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Estimates of Wood Energy Demand for Residential Use in Alaska: an Update

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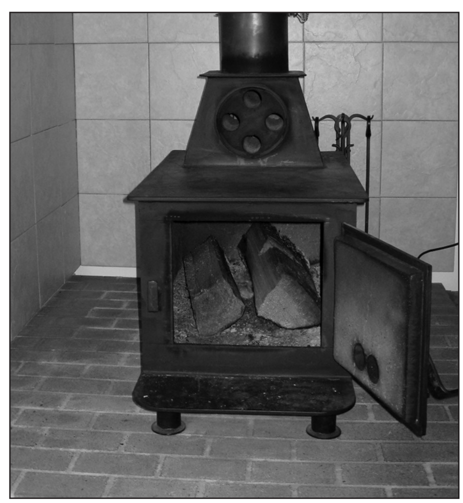

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Authors

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Abstract

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Efforts to amend the Tongass National Forest Land Management Plan have necessitated the development of several management scenarios to assist with planning efforts. One scenario focuses on increasing the utilization of sawmill residues and low-grade material as feedstock for expanding biomass energy markets. The development of a biomass industry is viewed as a solution for a variety of problems in Alaska, from high heating fuel costs to a persistent lack of markets for mill and logging residue and low-grade logs since the last Alaska pulp mill closed in 1997. To support scenario development and ongoing statewide energy assessments, we used the methods from an earlier study to estimate the volume of wood required to meet potential residential demand for wood energy products in the state. Specifically, results show that converting from heating oil to wood-based energy products in Alaska could generate demand for up to 367,000 cords of green wood or 590,000 tons of wood pellets. These estimates of the potential size and demand of local biomass markets are critically important for industry feasibility assessments, as well as attracting capital to develop an industry around biomass. The impact of combustion efficiency and consumer access to retail stove systems on residential conversion are discussed.

Keywords: Wood energy, Alaska, fuel cost, energy demand, distillate fuel use, heating oil, bioenergy.

Contents

Introduction

The Tongass Timber Reform Act (TTRA, 1990) states that the Secretary of Agriculture will "…seek to provide a supply of timber from the Tongass National Forest which (1) meets the annual market demand for timber from such forest and (2) meets the market demand for timber from such forest for each planning cycle." Since 1990, analyses to estimate this market demand to support planning on the Tongass have been performed by the Pacific Northwest Research Station. Typically, the analysis involves developing projections of alterative future scenarios that could affect demand for timber from the forest. One such scenario is based on expanding biomass energy markets. To that end, we used the methods from an earlier report (Brackley et al. 2010) to estimate the volume of wood required to meet existing and potential new demand for wood energy products in Alaska. This information will serve as an update to the previous report, and also will inform a biomass energy scenario for the Tongass timber demand study, based on a stated Forest Service goal of replacing 30 percent of heating oil use in southeast Alaska with wood-based energy over time (Deering 2014). Note that we make no assumptions about the feasibility or desirability of this management action compared to other planning options.

The biomass industry development is viewed as a solution for a multitude of problems.

The topic of bioenergy receives a lot of attention in Alaska; biomass industry development is viewed as a solution for a multitude of problems. Wood energy could provide opportunities for developing markets for low-grade and utility logs, as well as logging and mill residues that have been left in the woods since the pulp mills closed in the 1990s. Creating an integrated forest industry that can utilize both low- and high-grade material could make forestry operations more profitable by generating and diversifying additional revenue streams. Similarly, an integrated industry results in better utilization of mill residues, which lowers per-unit operating costs (Brackley et al. 2006). Alexander et al. (2010) identified energy costs and the disparity of access to affordable and reliable energy as a major barrier to developing an integrated forest products industry in Alaska. Wood energy also helps the state meet its own renewable energy goal of generating 50 percent of the state's electricity from renewable sources by 2025 (Renewable Energy Alaska Project 2015).

Wood-based energy is viewed as a viable alternative to the high costs of heating oil and electricity in some parts of the state. Alaska has some of the highest electricity and heating oil prices in the Nation. This is not surprising because Alaska is large, and many of its communities are remote, sparsely populated, and located far from road systems. These factors lead to high transportation costs for heating fuel and electricity. Nevertheless, Alaska produces a higher percentage of its electricity from petroleum than almost any other state because many remote rural communities use diesel fuel to generate electricity (ISER 2014). A large proportion of homes across rural Alaska use an oil furnace, stove, or boiler as their primary heating system. In addition, heating costs are highly variable across the state. Although this report focuses on residential consumption, these factors likewise apply to the commercial and industrial sectors.

Combined, 86 percent of homes in southeast Alaska use either fuel oil or electricity as their primary fuel source.

This analysis, as in the previous study, focuses on demand for fuel for residential space heating. Although about one third of homes in the entire state were heated by fuel oil in 2011, this figure is even higher in the southeast portion of the state (AEA 2011). Electric heating was a distant second in southeast Alaska at 16 percent, but this was still greater than the 10-percent figure for the state as a whole. Only 4 percent of homes in southeast Alaska used natural gas or propane. Combined, 86 percent of homes in southeast Alaska use either fuel oil or electricity as their primary fuel source. The cost of heating oil is particularly volatile and depends on many factors unique to Alaska. A report by the Institute of Social and Economic Research at the University of Alaska Anchorage studied the price of delivered fuel oil to ten Alaska communities, including communities in southeast Alaska, and found that prices in some areas were more than 100 percent higher than elsewhere in the state (Saylor et al. 2008).

Space heating is also an issue, owing to concerns that widespread adoption of electric space heating will increase the load on hydroelectric facilities to an unsustainable level. About 50 hydroelectric power plants supply Alaskan communities with electricity, providing about one-fifth of the state's total electricity generation. The majority of the state's developed and proposed sites for hydroelectric facilities are located near communities in the south-central, Alaska Peninsula, and southeast areas of the state. Communities supplied with hydropower include Cordova, Glennallen, Haines, Juneau, Ketchikan, Kodiak, Petersburg, Sitka, Skagway, Wrangell, and Valdez. In communities in which hydroelectric power is available, conversion from heating oil to electricity for space heating has been common in recent years, spurred by the lower relative cost of hydroelectric power. The increasing load on hydroelectric facilities has led to proposals to increase hydroelectric generation capacity and storage through expanding existing facilities and new construction. However, environmental concerns and high capital costs are substantial barriers. An economic analysis performed by the University of Alaska presented capital cost estimates and benefit/cost ratios for expanding hydroelectric power for 30 Alaskan communities. The report found that the high capital cost of hydropower (both absolute and especially on a per-kilowatt basis for smaller projects) was the chief impediment to economic feasibility, although results were modestly sensitive to assumptions about rising heating fuel prices (Crimp et al. 2008).

Given the key issues of price, availability, and sustainability of energy resources in Alaska, as well as the pressures they create at the household level, reliable estimates of potential renewable resource demand are particularly timely. The remainder of this report describes the objectives, methods, and results of our estimation.

Objectives

The goal of this analysis, as in Brackley et al. (2010), is to develop estimates of potential demand for wood energy products in Alaska. Our motives and focus are somewhat different, as this analysis will also be used to support forest plan amendment on the Tongass National Forest. Like Brackley's study, data constraints led us to focus on residential demand, although anecdotal evidence and local media coverage suggest that wood energy adoption by commercial businesses has increased (Grass 2012, Nicholls 2009). We relied primarily on the methodology described in the Brackley study to update estimates for:

- Sources of energy consumed by sector of the Alaska economy.
- Number and proportion of occupied residential units using all heating fuel types.
- Residential heating oil use in Alaska.
- Estimated volume of firewood consumed by the residential sector annually in Alaska.
- Average heating costs of occupied residential housing units by heating fuel type.
- Cost comparison per British thermal unit (Btu) of alternative sources of energy used in Alaska to find situations in which wood energy is an economically viable replacement for fossil fuels.
- Volume of wood or pellets required to replace fossil fuels used in the residential sector.
- Potential economic motivation for, and benefits of, conversion from fuel-oil space heating to wood-energy space heating.

Methods

This analysis is based on the most recent data published by the U.S. Census Bureau (USDC BC) and U.S. Energy Information Administration (USDE EIA) for the State of Alaska. The Census Bureau's American Community Survey for 2012 provides statistics on number of households and the type of energy consumed by census tract. Census tracts in Alaska are shown in figure 1, along with the proportion of

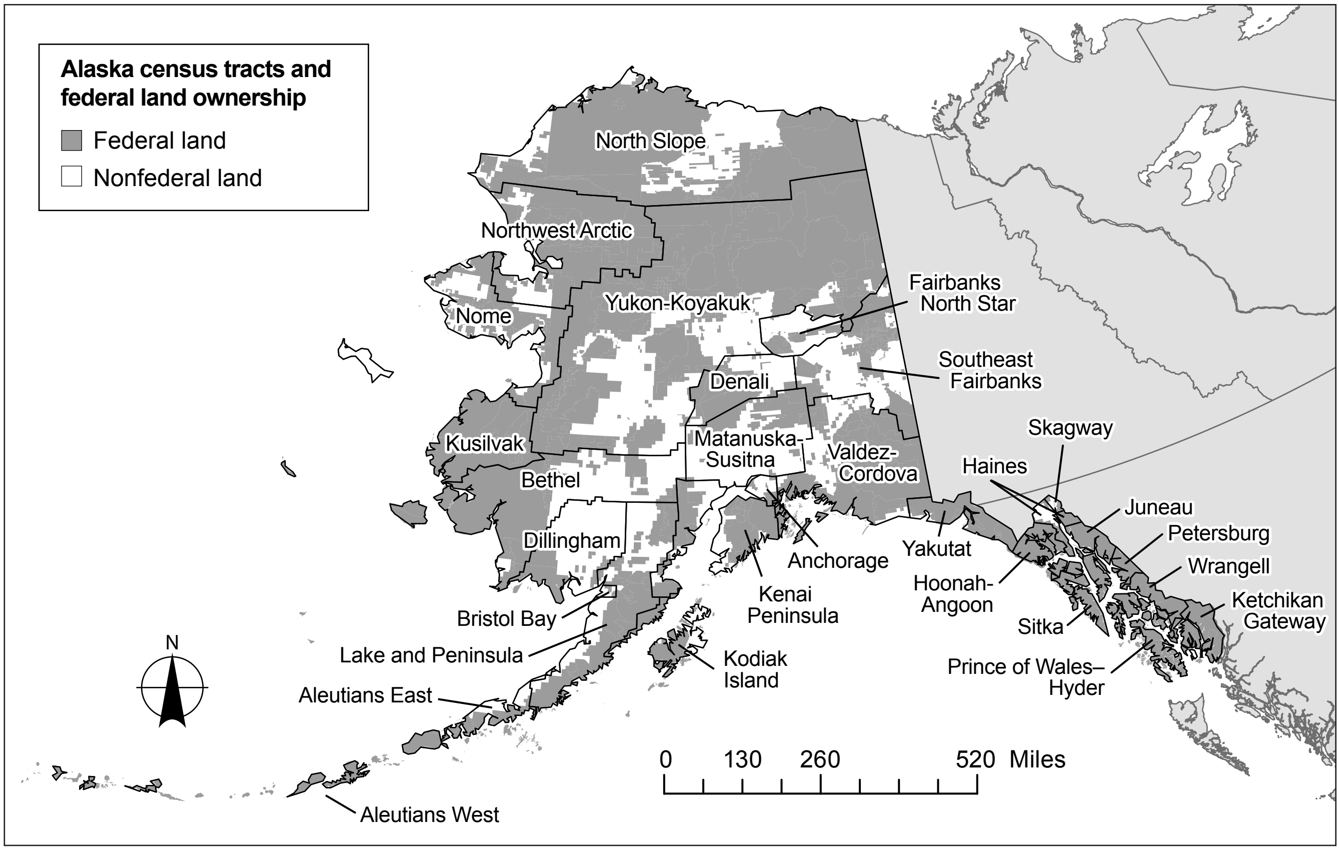

Figure 1—Census tracts and federal land ownership in Alaska.

land in Alaska in federal ownership. The EIA's State Energy Data System maintains an annual series of fuel consumption, prices, and expenditure estimates based on surveys of energy suppliers and various energy type-specific reports.

We present both additions to and deviations from the previous analysis, building on the work of Brackley et al. (2010) in several ways. The 2012 census data, combined with annual reported EIA data, allowed us to update statistics for energy use in Alaska that can be compared with the previous study. As in Brackley's 2010 study, we focused on the potential for Alaskan homeowners to replace distillate fuel use with wood energy products. Because the Tongass Land Management Plan amendment effort requires information pertaining specifically to southeast Alaska, we expanded several tables to include census area-level data adjusted for differences in climate across the state. We also expanded the analysis of fuel price equivalency to compare wood energy products to distillate fuels, natural gas, and electricity.

Our methodology diverges from Brackley et al. (2010) at two key points. First, we added explicit equipment efficiency assumptions for distillate-heated homes when calculating fuel energy equivalence. Second, we omitted the adjustments of census information for unoccupied, multi-unit, and mobile dwellings because a repeatable method of adjustment for space heating of unoccupied units, the size and efficiency of mobile homes, and the heating needs of apartments were not available in the literature. Brackley et al. (2010) added half of the unoccupied homes using distillate heat to the census counts used in consumption estimates, removed units in multiple-occupancy buildings, and subtracted half of the mobile homes for each area.

Much of the background methodology used herein is discussed in depth in the Brackley et al. (2010) report and will only be referenced here. This includes standard conversion factors, energy measurements and units, moisture content calculations, and a review of data sources. We relied heavily on Briggs (1994) for physical volume and energy calculations and for conversion factors, the EIA's State Energy Data System for Alaskan energy consumption, and the U.S. Census Bureau's American Community Survey for household units and heating trends across the state (USDE EIA 2015d, USDC BC 2008–2012).

Trends in Energy Consumption in Alaska

Figure 2 shows heating oil prices across Alaska in August 2014 (AEDG 2014). Setting aside the heavily subsidized prices of far northern regions, households in the Northwest Arctic Borough faced the highest price in August—essentially twice the price in the Anchorage area. Importantly, the disparity in fuel oil prices in many areas of the state provides the economic incentive to switch to a cheaper energy source. Significantly wider price variation is apparent at the community level, but is not included here.

The disparity in fuel oil prices in many areas of the state provides the economic incentive to switch to a cheaper energy source.

Figure 3 shows residential fuel use in Alaska by fuel type for 2004 and 2012 from Alaska Energy Authority data. In 7 years, the proportion of heating fuels consumed by Alaska residents has changed little. Natural gas still dominates; its consumption has risen by almost 10 percent. Electricity use has increased by less than 1 percent; otherwise, consumption of all other fuel types declined. Statewide, wood used for energy in the residential sector actually fell by 2.5 percent.

Table 1 shows an updated profile for energy consumed in Alaska for each economic sector and fuel type. Btu values are derived from reported physical units of consumption and conversion factors for each fuel type. This updated consumption profile contains several notable developments since the Brackley et al. (2010) publication. Statewide total energy consumption fell by roughly 20 percent between 2004 and 2012 (799 versus 637 trillion Btu, respectively). The reduction was mostly led by declines in the commercial and industrial sectors. In terms of absolute values, distillates were the only fuels of which consumption actually increased; since 2004 distillate fuel use rose from 9 to 13 percent. The residential sector accounted

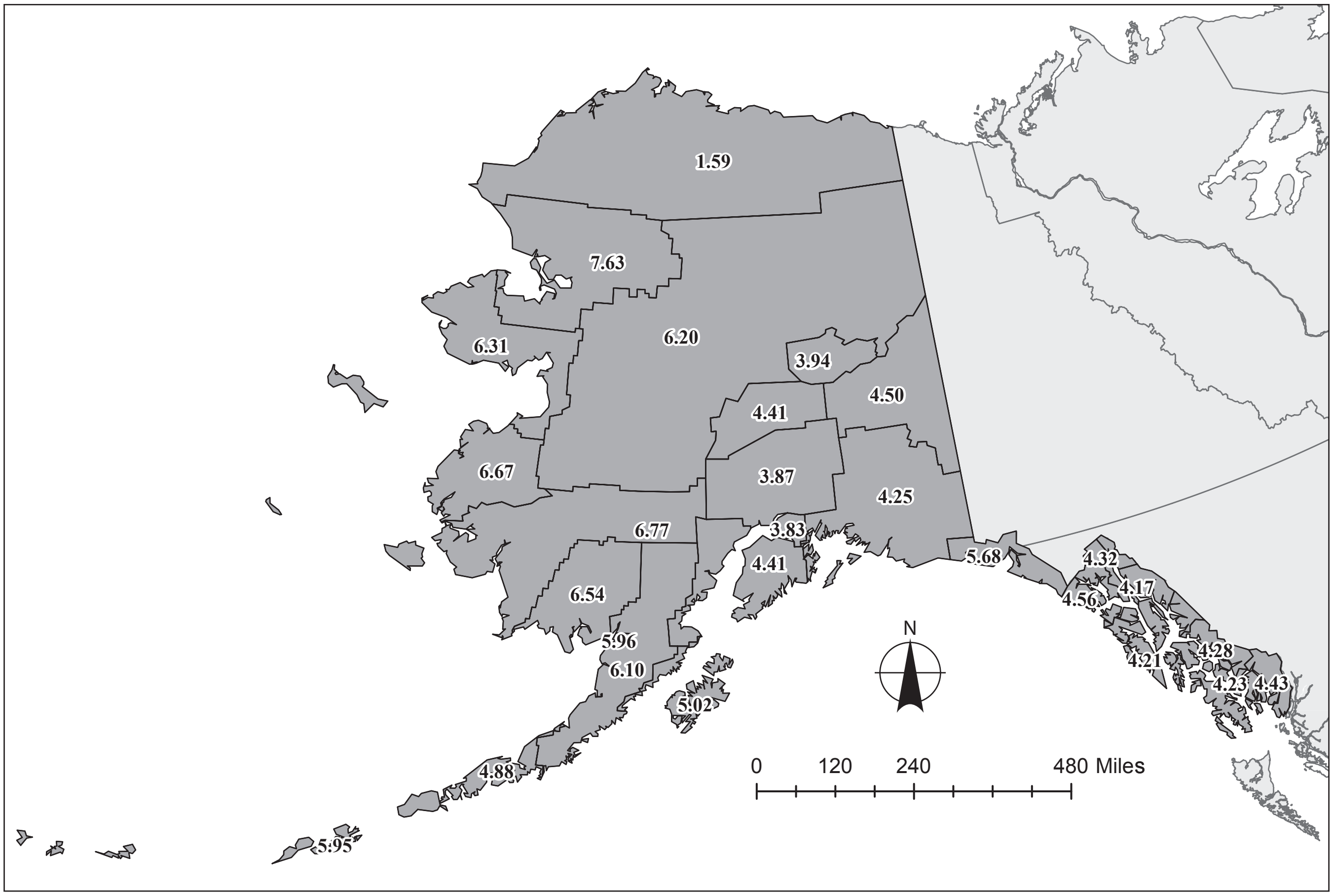

Figure 2—Heating oil prices by Alaska Census Tract, 2014.

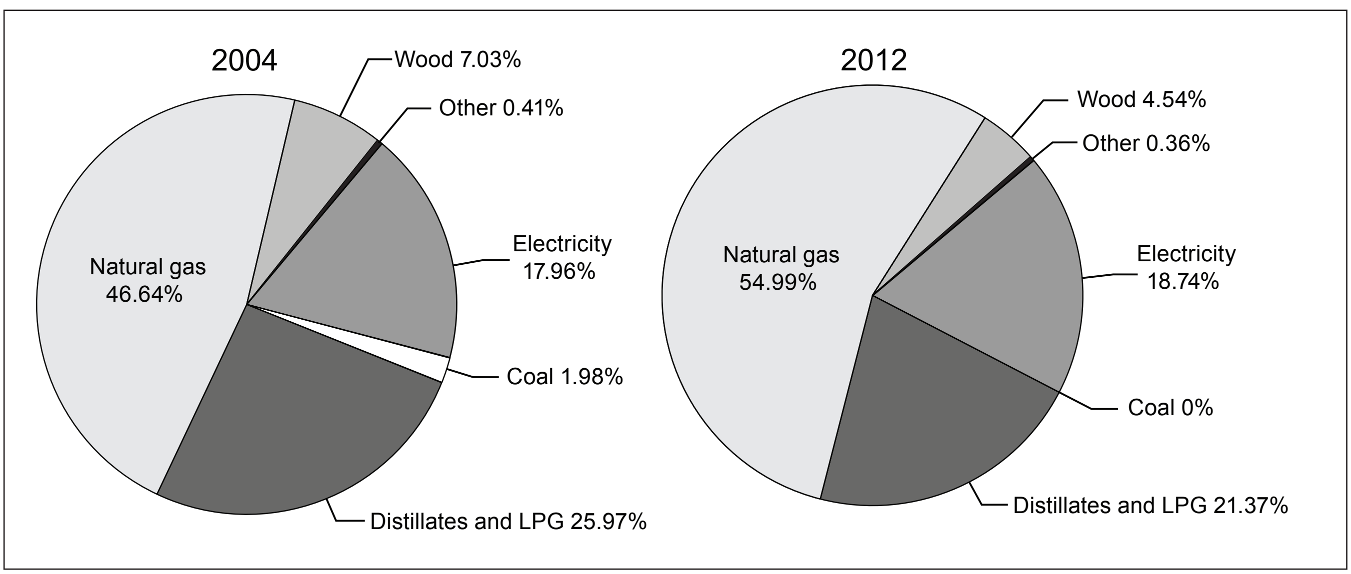

Figure 3—Comparison of 2004 and 2012 residential energy use.

Table 1—Sources of energy consumed by various sectors of the Alaska economy, 2012

Source	Alaska distribution	Residential	Commercial	Industrial	Transport	Electric	Total
	Percent	*- Trillion Btu*	*- - - - - - -*				
Asphalt/road oil[a]							
Aviation	0.13	—	—	—	0.8	—	0.8
Biomass	0.36	1.9	0.3	0.1	—	—	2.3
Coal	2.43	0	9.4	0.1	0	6	15.5
Distillate fuel	13.34	8.1	10.1	19.2	44.4	3.3	85.1
Ethanol	0	—	—	—	—	—	0
Hydroelectric	2.05	4.45	5.91	2.74	—	—	13.1
Jet fuel	18.53	—	—	—	118.2	—	118.2
Kerosene	0.03	0.1	0.1	—	—	—	0.2
LP gas	0.20	0.5	0.7	0.1		—	1.3
Lubricants	0.06	—	—	—	0.4	—	0.4
Motor gas	5.42		0.7	1	32.9	—	34.6
Natural gas	52.84	20.5	16.9	253.8	3.5	42.3	337
Other[b]	0.05	0.1	0.1	0	—	0.1	0.3
Other petroleum	4.25	—	—	27.1	—	0	27.1
Residual fuel	0.30	—	0	0	0.4	1.5	1.9
Subtotal	100.00	38.5	48	305.9	200.6	66.3	637.8
Fossil-fuel-based electricity consumed[c]		2.85	3.79	1.76			8.4
Total energy consumption		41.35	51.79	307.66			
Electricity sold to sector[d]		7.3	9.7	4.5			21.5

LP = liquefied petroleum.
[a] Part of other petroleum.
[b] Wind, geothermal, etc.
[c] Calculated by first subtracting hydropower from the total electricity sold to sectors, then distributing the residual fossil electricity among the residential, commercial, and industrial sectors according to their portion of total electricity sales.
[d] Energy Information Administration data.

for 7 percent of all fuel consumed. Although the residential sector increased their share of total consumption by almost 3.5 percent, distillate use declined by almost 4 percent to 1.3 trillion Btus. As in Brackley et al. (2010), we calculated the power generated from fossil fuels and assigned those Btus to the residential, commercial, and industrial sectors in proportion to their total electricity consumption.

We defined distillate fuels as the combination of fuel oil, kerosene, and liquefied petroleum gas. Table 2 shows the number of occupied housing units by fuel type for each Alaska borough or Census Bureau tract. As noted above, home heating is largely characterized by distillate fuel consumption in much of the state, accounting for more than half of home heating in 24 of 29 census areas. Electric and natural gas heating likewise represent a large share of occupied homes in many

We defined distillate fuels as the combination of fuel oil, kerosene, and liquefied petroleum gas.

Table 2—Number and proportion of occupied residential units in Alaska using all heating fuel types by Census Bureau tract, 2012

Region	Borough or census area[a]	Distillate fuels[b]		Natural gas		Wood		Electricity		Other[c]		Total occupied units
		Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*
Aleutians and Arctic	Aleutians East	367	93.15	6	1.52	10	2.54	10	2.54	1	0.25	394
	Aleutians West	892	90.01	4	0.40	20	2.02	46	4.64	29	2.93	991
	Kusilvak	1,334	78.29	27	1.58	312	18.31	26	1.53	5	0.29	1,704
	Nome	2,552	92.06	29	1.05	115	4.15	57	2.06	19	0.69	2,772
	North Slope	688	34.56	1,234	61.98	0	0	64	3.21	5	0.25	1,991
	Northwest Arctic	1,625	88.80	35	1.91	108	5.90	54	2.95	8	0.44	1,830
	Yukon-Koyukuk	1,024	49.68	22	1.07	982	47.65	13	0.63	20	0.97	2,061
Total and percentage		8,482	72.23	1,357	11.56	1,547	13.17	270	2.30	87	0.74	11,743
Greater Anchorage	Anchorage	2,964	2.81	87,145	82.59	690	0.65	14,004	13.27	714	0.68	105,517
	Kenai Peninsula	7,819	35.60	10,350	47.12	2,313	10.53	1,289	5.87	193	0.88	21,964
	Matanuska-Susitna	5,102	16.50	21,428	69.29	2,230	7.21	1,882	6.09	281	0.91	30,923
	Valdez-Cordova	2,751	74.23	98	2.64	763	20.59	64	1.73	30	0.81	3,706
Total and percentage		18,636	11.50	119,021	73.42	5,996	3.70	17,239	10.63	1,218	0.75	162,110
Greater Fairbanks	Denali	420	58.58	15	2.09	172	23.99	9	1.26	101	14.09	717
	Fairbanks North Star	28,064	78.52	1,850	5.18	2,352	6.58	2,279	6.38	1,195	3.34	35,740
	Southeast Fairbanks	1,297	54.04	55	2.29	858	35.75	161	6.71	29	1.21	2,400
Total and percentage		29,781	76.64	1,920	4.94	3,382	8.70	2,449	6.30	1,325	3.41	38,857
Southeast	Haines	687	60.32	46	4.04	381	33.45	25	2.19	0	0	1,139
	Juneau	8,761	71.09	225	1.83	501	4.07	2,688	21.81	148	1.20	12,323
	Ketchikan Gateway	3,663	68.25	96	1.79	389	7.25	1,152	21.46	67	1.25	5,367
	Prince of Wales-Hyder	1,253	54.69	15	0.65	776	33.87	238	10.39	9	0.39	2,291
	Sitka	2,280	62.93	37	1.02	209	5.77	1,058	29.20	39	1.08	3,623
	Skagway	336	24.10	17	1.22	30	2.15	8	0.57	1,003	71.95	1,394
	Hoonah-Angoon	673	67.37	31	3.10	282	28.23	4	0.40	9	0.90	999
	Wrangell	444	38.28	24	2.07	287	24.74	392	33.79	13	1.12	1,160
	Petersburg	917	54.88	77	4.61	273	16.34	401	24.00	3	0.18	1,671
	Yakutat	218	84.17	10	3.86	20	7.72	10	3.86	1	0.39	259
Total and percentage		19,232	63.63	578	1.91	3,148	10.41	5,976	19.77	1,292	4.27	30,226

Table 2—Number and proportion of occupied residential units in Alaska using all heating fuel types by Census Bureau tract, 2012. (continued)

Region	Borough or census area[a]	Distillate fuels[b]		Natural gas		Wood		Electricity		Other[c]		Total occupied units
		Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*
Southwest	Bethel	3,727	86.53	8	0.19	464	10.77	100	2.32	8	0.19	4,307
	Bristol Bay	365	97.33	0	0	5	1.33	0	0	5	1.33	375
	Dillingham	1,144	85.76	29	2.17	134	10.04	18	1.35	9	0.67	1,334
	Kodiak Island	3,644	81.56	159	3.56	198	4.43	390	8.73	77	1.72	4,468
	Lake and Peninsula	464	81.40	9	1.58	80	14.04	13	2.28	4	0.70	570
Total and percent		9,344	84.53	205	1.85	881	7.97	521	4.71	103	0.93	11,054
State total and percentage		85,475	33.65	123,081	48.46	14,954	5.89	26,455	10.42	4,025	1.58	253,990

[a] Airport or other degree day location.
[b] Fuel oil; kerosene; and liquefied petroleum gas.
[c] Coal, wind, or geothermal.

areas. Note that the share of homes heated with either wood or electricity in regions with access to inexpensive hydroelectric power and fuelwood are characterized by higher proportional use of each. Wood and electrical heating are commonly used in several areas in southeast Alaska.

Table 3 shows estimates of average residential distillate fuel use per occupied housing unit by Census Bureau tract. Despite the differences in the housing unit count between this analysis and Brackley et al. (2010), these per household and regional estimates are similar to the previous study. Following Brackley et al. (2010), the estimates of average Btu per home were calculated by applying the state average—adjusted to account for variation in regional temperatures—to the total number of homes using distillates in each area. The state average was first calculated by dividing the total consumption of distillate fuels (heating oil; kerosene; and bottle, tank, or liquefied petroleum gas) from the EIA (2012) by the total number of occupied Alaska homes using those fuels as their primary source of heat. The state average was then adjusted for heating degree days, using 65 °F basis, in each census area. This degree day adjustment accounts for regional differences in energy costs owing to the extreme temperature variation experienced across the state (Alaska Climate Research Center 2014).

This degree day adjustment accounts for regional differences in energy costs owing to the extreme temperature variation experienced across the state.

Table 3 illustrates the need to adjust regional fuel consumption for climate. First, consider the energy needs of the state's coldest areas. According to the census, 688 occupied housing units in the North Slope used distillate fuels as their primary heat source in 2012. Simply multiplying the state average fuel consumption per home to these units (roughly 99 million Btu) would likely underestimate total distillate consumption in this particularly cold area because it assumes that the

Table 3—Residential distillate fuel use in Alaska by Census Bureau Tracts, 2012

Region	Borough or census area[a]	Housing units	Heating degree days[b]	Btu per home
Aleutians and Arctic	Aleutians East	367	9,557	88,684,434.91
	Aleutians West	892	8,781	81,483,522.33
	Kusilvak	1,334	13,965	129,588,587.79
	Nome	2,552	13,703	127,157,351.84
	North Slope	688	19,399	180,013,534.88
	Northwest Arctic	1,625	15,385	142,765,515.44
	Yukon-Koyukuk	1,024	14,227	132,019,823.74
Total and average		8,482		125,958,967.28
Greater Anchorage	Anchorage	2,964	10,194	94,595,493.30
	Kenai Peninsula	7,819	10,508	97,509,264.63
	Matanuska-Susitna	5,102	10,301	95,588,402.64
	Valdez-Cordova	2,751	9,973	92,544,717.94
Total and average		18,636		95,059,469.63
Greater Fairbanks	Denali	420	12,867	119,399,667.68
	Fairbanks North Star	28,064	13,666	126,814,009.36
	Southeast Fairbanks	1,297	13,157	122,090,730.37
Total and average		29,781		122,768,135.80
Southeast	Haines	687	8,730	81,010,266.48
	Juneau	8,761	8,351	77,493,325.93
	Ketchikan Gateway	3,663	7,262	67,387,921.56
	Prince of Wales-Hyder	1,253	6,883	63,870,981.01
	Sitka	2,280	7,191	66,729,075.17
	Skagway	336	8,423	78,161,451.84
	Hoonah-Angoon	673	7,980	74,050,621.60
	Wrangell	444	7,458	69,206,708.75
	Petersburg	917	7,954	73,809,353.91
	Yakutat	218	9,018	83,682,770.12
Total and average		19,232		73,540,247.64
Southwest	Bethel	3,727	12,518	116,161,112.92
	Bristol Bay	365	10,880	100,961,248.49
	Dillingham	1,144	11,216	104,079,169.40
	Kodiak Island	3,644	8,794	81,604,156.18
	Lake and Peninsula	464	10,537	97,778,370.90
Total and average		9,344		100,116,811.58
State total and average		85,475	10,651	98,835,916.93

[a] Airport or other degree day location.

[b] Source: Alaska Climate Research Center (2014).

heating needs of homes in cold areas are equal to those of homes in more temperate areas. This can be seen most clearly by comparing the sparsely populated Aleutians and Arctic (AA) region with southeast Alaska, which has a relatively denser population and milder climate. Without adjusting for climate differences, southeast Alaska (with more than twice the distillate-using homes as the AA region) would appear to consume more than twice the heating fuel each year than its colder northern counterpart; accounting for climate differences reveals essentially the opposite relationship. In fact, 75 percent of households in the Fairbanks region are heated primarily with distillates. Still, total usage in that region was less than the AA region, despite the nearly 20,000 fewer homes using distillates for primary heat.

Table 4 contains estimates of firewood volume consumed annually in Alaska based on occupied household Btu values derived from the USDE EIA (2015d), the U.S. Census Bureau (2008–2012), Nicholls et al. (2010), and conversion factors found in Briggs (1994). In 2012, Alaskan households consumed roughly 89,000 cords of firewood and nearly 15,000 homes were primarily heated with wood fuel. The regional values in table 4 were calculated by adjusting the statewide consumption of 89,000 cords using the process described earlier for estimating distillate consumption. First, statewide average per-home consumption was calculated by dividing total statewide consumption by the Census Bureau's count of households

Table 4—Estimated volume of firewood consumed by the residential sector annually in Alaska by region

Region	Number of homes using wood as primary heat source	Primary heat, firewood purchased[a,b]		Number of homes using wood as secondary heat source[c]	Potential additional secondary heat, firewood estimated[d]	
		Cords	*Tons*		*Cords*	*Tons*
Aleutians and Arctic	1,547	11,564	28,909	2,020	4,040	10,100
Greater Anchorage	5,996	33,824	84,561	30,921	61,842	154,605
Greater Fairbanks	3,382	24,640	61,599	9,704	19,408	48,520
Southeast	3,148	13,738	34,346	5,876	11,752	29,380
Southwest	881	5,234	13,086	2,207	4,414	11,035
Total	14,954	89,000	222,500	50,729	101,458	253,645

[a] Calculated from climate-adjusted state average per-home consumption (USDC BC 2014, USDE EIA 2014).
[b] Assumes 2.5 tons per cord.
[c] Estimated from Robb (2007) survey data.
[d] Assumed consumption of two cords per household per year.

using wood as a primary heat source. We then adjusted this average by degree days to account for regional climate variation before applying it to the number of wood-heated homes in each region.[1] Weight equivalents assume 2.5 tons of material per cord, which tends to overstate the weight of a softwood cord (Brackley 2006). Note that our methodology assigns all 89,000 cords of wood reported in the EIA data to households using wood as their primary heating source.

The Census Bureau's home heating data does not include homes using wood as a secondary heat source. A survey conducted by the Fairbanks Economic Development Council in 2007 estimated the number of homes in Alaska using wood for secondary heating (Robb 2007). The survey of households in the southeast, southcentral, and Fairbanks regions of the state found that 22 percent, 20 percent, and 27 percent, respectively, reported using wood as a secondary heating fuel. Because the survey was conducted in three of the five regions examined here, we applied the southeast region's 22-percent secondary use to the southwest region, and the Fairbanks region's 27 percent to the Aleutians and Arctic regions in lieu of survey data to estimate the number of households using wood as a secondary heat source. Like Brackley et al. (2010), we attempted to estimate wood usage by assuming that secondary use amounted to burning two cords of firewood per year. As evident in table 4, this conservative approach yielded volume estimates for secondary heating that were greater than the statewide total wood consumption reported by the EIA. Even assuming one cord per year, the volume of potentially unaccounted wood is substantial.

These results suggest some limitations with EIA data. Wood consumption data are limited because they include only fuel wood that is purchased. In forested areas, firewood gathering is commonplace, but the volume of wood consumed in this manner is not recorded in EIA statistics. Another limitation is that data are lacking on the wood consumption patterns of households heated primarily by natural gas or fuel oil but supplemented by a fireplace or wood stove. Thus, the reported volume of firewood consumption, 89,000 cords, very likely understates the volume of wood actually consumed for heat in Alaskan households.

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[1] Mathematically, this allocation process produces regional totals that sum to a state total slightly lower than the original statewide total. This small residual (approximately 2,700 cords) was distributed to each region proportionally to its estimated share of statewide consumption.

Cost Comparisons for Alternative Energy Sources

To consider adopting wood energy products, a consumer must be able to compare the costs of alternative forms of energy used to produce a unit of heat. Table 5 illustrates the average cost to heat an occupied housing unit in Alaska by fuel type and region. We began with the average amount of energy (in Btus) required by distillate-heated homes from table 3 above. Using 2012 energy conversion factors from the EIA, we calculated the equivalent number of physical units (such as barrels or cords) of each alternative fuel necessary to match that requirement (USDE

Table 5—Average annual heating costs of occupied residential housing units by Alaska census region and heating fuel type.

Region	Average energy requirements	Fuel type	Units per year[a]	Unit	Price per unit	Annual cost
	Btu				*U.S. dollars*	
Aleutians and Arctic	125,958,967.28	Distillate[b]	917	Gallons	4.05	3,723.35
		LP gas	1,490	Gallons	3.25	4,844.38
		Natural gas	123.25	mcf	8.55	1,054.28
		Wood	6.30	Cord	338.80	2,133.74
		Electricity	36,916.46	kWh	0.18	6,601.51
Greater Anchorage	95,059,469.63	Distillate	693	Gallons	4.05	2,809.96
		LP gas	1,125	Gallons	3.25	3,655.99
		Natural gas	93.01	mcf	8.55	795.65
		Wood	4.75	Cord	338.80	1,610.31
		Electricity	27,860.34	kWh	0.18	4,982.07
Greater Fairbanks	122,768,135.80	Distillate	895	Gallons	4.05	3,629.03
		LP gas	1,452	Gallons	3.25	4,721.66
		Natural gas	120.13	mcf	8.55	1,027.57
		Wood	6.14	Cord	338.80	2,079.69
		Electricity	35,981.28	kWh	0.18	6,434.28
Southeast	73,540,247.64	Distillate	536	Gallons	4.05	2,173.85
		LP gas	870	Gallons	3.25	2,828.36
		Natural gas	71.96	mcf	8.55	615.53
		Wood	3.68	Cord	338.80	1,245.77
		Electricity	21,553.41	kWh	0.18	3,854.24
Southwest	100,116,811.58	Distillate	730	Gallons	4.05	2,959.45
		LP gas	1,184	Gallons	3.25	3,850.49
		Natural gas	97.96	mcf	8.55	837.98
		Wood	5.01	Cord	338.80	1,695.98
		Electricity	29,342.56	kWh	0.18	5,247.12

Btus = British thermal units; LP = liquefied petroleum; mcf = thousand cubic feet; kWh = kilowatt-hours.
[a] Calculated using Energy Information Administration (EIA) conversion values published for 2012.
[b] Average of fuel oil and kerosene price from the EIA.

Variation across fuel usage and costs is considerable.

EIA 2014). Fuel prices were available only at the state level; the average statewide price per fuel type was thus multiplied by the units of each fuel type to arrive at the annual heating cost.

Table 5 shows that variation across fuel usage and costs is considerable. Although natural gas is consistently the least expensive alternative in regions with access to it, wood-based heating is considerably cheaper than heating with distillate fuels; liquefied petroleum gas; or electricity in every region. Regional variation in costs is evident as well. Heating cost estimates for all fuels are generally higher for the coldest parts of the state. In the colder climate of the Aleutians and Arctic region, for example, the potential savings exceeds $1,600 per year. In southeast Alaska, a home using fuel oil could save $928 annually by switching to wood heat.

Next, we examined the relative costs of home heating by comparing the cost of energy recoverable from wood against three alternative fuels over a range of potential prices. Distillates, natural gas, and electricity were compared to cordwood and wood pellets.[2] For cordwood, we assumed that a cord would be burned in a unit with 60-percent combustion efficiency.[3] For pellets, we assumed they had 6.5-percent moisture content and 80-percent combustion efficiency. Figures 4, 5, and 6 show the cost comparisons between wood and heating oil, wood and natural gas, and wood and electricity, each converted into units typically purchased by consumers. Each figure shows a range of heating fuel prices and the equivalent price of a cord of wood and ton of wood pellets. Supporting tables 8 through 13 in the appendix display the price equivalent of cordwood and pellets across a range of prices of heating oil, natural gas, and electricity under two combustion efficiency assumptions.

For illustration, consider an Alaska household choosing between heating oil and a wood energy alternative. Table 6 reproduces regional heating oil prices published in the most recent Alaska Fuel Price Report (ADCCED 2015). The average price for a homeowner in the southeast region was $4.46 per gallon as of January 2015. Suppose a homeowner would like to compare the price of heating oil to that of cordwood and wood pellets. Graphically, the heating oil price appears in figure 4 as a vertical "break-even" line beyond which it is more economical to remain with fuel oil. Thus, a cost-minimizing consumer in southeast Alaska facing a price of $4.46 per gallon is better off choosing a wood fuel at a price below the break-even line at

[2] The costs of these fuels are not compared to each other in table 6 (for instance, comparisons were made between natural gas and wood and electricity and wood, but not between natural gas and electricity). A rough comparison can be made with the estimates in table 5.

[3] The recoverable heating value of a cord of wood is constant across a range of moisture contents, unlike values for weight measurements. As a cord dries, it gains gross heating value but loses weight. Recoverable heat is a function of both inputs.

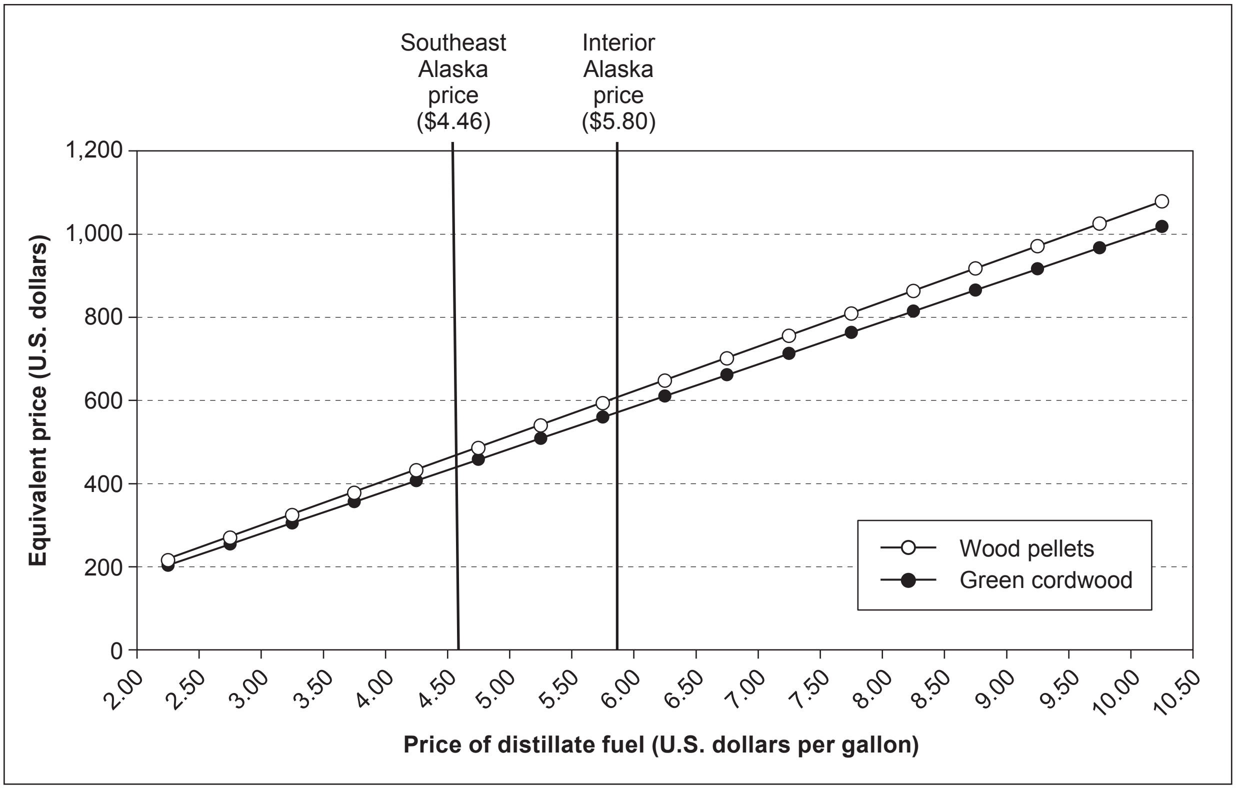

Figure 4—Equivalent prices for distillate fuels and wood energy products, January 2015.

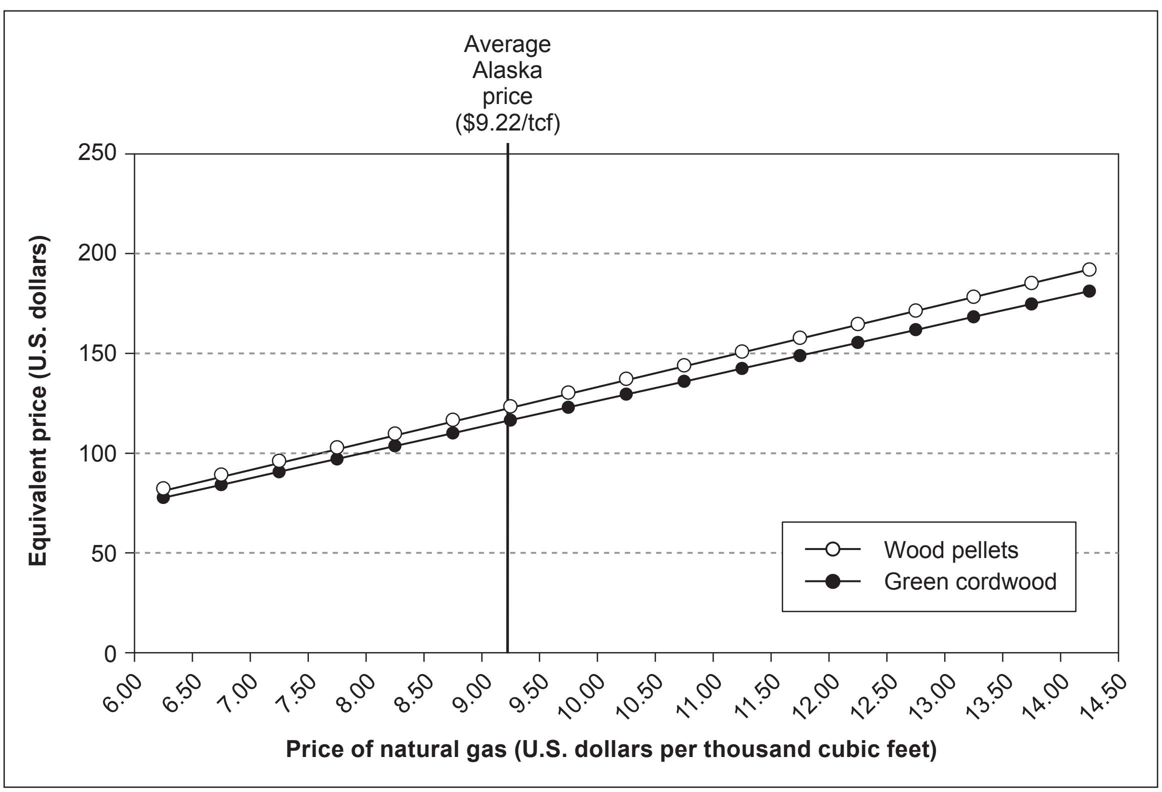

Figure 5—Equivalent prices for natural gas and wood fuels price equivalency, November 2014.

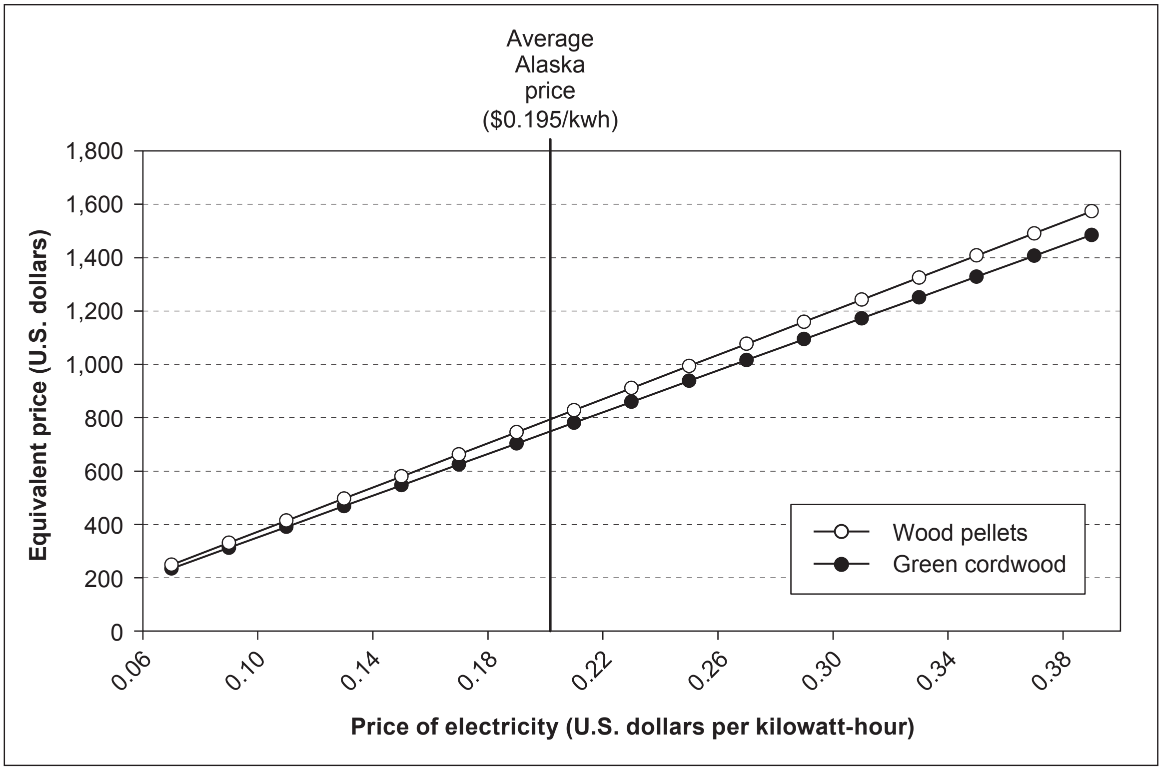

Figure 6—Equivalent prices for electricity and wood energy products, November 2014.

Table 6—Alaska regional heating oil prices in dollars per gallon, January 2015

	Gulf Coast	Interior	Northern	Northwest	Southeast	Southwest	Western
High	6.96	11.00	3.00	7.22	5.67	8.21	7.40
Low	3.11	3.05	1.40	4.90	3.68	3.68	5.36
Average	4.55	5.80	1.89	6.35	4.46	5.67	6.57

Figure 5 suggests that homes using natural gas as a primary heat source have a significant price advantage over wood fuels.

that price, which table 8 (see app.) shows to be $458 for a cord of firewood and $485 for a ton of pellets. Another household in Alaska's interior region would save money with either cordwood or pellets at a price below about $585 per cord and $620 per ton, respectively.

Natural gas prices for the residential sector are available only at the state level. The most recent reported price of natural gas delivered to residential consumers in Alaska was $9.22 per thousand cubic feet (tcf) in November 2014 (USDE EIA 2015a). Figure 5 suggests that homes using natural gas as a primary heat source have a significant price advantage over wood fuels. The break-even prices for cordwood at $120 per cord and $127 per ton of pellets (again assuming 60-and 80-percent combustion efficiency, respectively) are roughly one-third and one-half their actual current prices. For natural gas to be as costly as wood energy, the price would have to rise to about $20 per tcf. EIA data going back to 1990 show that the highest residential natural gas price ever recorded in Alaska was $12.00 per tcf.

Residential electricity prices are also available only at the state level. The state average price of electricity was 19.5 cents per kilowatt hour (kwh) in November 2014.[4] making wood fuels a cheaper choice for many Alaskan homes (USDE EIA 2015b). Figure 6 shows that, at a price of $0.195 per kwh, a home heated primarily with electricity would face a break-even price of $760 per cord and $807 per ton of pellets. This state average electricity price does not account for the significant disparity in electricity prices between communities with and without access to inexpensive hydropower. For homes facing the state's highest electricity prices, the potential savings from switching to wood fuels can be substantial; for those homes purchasing hydro-generated power, electric heat may be the cheaper form of energy.

The Impact of Combustion Efficiency

Combustion efficiency is a measurement of how well the fuel being burned is being utilized in the combustion process. The combustion efficiency assumptions in figures 4, 5, and 6 greatly affect the estimated break-even price at which cost-minimizing consumers would be prompted to switch fuels, as well as to choose between cordwood and pellet systems. For our calculations, we used liberal efficiency values for an oil-burning heating unit (85 percent) and conservative efficiency values for cordwood or pellet-burning units (60 and 80 percent, respectively). This combination sets the break-even line much higher than would be faced by many homes, particularly those with newer wood systems. For illustration, figure 7 shows how the relationship between heating oil, cordwood, and pellet prices is affected by the assumed combustion efficiency of a cordwood system. Recall the southeast Alaska home facing an average heating oil price of $4.46 per gallon discussed above. If the homeowner was faced with a choice to install a new wood stove that operated at 80-percent efficiency or a unit operating at 60-percent efficiency, the threshold for switching from fuel oil would jump from $458 to $610 per cord (well above typical prices). In addition, a densified wood pellet system operating at 80-percent efficiency would generate greater savings than a cordwood system operating at 60-percent efficiency. So if the purchase price for a ton of wood pellets is $270, fuel oil must cost less than $2.50 per gallon to remain competitive. As of January 2015, only the southeast and heavily subsidized northern region had a heating oil price less than $4.50 per gallon.

Combustion efficiency is a measurement of how well the fuel being burned is being utilized in the combustion process.

[4] This is a statewide average, which includes those areas affected by Alaska's power cost equalization program.

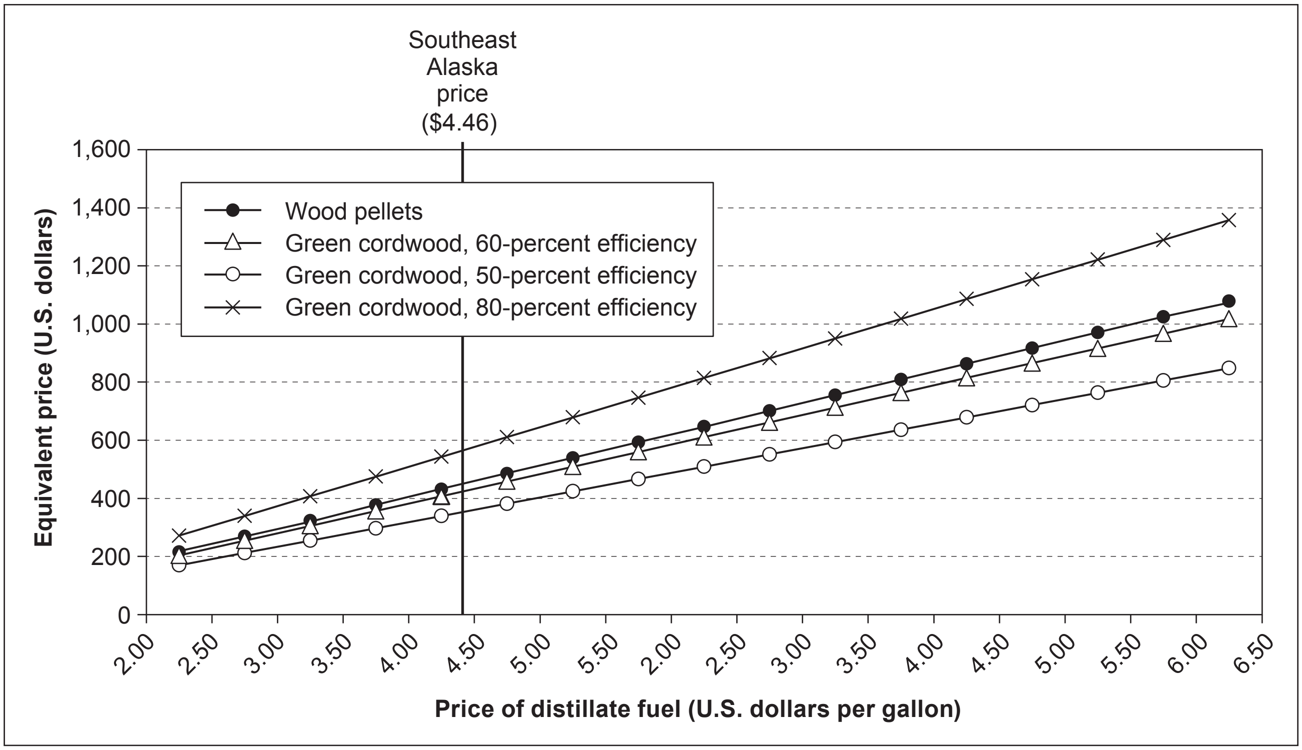

Figure 7—Comparison of equivalent prices for distillate fuels and wood energy products for 60- and 80-percent combustion efficiency in cordwood systems.

The price comparisons have identified households using primarily heating oil as those with the greatest incentive to switch to wood fuels.

As in the Brackley et al. (2010) study, the price comparisons in this section and in the appendix tables have identified households using primarily heating oil as those with the greatest incentive to switch to wood fuels. If a household can freely switch between heating systems, the cost savings is substantial in many parts of the state. Next, we estimated the total volume of cordwood and wood pellets needed to replace the energy used by distillate-heated homes.

Potential Demand for Wood for Residential Heating in Alaska

Estimating the volume of wood necessary to heat homes currently heated with distillates began with the number of households using distillate fuels from table 3 above. Continuing the previous assumptions that distillate fuel heating equipment is 85-percent efficient, cordwood heating equipment is 60-percent efficient, and pellet heating equipment is 80-percent efficient, we calculated the total number of therms that would need to be replaced with wood energy in each census area. The maximum amount of wood-derived energy required to heat these households was calculated by multiplying the average energy (in therms) required to heat a typical home in each census area by the number of homes assumed to make the conversion. Conversion factors were applied to calculate the equivalent weight and volume of cordwood and pellets necessary to replace the therms of energy provided from distillates. The results presented in table 7 represent the maximum potential new demand for either cordwood or wood pellets given a total residential conversion from distillate fuels. In other words, table 7 shows the number of cords of green wood or tons of pellets demanded if every distillate-heated home in Alaska made the switch. Statewide, we estimated this maximum to be just over 919,000 tons (367,000 cords) of green wood.[5] The estimated maximum additional demand for wood pellets (dried to 6.5-percent moisture content and burned at 80-percent efficiency) was approximately 590,000 tons. We estimated demand for cordwood and pellets separately, but in reality, a portion will likely be captured by each product.

Other Costs of Conversion to Wood Energy Systems

One assumption driving much of this analysis is that Alaskan consumers are able to freely switch between heating systems in response to relative changes in fuel costs. However, the cost of conversion may be prohibitive for some. In addition to the purchase of equipment such as a wood or pellet stove, homeowners must consider the cost and installation of venting systems, decommissioning existing fuel oil tanks, and the storage space needed to accommodate a season's worth of firewood or pellets. Most pellet stoves require some electricity to operate, which may be limiting to residents of Alaska's remote areas. In addition, actually purchasing a new wood or pellet stove could be problematic, as destinations in Alaska are sometimes ineligible for shipping.

One assumption driving much of this analysis is that Alaskan consumers are able to freely switch between heating systems in response to relative changes in fuel costs.

To gain a sense of barriers to switching to wood heating systems, we performed a spot check of three major home improvement retailers with a presence in Alaska for both the on-site stock of wood and pellet stoves available for purchase as well as shipping available to Alaskan residences. An Internet search of retailers Costco, Home Depot, and Lowe's for price, performance, and availability of wood and pellet stoves was conducted in February 2015. Costco has two stores in Anchorage and one in Juneau. Only three stoves are listed on the Costco website (two wood stoves and one pellet stove). The average price and coverage area of these units are \$1,282 and 2,300 ft^2, respectively. At Home Depot, the price of a wood-burning stove ranged from \$239 to \$1,399 to heat 600 to 3,000 ft^2. Pellet stove prices ranged from \$999 to \$1,999 for 1,500 to 2,200 ft^2 of area heated. Three stores were located in Anchorage, with additional locations in Fairbanks, Juneau, the Kenai Peninsula, and Wasilla. Lowe's has five stores in Alaska: three in Anchorage and one each in Fairbanks and Wasilla. Prices for pellet stoves ranged from \$1,104 to \$1,970 for

[5] Based on the average heating value of common Alaskan tree species. See Brackley et al. (2010) for details.

Table 7—Annual volume of cordwood or pellets required to replace distillate fuel used in the residential sector in Alaska by census area

Region	Borough/census area	Number of occupied units using distillate fuels	Total energy needed for conversion[a]	Cordwood[b,c]		Wood pellets[d]
			Therms	*Tons*	*Cords*	*Tons*
Aleutians and Arctic	Aleutians East	367	276,651	3,330	2,305	2,137
	Aleutians West	892	617,808	7,437	5,148	4,773
	Kusilvak	1,334	1,469,405	17,689	12,245	11,351
	Nome	2,552	2,758,297	33,205	22,986	21,308
	North Slope	688	1,052,719	12,673	8,773	8,132
	Northwest Arctic	1,625	1,971,949	23,739	16,433	15,233
	Yukon-Koyukuk	1,024	1,149,101	13,833	9,576	8,877
	Total	8,482	9,295,930	111,906	77,466	71,812
Greater Anchorage	Anchorage	2,964	2,383,239	28,690	19,860	18,411
	Kenai Peninsula	7,819	6,480,612	78,015	54,005	50,063
	Matanuska-Susitna	5,102	4,145,382	49,903	34,545	32,023
	Valdez-Cordova	2,751	2,164,019	26,051	18,033	16,717
	Total	18,636	15,173,253	182,659	126,444	117,214
Greater Fairbanks	Denali	420	426,257	5,131	3,552	3,293
	Fairbanks North Star	28,064	30,250,721	364,165	252,089	233,689
	Southeast Fairbanks	1,297	1,345,989	16,203	11,217	10,398
	Total	29,781	32,022,967	385,499	266,858	247,379
Southeast	Haines Borough	687	473,059	5,695	3,942	3,654
	Juneau	8,761	5,770,812	69,470	48,090	44,580
	Ketchikan Gateway	3,663	2,098,157	25,258	17,485	16,208
	Prince of Wales-Hyder	1,253	680,258	8,189	5,669	5,255
	Sitka	2,280	1,293,209	15,568	10,777	9,990
	Skagway	336	223,229	2,687	1,860	1,724
	Hoonah-Angoon	673	423,607	5,099	3,530	3,272
	Wrangell	444	261,186	3,144	2,177	2,018
	Petersburg	917	575,307	6,926	4,794	4,444
	Yakutat	218	155,064	1,867	1,292	1,198
	Total	19,232	11,953,888	143,903	99,616	92,344
Southwest	Bethel	3,727	3,679,926	44,300	30,666	28,428
	Bristol Bay	365	313,232	3,771	2,610	2,420
	Dillingham	1,144	1,012,066	12,183	8,434	7,818
	Kodiak Island	3,644	2,527,607	30,428	21,063	19,526
	Lake and Peninsula	464	385,638	4,642	3,214	2,979
	Total	9,344	7,918,469	95,324	65,987	61,171
	Total	85,475	76,364,507	919,292	636,371	589,920

[a] Adjusted for climate and assuming 85-percent distillate heating equipment efficiency.
[b] Assumes 20 percent moisture content, and 60-percent heating equipment efficiency.
[c] Assumes a gross heating value of 20,000,000 Btu per cord (Energy Information Administration), and 60-percent wood heating equipment efficiency.
[d] Assumes 6.5-percent moisture content and 80- percent wood pellet heating equipment efficiency.

1,500 to 2,200 ft^2 of heating area. Wood stove prices at Lowe's ranged from $395 to $1,641 for 600 to 3,000 ft^2 of coverage, respectively. We were unable to find information to validate the square feet of coverage claimed by the vendors.

Most stoves listed on store websites were not available for purchase locally, nor were they eligible for shipping to Alaska. No stoves were available in stock at Costco, but all online purchases were eligible for shipping to Alaska residences for an additional charge of $277.70. Of the 28 wood stoves listed on the Home Depot website, three could be purchased at the store and only five additional models could be shipped to Alaska. Only two of 17 Home Depot pellet stoves were available to buy locally and only two others were eligible for shipment to Alaska. Six of eight advertised wood stoves at Lowe's were available locally but none could be shipped to Alaska. All six of the pellet stoves listed in the store website were available at the store, but again none was eligible for shipping.

Most stoves listed on store websites were not available for purchase locally, nor were they eligible for shipping to Alaska.

We also checked the price of wood pellets and the combustion efficiency ratings of pellet and wood stoves. None of the Alaska Costco warehouses had pellets in stock when we called, but the customer service representative said that pellets were stocked at intermittent intervals during the winter. Forty-pound bags of pellets were available in stock at Home Depot for $5.88 and $5.98 at Lowe's. Information on the combustion efficiency of stoves was rare; only two of the 62 total models found during the Web search provided stove efficiency ratings. Several small models were listed as "mobile home approved," supporting our decision to include mobile homes in our count of residential households.

Conclusion

The results described above suggest that the maximum potential annual demand for renewable wood energy products to replace distillate fuels for heating in the residential sector of Alaska is about 367,000 cords of green wood or about 590,000 tons of wood pellets. This result varies depending on stove efficiency assumptions, but nevertheless illustrates that widespread conversion to biomass heating could generate substantial demand for woody material in Alaska. Our estimates are lower than were found in the previous report; the difference is primarily attributable to an assumption regarding the efficiency of heating oil systems. Rather than assume that the amount of distillate-derived energy to be replaced was the amount purchased by households, which implicitly assumes that their systems were 100-percent efficient, we realistically assumed that the amount of heat to replace is the amount actually felt by households, thus accounting for equipment efficiency losses on both sides of the conversion.

Our principal motivation for updating estimates of potential wood demand in Alaska has been to inform analyses for the Tongass National Forest plan amendment process. Our conclusions broadly confirm that the potential for large-scale conversion exists under a specific set of economic conditions. In addition to planning needs, this study could inform the multifaceted discussion surrounding bioenergy in both the unique region of southeast Alaska and forested areas elsewhere. Interest in reliable and locally available energy sources may presently be mitigated by temporarily falling fossil-fuel prices, and economically remote communities may presently be experiencing some relief owing to this recent global downturn, but neither situation is likely to be permanent. Assuming that attention to longer term trends in energy independence and the implications for forest management will prevail amidst these short-term fluctuations, the discussion of bioenergy will continue to foster wide-ranging interest that we hope our findings here will support.

Further Discussion and Research

The Forest Service aims to support efforts to substitute 30 percent of distillate fuel consumption in southeast Alaska with wood-based energy products (Deering 2014). No analysis has been published to date estimating the volume of wood required to meet that goal or the implications for harvest. The focus has instead been centered on the economic benefits of lower cost space heating and the impact on the wood products industry from growing wood-based energy markets. The wood necessary to meet demand from such a conversion could come from unutilized low-grade utility logs partly supplied by the Tongass, or sawmill residues produced by Alaska timber processors. Ultimately, the framework used to analyze the residential sector here will be combined with estimates for the commercial and industrial sectors in southeast Alaska to arrive at the volumes necessary to meet the 30-percent conversion goal in support of the Tongass National Forest's planning process in 2015.

Our qualitative assessment of stove availability from the spot check of Alaska retailers addresses some practical concerns for large-scale conversion to wood energy products in Alaska. Foremost is that Alaskans who are not in reasonable proximity to Anchorage, Fairbanks, Juneau, or Wasilla have limited retail purchasing opportunities, because few stoves can be shipped. Although local retailers are likely present in these locations, prices may not be competitive with large national chains. In addition, consumers may not have ready access to combustion efficiency values when evaluating choices between stoves. Given the sensitivity of cost comparisons to efficiency assumption shown by our analysis, marketing efforts to provide consumers with more information on combustion efficiency could help build interest in new, cleaner wood energy systems.

Marketing efforts to provide consumers with more information on combustion efficiency could help build interest in new, cleaner wood energy systems.

Recent declining oil prices have implications for the results of this analysis. As of February 2, 2015, national residential heating oil prices averaged less than $2.80 per gallon, $1.44 per gallon less than the previous year's price for the same week. Wholesale heating oil prices averaged $1.83 per gallon, $1.61 per gallon lower when compared to the same time last year (USDE EIA 2015c). Because the decline in fuel oil price affects the relative affordability of wood energy products, we briefly investigated current heating oil prices in Alaska. We contacted four southeast Alaska heating oil distributors in Haines, Juneau, Ketchikan, and Wrangell in mid-February 2015, asking for the current price of Fuel Oil #1. Prices ranged from $3.24 to $3.94 per gallon, with Juneau being the least expensive and Haines the most. Recall that the average southeast Alaska heating oil price reported in January 2015 was $4.46 per gallon. Table 8 in the appendix shows that the break-even price of wood alternatives to heating oil priced at $3.50 per gallon is $356 per cord for firewood and $377 per ton for pellets. Although fuel prices are expected to rebound, the price of wood energy products relative to heating oil may not be enough to motivate widespread conversion to wood systems currently.

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Acknowledgments

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Metric Equivalents

When you know:	Multiply by:	To find:
Cubic feet (ft^3)	0.0283	Cubic meters (m^3)
British thermal units (Btu)	3,412.14	Kilowatt-hour
British thermal units (Btu)	100,000	Therms
Pounds (lbs.)	2,400	Bone dry units
Cords (green weight)	2.5	Tons

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Appendix—Fuel price equivalencies between wood energy and heating oil, natural gas, and electricity

Table 8—Price equivalency between heating oil and wood energy alternatives, 60-percent combustion efficiency

Paying this price for a gallon of heating oil…	Is like paying this much for a cord of wood:	And this much for a ton of wood pellets:
	U.S. dollars	
2.00	203.59	215.73
2.50	254.48	269.67
3.00	305.38	323.60
3.50	356.27	377.53
4.00	407.17	431.47
4.50	458.07	485.40
5.00	508.96	539.33
5.50	559.86	593.27
6.00	610.76	647.20
6.50	661.65	701.13
7.00	712.55	755.07
7.50	763.45	809.00
8.00	814.34	862.93
8.50	865.24	916.86
9.00	916.14	970.80
9.50	967.03	1,024.73
10.00	1,017.93	1,078.66

Table 9—Price equivalency between natural gas and wood energy alternatives, 60-percent combustion efficiency

Paying this price for a thousand cubic feet of natural gas…	Is like paying this much for a green cord of wood:	And this much for a ton of wood pellets:
	U.S. dollars	
6.00	77.67	82.30
6.50	84.14	89.16
7.00	90.61	96.02
7.50	97.09	102.88
8.00	103.56	109.74
8.50	110.03	116.60
9.00	116.50	123.46
9.50	122.98	130.31
10.00	129.45	137.17
10.50	135.92	144.03
11.00	142.39	150.89
11.50	148.87	157.75
12.00	155.34	164.61
12.50	161.81	171.47
13.00	168.28	178.33
13.50	174.76	185.18
14.00	181.23	192.04

Table 10—Price equivalency between electricity and wood energy alternatives, 60-percent combustion efficiency

Paying this price for a kilowatt-hour of electricity…	Is like paying this much for a green cord of wood:	And this much for a ton of wood pellets:
	U.S. dollars	
0.06	234.47	248.46
0.08	312.62	331.28
0.10	390.78	414.09
0.12	468.93	496.91
0.14	547.09	579.73
0.16	625.24	662.55
0.18	703.40	745.37
0.20	781.56	828.19
0.22	859.71	911.01
0.24	937.87	993.83
0.26	1,016.02	1,076.64
0.28	1,094.18	1,159.46
0.30	1,172.33	1,242.28
0.32	1,250.49	1,325.10
0.34	1,328.64	1,407.92
0.36	1,406.80	1,490.74
0.38	1,484.96	1,573.56

Table 11—Price equivalency between heating oil and wood energy alternatives, 80-percent combustion efficiency

Paying this price for a gallon of heating oil…	Is like paying this much for a green cord of wood:	And this much for a ton of wood pellets:
- - - - - - - - - -	*U.S. dollars*	- - - - - - - - - -
2.00	271.45	215.73
2.50	339.31	269.67
3.00	407.17	323.60
3.50	475.03	377.53
4.00	542.90	431.47
4.50	610.76	485.40
5.00	678.62	539.33
5.50	746.48	593.27
6.00	814.34	647.20
6.50	882.20	701.13
7.00	950.07	755.07
7.50	1,017.93	809.00
8.00	1,085.79	862.93
8.50	1,153.65	916.86
9.00	1,221.51	970.80
9.50	1,289.38	1,024.73
10.00	1,357.24	1,078.66

Table 12—Price equivalency between natural gas and wood energy alternatives, 80-percent combustion efficiency

Paying this price for a thousand cubic feet of natural gas…	Is like paying this much for a green cord of wood:	And this much for a ton of wood pellets:
	U.S. dollars	
6.00	103.56	82.30
6.50	112.19	89.16
7.00	120.82	96.02
7.50	129.45	102.88
8.00	138.08	109.74
8.50	146.71	116.60
9.00	155.34	123.46
9.50	163.97	130.31
10.00	172.60	137.17
10.50	181.23	144.03
11.00	189.86	150.89
11.50	198.49	157.75
12.00	207.12	164.61
12.50	215.75	171.47
13.00	224.38	178.33
13.50	233.01	185.18
14.00	241.64	192.04

Table 13— Price equivalency between electricity and wood energy alternatives, 80-percent combustion efficiency

Paying this price for a kilowatt-hour of electricity…	Is like paying this much for a green cord of wood:	And this much for a ton of wood pellets:
	U.S. dollars	
0.06	312.62	248.46
0.08	416.83	331.28
0.10	521.04	414.09
0.12	625.24	496.91
0.14	729.45	579.73
0.16	833.66	662.55
0.18	937.87	745.37
0.20	1,042.07	828.19
0.22	1,146.28	911.01
0.24	1,250.49	993.83
0.26	1,354.70	1,076.64
0.28	1,458.90	1,159.46
0.30	1,563.11	1,242.28
0.32	1,667.32	1,325.10
0.34	1,771.53	1,407.92
0.36	1,875.73	1,490.74
0.38	1,979.94	1,573.56

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