Oregon Sawmill Energy Consumption and Associated Emissions, 2017

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Executive Summary

Purpose and Objectives

This report was made possible through a partnership between the Oregon Department of Forestry (ODF), the US Forest Service's Forest Inventory and Analysis (FIA) Program, and the University of Montana's Bureau of Business and Economic Research (BBER).

The purpose of this report was to analyze how on-site energy production and consumption at Oregon's sawmills contributed to Oregon greenhouse gas (GHG) emissions, which totaled 64 million metric tons (MMT) of carbon dioxide equivalents (CO_2e) in 2017. The Oregon Global Warming Commission reported Oregon's GHG emissions increased 13.2% from 56 MMT CO_2e between 1990 and 2020 and peaked at 72 MMT CO_2e in 1999. The objectives of this sawmill energy consumption analysis were to use sawmill energy survey response data, timber product output (TPO) data, and published energy conversion factors to estimate the energy consumed per million board feet (MMBF) of lumber produced by Oregon sawmills; to estimate selected greenhouse gas and criteria pollutant emissions associated with sawmill on-site energy consumption; and to identify opportunities for energy efficiency gains, industrial bioenergy expansion, and potential fossil fuel displacement in the sawmill industry.

Methods

The primary data for this analysis was collected through an on-site energy use survey of Oregon sawmills. Data was not collected on energy used in the forest for timber harvesting, to transport the logs to sawmills, or to transport finished products from sawmills to consumers. Only energy used within the boundaries of the sawmill facility were considered.

As shown by the 2017 Oregon TPO report, 2,852 MMBF, Scribner of sawlogs were harvested from Oregon's 23.7 million acres of timberland, most of which was received by the state's 75 active sawmills. During 2018 and 2019, BBER distributed a questionnaire to these sawmills to capture on-site energy consumption data for 2017, which allowed for a direct comparison to the 2017 Oregon TPO report. Nonresponding mills were called multiple times to complete the survey. Finally, 10 of the larger sawmills were visited in person to collect data. The energy data collected included fuel for rolling stock (e.g., forklifts, log loaders, light-duty trucks, etc.), fuel for heat and steam generation, fuel for electricity generation (if different from heat and steam generation), electricity purchased from utility providers, and the name of the utility provider.

Using published energy factors, the physical units of each fuel type were converted into millions of British thermal units (MMBtu). Energy data reported in MMBtu were converted into selected emissions (i.e., carbon dioxide [CO_2], methane [CH_4], particulate matter smaller than 10 micrometers [PM_{10}], nitrogen oxides [NO_x], and sulfur oxides [SO_x]) using emissions factors from various published sources. An estimate was developed of the amount of potential energy in logging residue generated during the harvesting of the sawlogs.

Results

Of the 75 active sawmills in Oregon, 30 mills (40%) completed the energy questionnaire. These responding sawmills accounted for 56.5% of the sawlog volume processed and 59.2% of 2017 lumber production in Oregon. The amount of lumber produced by the responding sawmills ranged from 0.04 MMBF to 448 MMBF of lumber and averaged 103.5 MMBF of lumber per sawmill. Mills with a lumber production capacity > 100 MMBF represented 50% of responding sawmills, and those with capacities < 10 MMBF represented 30%. All but four of the responding sawmills were in the western resource areas, with 15 mills located in the Southwest Resource Area (i.e., Lane County and south) and 11 mills in the Northwest Resource Area (i.e., north of Lane County). The mill size, location and production characteristics of responding and non-responding mills are reasonably similar and suggest the responding mills are representative of Oregon's sawmill sector.

The 30 responding sawmills consumed a variety of fuel types on-site. Twenty-nine consumed electricity, 28 consumed diesel, 24 consumed gasoline, 23 consumed propane, 14 consumed hogfuel, and three consumed natural gas. Only one of the mills produced electricity on-site. Hogfuel (i.e., wood and bark sawmill residue) was the only renewable fuel consumed on-site to produce energy and comprised 69.7% of total energy (and 82.9% of the renewable energy) consumed by the responding sawmills. Electricity comprised 19.7% of total energy consumed by the responding sawmills. In total, 26.8% (238,310 MMBtu) of utility-provided electricity delivered to the responding sawmills was generated using nonrenewable resources, and 73.2% (652,522 MMBtu) was generated from renewable resources. The responding sawmills used an estimated 1,458.1 MMBTU of energy per MMBF of lumber.

Across all fuel types, 99.22% of emissions (on a weight basis) were CO_2, 0.09% was CH_4, 0.15% was PM_{10}, 0.44% was NO_x, and 0.10% was SO_x. Burning hogfuel produced 84.7% of all emissions but did not produce the greatest amount of each emissions type. Hogfuel comprised 85% of all CO_2 emissions, 99.3% of all CH_4 emissions, 20.7% of all PM_{10} emissions, 48.4% of all NO_x emissions, and 11.3% of all SO_x emissions. Electricity from nonrenewable energy sources (e.g., coal, natural gas) contributed the majority shares of PM_{10} (70.7%) and SO_x (75.9%) emissions, while on-site diesel consumption contributed about 41.3% of NO_x emissions. Total CO_2 emissions for Oregon sawmills per unit of lumber were estimated at 116.531 short tons/MMBF. Thus for 2017, it is estimated that Oregon sawmills produced approximately 0.554 MMT CO_2 (about 0.86% of total 2017 Oregon GHG emissions) while producing 5,239.5 MMBF of lumber.

About 2.6 million green tons of logging residue were associated with the sawlogs processed by the mills in this study. Approximately 28.8 million MMBtu of energy could potentially be generated from burning logging residue as fuel, an amount equivalent to more than six times the on-site energy used by the 30 sawmills in this study. Open burning of this logging residue in the forest produced about 2.44 million short tons (2.22 MMT) of selected emissions (Table 9). Assuming all the logging residue associated with the sawlogs in this study were able to be collected and burned for biomass energy rather than burned as slash in the forest, the resulting emissions could change considerably. CO_2 emissions would increase by 16%, but the other selected emissions would decrease. For example, CH_4 emissions, which trap heat at a rate 28 times greater than CO_2, would decrease by 91%. Likewise, PM_{10} emissions would also decrease by 91%.

Discussion and Conclusions

In this analysis, the 30 responding Oregon sawmills used an estimated 1,458 MMBtu of energy per MMBF of lumber produced in 2017. This amount is equivalent to 28% of the energy used by California mills in 2016; 38% of that used by Montana mills in 2009; but is 32% higher than energy used by Southwest mills in 2012. These differences can be due to several factors, including the mix of fuels used on-site at each mill, the resource mix used by utility providers to produce electricity, the quantity and degree of processing of the lumber produced by each mill, the efficiency of mill equipment, the species mix and moisture content of hogfuel and lumber, and regional climate (e.g., relative humidity and temperature), which impacts the amount of energy needed to dry wood.

Relatively low overall energy use per unit of lumber in Oregon is partially due to the state's notable green-lumber market. Drying lumber is usually the largest use of energy in sawmills. The amount of green lumber versus kiln-dried lumber produced by individual mills was not captured in this analysis, nor the 2017 Oregon TPO analysis or the 2016 California TPO and sawmill energy analyses, making it difficult to estimate the amount of energy specifically associated with drying lumber in the two states. However, the Western Wood Products Association estimated that 52% of lumber produced in Oregon during 2017 was green, whereas 43.5% of lumber produced in California during 2016 was green.

This sawmill energy analysis and studies in other western states indicate that Oregon sawmills are relatively efficient with respect to energy use, emissions production, and utilization of mill residue. Likewise, logging utilization studies among the western states also suggest that Oregon timber harvesting efficiency is not significantly different from other western states (i.e., Oregon logging does not generate significantly more logging residue per unit of timber delivered to mills compared to other western states).

Oregon does not have a significant bioenergy infrastructure, partly because hydroelectric dams provide relatively low-cost renewable electricity, natural gas prices are low, and an extensive pulp and paper industry uses mill residues and roundwood. Consequently, there is little incentive to collect or try to use logging slash for energy. Onsite broadcast or piling and burning are the traditional treatments used to reduce or eliminate slash in Oregon forests, and there are rules for the treatment of logging slash in Oregon.

Oregon, unlike the southwest US, already has a substantial portion of its grid-delivered electricity provided from renewable sources. Substituting or replacing hydroelectric based energy with additional biomass energy – which may not be as carbon-friendly – may not be desirable. Rather, increasing the utilization of felled trees for solid (e.g., posts) or reconstituted wood products (e.g., pulp & board, possibly biochar) may be more beneficial, from a carbon and other emissions standpoint, than burning the wood waste for bioenergy. Carbon management policy should recognize that Oregon sawmills sell much or all of their residue for pulp and non-structural panels or use their wood waste internally for energy. These sawmills are efficient in the sense that they are avoiding some fossil fuel consumption by using their wood waste for energy, thus not drawing that amount of energy from the grid or are already contributing to the reuse or recycling of carbon as wood fiber.

Turning logging residue (or slash) into products – whether fiber or energy – requires the use of energy and results in some emissions from collection, transportation, and processing. Whether or not that energy and those emissions and products result in net reductions of emissions or energy from non-renewable sources is a complex question, requiring additional information and analyses of energy substitution, alternative products, and their associated emissions. Likewise, there are numerous financial and economic, as well as other natural resource (e.g., water, wildlife, wildfire) considerations and trade-offs beyond energy emissions that should be considered.

Introduction: Emissions accounting in Oregon

The Oregon Department of Forestry (ODF) has established a forest carbon accounting system to understand the stocks and flux of carbon in Oregon's forests and harvested wood products (HWP). Forest managers can use various management techniques and tools to increase long-term forest carbon storage, including avoiding deforestation, reforestation, lengthening harvest rotations, and increased production of longer-lived wood products (Smyth et al. 2020). However, the transportation and manufacturing of HWP requires energy, which produces emissions that are accounted for in state-level greenhouse gas (GHG) inventories of those sectors (e.g., transportation and industrial).

In 2020, the Governor of Oregon issued Executive Order 20-04 that modified the existing (OR HB 3543, 2007) GHG emissions reduction mandate to 45% lower than 1990 levels by 2035, and 80% lower by 2050. According to preliminary estimates for 2017 from the Oregon Global Warming Commission (OGWC 2018), Oregon's GHG emissions increased by13.2% between 1990 and 2020, from 56 million metric tons of carbon dioxide equivalent (MMT CO_2e) to 63 MMT, and peaked at 72 MMT CO_2e in 1999. Oregon GHG emissions constituted 1% of total 2017 US GHG emissions of 6,487 MMT CO_2e (US EPA 2020).

Harvested wood products not only store large amounts of carbon for long periods of time they can also displace and reduce fossil fuels used for energy production and manufacturing (Tilman et al. 2009). This report analyzes how the Oregon sawmill industry's on-site energy production and consumption contribute to the total calendar year (CY) 2017 Oregon GHG emissions of 64 MMT CO_2e (ODEQ 2020) and discusses how utilizing bioenergy may potentially displace the fossil fuel portion of this consumption. Rather than relying on published energy production/consumption data for this analysis, the primary data was collected through a survey of Oregon sawmills. Data were not collected on energy used in the forest[1] (e.g., forest management practices, timber harvesting, etc.), to transport the logs to sawmills, or to transport finished products from sawmills to consumers. Only energy used within the boundaries of the sawmill facility were considered to focus on energy used in primary manufacturing of wood products.

[1] For information on diesel emissions from off-road equipment, see Eastern Research Group 2020.

Objectives

The objectives of this sawmill energy consumption analysis consist of the following:

1) Use survey response data, timber product output (TPO) data and published energy conversion factors to estimate the energy consumed per million board feet (MMBF) of lumber produced by Oregon sawmills.
2) Use emissions conversion factors to estimate selected greenhouse gas and criteria pollutant emissions[2] associated with on-site energy consumption.
3) Identify opportunities for carbon reductions through gains in energy efficiency, industrial bioenergy expansion, and potential fossil fuel displacement in the sawmill industry.

Methods

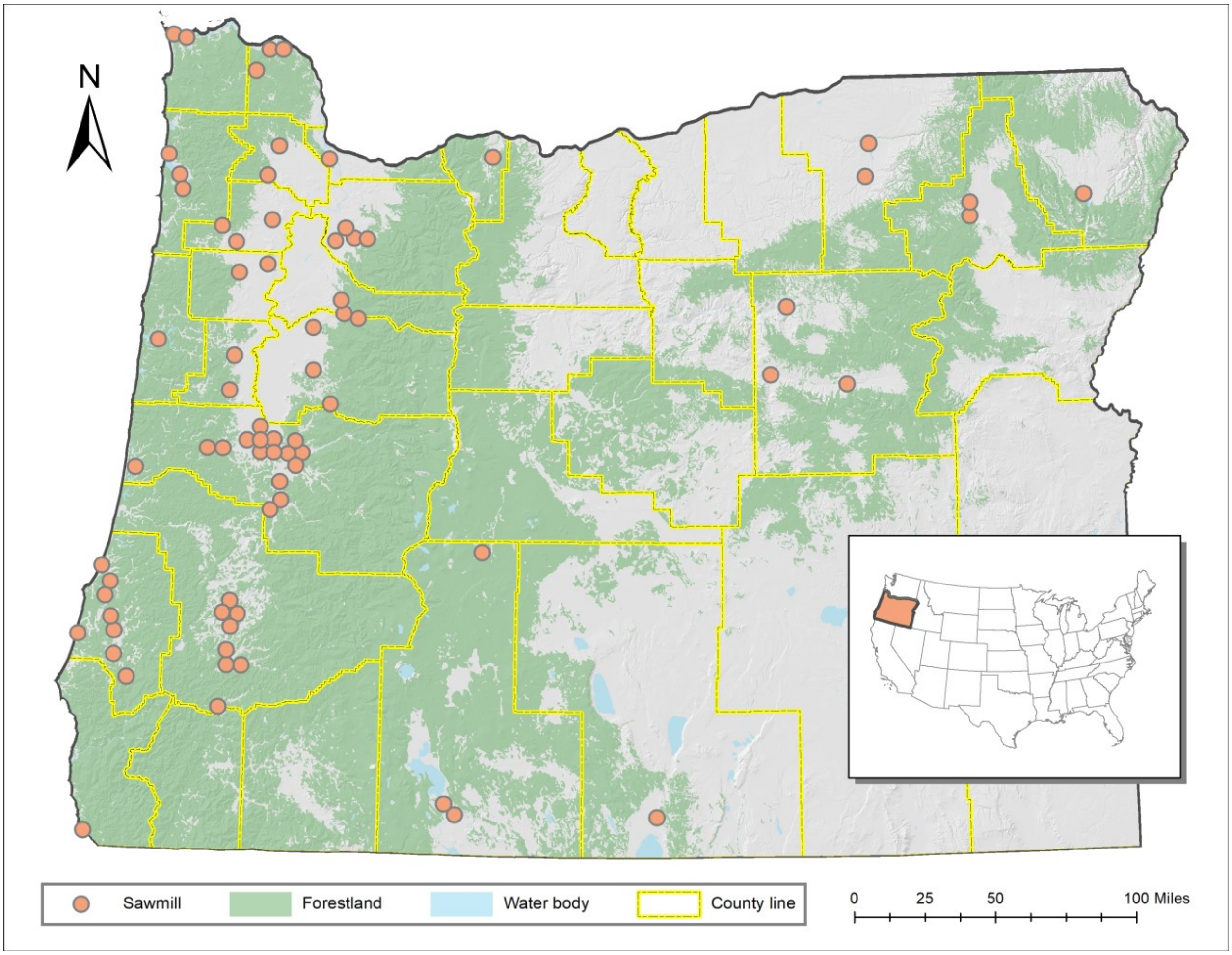
This analysis focuses on energy production and consumption by the Oregon sawmill industry during CY2017. The description of the methods below follows Loeffler et al. (2016a, b) and Morgan and Donahue (2019). Data was collected and analyzed to estimate the amount of energy generated and consumed at mill sites per board foot of lumber produced and the related GHG and criteria pollutant emissions. Simmons et al. (in press) collected Oregon lumber production and mill residue disposition information for CY2017, allowing for direct comparison between TPO data and energy data.

Study area

Oregon consists of 93 million acres that include rocky coastlines and dense forestland to the west and high elevation deserts to the east. In 2017, 2,852 million board feet (MMBF) Scribner of sawlogs were harvested from Oregon's 23.674 million acres of timberland, most of which was received by 75 active sawmills in Oregon (Simmons et al. in press). The general locations of these mills are shown in Figure 1. Sawmills are concentrated in western Oregon where most of the highly productive timberland is located.

[2] Criteria pollutants are air pollutants that cause health and environmental damage (i.e., particular matter 10 micrometers or smaller, nitrogen oxides, and sulfur oxides).

Figure 1: Active sawmills in Oregon during CY 2017



Sawmill Surveys

BBER conducts a periodic census of all primary wood processing facilities[3] in the state of Oregon, providing detailed data on timber harvest and use (Simmons et al. in press). Additionally, BBER has contributed to a series of sawmill energy studies in the western US that highlight on-site energy consumption and potential energy production from woody biomass (Loeffler et al. 2016a, b; Morgan and Donahue 2019). ODF requested a similar analysis be conducted for Oregon.

During 2018 and 2019, BBER distributed a questionnaire to Oregon sawmills to capture on-site energy consumption data for CY2017 activity, which allowed for a direct comparison to the 2017 Oregon TPO report (Simmons et al. in press). Energy data collected included fuel for rolling

[3] Primary wood products are manufactured directly from roundwood logs and chipped or ground logs, and include lumber, veneer, plywood, posts, poles, pilings, timbers, shakes, and shingles; as well as products made from mill residuals (e.g., bark, sawdust, and planer shavings), including pulp, paper, particleboard, medium-density fiberboard, fuel pellets, and thermal and electrical energy. Secondary wood products, by contrast, are made from primary products and include items such as doors, furniture, trusses, laminated beams, window frames, cabinets, etc.

stock (e.g., forklifts, log loaders, light-duty trucks, etc.), fuel for heat and steam generation, fuel for electricity generation (if different from heat and steam generation), electricity purchased from utility providers, and the name of the utility provider. Fuel types consumed included diesel, propane and gasoline for rolling stock, natural gas and hogfuel (i.e., wood and bark waste) for heat, steam and electricity generation. Diesel, natural gas, gasoline and propane constitute non-renewable fuel types. Renewable fuel types consist of hogfuel, hydroelectric, wind, and solar. Utility-provided electricity was determined renewable or nonrenewable based on fuel types reported by the Oregon Department of Energy (ODOE 2020).

An email containing a link to an online survey was sent to each of the 75 sawmills in Oregon. For those without an email address, a paper version of the survey was mailed through the US Postal Service (USPS). After one month, four sawmills had responded using the online survey. A fillable PDF and an identical paper form were distributed to the remaining sawmills via email and USPS. Nonresponding mills were called multiple times to complete the survey. Finally, 10 of the larger sawmills were visited in person to collect the data.

In 2008, Oregon Department of Environmental Quality (DEQ) approved the Oregon Greenhouse Gas Reporting program, which requires facilities to report annual emissions to DEQ if these equal or exceed 2,500 metric tons of carbon dioxide equivalent (CO_2e) (OAR 340-215 2008). During the 2017 reporting period, DEQ received data on GHG emissions for 22 sawmills, 14 of which also reported biogenic[4] GHG emissions, likely derived from burning hogfuel (ODEQ 2020). Of the 22 sawmills reporting to DEQ, four also responded to the sawmill energy survey questionnaire. However, accounting methods differ in terms of what types of emissions were reported. Data for this study used estimates of carbon dioxide (CO_2) and methane (CH_4) while DEQ data were reported in CO_2e, which encompass more greenhouse gasses than just CO_2 and CH_4. Thus, the two data sets are not directly comparable.

Energy conversions

Standardizing fuel measurement units

Sawmills responded to the BBER questionnaire using physical units of measure for different fuel types, such as gallons, dekatherms, and bone-dry tons (BDT). Using the US Energy Information Administration's (US EIA 2020) conversion factors (Table 1), the physical units of each fuel type were converted into millions of British thermal units (MMBtu), which is a common unit for the measurement of heat energy. Energy contents for the same fuel type vary depending on the global region from which the fuel was extracted. All Btu conversion factors used in this analysis were for US-extracted fuels.

Estimating renewable and nonrenewable electricity

The resources used for generating utility-provided electricity were categorized into renewable (i.e., hydro, waste, biogas, biomass, solar, geothermal and wind) and non-renewable (i.e., coal, nuclear, natural gas, petroleum and other non-biogenic sources). The 2017 resource mix for

[4] Biogenic greenhouse gases are produced from living organisms and burning biomass for energy.

electricity providers is published on the Oregon Department of Energy website (ODOE 2020) and was used to determine the number of total kilowatt-hours (kWh) generated from each resource.

Table 1. Assumed energy contents per physical unit of fuel.

Fuel	Unit	MMBtu[a]/unit
Diesel	Gallons	0.137381
Gasoline	Gallons	0.120333
Propane	Gallons	0.091333
Natural gas	Dekatherms	1.000000
Electricity	Kilowatt hours	0.003412
Hogfuel	---------------	------------
Wood	Tons[c]	11.306511[b]
Bark	Tons[c]	10.292085[b]
Logging residue	---------------	------------
Wood	Tons[c]	11.211163[b]
Bark	Tons[c]	10.362686[b]

[a] MMBtu = million British thermal units.
[b] Based on moisture contents and specific gravities of the harvested species mix (Table 2).
[C] U.S. short tons = 2,000 pounds.
Source: US EIA 2020.

Utility providers commonly purchase some electricity from the open market to meet energy demands, also referred to as unspecified market purchases. The source fuel of these market purchases is practically impossible to trace. However, ODOE (2020) provides the annual overall state resource mix for all unspecified market purchases. Therefore, the state-level unspecified market purchase resource proportions were applied to the unspecified market purchase volumes for each utility provider in this study.

Estimating energy content of mill residue used as fuel

Wood and bark, often referred to as woody biomass or hogfuel, can be burned to produce heat and steam, which may be used for drying lumber, other industrial processes, or electricity generation. Sawmills create large amounts of woody biomass as mill residue during the milling process. Mill residues come in the form of coarse (e.g., chips), fine (e.g., sawdust, shavings) and bark that can be sold to other wood product facilities or burned on-site (Blatner et al. 2012). Sawmills will often burn their mill residue to create steam to dry “green” lumber. Less common in Oregon sawmills is co-generation of heat and electricity.

Energy content of mill residue varies by tree species and their associated moisture content (Jenkins et al. 1998). The Oregon-specific species mix from Simmons et al. (in press) and species moisture contents and higher heating values from Wilson et al. (2010) were used to calculate the average energy content of mill residue burned for energy at responding sawmills (Table 2).

Table 2. Species weighting percent, assumed moisture content and higher heating value for wood and bark used as hogfuel.

Species	Weighting percent	Percent moisture content		Higher heating value	
		Wood	Bark	Wood	Bark
	(%)	*--- total weight basis ---*		*------ Btu/dry lb------*	
Douglas-fir *(Pseudotsuga menziesii)*	83.70	32.80	50.80	8,759	10,109
Western hemlock *(Tsuga heterophylla)*	5.76	43.65	41.00	8,515	9,422
White fir *(Abies concolor)*	5.17	56.50	38.65	8,795	9,641
Ponderosa pine *(Pinus ponderosa)*	4.35	50.95	30.40	9,120	9,516
Lodgepole pine *(Pinus contorta)*	1.03	36.00	42.50	8,600	10,035
Weighted Average	**n/a**	**35.47**	**48.64**	**8,761**	**10,019**

Source: Simmons et al. (in press); Wilson et al. 2010

Emissions conversions

Energy data reported in MMBtu were then converted into selected GHG emissions (i.e., CO_2 and CH_4) and criteria pollutant emissions (i.e., particulate matter greater than 10 micrometers [PM_{10}], nitrogen oxides [NO_x], and sulfur oxides [SO_x]) using conversion factors from several sources (Table 3). Conversion factors for fossil fuels were obtained through the US EPA AP-42 and factors for renewables were obtained using multiple other sources (CFR 2019, Forest Products Laboratory 2004, Hardy et al. 2001, Spath et al. 1999, Urbanski 2010, US EPA 1995, Yokelson et al. 1996). Nuclear was the only nonrenewable fuel type assumed to have zero emissions, and biomass was the only renewable fuel type assumed to have emissions.

Table 3. Various fuels and emissions factors.

Fuel	Emission conversion factors				
	CO_2	CH_4	PM_{10}[a]	NO_X	SO_X
Diesel fuel (lb/MMBtu)[1, 2]	164	0.0066	0.3100	4.4100	0.2900
Gasoline fuel (lb/MMBtu)[1, 2]	154	0.0066	0.1000	1.6300	0.0840
Propane (lb/MMBtu)[1]	137	0.0022	0.0121	0.2080	0.0055
Natural gas—generator (lb/MMBtu)[1]	110	0.0086	0.0066	0.3200	0.0034
Natural gas—boiler (lb/MMBtu)[1]	118	0.0023	0.0075	0.0964	0.0006
Coal (lb/MMBtu)[1,3]	210	0.0022	6.3827	2.0221	4.2341
Biomass—stack (lb/MMBtu)[1, 4, b]	195	0.2101	0.0740	0.4900	0.0250
Biomass—pile burn (lb/ton)[5, 6, 7, c]	1860	6.5146	9.1465	3.8900	2.3502

[a] PM_{10} = particulate matter $\leq$ 10 µm.
[b] Hogfuel: moisture content estimated using harvested species mix and respective moisture contents.
[c] Logging residue: in short tons; moisture content estimated using harvested species mix and respective moisture contents, and assumption that all but 5% of logging slash piles are fully consumed.
Sources: [2]CFR 2019, [4]Forest Products Laboratory 2004, [6]Hardy et al. 2001, [3]Spath et al. 1999, [7]Urbanski 2010, [1]US EPA 1995, [5]Yokelson et al. 1996.

Logging residue

Logging residue, or slash, is the unused wood material left in the forest after timber harvests, including limbs, treetops, and smaller trees that do not meet merchantability requirements (Berg et al. 2018, Oswalt et al. 2019, Simmons et al. 2016b). Sometimes slash is collected from the logging site, processed, and used for biomass energy, soil remediation, or other products. For example, California has a sizeable but shrinking biomass energy industry that uses material directly from the forest as well as mill residuals and other biomass such as agricultural waste (Marcille et al. in press, McIver et al. 2015). Onsite burning is the traditional treatment to reduce or eliminate slash in Oregon (Adams and Storm 2012, Wright et al. 2010), and there are rules for the treatment of logging slash in Oregon (OAR 629-615 1997; Cloughesy and Woodward 2018). In Oregon, logging residue is typically piled and burned or, less frequently, broadcast burned (Wright et al. 2010). In this report, logging residue is considered a potentially renewable fuel source and discussed separately based on the assumption that fossil fuel energy use could be replaced in part by collecting logging residue and burning it for biomass energy.

The amount of logging residue associated with the sawlogs delivered to sawmills was estimated using sawlog input data from the sawmills that responded to the energy survey, an Oregon logging utilization study (Simmons et al. 2016b), and tree component and whole tree volumes from Van Hooser and Chojnacky (1983). Logging residue from sawlogs harvested out of state and delivered to Oregon sawmills was included in this estimate using the same TPO calculations as in-state harvest. Out-of-state timber accounted for just 0.64% (8.8 MMBF, Scribner) of the sawlog volume received by the Oregon sawmills in this analysis.

Moisture content of dead wood decreases over time, which affects the amount of possible energy that can be produced. Higher moisture content in the fuel reduces the heating value compared to a drier fuel (Jenkins et al. 1998). Given that logging residue is left in the forest for unknown lengths of time, this analysis used the moisture contents associated with green tree volumes and the respective specific gravities[5] of tree species (Table 2) to estimate the MMBtu per green ton[6] of logging residue (Table 1). The amount of potential energy stored in logging residue was used to give a conservative estimate for the potential energy substitution and fossil fuel emission abatement. Emissions from the burning of logging residue piles in the forest were estimated using the green tree moisture contents as described above to estimate the potential emissions if burned for bioenergy (Table 3). All but 5% of logging residue was assumed to be consumed during pile burning. Emissions from burning logging residue for energy at a facility were estimated using the emission factors for biomass (Table 3).

Results

Simmons et al. (in press) found 75 active Oregon sawmills in 2017, all of which received the sawmill energy survey. Of these, 30 mills (40%) completed the energy questionnaire. All responding sawmills' data were aggregated to ensure facility confidentiality. Sawmills with a lumber production capacity larger than 100 MMBF represented 50% of responding sawmills; mills with capacity between 50 and 100 MMBF represented 10%; mills with capacity between 10 and 50 MMBF represented another 10%; and those with capacities under 10 MMBF represented 30% of the energy survey responses.

Harvest volumes, volumes per acre, mill capacity and production levels are different (lower on average) in eastern Oregon (Central & Blue Mountains Resource Areas) than in western Oregon (Simmons et al in press). Opportunities to use smaller-diameter material, which would end up as logging residue may be more limited in eastern Oregon. All but four of the responding sawmills were in the western resource areas, with 15 mills located in the Southwest Resource Area (i.e., Lane County and south) and 11 mills in the Northwest Resource Area (i.e., north of Lane County). Sawmills in the Southwest Resource Area accounted for about 58% of the total energy consumed and 61% of lumber output among the responding mills, and mills in the Northwest Resource Area accounted for 37% of energy use and 35% of lumber production.

In total, the 75 active Oregon sawmills produced 5,239.5 MMBF (lumber tally) of lumber from 2,452 MMBF Scribner (log scale) of logs in 2017, using 67.1% of annual production capacity (Simmons et al. in press). The 30 Oregon sawmills that responded to the energy survey accounted for 56.5% of the 2017 sawlog volume processed and 59.2% of lumber production in Oregon during 2017 (Table 4). Responding sawmills each produced between 0.04 MMBF and 448 MMBF of lumber, with an average production of 103.5 MMBF of lumber per sawmill. Although 22 of the responding sawmills indicated having dry kilns, only a small number of them supplied enough information to estimate the proportion of their 2017 lumber production that was kiln dried. Nonetheless, the 22 mills with kilns did account for 97% of total energy consumption and 92% of lumber production among responding mills. The mill size, location and production

[5] Specific gravity is the ratio of a tree species' density compared to the density of water.
[6] A green ton equals 2,000 pounds of undried wood.

characteristics of responding and non-responding mills are reasonably similar and suggest the responding mills are representative of Oregon's sawmill sector.

Table 4. Energy survey results for Oregon sawmills operating in 2017.

	Contacted	Responded	Response rate
Sawmills	75	30	40.0%
Sawlog input (MMBF Scribner)	2,452.0	1,385.6	56.5%
Lumber production (MMBF)	5,239.5	3,103.7	59.2%

Simmons et al. (in press) captured the mill residue generated from milling sawlogs into lumber for the 75 active sawmills in Oregon during CY 2017 (Table 5). The sawmill energy survey did not request information on the total amounts of mill residues but did ask for the BDT of hogfuel used for energy production. In Oregon 73.8% of mill residue was used to manufacture products other than lumber, primarily paper products and non-structural panels. Residues used for energy were either used on-site or sold off-site and accounted for 26.2% of mill residue disposition. Less than 0.05% of Oregon sawmill residue was not utilized. Similar disposition proportions have been observed at least as far back as 2003 (Brandt et al. 2006, Gale et al. 2012, Simmons et al. 2016a, Simmons et al. in press).

Table 5. Mill residues generated by all (75) active sawmills in Oregon during CY 2017.

	Coarse	Fine	Bark	Total
Residues used for products (BDT)[a]	1,835,594	905,436	70,445	2,811,475
Residues used for energy (BDT)	40,091	187,724	771,173	998,987
Residues not used (BDT)	12	233	880	1,124
Total residue	**1,875,697**	**1,093,393**	**842,497**	**3,811,586**

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

Some mills are using their residue internally for process heat and steam, some are selling mill residue to pulp or reconstituted board facilities, some are doing both, but only six (each producing less than 5 MMBF of lumber annually) indicated not using or selling all their mill residue. The unused residue totaled 0.04% of all mill residue generated by the 30 mills responding to the energy survey and less than 0.02% of all mill residue generated in Oregon during 2017 (Simmons et al. in press).

Mill residue utilization was very similar in eastern and western Oregon, with utilization in both parts of the state exceeding 99%. The eastside rate for unutilized sawmill residue (0.076%) was three times the west-side rate (0.025%), but both were very low (BBER unpublished mill residue data for 2017 Oregon mill census). The percentage of mill residue used for pulp and board was a little lower in eastern than western Oregon (66% vs. 72%, respectively). The category for "Other" uses was three times higher (6.6% vs. 2.1%) in eastern vs. western Oregon, but mill residue used for fuel was approximately the same (26%).

Fuel consumption and energy production

The 30 responding sawmills consumed a variety of fuel types on-site. Twenty-nine consumed electricity, 28 consumed diesel, 24 consumed gasoline, 23 consumed propane, 14 consumed hogfuel, and three consumed natural gas. Only one of the mills produced electricity on-site. Total energy use by the 30 responding mills was about 4.5 trillion Btu, approximately 1,458.1 MMBtu per MMBF of lumber production (Table 6).

Fossil fuels are used to power various machines and vehicles at sawmills, such as boilers for heat and steam generation and rolling stock. Diesel provided the largest amount of fossil fuel-energy consumed for these purposes, followed by natural gas, gasoline and propane (Table 6). Diesel and natural gas together comprised 93.9% of the fossil fuel energy consumed on-site, 62.8% of total nonrenewable energy, and 10% of all energy consumed on-site.

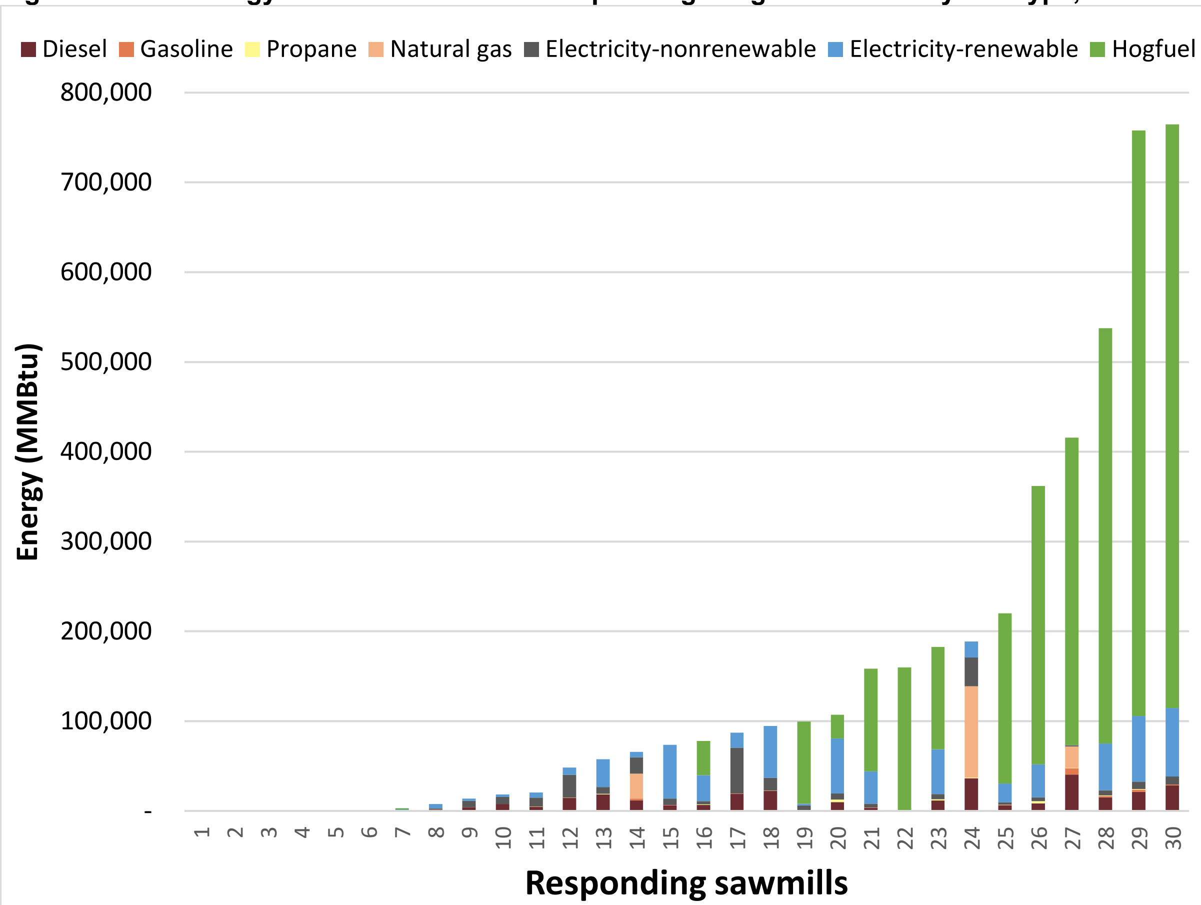
Table 6. Total on-site fuel and energy consumption and fuel consumption per unit of lumber produced at Oregon sawmills in this analysis, 2017.

Fuel	Total fuel consumed		Total energy consumed	Percent of total energy	MMBtu per MMBF of lumber
	--various units--		*MMBtu*		
Diesel	2,177,155	gal	299,100	6.6%	96.4
Gasoline	146,330	gal	17,608	0.4%	5.7
Propane	130,643	gal	11,932	0.3%	3.8
Natural gas	153,601	dt	153,601	3.4%	49.5
Electricity, nonrenewable	69,844,541	kWh	238,310	5.3%	76.8
Electricity, renewable	191,243,349	kWh	652,522	14.4%	210.2
Hogfuel	308,274	BDT	3,152,553	69.7%	1,015.7
Total from nonrenewable			720,551	15.9%	232.2
Total from renewable			3,805,075	84.1%	1,226.0
Grand total			**4,525,626**	**100%**	**1,458.1**

Note: Totals may not add up to 100% due to rounding. Hogfuel includes wood and bark. BDT = bone dry ton, gal = gallons, dt = dekatherms, kWh=kilowatt hours.

Wood and bark were the only renewable fuels consumed on-site to produce energy. The 14 sawmills that consumed hogfuel burned the wood and bark in boilers, creating heat and steam to dry lumber in kilns or provide heat for other processes. Eight of the 22 mills with kilns did not report using any hogfuel, and may have used natural gas, electricity, or another fuel source to operate the kilns. However, most mills did not indicate whether they operated kilns or what portion of their lumber was kiln-dried. Of the total energy produced (and consumed) on-site from hogfuel, bark comprised 61.6% and wood comprised 38.4%. Hogfuel comprised 82.9% of all renewable energy consumed by the 30 responding sawmills (including renewable electricity from utility providers) and 69.7% of total energy consumed by these same mills (Table 6). In other words, the 14 sawmills burning wood residue generated an amount of energy equivalent to 70% of all responding sawmills' total on-site energy consumption. Figure 2 shows the amount of energy used by each sawmill, and which fuels were consumed.

Figure 2. Total energy consumed on-site at responding Oregon sawmills by fuel type, 2017.



Electricity from utilities

In 2017, Oregon had two privately-owned utilities and 39 consumer-owned utilities, of which most procured all their electricity from Bonneville Power Administration (BPA). BPA's 2017 resource mix was 89.3% hydroelectric power, 8.9% nuclear power and less than 2% of coal, natural gas, biomass, petroleum, waste, and other non-biogenic sources combined (ODOE 2020).

The 29 responding sawmills that consumed electricity received it from 11 consumer-owned utilities and both privately-owned utilities. Privately-owned utilities provided electricity to 14 responding sawmills during CY2017. Figure 3 shows the resource mix used to generate utility-provided electricity for each of the responding sawmills. Each utility had some portion of their electricity generated from hydro and biomass (Table 7), as well as coal, natural gas, nuclear, petroleum, waste, and other non-biogenic electricity. In total, 26.8% (238,310 MMBtu) of utility-provided electricity delivered to the responding sawmills was generated using nonrenewable resources, and 73.2% (652,522 MMBtu) was generated from renewable resources (Table 7). Electricity comprised 19.7% of all energy consumed by the 30 responding sawmills, with about

11% of electricity coming from unspecified market purchases. Because only one sawmill reported on-site electricity generation, that mill's energy production and emissions are not disclosed in this report to maintain confidentiality.

Figure 3. Utility-provided electricity consumed by responding Oregon sawmills by fuel type, 2017.

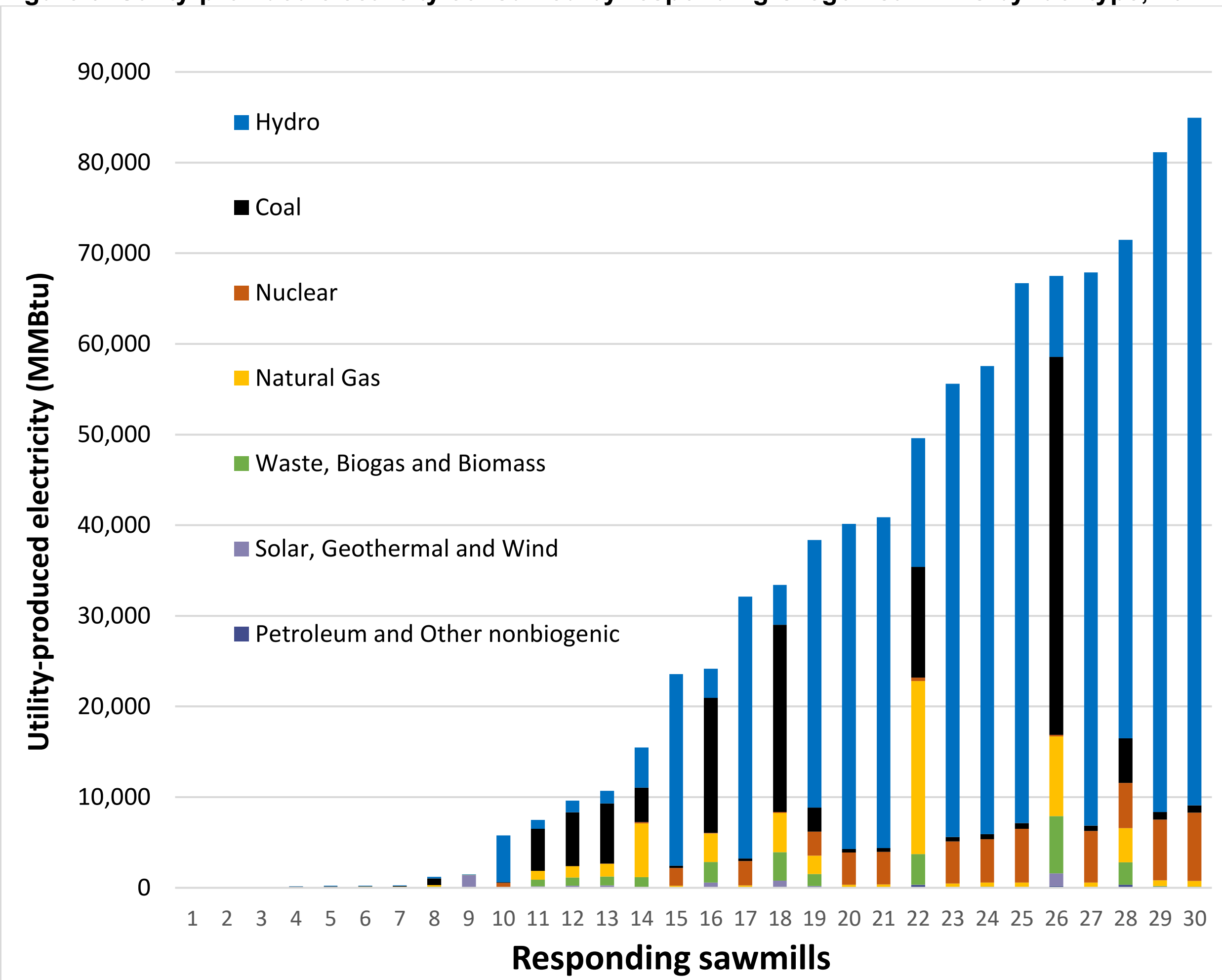


Table 7. Fuels used by utilities to generate electricity for sawmills in this analysis, 2017.

Fuel type	Providing utilities	Total	Percent of total
		MMBtu	
Hydro	13	624,334	70.1
Coal	12	124,788	14.0
Nuclear	12	56,314	6.3
Natural gas	12	55,507	6.2
Waste, biogas, biomass	13	23,423	2.6
Solar, geothermal, wind	5	4,765	0.5
Petroleum and other non-biogenic	12	1,700	0.2
Total		890,832	100

Note: Totals may not sum to 100% due to rounding.

Emissions associated with energy production

Fossil fuels and biomass burned for energy release an assortment of emissions, however, this study was limited to identifying two greenhouse gasses (CO_2 and CH_4) and three criteria air pollutants (PM_{10}, NO_x and SO_x). By applying emission factors from Table 3 to the energy (MMBtu) output from Table 6, emissions were calculated for these GHG and criteria air pollutant emissions. Across all fuel types, 99.22% of emissions were CO_2, 0.09% was CH_4, 0.15% was PM_{10}, 0.44% was NO_x, and 0.10% was SO_x (Table 8). Note that the weight alone of each emissions type does not determine its global warming potential or health and environmental impacts, which are also determined by chemical composition.

Table 8. Total selected emissions from energy used by 30 Oregon sawmills in this analysis, 2017.

Fuel	CO_2	CH_4	PM_{10}	NO_x	SO_x
	------------	------------	*short tons*	------------	------------
Diesel	24,526.2	1.0	46.4	659.5	43.4
Gasoline	1,355.8	0.1	0.9	14.4	0.7
Propane	817.3	0.0	0.1	1.2	0.0
Natural gas	9,035.4	0.2	0.6	7.4	0.0
Electricity, nonrenewable	16,287.4	0.4	398.5	135.2	264.3
Electricity, renewable	2,283.8	0.6	0.9	5.7	0.3
Hogfuel	307,373.9	331.2	116.6	772.4	39.4
Total—nonrenewable	52,022.2	1.6	446.4	817.7	308.5
Total—renewable	309,657.7	331.8	117.5	778.1	39.7
Grand total	**361,679.8**	**333.4**	**563.9**	**1,595.8**	**348.2**
Short tons/MMBF of lumber	116.531	0.107	0.182	0.514	0.112

Burning hogfuel yielded 84.7% of all emissions but did not produce the greatest amount of each emissions type. Hogfuel comprised 85% of all CO_2 emissions, 99.3% of all CH_4 emissions, 20.7% of all PM_{10} emissions, 48.4% of all NO_x emissions, and 11.3% of all SO_x emissions (Table 8). Electricity from nonrenewable energy sources (e.g., coal, natural gas) contributed the majority shares of PM_{10} (70.7%) and SO_x (75.9%) emissions, while diesel contributed about 41.3% of NO_x emissions.

Multiplying the state's total 2017 lumber production (5,239.5 MMBF lumber tally) by 1,458 MMBtu/MMBF (from Table 6), it was estimated that all Oregon sawmills used a total of 7.64 trillion Btu. Likewise, multiplying the 2017 total lumber production figure by the emissions per MMBF, it was estimated that Oregon sawmills produced a total of approximately 0.558 MMT of selected emissions, including 0.554 MMT CO_2 (about 0.87% of the total 2017 Oregon GHG emissions.

Potential offsets from logging residue utilization

About 2.595 million green tons (86.502 million cubic feet) of logging residue were associated with the approximately 1,385.6 MMBF, Scribner of sawlogs processed by the 30 Oregon sawmills in this study. The proportion of logging residue that is wood or bark has been estimated to be approximately 85% wood and 15% bark (Foulger et al. 1976, Sessions et al. 2017, Zhang et al. 2012). The amount of potential energy in logging residue is in the trillions of Btu at approximately 28.763 million MMBtu, an amount equivalent to more than six times the on-site energy used by the 30 sawmills in this study. Open burning of this logging residue in the forest was estimated to produce about 2.44 million short tons (2.22 MMT) of selected emissions, assuming all but 5% of the logging residue was consumed during combustion (Table 9).

Table 9. Amount of energy and selected emissions in logging residue, with potential offsets if used for biomass energy production compared to open burning.

	Energy	**CO_2**	**CH_4**	**PM_{10}**	**NO_x**	**SO_x**	**Total**
	MMBtu	*---------------------- short tons[a] --------------------*					
Logging residue — no energy capture (if burned in forest)	N/A	2,413,104	8,453	11,868	5,047	3,049	2,441,522
Logging residue — with energy capture (if used for bioenergy)	28,763,441	2,804,435	792	1,064	3,164	360	2,809,816
Potential offsets[b]	N/A	(391,331)	7,661	10,804	1,883	2,690	(368,294)

[a] Short ton = 2,000 pounds

[b] Emissions from pile burning minus emissions from hypothetically burning logging residue for energy. Positive numbers signify emissions abatement, and negative numbers (in parenthesis) signify an increase in emissions.

Assuming all the logging residue associated with the sawlogs in this study could be collected and burned for biomass energy, the resulting emissions would change considerably (Table 9). While CO_2 emissions would increase by 16%, the other selected emissions would decrease. CH_4 emissions, which trap heat at a rate 28 times greater than CO_2 (IPCC 2013), would decrease by 91%, as would $PM_{10.}$ NO_x emissions would decrease by 37%, and SO_x emissions would decrease by 88%. These estimates are for general comparison purposes only and rely on three major assumptions: 1) the biomass would be burned for energy and pollution control devices would be used, 2) they do not consider emissions that would occur from collecting and transporting logging residue to energy production facilities, and 3) they do not integrate the economic feasibility of developing and maintaining a forest-to-facility bioenergy production system.

Discussion and conclusion

When examining energy use and emissions associated with lumber production, it is necessary to consider the amounts and types of fuels consumed on-site, the resource mix used to generate electricity provided by utilities, and differences in lumber production (e.g., kiln-dried vs air-dried vs. green lumber). In this analysis, the 30 responding Oregon sawmills used an estimated 1,458 MMBtu of energy per MMBF of lumber produced in 2017. This amount is equivalent to 28% of the energy used by California mills in 2016 (5,267 MMBtu/MMBF); 38% of that used by Montana mills in 2009 (3,829 MMBtu/MMBF); but is 32% higher than energy used by Southwest (Arizona, Colorado and New Mexico) mills in 2012 (1,108 MMBtu/MMBF) (Morgan and Donahue 2019; Loeffler et al. 2016a, b). These differences can be due to several factors, including the mix of fuels used on-site at each mill, the resource mix used by utility providers to produce electricity, the quantity and degree of processing of the lumber produced by each mill, the efficiency of mill equipment, the number of sawmills using hogfuel for energy versus selling some or all of their residue, different data years, the species mix and moisture content of hogfuel and lumber, and regional climate (e.g., relative humidity and temperature) which impacts the amount of energy needed to dry wood. Differences may also be due to the accuracy of information provided by responding mills and information withheld by nonresponding mills. Here it is assumed that the accuracy of information provided by responding mills in different states is comparable, and that the energy intensity of responding mills is similar to that of nonresponding mills.

Relatively low overall energy use per unit of lumber in Oregon is also partially due to the state's notable green-lumber market. Drying lumber is usually the largest use of energy in sawmills (Wengert and Meyer 1992, Forest Products Laboratory 2010). Loeffler et al. (2016b) summarize additional literature related to energy use and drying lumber. During the mill visits that occurred in 2019 and 2020, some mill operators indicated that a large portion, if not all, of the lumber they produce leaves the sawmill green, while others indicated that most of the lumber they produce is dried. The amount of green lumber versus kiln-dried lumber produced by individual mills was not captured in this study or the 2017 Oregon TPO analysis nor in the 2016 California TPO and sawmill energy analyses, making it difficult to estimate the amount of energy specifically associated with drying lumber. The Western Wood Products Association estimated that 52% of lumber produced in Oregon during 2017 was sold as green, not dried (WWPA 2018), whereas in 2016 43.5% of lumber produced in California was green (WWPA 2017).

Energy consumption differences by fuel type (e.g., hogfuel, electricity, and natural gas) among Oregon mills and between Oregon and California suggest substantial variation in mill configurations and availability of different fuels. Hogfuel was the majority fuel source (over 50% of total energy) for 10 sawmills and the second largest fuel source at three other mills in this Oregon analysis, suggesting that those mills used wood-fueled kilns for drying at least a portion of their lumber production. Electricity was the majority fuel source at 12 Oregon mills, while natural gas was the majority fuel source at just two Oregon mills. Electricity use for Oregon sawmills was estimated at 287 MMBtu/MMBF (Table 6), which was 94% greater than in California (148.3 MMBtu/MMBF), while natural gas use in Oregon (49.5 MMBtu/MMBF) was about 17% (296.8 MMBtu/MMBF) of that of California sawmills (Morgan and Donahue 2019). Energy efficiencies for various fuels, different equipment, and equipment configurations impact the amount of electricity and other fuels sawmills require. However, the survey approach used for this analysis did not gather sufficient details on equipment and configuration to address those differences among mills that responded, or in comparison to other states like California.

This sawmill energy analysis and studies in other western states indicate that Oregon sawmills are relatively efficient with respect to energy use, emissions, and utilization of mill residue. Likewise, logging utilization studies (Berg et al. 2018, Morgan and Spoelma 2008, Simmons et al. 2014, 2016b) among the western states also suggest that Oregon timber harvesting efficiency is not significantly different from other western states (i.e., Oregon logging does not generate significantly more logging residue per unit of timber delivered to mills compared to other western states).

Oregon does not have a significant bioenergy infrastructure partly because hydroelectric dams provide relatively low-cost renewable electricity, natural gas prices are low, and an extensive pulp and paper industry uses mill residues and roundwood. Consequently, there is little incentive to collect or try to use logging slash for energy. Onsite broadcast or piling and burning are the traditional treatments used to reduce or eliminate slash in Oregon forests (Adams and Storm 2012, Wright et al. 2010), and there are rules (e.g., OAR Chapter 629-Division 615) for the treatment of logging slash in Oregon (Cloughesy and Woodward 2018). However, from the literature reviewed, it is not clear exactly how many or what proportion of harvested acres are treated with broadcast or pile burning each year (Lord et al. 2006, Wright et al. 2010, Adams and Storm 2012, Law et al. 2018).

The amount of logging residue produced varies greatly depending on the market for small-diameter wood and changes in harvesting and milling technology (Keegan et al. 2010 a, b; Simmons et al. 2014). Pulp mills, wood pellet manufacturers, and bioenergy facilities are typical users of small-diameter wood, yet associated harvesting, hauling, and processing costs are limiting factors for all users, contributing to the amounts of logging residue left in the forest.

When burned in the forest or at the log landing, logging residue releases large amounts of emissions freely into the atmosphere, similar to a wildfire. During bioenergy production, however, emissions-control technologies are used that can substantially reduce air pollution. Under current forest industry and energy sector conditions in Oregon, collecting logging residue from the forest has limited potential to increase bioenergy production and displace some emissions associated with combustion of fossil fuel energy. As indicated in Table 9, burning the logging residue associated with logs delivered to sawmills could produce an amount of energy equivalent to six times what was consumed by the 30 sawmills in this analysis. From an emissions standpoint, alternative disposal methods should also be considered. Mulching the logging slash, converting logging slash into pellets or biochar[7], using an air curtain destructor, or delivering logging slash to a bioenergy facility might be preferred methods for altering the amounts and types of emissions released (Ganguly et al. 2018, Zahn 2005). However, in order to implement these alternative disposal methods for logging slash, financial feasibility, and emissions associated with transporting logging slash to energy production facilities must be considered. The costs of additional equipment and related logistics (e.g., transportation of logging slash, processing of woody materials), as well as the potential revenue from products (e.g., pellets, biochar, electricity), will impact the feasibility of these methods. Beyond financial feasibility, the proper policies are not currently in place to allow the acceleration of alternative disposal methods (Aguilar et al. 2011, Sahoo et al. 2018, Sessions et al. 2013, Smith et al. 2017, Zamora-Cristales et al. 2015, 2017).

[7] Biochar is made through pyrolysis from woody biomass, and is used as a soil amendment.

Despite the ability of biomass energy derived from using logging residue to potentially replace all the fossil fuel-derived energy used by Oregon sawmills in 2017, the technology is not sufficiently advanced, nor available on a sufficiently large scale to allow for operation of current sawmill infrastructure with bio-based fuels only. Oregon's existing pulp and paper industry, which purchases much of the mill residue generated by Oregon sawmills, and uses comparably sized roundwood as biomass energy facilities, in addition to affordable conventional energy markets do not encourage increasing the state's bioenergy production or capacity. Likewise, State and Federal incentive programs for using bioenergy have thus far not encouraged widespread bioenergy expansion within the state of Oregon. Conversions from fossil fuels to biofuel, or from fossil fuel electricity to biomass power, are becoming more common, but for many sawmills there may be little to gain financially from converting. Costs and availability of such conversions were not considered in this analysis, but as is the case with other types of renewable energy infrastructure, costs are likely to decrease and availability is likely to increase as technology develops.

At this time, the low costs associated with existing hydropower and natural gas energy development compared to biomass energy development create little incentive for the wood product industry to invest in bioenergy technology, and little incentive for utility providers to procure relatively costly bioenergy (Geiver 2012, Simet 2012). As Oregon considers policies to better manage carbon emissions, the wood products industry may support and benefit from policies that encourage reductions in fossil fuel consumption, promote renewable energy use including wood-based energy, and support development of new wood-based products that use less energy and stay in use longer. Moreover, incentives will be necessary to increase the utilization of more cut-tree material (e.g., logging and mill residue) in areas with lower utilization. For example, haul costs could be subsidized when moving slash or mill residue to facilities that can use it (e.g., pulp mills, medium density fiberboard/particleboard plants, biomass energy facilities, biochar facilities, etc.), possibly with higher incentives for fiber (e.g., pulp/board) vs. fuel uses.

Oregon, unlike the southwest US, already has a substantial portion of its grid-delivered electricity provided from renewable sources (Loeffler et al. 2016a). Substituting or replacing hydroelectric-based energy with additional biomass energy – which may not be as carbon-friendly – may not be desirable. Rather, increasing the utilization of felled trees for solid (e.g., posts) or "reconstituted" wood products (e.g., pulp and board, maybe biochar) may be more beneficial, from a carbon and other emissions standpoint, than burning the wood waste for bioenergy (Smyth et al. 2020). Carbon management policy should recognize that Oregon sawmills sell much or all of their residue for pulp and non-structural panels or use their wood waste internally for energy. These sawmills are efficient in the sense that they are avoiding some fossil fuel consumption by using their wood waste for energy, not demanding that amount of energy from the grid, or are already contributing to the reuse or recycling of carbon as wood fiber.

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