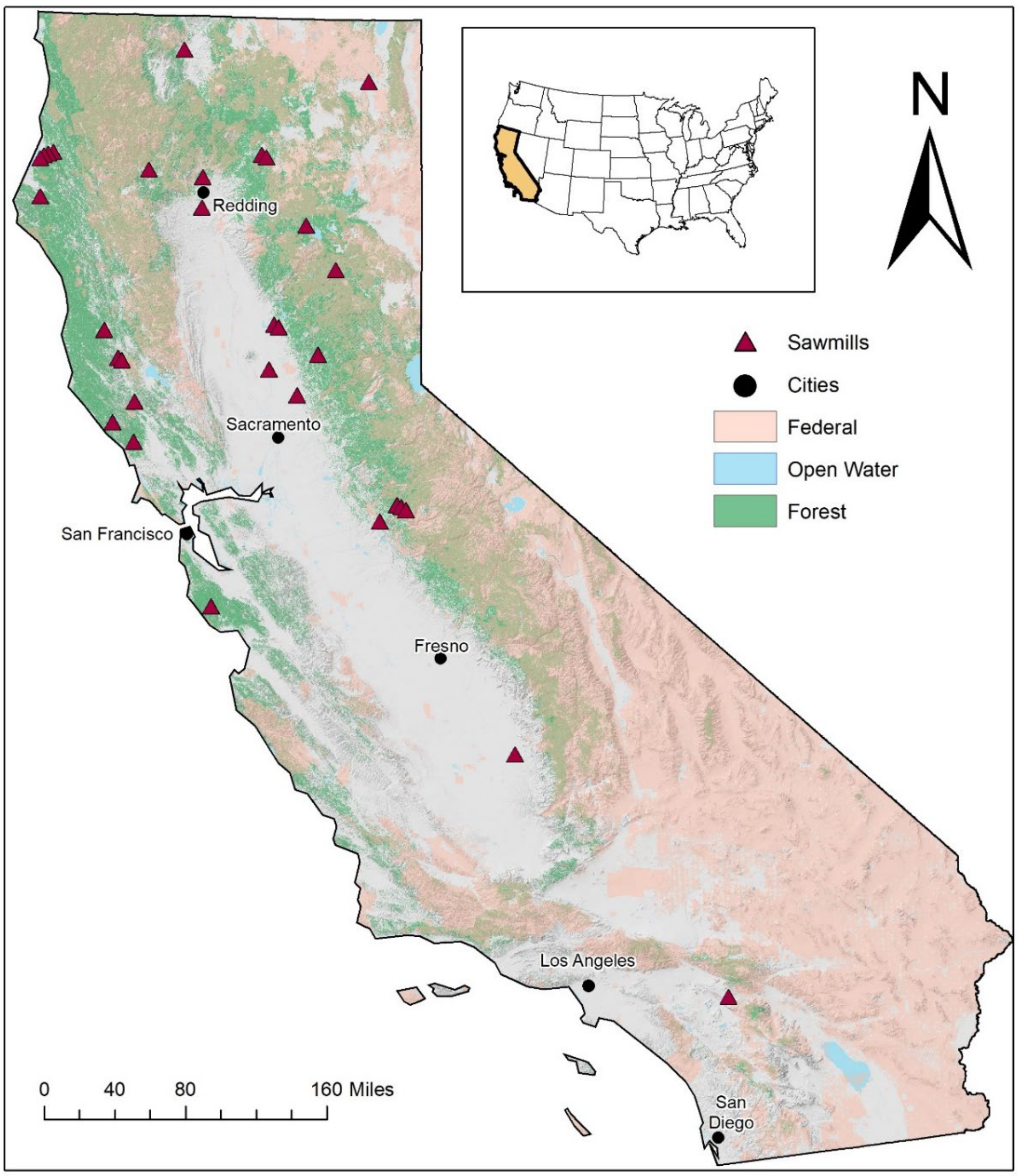
This analysis focuses on energy use by the sawmill industry in California, and follows the methods of Loeffler et al. (2016a, b). To analyze the California sawmill sector's energy consumption and GHG emissions, we collected and analyzed energy consumption data from California sawmills operating during calendar year (CY) 2016. Detailed timber harvest and use, lumber production and sales, and mill residue disposition information were also collected from sawmills (and other primary wood products industry sectors) in California for CY 2016 activities (Marcille 2019, Marcille et al. in prep.). This research synthesis allows for direct comparison of onsite energy consumption with production of lumber at sawmills.

Study area

California is the most populous state in the US. During 2018, an estimated 39.3 million people resided in California (CA DOF 2019). Total energy production in 2016 for California was the tenth largest in the US at 2,431.1 trillion British thermal units (Btu), 7 percent of US electricity production was in California (US DOE 2019); and total energy consumption in California was the second largest among the states at 7,830 trillion Btu, behind Texas. Interestingly, per capita energy consumption was the fourth smallest in the US at 199 million Btu, and approximately 38 percent was from renewable energy sources (US EIA 2019a).

California contains approximately 99.6 million acres of land area, and approximately half is federally owned (Figure 1; Yang et al. 2018). California has 31.7 million acres of forest, and 39 percent is privately owned, with the remaining forestland publicly owned, primarily by the US Forest Service, which controls about 15.3 million acres (USFS 2019).

Figure 1— Sawmills, federal and forest land in California.



Of the 80 primary wood product facilities operating in California during 2016, 32 were sawmills (Marcille et al. in prep.). By comparison, in 1968 there were 216 sawmills operating in the state (Barrette et al. 1970, Morgan et al. 2004). Sawmills accounted for about two-thirds ($984 million) of primary wood products industry sales value, producing 2,022 million board feet (MMBF) of lumber from approximately 1,235 MMBF Scribner of sawlogs during 2016 (Marcille et al. in prep.).

Survey

The University of Montana's Bureau of Business and Economic Research (BBER) has conducted periodic censuses of the primary wood products industry in California (Morgan et al. 2004, 2012, McIver et al. 2015, Marcille et al. in prep.) since 2000 on behalf of the USDA Forest Service's Forest Inventory and Analysis (FIA) Program. FIA reports timber products output (TPO) information for the entire US. The California Department of Forestry and Fire Protection (CalFire) requested an analysis of sawmill energy use similar to previous studies in Montana (Loeffler et al. 2016a) and the US Southwest (Loeffler et al. 2016b) in conjunction with the California TPO effort for CY 2016. California's sawmill industry responded to a statewide survey designed to collect information about the energy used on-site, the industry's contribution to renewable energy production through the use of woody biomass used on-site, and the industry's use of renewable and non-renewable energy from electricity purchased from utilities.

The energy survey asked for each sawmill's consumption of diesel, gasoline, and propane for on-site rolling stock; consumption of wood and bark, natural gas, heating oil, and propane for heat and steam; consumption of electricity, including power purchased from electrical utilities; and on-site electricity generation (for example, co-generation) with associated fuels required.

Sawmills consume an enormous amount of electricity (Bond 2008, Lin et al. 2012, Loeffler et al. 2016a,b, Quesada-Pineda et al. 2016), and California is the nation's fourth largest hydropower producing state, generating 9 percent of the US total (US EIA 2019b). The survey also asked for each sawmill's electricity provider (i.e., utility). This information was used to determine the proportions of electricity in each provider's energy portfolio produced from various sources, including fossil fuels and other non-renewable energy, and renewable energy sources such as hydroelectric, biomass, wind, and solar.

The survey captured on-site energy consumption from 16 of the state's 32 sawmills operating during 2016, which is a response rate of 50 percent. However, the 16 sawmills from which survey data were collected represented 86.8 percent of the state's sawlog harvest and 92.1

percent of lumber production in California during 2016. In this analysis, only on-site energy consumption (i.e. fuel consumed inside the gate) of each sawmill is considered, as well as the electricity used on-site but generated and delivered by utilities. We exclude energy used off-site, such as energy used for timber harvesting and transportation of raw materials (i.e., logs) and transportation of finished goods (i.e., lumber). Data from the surveys are summarized to ensure confidentiality of firm and facility level information.

Energy content of sawmill fuels

California sawmills consume a variety of fuels, both renewable and non-renewable. For each sawmill responding to the survey, the quantity of energy consumed on-site and associated emissions were calculated from the quantities of each type of fuel reported as used by the mill, using the assumed energy contents (Table 1) published by the US Energy Information Administration (US EIA 2019c). All fuels were categorized as either renewable (e.g., wood, bark, wind, solar, hydroelectric, geothermal) or non-renewable (e.g., fossil fuels, nuclear, and contract electricity).

Table 1. — Assumed energy contents per unit of fuel

Fuel	Unit	MMBtu/unit[a]
Diesel	Gallon	0.1374
Gasoline	Gallon	0.1205
Propane	Gallon	0.0913
Electricity	Kilowatt hour	0.0034

[a] MMBtu = million British thermal units.
Source: US EIA 2019c

Electricity is generated from many sources including fossil fuels, wind, solar, hydroelectric dams, geothermal sources, and nuclear. Wood and bark can also be burned to create heat and steam for generating electricity. Electricity providers often acquire contract power that they purchase but did not generate. The origin of contract power is unknown and considered non-renewable in this analysis, although some contract electricity is likely from renewable sources. Therefore, we likely underestimate total electricity produced from renewable sources. The State of California considers hydroelectric dams greater than 30 MW non-renewable (SB 350), but for consistency with previous studies (Loeffler et al 2016 a, b) this report combines small and large hydroelectric dams and categorizes them both as renewable.

Sawmills generate large amounts of wood residues in the form of coarse residue (e.g., chips), fines (e.g., sawdust, shavings), and bark that can be sold, converted into products or used for fuel to fire boilers (Blatner et al. 2012). In contrast to other regions such as the southwest US, where lumber is dried with the atmospheric heat and ambient aridity (Loeffler et al 2016b), many of California's sawmills use energy-intensive dry kilns (Wengert and Meyer 1992, Bond 2008). When wood and bark are used for energy, moisture must be accounted for because of its impact on heating value (Jenkins et al. 1998). To account for moisture content in wood and bark residues with regard to heating values, a weighted average was calculated from the most harvested species. Moisture contents and higher heating values were from Wilson et al. (1987, 2010), and species information was from Marcille et al. (in prep.). The six most harvested tree species in California during 2016, and their proportion of total harvest, were true firs (*Abies spp.*; 27 percent), Douglas-fir (*Pseudotsuga menziesii*; 24 percent), ponderosa pine (*Pinus ponderosa*; 23 percent), redwood (*Sequoia sempervirens*; 14 percent), sugar pine (*Pinus lambertiana*; 7 percent), and incense cedar (*Calocedrus decurrens*; 3 percent). Moisture contents and heating values (i.e., Btu per dry pound) used in this analysis are presented in Table 2.

Table 2. — Assumed moisture contents and higher heating values for wood and bark.

	Percent moisture content (wet basis)		Higher heating value (Btu/dry lb)	
Species	Wood	Bark	Wood	Bark
White Fir	56.9	26.7	8,795	9,641
Doug-fir	33.7	51.6	8,759	10,125
Ponderosa Pine	52.4	21.8	9,120	9,717
Redwood	53.5	12.2	9,030	8,350
Sugar pine	57.8	46.8	8,600	8,600
Incense cedar	51.9	20.0	8,900	8,900
Wt. Avg.	49.7	30.7	8,884	9,490

Source: Wilson et al. 1987, 2010

Forest operations to harvest sawlogs can generate large amounts of logging slash, which are the unmerchantable tree tops and limbs from larger trees and small unmerchantable diameter trees cut as part of the silvicultural prescription (Morgan and Spoelma 2008, Oswalt et al. 2019). Slash can be left in the forest or transported to a facility and used. Slash that is not used but is left in the forest or at the landing deck (i.e., where log trucks are loaded) is referred to as "logging residue." In the western US, logging residue is typically disposed of by broadcast burning or burning slash piles. Slash that is taken to a facility and used as fuel is referred to as "woody biomass" or "fuelwood."

The quantities of logging residue generated during the harvest of sawlogs received by the 16 responding sawmills were estimated using the same methods used for California in the national TPO database, including logging utilization studies (Morgan and Spoelma 2008, Simmons et al. 2014, BBER 2019) as well as tree component (e.g., limbs and tops) and whole-tree volume information (Van Hooser and Chojnacky 1983). These estimates were used to identify amounts of logging residue potentially available for woody biomass energy production and possible emissions from assuming all logging residue is burned in-forest.

Emissions factors

In California, facility level emissions are available from the Air Resources Board in carbon dioxide equivalents (CO2e) but do not include emissions from all energy sources consumed on-site (ARB 2019). Many of the facilities (i.e., sawmills) in this analysis were not required to report any emissions under the Mandatory Reporting Regulations; only forest products facilities using "forest-derived wood and wood waste" for electricity generation were required to report emissions in CO2e. In this analysis, quantities of selected emissions were estimated following the methods of Loeffler et al. (2016a, b). The emissions quantified include carbon dioxide (CO2), methane (CH4), particulate matter less than or equal to 10 micrometers (PM10), nitrogen oxides (NOx), and sulfur oxides (SOx) – from all fuels used on-site and from fuels used off-site to generate the electricity delivered to the facility through utilities. Both on-site fuel consumption emissions and off-site electricity production emission were estimated from fuel energy contents (Tables 1 and 2) and US Environmental Protection Agency (US EPA 1995) emission factors (Table 3). Contract electricity was assumed to have the same emissions as natural gas.

Table 3. — Factors used to estimate emissions from California sawmills, 2016.

Fuel	CO_2	CH_4	PM_{10}[a]	NO_X	SO_X	References
Diesel fuel (lb/MMBtu)	164	0.0066	0.3100	4.4100	0.2900	US EPA 1995, CFR 2019
Gasoline fuel (lb/MMBtu)	154	0.0066	0.1000	1.6300	0.0840	US EPA 1995, CFR 2019
Propane (lb/MMBtu)	137	0.0022	0.0077	0.1424	0.0011	US EPA 1995
Natural gas (lb/MMBtu)[b]	118	0.0023	0.0075	0.0022	0.0006	US EPA 1995
Biomass—stack (lb/MMBtu)[c]	195	0.0210	0.0740	0.4900	0.0250	US EPA 1995, Forest Products Laboratory 2004
Biomass—pile burn (lb/ton)[d]	2,175	7.5810	8.2460	3.8900	2.3500	Yokelson et al. 1996, Hardy et al. 2001, Urbanski 2010[e]

[a] PM10 = particulate matter ≤ 10 μm.

[b] Same factors used to estimate electricity emissions.

[c] Assume 40 percent moisture content at time of combustion.

[d] Assume 30 percent moisture content at time of combustion and all but 5 percent of logging slash piles fully consumed.

[e] Sean Urbanski, Missoula Fire Science Laboratory, personal communication, 2010.

Emissions produced from burning logging residue generated during the harvest of sawlogs were also estimated. This analysis assumes this logging residue was disposed of by open burning, to comply with laws and policies designed to restrict the build-up of slash and thus reduce fire hazard. Burning logging residue in the forest is different than in a co-generation boiler or biomass energy plant, because instead of emissions exiting through a pollution-controlled system associated with a boiler or biomass energy facility, emissions from open burning of logging residue disperse freely into the atmosphere. Emissions associated with burning logging residues were estimated using emission factors in Table 3, 30 percent moisture content, and all but 5 percent of logging residues being fully consumed.

Results

During CY 2016, the 16 sawmills responding to the energy survey produced 1.86 billion board feet of lumber from 1.12 billion board feet (Scribner) of logs. These mills accounted for 92.3 percent of California's 2016 lumber production of 2.02 billion board feet (Marcille et al. in prep.), equivalent to 5.7 percent of total US lumber production, and 13.6 percent of western US lumber production (WWPA 2016). Lumber production from the respondent sawmills ranged from 8.9 to 268.4 MMBF with average lumber production of 116.4 MMBF.

Total mill residue production was not requested in the sawmill energy survey, but data from Marcille et al. (in prep.) show all California sawmills produced 1.90 million bone dry tons (BDT; a BDT is 2,000 pounds with moisture content of zero percent) in 2016 (Table 4). The majority (58 percent) of mill residue was used for energy production; 27 percent (514.5 thousand BDT) of total sawmill residue was bark, and the remainder was wood. About 28.6 percent of all sawmill residue (543.2 thousand BDT) was sold for energy purposes; 29.4 percent (559.3 thousand BDT) was used on-site for energy purposes; and 41.7 percent (793.5 thousand BDT) was sold for products including pulp and board, animal bedding, landscaping and soil additives. Less than 0.2 percent of total sawmill residue was unused. Biomass energy, whether produced at stand-alone biomass electricity facilities or at sawmills, has been the largest use of mill residue in California since at least 2000 (Morgan et al. 2004, 2012; McIver et al. 2015; Marcille et al. in prep.).

Table 4.—Distribution of California sawmill residues, 2016.

	Coarse	Fine	Bark	Total
Residues sold for products (BDT)[a]	285,969	262,420	245,140	793,529
Residues used for energy (BDT)	511,432	322,826	268,317	1,102,575
Residues not used (BDT)	78	1,820	1,052	2,950
Total residue	797,479	587,066	514,509	1,899,054

[a] 1 Bone dry ton (BDT) = 1 ton (2,000 pounds) of residue at 0 percent moisture content.
Source: Marcille et al. in prep.

The logging residues associated with the 1.12 billion board feet (Scribner) of logs harvested for use by the 16 sawmills was approximately 906,985 BDT. Logging residues typically require disposal to meet silvicultural treatment objectives, usually through broadcast burning or burning slash piles at logging sites. However, when financially feasible, slash may be ground or chipped, most often as fuel for biomass energy or a co-generation boiler. Regardless, slash is frequently burned, either as fuelwood with energy capture (i.e., in a boiler) or as logging residue without energy capture (i.e., open burning of slash). California does not have a pulp industry, which often uses some of the material not suitable for sawlogs.

On-site sawmill energy consumption and fuel types

Of the 16 sawmills in this analysis, half used gasoline, wood and bark onsite; seven consumed propane and five used natural gas. All of the sawmills consumed diesel fuel and electricity. Eight sawmills used electricity generated on-site in addition to electricity purchased from utilities.

Fossil fuels were used to power a variety of machines and vehicles around the mill yard. All 16 sawmills reported using diesel fuel for on-site rolling stock while just five reported using natural gas for heat and steam. Table 5 shows natural gas provided the greatest amount of fossil fuel-produced energy (552,862 MMBtu) and diesel fuel provided slightly less (376,938 MMBtu). Together, natural gas and diesel fuel accounted for nearly 99 percent of fossil-based energy used on-site (i.e., excluding fossil-based electricity from utilities). Gasoline was consumed at seven sawmills and propane at eight, but collectively provided just over 1 percent (9,601 MMBtu) of the fossil-based energy used at sawmills during 2016.

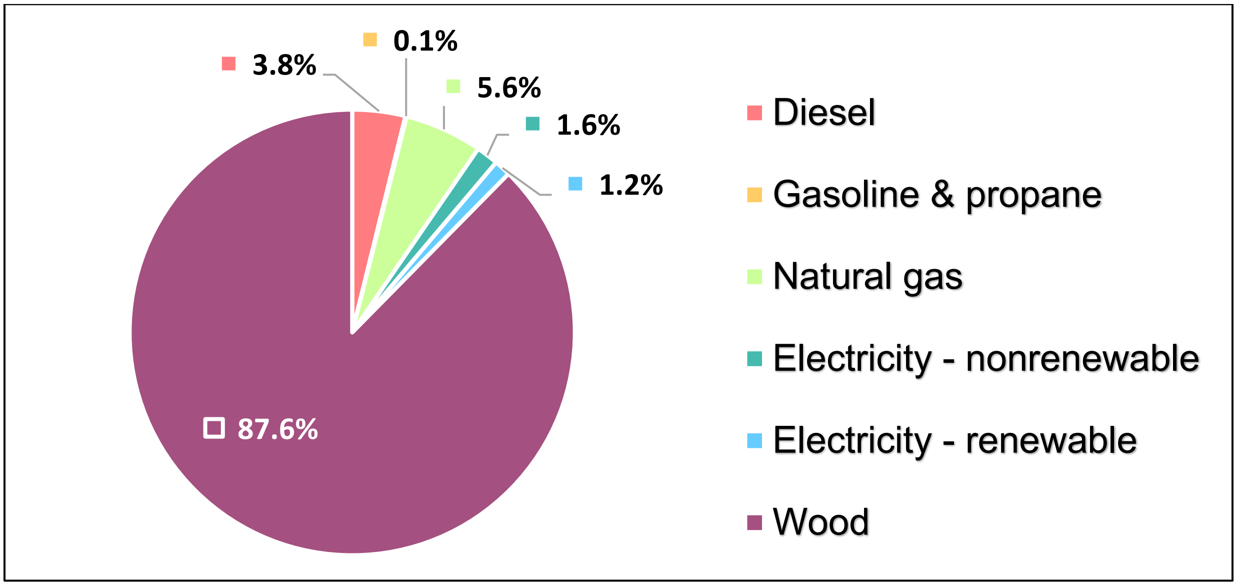
Table 5.—Total on-site fuel and energy consumption and fuel consumption per unit of lumber produced at California sawmills in this analysis, 2016.

Fuel	Total fuel consumed	Total MMBtu consumed	MMBtu percent of total	MMBtu/MMBF of lumber
Diesel (gal)	2,743,744	376,938	3.8	202.4
Gasoline (gal)	54,244	6,534	0.1	3.5
Propane (gal)	33,586	3,067	0.0	1.6
Natural gas (dt)	552,994	552,862	5.6	296.8
Electricity, nonrenewable (kWh)	46,346,233	158,138	1.6	84.9
Electricity, renewable (kWh)	34,601,287	118,063	1.2	63.4
Wood, 40% moisture (ton)	830,606	8,596,011	87.6	4,614.6
Total from nonrenewable		1,097,540	11.2	589.2
Total from renewable		8,714,074	88.8	4,678.0
Grand total		9,811,613	100	5,267.2

Note: MMBtu = million British thermal units; MMBF = million board feet lumber tally.

Wood and bark were the only renewable fuels consumed onsite. Wood and bark residues are a by-product from lumber production, which can allow sawmills that operate wood-burning equipment to reduce their demand for other fuels and electricity from utilities. Half of the 16 sawmills reported utilizing wood and bark residues for energy production, and wood and bark provided over 87 percent (8,714 billion Btu) of the total energy consumed by sawmills in this analysis (Figure 2). Combined on-site and off-site (i.e., electricity provided from utilities) energy use for respondent sawmills was 88.8 percent renewable, with wood supplying nearly 98 percent of the renewable energy. Respondent sawmills were 87 percent self-reliant via energy produced from wood and bark mill residues.

Figure 2—Total energy consumed on-site at California sawmills in this analysis by fuel type, 2016.



Eight of the 16 sawmills in this analysis reported using wood and bark to produce heat, steam, and electricity onsite. Respondent sawmills reported using 830,606 BDT of wood and bark mill residue for energy, equivalent to 8.6 trillion Btu. All on-site electric, heat and steam generation was produced using renewable wood and bark (i.e., mill residues). The 8.6 trillion Btu of wood-based energy was used to produce 242.8 Gigawatt hours of electricity at sawmills with co-generation facilities during 2016, and 88 percent of total sawmill electricity demand was met from on-site co-generation.

An estimated 906,985 BDT of logging residue was generated from the 1,122 MMBF (Scribner) of timber harvested in 2016 for sawmills in this analysis. Tree tops, limbs, above-ground portions of stumps, and other woody material left in the logging unit after timber harvest is referred to as "logging residue." The energy contained in this residue was slightly more than 10 trillion Btu, approximately 11.04 MMBtu/ton. This suggests that the logging reside has over 8 times enough energy to replace the 1.2 trillion Btu of non-wood-based energy consumed on-site. In fact, the 10 trillion Btu of energy in the logging residues represents sufficient energy to power all 16 sawmills entirely, roughly a 9.8 trillion Btu demand (Table 5). However, the potential energy associated with the logging residue would not necessarily be in a form usable for all the mills' energy needs; i.e., it may not be possible to fuel rolling stock or other equipment currently using liquid fossil-based fuels with logging residue.

Electricity from utilities

The State of California requires all retail electricity suppliers to disclose power content labels that break down the supplied electricity by the fuel types used to generate the electricity (CA EC 2019). California's overall power mix for 2016, when large hydroelectric is included with renewables, shows renewable sources supplied 35 percent of electricity and 65 percent was supplied from non-renewable sources (CA EC 2019).

Four different electricity utilities or providers supplied the 16 sawmills in this analysis during 2016, with each provider having its own portfolio of generation sources. One utility (Pacific Gas and Electric - PG&E) supplied 13 of the 16 sawmills. Using the reported electric utility companies' power content labels, we were able to sort individual sawmills' purchased electricity by their respective fuel sources (Figure 3).

Contract electricity, although untraceable to its fuel type, provided the largest share (22.5 percent) of utility-provided electricity to the 16 respondent sawmills (Table 6). One utility (and one sawmill) received 100 percent of its power from hydroelectric dams and the other three providers received electricity from a mix of sources: biomass, geothermal, solar, hydropower, wind, natural gas, nuclear and contract sources. No electricity consumed by these California sawmills was produced from coal-fired power plants, as none of the electricity providers reported using coal as an energy source. Combined across all four providers, 57.3 percent (46,346,233 kWh) of utility-supplied electricity used during 2016 by sawmills in this analysis came from non-renewable sources and 42.7 percent (34,601,287 kWh) from renewable sources.

Figure 3—Fuel sources of utility-provided electricity consumed by the 16 California sawmills in this analysis, 2016.

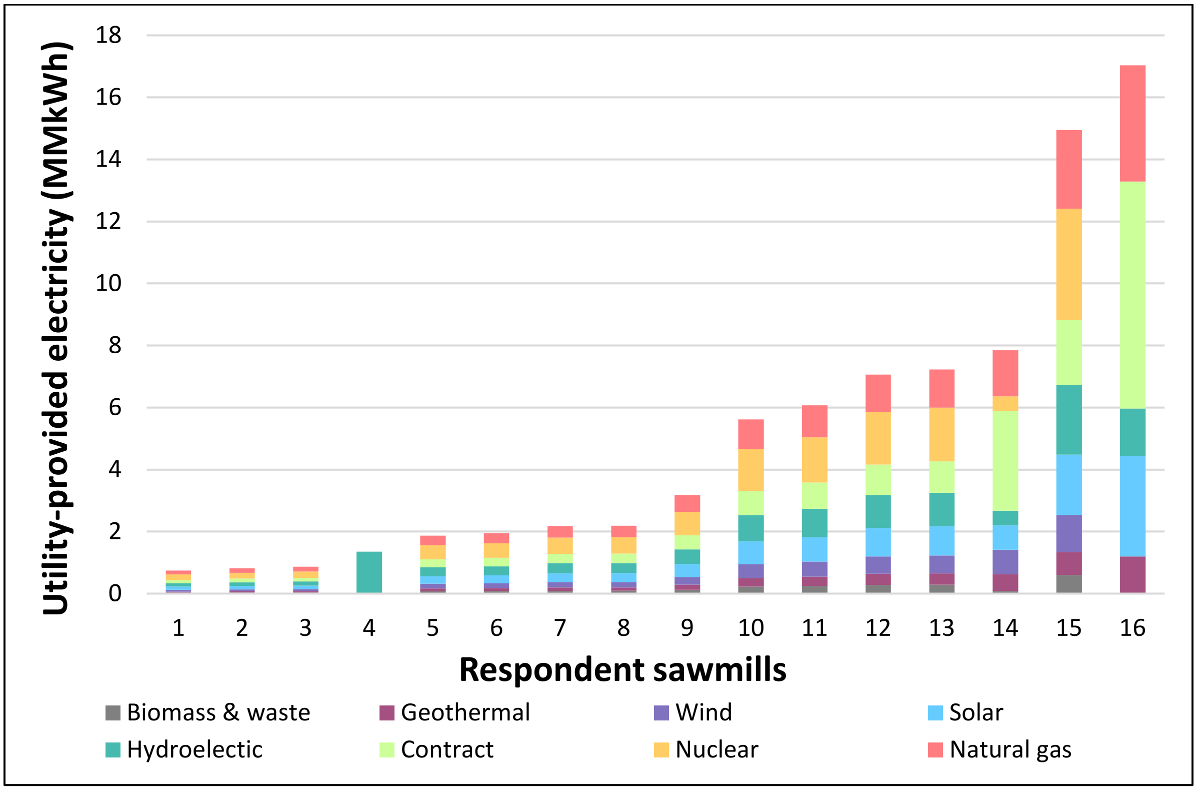


Table 6.—Fuels used to generate utility-provided electricity for sawmills in this analysis, 2016.

Fuel	Total (kWh)	Percent
Natural gas	14,540,596	18.0
Nuclear	13,600,647	16.8
Contract	18,204,990	22.5
Hyroelectric[a]	11,560,649	14.3
Solar	11,134,551	13.8
Wind	5,161,619	6.4
Geothermal	4,477,694	5.5
Biomass & waste	2,266,774	2.8
Total	80,947,520	100

[a] Includes large and small hydroelectric dams as defined by the State of California.

Emissions from on-site sawmill energy consumption

Greenhouse gas and criteria pollutant emissions are a by-product of using fossil fuels for energy. Those same emissions are released when burning wood, a renewable fuel, for energy. Applying the emission factors from Table 3 to the energy (MMBtu) output from each fuel, total selected emissions by fuel type were calculated. Across the fuel types used by sawmills, 99.6 percent of emissions was CO2, 0.01 percent was CH4, 0.04 percent was PM10, 0.33 percent was NOx, and 0.02 percent was SOx (Table 7).

Table 7.—Total selected emissions (lb) from California sawmills in this analysis, 2016.

Fuel	CO_2	CH_4	PM_{10}	NO_x	SO_x
Diesel fuel	61,817,880	2,488	113,851	1,662,298	109,312
Gasoline fuel	1,006,205	43	653	10,650	549
Propane	419,821	7	37	638	17
Natural gas	64,981,692	1,297	4,112	55,098	347
Electricity	13,749,721	1,112	2,970	39,404	571
Wood	1,676,222,123	171,920	636,105	4,212,045	214,900
Total	1,818,197,442	176,728	760,728	5,980,128	325,697
lb/MBF	976.1	0.1	0.4	3.2	0.2

Note: PM_{10} = particulate matter ≤ 10 µm; MBF = thousand board feet lumber tally.

Wood (and bark, combined) accounted for 87.6 percent of total energy consumed by sawmills in this analysis (Table 5) and 92.1 percent of total selected emissions (Table 7), accounting for 66 percent (SOx) to 97.2 percent (CH4) of each pollutant's total weight. Within the "wood" category, bark accounted for 33.5 percent of the 830,606 BDT consumed and 42.6 percent of emissions. Since wood energy is categorized as renewable in California, the California Air Resource Board includes these emissions for informational purposes only and does not count them in the total emissions for the energy sector.

Emissions from burning logging residue

Substantial logging residue was generated from the 1,122 MMBF (Scribner) of timber harvested for sawmills in this analysis. Open burning of the 906,985 BDT of logging residue in the forest would have produced almost 2 billion pounds of selected emissions assuming it was all burned (Table 8).

The amount of logging residue generated during timber harvest can vary depending on a variety of factors, including harvesting system and whether or not there are local markets for material that can't be used for sawlogs (Berg et al. 2016, Simmons et al. 2016). Pulp mills, biomass energy facilities, and wood pellet manufacturers, are typical users of smaller-diameter logs or tree parts not used for saw or veneer logs. But presence of these industries alone is not sufficient; the costs of harvesting, hauling, and processing that raw material must be sufficiently greater that the value of the products produced for utilization to be financially feasible for the industry supply chain. Long hauling distances or other factors impacting cost can be prohibitive. Likewise, poorly developed markets or low prices for the end products or substitute products (e.g., electricity from biomass vs. natural gas) can also make the use of logging slash financially infeasible, thus leading to larger amounts of logging residue.

Table 8.—Total selected emissions and emissions per unit of timber from open burning of logging residues associated with timber harvested for California sawmills in this analysis, 2016. [a]

Type of emission	Pounds (lb) of emissions	Pounds of emissions per million board feet (lb/MMBF) Scribner of timber harvested
CO_2	1,972,901,242	1,758,379
CH_4	6,874,947	6,127
PM_{10} [b]	7,482,627	6,669
NO_x	3,528,172	3,145
SO_x	2,131,415	1,900

[a] Assumes 30 percent moisture content and 95 percent of logging residue combusted.

[b] PM10 = particulate matter ≤ 10 µm.

Open burning of the logging residue would have produced approximately 9 percent more emissions than all the fuels consumed for sawmill energy (1.82 billion pounds). Emissions of CO2 accounted for 99 percent of logging residue emissions and were approximately 9 percent higher for logging residue burning than for sawmill energy. Nearly 38.5 times the CH4 and 10 times the PM10 were emitted, and over 6.5 times the SOx was emitted from burning logging residues versus generating energy for consumption at sawmills. Only NOx emissions associated with sawmill energy outweighed logging residue emissions.

Discussion and Conclusions

This analysis determined that energy use per unit of lumber produced by California sawmills during 2016 was approximately 5,267 MMBtu/MMBF (Table 5), which is about 38 percent higher than estimated energy use by Montana sawmills during 2009 (3,828 MMBtu/MMBF; Loeffler et al. 2016a) and almost 4.8 times higher than energy use in the Southwest during 2012 (1,108 MMBTU/MMBF; Loeffler et al. 2016b). These differences could be due to several factors: different data years, the species mix and moisture content of logs and lumber processed, the types and quantities of fuels consumed on-site by sawmills and in the portfolios of the electricity providers, as well as variations in milling processes, climate (e.g., relative humidity and temperature) conditions, potential energy use on-site for non-production functions, and possibly other factors.

At the national level, variations in energy use per unit of lumber produced can be relatively large. For example, using publicly available energy consumption data (i.e., the Manufacturing Energy Consumption Survey – MECS) from EIA (US EIA 2019d) and domestic lumber production data from USDA (2018), energy use at US sawmills went from 2,795 MMBtu/MMBF in 2006, up to 7,616 MMBtu/MMBF in 2010, and down to 3,090 MMBtu/MMBF in 2014. The MECS energy consumption data published by EIA are not available every year; 2006, 2010, and 2014 are the three most recent years available. But these three years of data indicate fairly substantial variation in energy use per unit of lumber at the national level. Repeated observations for individual states using the methods in this California analysis and the previous Southwest and Montana analyses have not been completed.

Energy use per unit of lumber in the Southwest was notably lower than in both California and Montana because lumber at the Southwest mills was air-dried, and not kiln-dried, and as a result much less fuel (particularly wood) and total energy was consumed per unit of lumber by Southwest sawmills (Loeffler et al. 2016b). These differences in lumber processing and resulting energy use are important at the state level and among mills within a state and should not be overlooked, particularly if attempting to compare energy use efficiency among mills or states. Likewise, efforts or policies that may seek to increase sawmill energy efficiency or reduce sawmill energy consumption should be sensitive to processing differences that may be associated with demand for certain products (e.g., kiln-dried lumber vs. green lumber) or log supply (e.g., seasonal, geographic, and species variations in moisture content of logs).

The differences in sawmill energy consumption per unit of lumber between California and Montana are most notable in electricity and wood use. While sawmills in both states commonly use kilns to dry lumber, and wood fuels account for the majority of energy used in California (87.6 percent) and Montana (77.2 percent; Loeffler et al. 2016a), California mills used 56 percent more wood-based energy (4,614.6 MMBtu/MMBF) than Montana mills (2,958 MMBtu/MMBF) per unit of lumber. Whereas Montana sawmills used more than 4 times as much electricity per unit of lumber (616 MMBtu/MMBF) compared to California sawmills (148 MMBtu/MMBF).

So, while it is possible to compare sawmill energy use among states using a consistent approach (i.e., the methods used in this analysis and Loeffler et al. 2016a, b), and it is likewise possible to make estimates through time for the nation as a whole (i.e., with EIA and USDA data), the variability of these estimates is not well established. Conclusions about the relative energy efficiency of specific mills with in a state, a state's sawmill industry compared to other states or the nation as a whole may not be well supported. Further investigation, using comparable, repeated observations and statistical modeling techniques is recommended to better document, quantify, and ultimately understand similarities and differences in sawmill energy efficiency at various scales.

Total selected emissions from California sawmill energy use were 980 lb/MBF (Table 7), which is about twice as high as from Southwest sawmills (448 lb/MBF) as reported in Loeffler et al. (2016b). However, California sawmill emissions per unit of lumber were lower for all of the five selected emissions except CO2. The substantial difference in CO2 emissions per unit of lumber produced was due to the larger amount of total energy consumed by California sawmills, in particular the wood used for on-site dry kilns and cogeneration of electricity. As discussed above, Southwest sawmills air-dry most of their lumber, whereas California (and Montana) sawmills use substantial amounts of their mill residue for drying lumber. The lower emissions per unit of lumber for the other four emission types are related to the quantities of other fuels (e.g., diesel or propane) used on-site and in the portfolios of the electricity providers supplying the mills.

Comparisons of emissions per unit of lumber produced should be considered with regard to the types and quantities of fuels consumed on-site by sawmills and in the portfolios of the electricity providers, as well as variations in milling processes (e.g., kiln-drying lumber), potential energy use on-site for functions other than lumber production (e.g., heating or cooling the workplace, producing electricity), and possibly other factors. Current policies and financial considerations do not appear to be moving California toward increased use of woody biomass for energy, and sawmills' use of wood for on-site energy may be more attributable to a shortage of other in-state mill-residue-using sectors (e.g., pulp mills and particleboard plants) than to a desire to be in the biomass energy business.

As indicated in Table 8, open burning of the logging residue (i.e., slash) associated with the sawlogs harvested for use by the 16 sawmills in this analysis was estimated to produce almost 2 billion pounds of selected emissions, mostly CO2. Alternative slash disposal methods, for example grinding and leaving it on the logging site (like a mulch), converting it into wood pellets or biochar, burning in an air curtain destructor at the logging site, or transporting it to an existing biomass energy facility may be preferable to traditional open piling and burning from an emissions perspective (Ganguly et al. 2018, Zahn 2005). However, financial and logistics considerations – including woody residue processing and transportation methods – will substantially impact the feasibility and costs of these alternative slash disposal methods compared to open burning. Likewise, potential revenue from bio-based products (e.g., pellets, biochar, liquid biofuels) would be a factor in the financial feasibility of utilizing slash. Further, policies have thus far not aligned to make alternative slash disposal or utilization common practices in the western US (Aguilar et al. 2011; Zamora-Cristales et al. 2015, 2017; Morris 2000; Sahoo et al. 2018; Sessions et al. 2013; Smith et al. 2017).

In the short term, wood residue or other renewables seem unlikely to completely replace fossil fuels consumed on-site at California sawmills. An analysis of costs and availability of equipment to fully convert mills' rolling-stock fleets to renewable fuels are beyond the scope of this project, but potentially a factor. Also, low natural gas prices compared to woody biomass, and capital costs associated with changing fuels can be disincentives to wood products facilities, as well as electric utilities (Geiver 2012; Rhyne et al. 2015; Simet 2012). Federal and state government policies promoting the use of woody biomass for energy feedstocks will continue to play a major role in the adoption of woody residues for energy production (Aguilar et al. 2011).

As California's renewable portfolio standards increase the requirements for retail electricity to use more renewable energy, it is possible that demand for wood biomass energy will also increase (SB 100, 2018; Schwarzenegger S-06-06). Increasing the use of slash for energy or other products can reduce emissions from open burning of logging residue, may replace some non-renewable consumption, and could increase the supply of renewable forest products. Perhaps California can lead the way in developing policies and incentives that simultaneously result in lower GHG and criteria pollutant emissions, commercial profitability for timber and biomass energy related industries, and more sustainable forest management.

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