On-Site Energy Consumption at Softwood Sawmills in Montana

Dan Loeffler
Nathaniel Anderson
Todd A. Morgan
Colin B. Sorenson

Abstract

Total on-site energy requirements for wood product manufacturing are generally not well understood or publicly available, particularly at subregional scales, such as the state level. This article uses a mail survey of softwood sawmills in Montana to develop a profile of all on-site energy consumption. Energy use is delineated by fuel type on a production basis for both renewable and nonrenewable sources for production year 2009. Survey respondents represented 92 percent of total Montana softwood lumber production of 449 million board feet, which is 4 percent of western US production and 2 percent of national production. Total annual on-site sawmill energy required was 1.6 trillion British thermal units. Seventy-seven percent was derived from wood and bark, primarily for process heat and steam for lumber drying; 16 percent was from electricity; 5 percent was from diesel used for on-site rolling stock; and the remainder was from gasoline, propane, and natural gas. Energy produced from renewable sources accounted for 86 percent of total on-site energy consumption. In addition to providing an energy profile of Montana sawmills for policymakers, aggregated results may be useful to individual firms in characterizing their energy requirements relative to the state average and in identifying potential opportunities for bioenergy expansion.

Worldwide, the United States is the largest consumer of total primary energy. In 2010, total energy consumption in the United States was 98,000 trillion British thermal units (Btu; US Energy Information Administration [EIA] 2014a), and of this amount, wood product manufacturing consumed 473 trillion Btu (EIA 2014d)—enough energy to power 5.3 million homes for 1 year (EIA 2014c). Compared with other manufacturing industries in the United States, sawmills are major consumers of renewable energy. The US Environmental Protection Agency (2007) has estimated that more than 65 percent of the total wood product manufacturing energy requirements were derived from wood bioenergy, and the American Wood Council (2013) has estimated that 58 percent of the energy requirement for softwood lumber production comes from wood bioenergy.

Sawmills are also leaders in renewable energy production. The lumber supply chain produces an excess of woody biomass in the form of logging slash and primary processing residues (hereafter referred to as biomass) that can be used as fuel (US Department of Energy [DOE] 2011). Renewable energy produced by the wood products manufacturing sector, including the sawmill industry, is mostly in the form of process heat and electricity generated from the combustion of these biomass by-products. In addition to potential cost savings associated with on-site heat and power from biomass, a variety of public policies, especially in North America and Europe, have incentivized the use of biomass for fuel to meet broader utility and industrial energy needs and policy goals.

Lumber drying is typically the most intensive energy requirement at a sawmill, followed by sawing and material handling (Wengert and Meyer 1992, Forest Products Laboratory 2010). In his description of potential energy savings at sawmills, Bond (2008) reported in 2002 that 43 percent of all sawmills had dry kilns, 63 to 80 percent of total sawmill energy was produced from wood residues, and kiln drying lumber consumed six to nine times more energy than is consumed in the milling processes. Milota et al.

The authors are, respectively, Economist, College of Forestry and Conservation, Univ. of Montana, Missoula (drloeffler@fs.fed.us [corresponding author]); Research Forester, Rocky Mountain Research Sta., USDA Forest Serv., Missoula, Montana (nathanielmanderson@fs.fed.us); Director, Forest Industry Research, Bureau of Business and Economic Research, Univ. of Montana, Missoula (todd.morgan@mso.umt.edu); and Economist, Northern Region, USDA Forest Serv., Missoula, Montana (colinsorenson@fs.fed.us). This paper was received for publication in December 2014. Article no. 14-00108.

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(2005) surveyed western and southern US softwood sawmills to conduct a life-cycle inventory and found that southern mills consumed 15 percent more total energy per board foot of lumber produced than western mills, with nearly twice as much energy derived from wood. The difference in overall efficiency is tied to the South using mostly biomass energy for steam generation, which generally has lower boiler efficiency than fossil fuels and requires more steam produced from higher–moisture content biomass to dry sawn products, which also have higher moisture contents than sawn products in the West. Simpson (1991) and Nicholls et al. (2004) provided great detail regarding kiln operations and operating parameters that affect energy consumption and drying efficiency, including moisture content, wood condition, lumber thickness, wood species, insulation, and type and number of drying fans. Breiner et al. (1987) reported previous work published beginning in the 1950s that quantified energy consumption of commercial dry kilns and also measured and reported energy required to dry four softwoods, with Douglas-fir requiring half the energy necessary to dry ponderosa pine. The authors also noted that lumber conditioning can require up to 14 percent of dry kiln energy, whereas fan-operated energy is approximately half that of conditioning.

The different requirements to produce process heat at a sawmill relate directly to on-site energy production. Heat for dry kilns can be generated by combustion-only systems or combined heat and power systems (CHP) using a variety of fuels. Most milling equipment is powered by electricity, which can be provided by local utilities or by on-site CHP or even on-site solar or wind power. The energy portfolios of electric power utilities can be composed of highly variable production sources, depending on location. In contrast, currently, most rolling stock, such as log loaders, forklifts, and trucks, typically require liquid fuels or occasional compressed gas. The relative mix of energy needs and sources has important implications for the types of energy consumed and the potential to increase overall renewable energy production from biomass in the sawmill industry.

Bioenergy Expansion in the Sawmill Industry

The DOE (2011) has estimated that demand for biomass energy will increase in the coming decades, primarily through expansion of cofiring with coal for electricity production. Substitution of renewable energy sources, such as solar, wind, hydropower, and biomass for fossil fuels, has several benefits, including decreasing foreign energy dependence, diversifying energy portfolios and energy infrastructure, creating local jobs, stimulating local economic development, and reducing health-degrading emissions from fossil fuels, especially from coal and petroleum oil (Solomon et al. 2009, Jones et al. 2010, McIver et al. 2013, Loeffler and Anderson 2014, Oliver et al. 2014). Also, in the context of increasing awareness and acceptance of climate change resulting from anthropogenic greenhouse gas emissions, the potential climate benefits of renewable energy are also important. Sustainably sourced biomass energy recycles biospheric carbon dioxide rather than adding permanently sequestered carbon into the atmosphere through extraction and combustion of fossil fuels (Morris 2008, Puettmann and Lippke 2012).

Many authors have identified critical challenges associated with bioenergy expansion (Cook and Beyea 2000; Searchinger et al. 2008, 2009; Searchinger 2010; Zanchi et al. 2010), but others note that sustainably harvested wood and forest residues have the potential to substantially displace fossil fuels (Fargione et al. 2008, Tilman et al. 2009). Research has also found that expanding biomass energy in some US markets is unlikely to displace existing capacity in the wood products manufacturing sector and that wood supply chains are well positioned to take advantage of expanding biomass energy markets. However, it is unknown to what degree dedicated biomass facilities and traditional mills would compete for raw materials (Conrad et al. 2010, 2011). This is a significant concern in regions where the wood procurement operations of paper and wood products manufacturers overlap with expanding bioenergy production.

Recently developed literature that quantifies regionally specific, direct on-site energy consumption at wood products manufacturing facilities is modest and has been developed by the Consortium for Research on Renewable Industrial Materials (CORRIM) mostly for life-cycle inventories (CORRIM 2014). CORRIM and its contributors conducted surveys of various facilities throughout the United States. The results contained in CORRIM's vast library are for large geographies and serve as inputs for life-cycle inventories. Few recent empirical analyses of energy consumption at US sawmills outside of the CORRIM contingent are available. However, Lin et al. (2012) conducted a survey of eastern US hardwood sawmills to examine energy consumption and efficiency, concerning primarily electricity use. Their results included recommendations for upgrades to lighting and compressors.

There are compelling reasons why further research into energy consumption by the sawmill industry is needed. This industry is already a major producer and consumer of renewable energy, but a significant portion of its energy needs are met by sources other than bioenergy. Based on its large scale, energy intensity, generation of biomass by-products, and existing integration of on-site renewable energy production, this industry is a logical area to develop new bioenergy capacity (EIA 2014d). Available literature lacks basic information describing current status of important aspects of energy consumption at scales that can adequately inform decision making. Of the several most recent studies, all are regional in nature and focus primarily on the US South or Northeast. Studies focused on modeled life-cycle inventories tend to be difficult for individual facilities to translate into improvements in technology, energy efficiency, and renewable energy expansion. Modeled life-cycle inventories also do not allow for easy interpretation and comparison of results for an individual facility to gauge its position among competitors within a reasonably scaled geographic boundary. Also, the only recent study that included the Rocky Mountain region used data collected from four respondents in portions of four states, representing only 16 percent of lumber production in the analysis area (Puettmann et al. 2010). While firm-level audits of energy consumption at softwood mills are routinely procured to guide internal decision making, results are typically proprietary and rarely aggregated in ways that make industry-level information available to the public, policymakers, and other stakeholders. Furthermore, results are representative of specific mill operations and do not account for efficiency variation among mills. Because the structure and productivity of wood products industries varies from state to state, simply applying or extrapolating national- or regional-level energy figures to individual states or specific industries within a state is not appropriate.

Objectives

Individual mill managers have an acute awareness of each mill's operating requirements, such as labor, land, capital, raw materials, and energy. Furthermore, industry-level energy accounting at the national level is robust. However, a knowledge gap exists between national and regional energy consumption reporting and individual facility audits. Analysis at state-level resolution is most important to state and local policymakers, especially in areas that have experienced significant upheaval in wood product industries. Specifically, empirical energy consumption data and high-resolution profiles of energy use are needed to identify opportunities for efficiency gains and industrial bioenergy expansion in the sawmill industry. In this effort, we begin to address this knowledge gap by providing energy consumption data and analysis for softwood sawmills in Montana using a survey and present results in light of production trends in the industry. Given that 93 primary processing facilities, including 32 sawmills, have closed in Montana since 1998 (McIver et al. 2013), the sawmills that remain in production represent a significant change in the industry landscape and are under significant market pressure to remain competitive in national and global markets, especially by reducing costs and increasing efficiency. Aggregating energy consumption at this level is detailed enough to allow individual firms to gauge energy efficiency relative to competitors yet broad enough to afford policymakers a solid basis for decision making by characterizing an entire economically important manufacturing industry at the state level.

Methods

This study focused on the softwood sawmill industry of the wood product manufacturing sector in Montana. To address the knowledge gap that exists between regional- and facility-scale energy assessments and to better understand the types and quantities of energy consumed by sawmills, we compiled energy consumption information for sawmills operating in Montana during calendar year 2009. This year was selected because detailed primary processing mill production data were being collected by the authors in conjunction with another research effort (McIver et al. 2013). Energy consumption is quantified by fuel type and renewable or nonrenewable designation and presented in units of both total energy consumption and per unit production.

It is worth noting here that 2009 was an unusual year for this industry. In 2009, softwood lumber production in the United States was 23,200 million board feet (MMBF; Howard and Westby 2013), the lowest production level in several decades (Woodall et al. 2012). In the western United States, which is the largest softwood lumber–producing region (Spelter et al. 2009, Howard and Westby 2013), wood product manufacturing reached a low point in 2009 but has seen a notable turnaround since then. By 2012, softwood lumber production in the western United States had increased by 20 percent (Zhou 2013). Together with broad economic recovery, near-term demand for softwood lumber will likely remain stable or increase further. The potential impacts of the economic downturn on the results are presented in the ''Results and Discussion.''

There are several reasons why we chose not to include other wood product sector industries in this survey. Limited state-level information is publicly available that describes energy consumption in wood product industries in general. The plywood, veneer, and engineered wood product industries use substantial quantities of timber, operate sizable facilities, and report outputs in fairly standard units of measure that allow accurate comparison. However, these industries have too few facilities in Montana to report industry-level data without potentially disclosing proprietary information. In contrast, the post-and-pole, log home, log furniture, and other industries each have numerous facilities in Montana, but those facilities are often part-time operations, use relatively small volumes of timber, and report outputs in a variety of nonstandard units of measure, making comparisons with other industries or geographic areas very difficult.

Study Area

The geographic boundary for this analysis is the state of Montana (Fig. 1). Wood product manufacturing in Montana dates back to 1845, when the first known sawmill was built near present-day Stevensville in the Bitterroot Valley of western Montana. The Blackfoot mill in Bonner was completed in 1886 and operated primarily to supply wood products to the railroad and mining industries (Kuehn 2000). Since that time, wood products have remained an important part of the Montana economy amid numerous changes in land management practices, technology, and wood product markets. However, the Montana lumber industry has fluctuated significantly in recent decades, following a generally downward trend. Lumber production was at its peak in 1987 with 1,640 MMBF produced, and a low of 449 MMBF produced in 2009 during the Great Recession coincided with the lowest level of US housing starts in six decades (Morgan et al. 2011, Woodall et al. 2012, McIver et al. 2013). In 2009, there were 126 wood products manufacturers in Montana that converted timber into lumber, plywood and veneer, house logs, post and poles, log furniture, and fuelwood; 41 of these facilities were sawmills that employed 1,166 people (McIver et al. 2013, US Bureau of Labor Statistics 2014).

Survey

Statewide censuses of timber processing facilities are periodically conducted as part of a national effort to collect and report timber products output (TPO) information for the US Forest Service Forest Inventory and Analysis Program. In 2010, an energy questionnaire was designed to coincide with the TPO census of Montana timber processors for calendar year 2009 in order to collect energy consumption information for the same year. The questionnaire was designed to collect information about each facility's energy consumption by energy source. A mail survey was paired with follow-up phone calls to increase participation in the survey.

The energy questionnaire asked for consumption of diesel, gasoline, and propane for on-site rolling stock; electricity, natural gas, and propane consumption for the mill and its internal components; and wood and bark consumption for firing boilers serving drying kilns or for

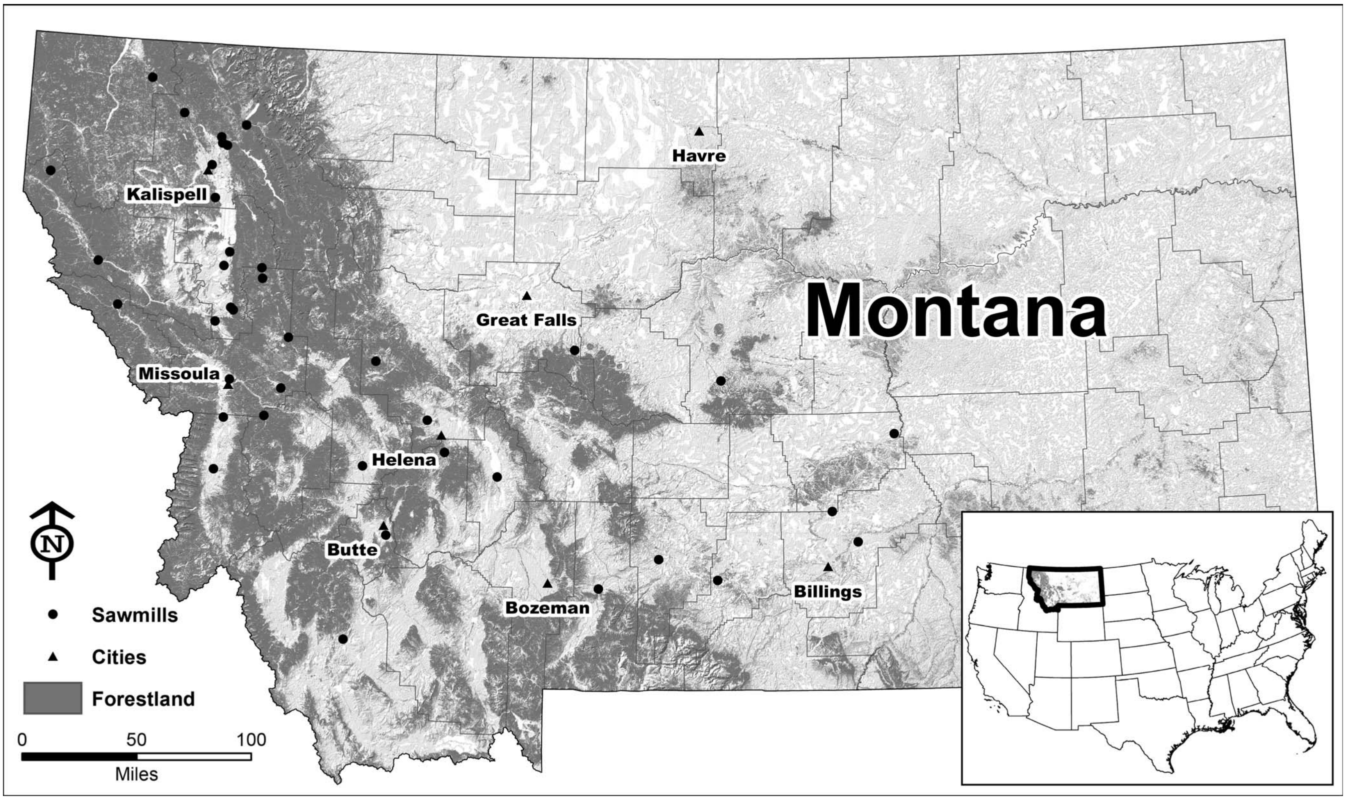

Figure 1.—Location of all Montana sawmills in 2009.

other thermal energy needs. Furthermore, each respondent's electricity provider was identified, and this information was used to determine the percentage of electricity in each provider's energy portfolio produced from various sources, such as fossil fuels, nuclear, and renewables. Clarification of questionnaire responses was made using follow-up phone interviews. As previously discussed, the sawmill industry was selected, and other industries were excluded to protect proprietary data for individual firms, ensure an adequate number of responses, and produce results that could be readily compared with other state- and national-level figures. This analysis includes 11 of the 41 Montana sawmills active in 2009, which is a response rate of 27 percent. However, these 11 sawmills accounted for 92 percent of sawmill production. In this article, we analyze only energy consumption on the premises of each sawmill and exclude energy used in other elements of the supply chain, including transportation of raw materials and finished goods. Data from the survey are summarized to ensure confidentiality.

Fuel consumption and energy

The unit of energy reported in this analysis is the British thermal unit, which is the amount of energy needed to move the temperature of 1 pound of water at maximum density through 1°F. We express energy consumption in orders of magnitude of British thermal units, where each ''M'' represents 10^3 Btu. Although not an accepted unit in the International System of Units, the British thermal unit is a common energy measurement in the United States and very much part of the industry vernacular. However, we note that 1 Btu is equivalent to 1.055 kilojoules. Lumber production and associated compound units are presented in board feet lumber tally, which is the standard unit of production used in the study region.

All of the sawmills in this study had different mixes of fuels used on-site for lumber manufacturing, which we categorize as either nonrenewable (generated from fossil fuels or nuclear reaction) or renewable (generated from nonfossil and nonnuclear sources). In this analysis, on-site wood and bark combustion and those portions of electricity produced from hydropower dams, solar, and wind are considered renewable. No sawmills in this study had on-site hydropower, solar, wind, or geothermal capacity.

Fossil fuel

Energy content for fossil fuels and electricity consumed on-site at Montana sawmills in 2009 were obtained from the EIA (2014b) and are displayed in Table 1.

Wood and bark

Biomass energy in the form of wood and bark consumed at sawmills was almost exclusively residues from on-site sawmilling processes, and residues are not often stored for extended lengths of time that allow for substantial drying.

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

Fuel	Unit	MMBtu/unit
Diesel	Gallon (gal)	0.1387
Gasoline	Gallon	0.1242
Propane	Gallon	0.0913
Natural gas	Dekatherm (Dth)	1.0000
Electricity	Kilowatt-hour (kWh)	0.0034

Moisture content has a significant impact on the heating value of wood and bark (Jenkins et al. 1998), and there is general consensus that a linear relationship exists between moisture content and higher and lower heating values of wood and bark (Shelton 1942, Bowyer et al. 2007). Moisture content of wood and bark at the time of combustion is highly variable and dependent on many factors, including time since harvest, species, and section of tree from which the fuel originated. The sawmills in this analysis do not routinely measure moisture content of wood and bark used for energy. Therefore, we estimated moisture content on a wet basis for each of three common species using reasonable combinations of moisture contents for different portions of wood and bark reported in Wilson et al. (1987). The average of the three moisture contents was used to determine the higher heating values (HHV) used in this analysis (Table 2).

Energy contents for wood and bark were determined as the weighted average of the three most commonly harvested species of conifers—lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), and ponderosa pine (*Pinus ponderosa*)—which together made up 81 percent of total timber harvest in 2009 (McIver et al. 2013). Using species-specific HHV for combinations of wood and bark found in Wilson et al. (1987), energy contents were weighted based on each species proportion of total harvest of the three species. Percentages of total harvest of the three species were 42 percent lodgepole pine, 39 percent Douglas-fir, and 19 percent ponderosa pine. Finally, weighted average energy contents were adjusted to reflect the average moisture contents at the time of combustion based on the following equation:

$$\text{Energy content} = \text{HHV} \times \left[1 - \frac{\text{Percent moisture content (wet basis)}}{100}\right]$$

Electricity

We looked at the energy production portfolio of each mill's electricity provider to determine the portion of electrical energy attributable to renewable and nonrenewable sources. Electricity production in the US Northwest varies from production in other regions, such as the Northeast and Southeast (Milota et al. 2005; Bergman and Bowe 2010, 2012). In the Northwest, there is greater access to electricity produced from hydropower dams, such as those under control of the Bonneville Power Administration (BPA), than in other regions. Of the 24 electric cooperatives and two regulated suppliers and utilities in Montana (Montana Electric Cooperatives Association 2014, Montana Public Service Commission 2014), sawmills in this analysis purchased power from three cooperatives, one regulated supplier and utility, and one tribally controlled electric power entity. Two of the three cooperatives were supplied exclusively from BPA, which in 2009 had an energy production portfolio that was 83 percent hydropower, 2 percent solar and wind, and 8 percent nuclear. The remaining 7 percent of BPA electricity was obtained from contract sources, the origin of which is unverifiable and considered nonrenewable in this analysis. Effectively, this amounts to a BPA energy portfolio that was 85 percent renewable energy in 2009. The remaining cooperative received 85 percent of its power from the BPA, 10 percent from nuclear, and 5 percent from contract sources. The energy portfolio of the single regulated supplier and utility was 8 percent renewable, 13 percent coal, and 79 percent contract sources. The tribal entity was supplied 100 percent by hydropower. Using the energy portfolios from the electricity providers, the portion of each sawmill's electricity consumption attributable to renewable and nonrenewable production was determined. Although a portion of contract sources is likely to be renewable in this region, this cannot be verified. Therefore, the categorization of contract sources as nonrenewable in this study means that the distribution of renewable and nonrenewable sources should be viewed as a minimum renewable scenario.

Table 2.—Assumed moisture contents and higher heating values for wood and bark consumed for energy at Montana sawmills in 2009.[a]

	% Moisture content (wet basis)		Higher heating value (Btu/dry lb)	
Species	Wood	Bark	Wood	Bark
Douglas-fir	33.7	51.6	8,759	10,109
Lodgepole pine	49.8	46.0	8,600	10,035
Ponderosa pine	52.4	33.1	9,120	9,516
Avg.	45.3	43.5	8,826	9,887

[a] From Wilson et al. (1987).

Results and Discussion

In total, Montana softwood lumber production was 449 MMBF in 2009, or 43 percent of production capacity, accounting for 2 percent of total 2009 US softwood lumber production and 4 percent of all western US softwood lumber production (Zhou 2013). This analysis includes 11 of the 41 Montana sawmills active in 2009, which accounted for 92 percent of production, or 414 MMBF of lumber. Annual production by sawmills in this analysis ranged from 2 to 65 MMBF, with average production of 37.6 MMBF. For comparison, nonrespondent mills averaged 1.2 MMBF in annual production. Total 2009 residue production at all Montana sawmills was 526,000 tons, of which 100,000 tons was bark; 78 percent of mill residues went to pulp and board manufacturers, 16 percent was used for energy, and 6 percent went to other uses (unpublished data from McIver et al. 2013). Table 3 displays volumes and distribution of residues from the 11 sawmills in this analysis. Also in 2009, 55 percent of lumber produced at Montana sawmills was dried in kilns (Western Wood Products Association 2010), and there were 16 wood processing facilities that had dry kilns served by wood-fired boilers. In this analysis, nine sawmills had dry kilns served by wood-fired boilers, one had a dry kiln served by a natural gas–fired boiler, and the remaining sawmill air-dried its products.

Weighted average energy contents of wood and bark for the three most commonly harvested species in 2009, adjusted to 45 and 44 percent moisture content, respectively, were determined to be 9.6 MMBtu/ton of wood and 11.3 MMBtu/ton of bark. Of the total wood and bark energy used by Montana sawmills, wood provided 40 percent, and bark provided 60 percent; of the total tons of wood and bark, wood accounted for 44 percent, and bark accounted for 56 percent. On average, mills with wood-fired boilers had fuel blends of 72 percent bark and 28 percent wood.

Table 3.—Distribution of Montana sawmill residues in this analysis in 2009.[a]

Residues sold for products (BDT)									
Coarse	Sawdust		Shavings		Bark				
Pulp or board	Pulp or board	Animal bedding	Pulp or board	Animal bedding	Pulp or board	Landscaping	Other bark	Other	Total
205,908	101,228	108	65,531	120	1,649	5,998	12,756	54	393,352

Residues used for energy (BDT)								
Coarse	Sawdust		Shavings		Bark			
Sold for energy	Internal energy	Sold for energy	Internal energy	Sold for energy	Internal energy	Sold for energy	Unused	Total
1,312	576	234	230	360	32,849	41,666	160	77,228

[a] One bone dry ton (BDT) equals 1 ton (2,000 lb) of residue at 0 percent moisture content.

Fuel and associated energy consumption at Montana sawmills in 2009 are displayed in Figure 2 and Table 4. The 11 Montana sawmills in this study consumed approximately 1.6 million MMBtu of energy in 2009. Wood and bark made up the vast majority of energy consumption at sawmills, representing 77 percent of total energy. Electricity made up 16 percent of total energy, and diesel fuel made up 5 percent; gasoline, propane, and natural gas made up 2 percent combined. All sawmills used a substantial amount of electricity and diesel fuel on-site, and all but one sawmill reported using gasoline on-site. Eight sawmills reported using propane. Four sawmills reported using natural gas, and all but one sawmill consumed wood, bark, or both for on-site energy. The majority of propane and all diesel and gasoline were reported as used for on-site support equipment, such as rolling stock (e.g., log loaders, forklifts).

Although dwarfed by total wood and bark energy consumption, Montana sawmills consumed a substantial amount of electricity in 2009, which provided 16 percent of total energy. In general, the aggregate portfolio is favorable toward renewables; however, 3 of the 11 sawmills, representing 36 percent of total sawmill electricity consumption, obtained electricity from the supplier and utility that had only 8 percent of its portfolio from renewable energy sources. Of total electricity consumption, 57 percent was generated from renewable sources, primarily hydropower, and 43 percent from nonrenewable sources, including coal, nuclear, and unverifiable contract sources. Table 5 displays the distribution of electricity generation sources consumed on-site at sawmills: 56 percent of electricity was obtained from hydropower, 33 percent from contract, 5 percent from coal, 5 percent from nuclear, and 1 percent from solar and wind sources. Although we have categorized contract sources as nonrenewable, it is likely that an unknown portion of contract sources are from renewable sources and that total renewable energy consumption is underestimated.

Fourteen percent (0.21 million MMBtu) of total sawmill energy consumed on-site was derived from nonrenewable sources. Of the total energy generated from nonrenewable sources, electricity accounted for 51 percent, diesel fuel accounted for 37 percent, natural gas accounted for 7.5 percent, and gasoline and propane accounted for 4.5 percent combined. Renewable energy accounted for 86 percent of total energy consumed on-site. Of the 1.37 million MMBtu of renewable energy consumed, wood and bark accounted for 35 and 54 percent, respectively, and 11 percent was obtained from electricity generated from renewable sources. To put the sawmills' renewable energy consumption into perspective, 1.37 million MMBtu is equivalent to the energy contained in 236,200 barrels of crude oil, 580 railcars of coal, or 11 million gallons of gasoline, which is enough gasoline for 236.6 million passenger vehicle miles.

Nationwide, the sawmill industry consumed 232 million MMBtu in 2010 (EIA 2014d) and produced 24,800 MMBF (Howard and Westby 2013)—approximately 9,355 Btu per board foot produced in 2010. Although similar national level data for 2009 are not available to make a perfect comparison, across the 11 sawmills in this analysis, total energy consumption was 1.6 million MMBtu, and 414 MMBF of lumber was produced in 2009. This compares extremely favorably to the national average in 2010. Sawmills in this analysis required an average of 3,830 Btu to produce 1 board foot of lumber in 2009, or 59 percent less energy than the national average in 2010. This is likely due to many factors, including species mix, fuels consumed, climate, and energy efficiency.

Related to this favorable energy-to-production ratio, sawmills in this analysis consumed less than 1 percent of total US sawmill industry energy yet produced nearly 2 percent of the nation's softwood lumber in 2009. According to Adair and McKeever (2009), the average-size single-family house is currently 2,470 ft^2 and requires approximately 14,800 board feet of lumber, not including structural and nonstructural panels. The 11 sawmills in this analysis produced enough lumber for the construction of 28,000 new homes, or 5.1 percent of nationwide housing construction starts in 2009 (US Census Bureau 2014). In 2009, the

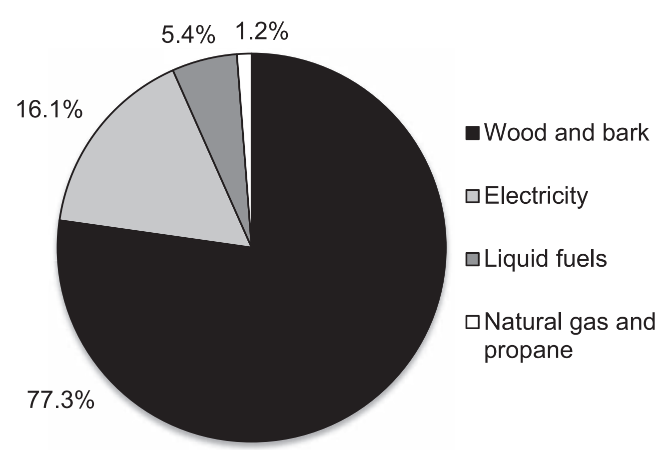

Figure 2.—Categorical distribution of energy consumed on-site at Montana sawmills in 2009.

Table 4.—Total fuels and energy consumed on-site at Montana sawmills in 2009 and fuel energy consumption on a production basis.

Fuel	Total fuel consumed on-site	Total MMBtu consumed on-site	MMBtu (% of total)	MMBtu/MMBF of lumber
Diesel (gal)	572,610	79,415	5.01	191.78
Gasoline (gal)	53,982	6,708	0.42	16.20
Propane (gal)	36,210	3,306	0.21	7.98
Natural gas (Dth)	16,023	16,023	1.01	38.69
Electricity—nonrenewable (kWh)	32,080,201	109,461	6.90	264.34
Electricity—renewable (kWh)	42,725,611	145,784	9.19	352.06
Wood (tons: 45% moisture)	50,841	487,310	30.74	1,176.83
Bark (tons: 44% moisture)	65,527	737,491	46.51	1,781.00
Total from nonrenewable		214,913	13.55	519.00
Total from renewable		1,370,584	86.45	3,309.89
Total		1,585,497	100	3,828.89

average Montana sawmill energy requirement to produce the lumber necessary for a single-family home was approximately 56.7 MMBtu, which is equivalent to 63 percent of the average annual household energy consumption (EIA 2014c).

It is difficult to provide more detailed analysis while maintaining confidentiality, but even when overall renewable energy use is high, specific mills are good candidates for facilitating additional, new combined heat and electric capacity. Recall that three of the sawmills in this analysis were provided with electricity generated from mostly nonrenewable sources, and a substantial portion of total on-site energy consumption at these mills was from electricity. While there are few options regarding a firm's ability to choose an electricity supplier, the Montana Renewables Portfolio Standard required all public utilities and electricity suppliers to obtain 15 percent of electricity from renewable sources by 2015. Had this standard been in place in 2009, electricity from renewable sources would have been 5 percent greater (Table 5). Additionally, one sawmill dried lumber in a kiln served by a boiler fired with natural gas. If this mill were to use residues in a wood-fired boiler at a rate comparable to other mills with similar output, replacing that single boiler with a wood-fired boiler would displace 6.5 million ft^3 of nonrenewable natural gas with approximately 12,975 tons of renewable biomass. This substitution would increase the renewable share of overall energy consumption by 2 percent. However, this calculation does not account for the marginal costs and benefits of bioenergy expansion in this industry, which is already strongly invested in renewables. It would be useful for future analysis to examine the economics of such a substitution. Such analysis would also provide information needed to fully understand energy use decisions made by individual sawmills as well as optimal allocation of resources.

The energy mix of Montana's sawmilling industry highlights a broader issue related to the expansion of biomass energy and other renewable energy sources. The markets for sawmill residues are well established, and although markets fluctuate, in 2009 there was only a small fraction of residues from sawmills in this analysis that went unused (Table 3), which applies generally across all Montana sawmills. In 2009, sawmills in this analysis used approximately 16 percent of residues for energy, with the remainder going mostly to pulp or board production. The distribution of sawmill residues displayed in Table 3 asserts that clean residues have higher value than fuel for boilers, whereas bark is better suited for thermal energy generation. Based on the fact that sawmill residues are already leveraged, additional bioenergy capacity at sawmills is likely to be fueled by logging slash and not sawmill residues. Yet often because of financial constraints, there are large quantities of unutilized logging slash that is burned on-site at logging units because the costs of logistics to process and deliver the material exceed the delivered price. While

Table 5.—Distribution of fuels used to generate electricity off-site for Montana sawmills in 2009.

	Kilowatt-hours by energy generation source						
	Renewable				Nonrenewable		
Electricity provider	Hydropower	Solar	Wind	Biomass	Coal	Nuclear	Unverifiable contract sources
Supplier and utility		2,159,712[a]			3,509,532		21,327,158
Cooperative 1	21,146,840	509,562[b]		0	0	2,038,250	1,783,468
Cooperative 2	1,590,297	38,320[b]		0	0	378,696	246,829
Cooperative 3	6,233,221	115,430[b]		0	0	461,720	404,005
Cooperative 4	10,676,100	257,255[b]		0	0	1,029,022	900,394
Total	41,806,170	920,568			3,509,532	3,907,687	24,661,854
Percentage of total	56	1			5	5	33

[a] Reported only as renewable energy, with unknown combination of hydropower, solar, wind, or biomass sources. For percentage calculation, this amount is included as hydropower.

[b] Reported as combined solar and wind.

the literature discussing this topic is vast (Loeffler et al. 2010), additional research is necessary to determine financially optimal methods for utilizing otherwise wasted wood resources, especially logging slash.

Finally, there are situations, though relatively rare in terms of the overall national energy portfolio, in which additional renewable capacity may not have the intended effect of reducing fossil fuel use and increasing the proportion of the energy portfolio represented by renewables. For example, replacing hydropower with biomass energy is unlikely to reduce overall fossil fuel use or have positive net gains in renewable energy consumption. However, there may be other reasons to install new biomass energy capacity, including residue management and energy cost savings. In general, this case emphasizes the need to have high-resolution data and information for decision making and public policy as well as the importance of details when predicting the effects of alternative energy scenarios.

Conclusions

Similar to other work, we have found that the majority of energy used on-site at sawmills is derived from renewable sources. In the case of Montana, this is due primarily to both on-site use of wood and bark for energy and also the significant portion of electricity consumption generated from hydropower. As an industry, most of the energy demand is met by renewables; however, on a facility basis, individual firms may have much different portfolios. This is especially true if there are no on-site biomass energy systems or if drying kilns, which consume the most on-site energy, are served by a boiler fired with fossil fuel. Because so much sawmill energy consumption is electric power and process heat rather than liquid fuels for on-site equipment or generators, changes in on-site heat and electricity power generation can have significant impacts at both the facility and the industry level, even if the industry as a whole already has a strong renewables component. More broadly, state-level information like this can help guide state and local energy policy and inform more detailed life-cycle inventories and other analyses that quantify the environmental costs and benefits beyond the gates of the wood products facility.

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