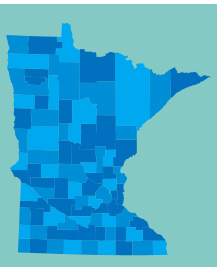
Air quality

May 2019

Minnesota residential wood combustion survey results

Results from May 2017 – April 2018

MINNESOTA POLLUTION CONTROL AGENCY



Acknowledgements

This project was funded by the Minnesota Pollution Control Agency as part of its ongoing efforts to improve outdoor air quality. The MPCA thanks our cooperating partners:

Minnesota Department of Natural Resources – Division of Forestry

U.S. Forest Service – Northern Research Station – Forest Inventory and Analysis

The agency also appreciates the assistance provided by the North Central Hearth, Patio and Barbecue Association in providing photographs and by John Gulland and Associates for allowing the use of wood-burning equipment drawings.

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Summary

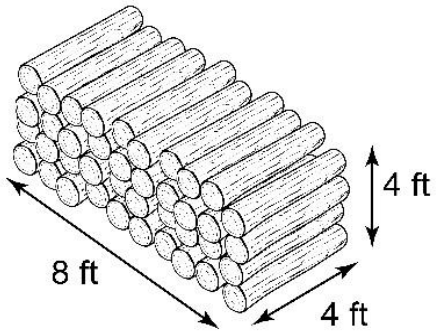
In 2018, the Minnesota Pollution Control Agency (MPCA) conducted a statewide survey to find out how much wood is harvested and burned annually for heat or pleasure in Minnesota. This survey has been conducted in varying forms every few years since 1960, the previous survey having been conducted in 2015. The most recent study was conducted for the 2017-2018 heating season, May 2017-April 2018. Historically, the survey was conducted by the Minnesota Department of Natural Resources (DNR) and the U.S. Forest Service (USFS), but the MPCA has been the primary sponsor since 2008. These data have been used by state and federal agencies, as well as trade organizations, to manage forests, inform policymakers and scientists, and assist the hearth and fireplace industry by examining trends in wood burning.

The MPCA conducted this latest survey to gather information about residential wood combustion practices. Due to the levels of fine particles ($PM_{2.5}$) in ambient air, it is important to have accurate information about the sources of this pollutant. Residential wood combustion is an important source of fine particle emissions and accounted for 55% of Minnesota's direct fine particle emissions[1] in 2014[2]. This survey provides an improved understanding of residential wood burning in Minnesota by type of equipment, purpose for burning, source of wood fuel, and region of the state.

In May 2018, the DNR sent out 7,000 invitations to complete the survey to randomly selected households throughout the state. For purposes of data collection and analysis, the state was divided into five regions. These regions are characterized by their main forest type and the expectation that their populations will have similar wood burning practices. These regions (Northern Pine, Aspen-Birch, Prairie, Metro, and Central Hardwood; see Figure 2) have been used in past surveys.

While it is reasonable to look for trends in wood burning behavior over time, using multiple years' worth of survey results, trends should be interpreted with caution due to changes made to the survey each time it is administered. This year's survey showed Minnesota households burned an estimated 1.45 million cords over the course of a year. This amount of wood would completely fill US Bank Stadium in Minneapolis. This is a decrease from the estimated amount of wood burned in 2015; however, it is possible that the 2015 survey results were overestimated due to a possible bias in the survey responders. Besides the apparent decrease in burning from 2015 to 2018, over the longer term, residential wood burning appears to be increasing (see Figure 3). However, again, trends over time cannot be concluded from survey results with certainty, due to changes in survey design each year it was administered.

Figure 1: One cord of wood



[1] *Direct fine particle emissions are released from pollution sources. Fine particles in the air are a mixture of the directly released fine particles and those that are created in the air by chemical reactions between other pollutants such as the gases released from coal plants and vehicles.*

[2] *Minnesota Pollution Control Agency's 2014 Emissions Inventory*

Key findings

- Residential wood burning appears to be increasing over time.
- Roughly, 980,000 households, about 46% of all Minnesota households, burned some wood between May 2017 and April 2018.
- Statewide, the greatest volume of wood burned was for primary heat, but burning for pleasure was the most common reason a household burned wood.
- Wood stoves burned the largest amount of wood of all equipment types, while wood boilers burned the largest amount of wood per piece of equipment.
- Less than half of Minnesota households stored their wood protected from the elements.
- About one third of wood stoves and one quarter of fireplace inserts used were manufactured prior to 1989; these older models pollute significantly more than those manufactured later do.

Implications

This survey provides data to support the MPCA's air emission inventories for criteria pollutants, criteria precursors, and hazardous air pollutants. These inventories are released every three years for all air emission sources to support effective air quality tracking for pollution reduction programs and health risk assessments. This survey will inform a more complete picture of the overall impact of wood burning on air quality across the state.

This survey, along with other data on wood burning collected by the MPCA and other agencies, is an important tool to help Minnesota policy planners make informed policy decisions regarding overall forestry management and environmental strategies, especially relating to air emissions in the state. For example, the data collected in this survey help inform the need for appliance change-out incentive programs.

The data collected are also used to estimate the amount of residential fuel wood burned as reported in the annual Minnesota Department of Natural Resources' Forest Resource Report. This report describes Minnesota's forest resources, such as current conditions and trends in forest resources and forest resource industrial use.

Introduction

Project purpose

For more information on wood smoke and wood burning in Minnesota, visit https://www.pca.state.mn.us/air/wood-smoke

Between April and June 2018, the Minnesota Pollution Control Agency (MPCA), assisted by Wilder Research (Wilder), the Minnesota Department of Natural Resources (MDNR), and the US Forest Service (USFS), surveyed randomly selected households across Minnesota to estimate the volume of residential wood burned between May 1, 2017 and April 30, 2018. Similar surveys were conducted for the years of 1960, 1969-1970, 1979-1980, 1984-1985, 1988-1989, 1995-1996, 2002-2003, 2007-2008, 2011-2012, and 2014-2015. These surveys are part of a long-term effort to monitor trends in the use and harvesting of Minnesota's wood supply by Minnesota households.

These surveys provide data for Minnesota's air pollutant emission inventories, which are assessed every three years by the MPCA. The MPCA estimates statewide emissions of various air pollutants, such as fine particles ($PM_{2.5}$), volatile organic compounds (VOCs), and other pollutants released from factories, vehicles, residential wood combustion, and other activities. The emission inventories offer valuable information about the activities that contribute to ambient air concentrations of fine particles and other air pollutants. In recent years, Minnesota's emission inventory has indicated that residential wood combustion is a primary source of directly emitted fine particles from combustion processes.

The collected data are used to estimate residential wood fuel burned for DNR's annual Forest Resource Report. The Forest Resource Report describes Minnesota's current forest conditions and trends in forest resource use.

Results of the survey are described in graphic form in the results section of this report. Reference to data tables is provided for some of the figures. These data tables are provided in Appendix B.

Survey objectives

The objectives for this survey were similar to those framed by the MPCA, DNR, and USFS for previous surveys. They were to:

1. Estimate the total volume and type of residential wood burned from May 1, 2017 through April 30, 2018 by category of equipment used and geographic location.
2. Estimate the amount of wood burned for various purposes, including heat (primary or secondary), pleasure, disposal of wood from residential properties, or more than one of these reasons.
3. Compare with results of previous surveys to identify wood burning trends.
4. Estimate the temporal distribution of wood burning throughout the year.
5. Inform air pollution reduction strategies by understanding the amount and location of wood burned, equipment used to burn wood, and reasons for burning.
6. Estimate the volume and type of fuel wood harvested or obtained, including the amounts harvested from living or dead trees and from land owned by different entities (state, federal, county, forest industry, and private lands).

Results

Household burning practices

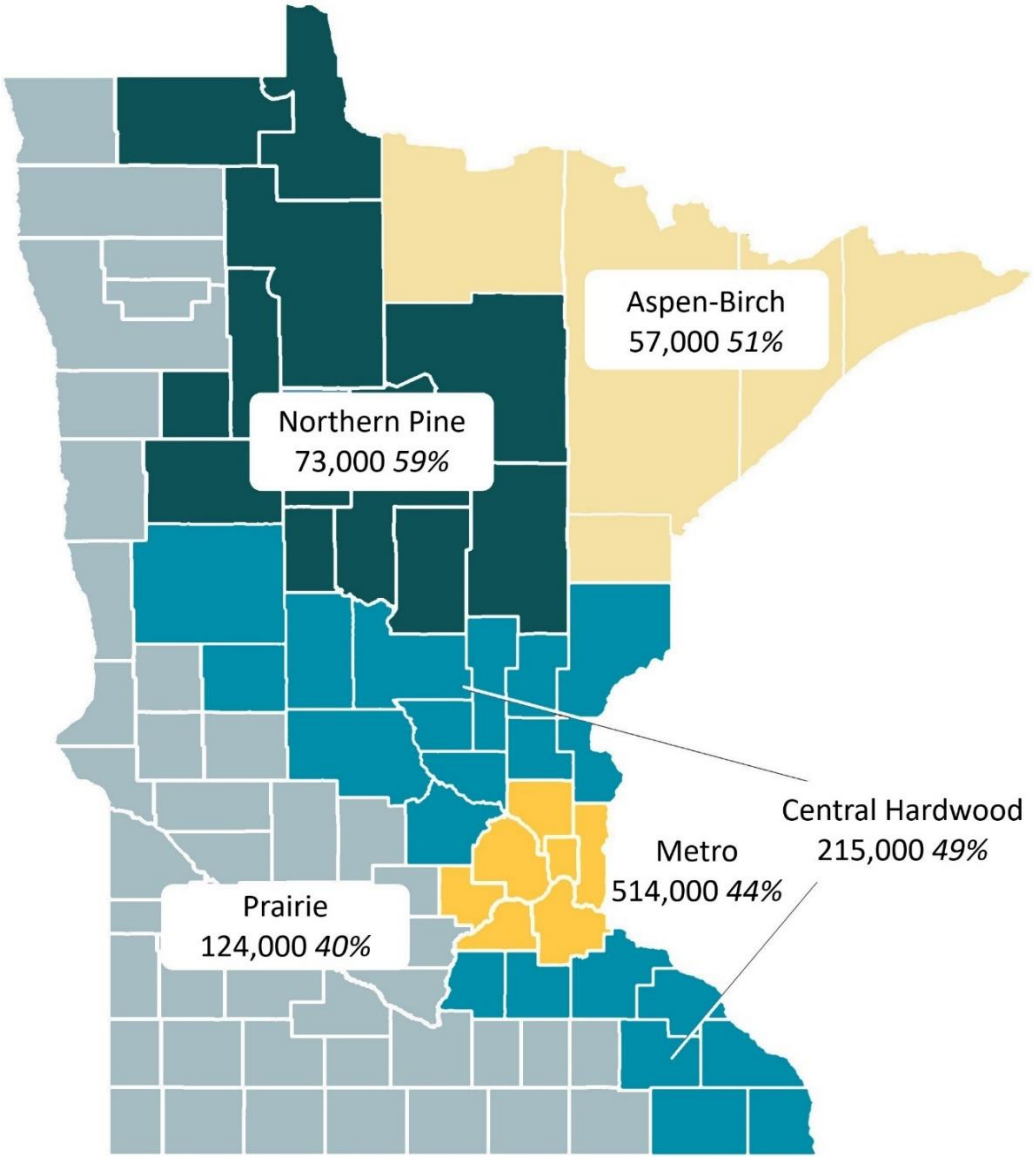
Between May 1, 2017 and April 30, 2018, an estimated 980,000 Minnesota households burned some wood, about 46% of occupied households in the state.

For purposes of data collection and analysis, the state was divided into five regions: Northern Pine, Aspen-Birch, Prairie, Metro, and Central Hardwood (Figure 2). These regions have been used in analyzing several previous surveys as well. They are characterized mainly by forest type, but also serve to stratify the statewide household population into subgroups that are expected to have similar wood burning practices.

Burning rates (the percentage of all occupied households in a region that burned wood at any location) varied by region. The highest burning rate was in the Northern Pine region, where 59% of households whose primary residence was in the region reported burning wood. The burning rate was lowest in the Prairie region (40%). The Metro region's burning rate was also comparatively low (44%), but because it is more densely populated, it has the greatest number of households estimated to have burned wood (0.5 million).

This year's estimated burning rates were significantly lower than those estimated from the previous survey in 2015 were. However, trends in wood-burning rates between 2015 and 2018 should be drawn with caution. The overall survey response rate in 2018 was 23%, improved from the 18% response rate in 2015. In addition, this year's survey was modified to emphasize that a response was desired from every household, regardless of whether it burned wood in the previous year or not. This change was made because of a concern that the 2015 survey's design may have made it more likely that households that did not burn wood disregarded the survey, thus leading to an overrepresentation of wood-burning households and an overestimation of household wood burning rates and amounts. In fact, Figure 10 shows that the average cords burned per household statewide increased between 2012 and 2015, and also between 2015 and 2018. This suggests selection bias by responders that burned wood in 2015.

Figure 2: Estimated number and percent of household population that burned wood by region[3]



The percentages in Figure 2 are based on the location of the primary residences of the households that reported burning wood in any amount anywhere in the state. Since some households also burned wood in regions outside their region of primary residence (such as at a secondary residence or a campsite), these results do not necessarily reflect the amounts of wood burned in each region.

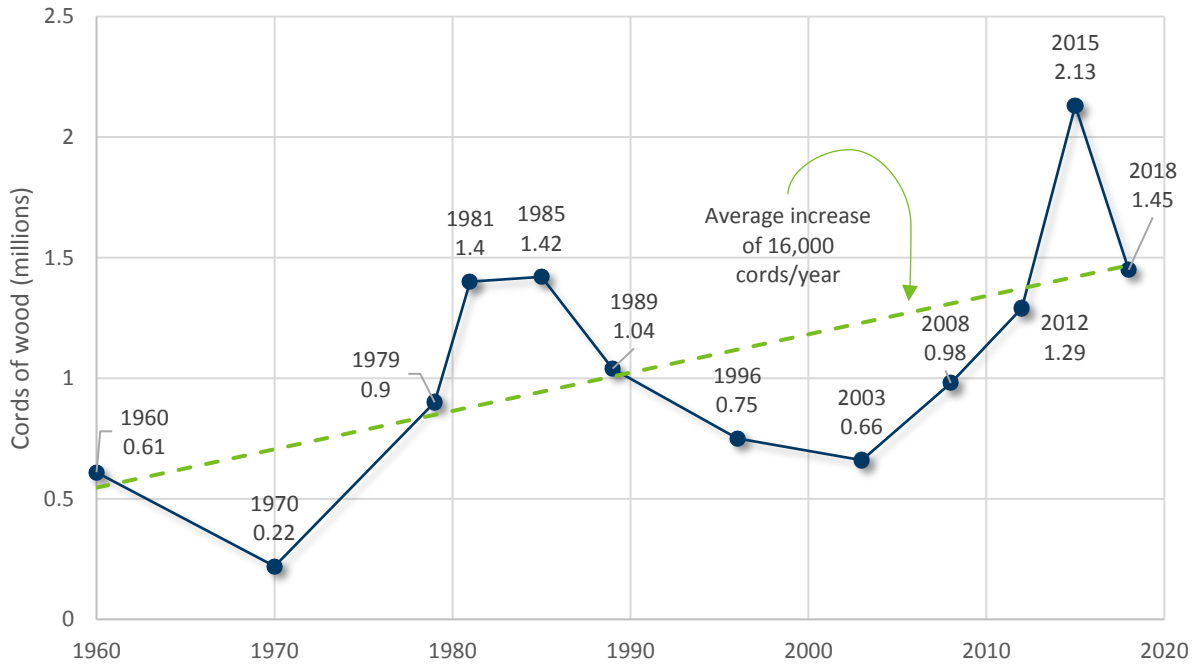
[3] *See Appendix C, Table 8 for unrounded estimated values.*

Volume of wood fuel burned

Total volume

Between May 1, 2017 and April 30, 2018, Minnesota households burned an estimated 1.45 million cords of wood.[4] This is a 32% decrease from 2015 (Figure 3). While this is a substantial decrease in the total volume of wood burned, the estimated amount of wood burned over all survey years has increased by an average of about 16,000 cords per year. Since 2003, the estimated amount of wood burned has increased by about 75,000 cords per year. Despite varying differences between years, wood burning in general appears to be increasing over time.

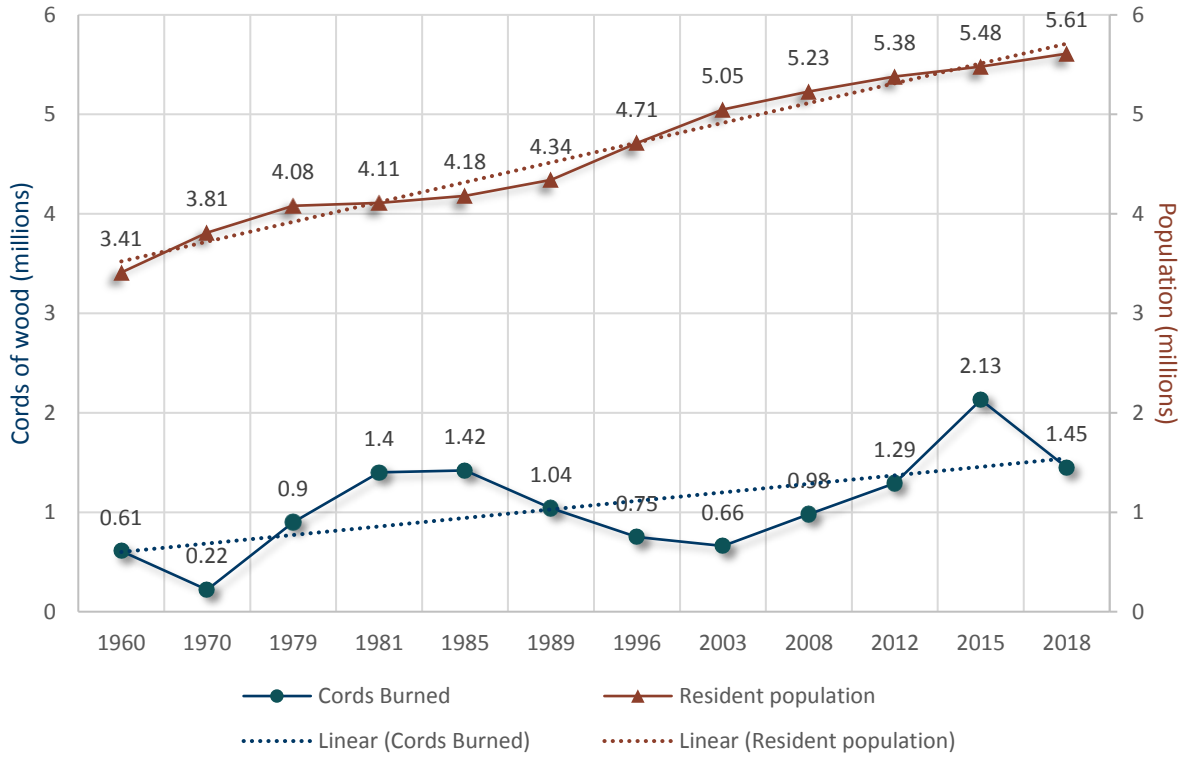
Figure 3: Estimated volume of wood burned over all survey years



Concurrent to the general increase in the amount of wood burned over all survey years, Minnesota's resident population has been increasing at a rate of approximately 39,000 per year (Figure 4), corresponding to a 0.86% average annual growth rate. However, the average annual growth rate of wood burned over the same time period, at 1.5%, exceeds that of population. Since 2003, the volume of wood burned has been increasing by an average growth rate of 5.3% annually, while population has only increased by 0.7% per year since then. These estimates give a general idea of how growth in wood burning has compared to population growth, rather than a precise estimate.

[4] *One cord of wood measures 8 x 4 x 4 feet (Figure 1). Unless otherwise noted, "wood" may include wax logs, wood reported in cords, face cords or bundles, wood pellets, pallets, slabs, and tree branches and woody brush. Table 1 describes the breakdown.*

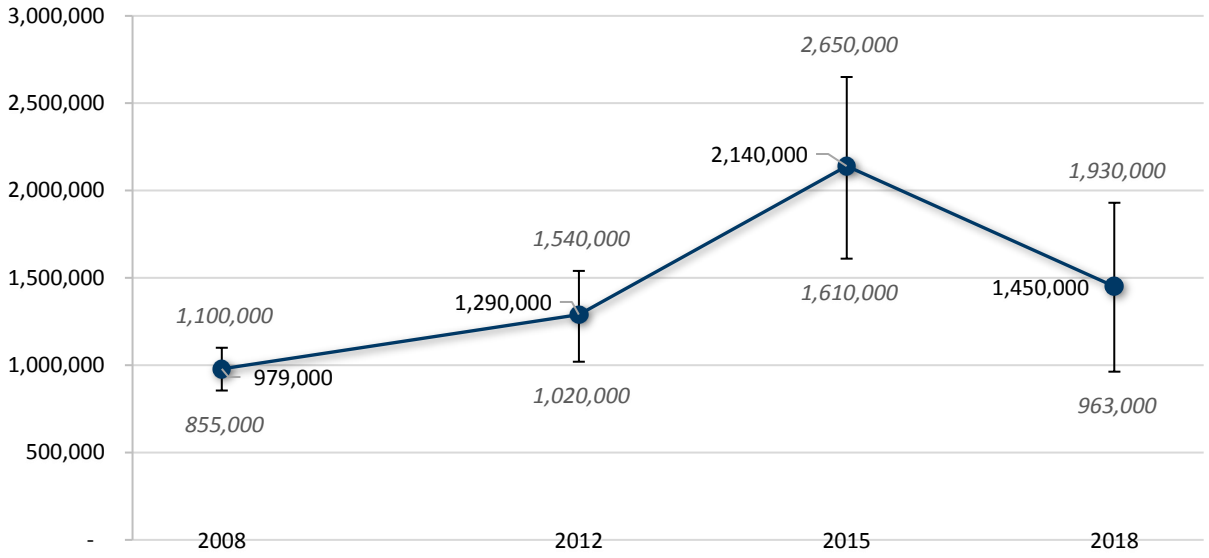
Figure 4: Estimated volume of wood burned and resident population over all survey years[5]



When applying a 95% confidence interval around the estimation of total wood burned in the 2018 survey, the result ranges from 0.96 to 1.93 million cords (Figure 5). In the 2015 report, the 95% confidence interval yielded a range between 1.61 and 2.65 million cords. The considerable overlap between these two intervals suggests that a statistically significant decrease in wood burning between the two survey years cannot be concluded.

[5] *US Census Data collated https://www.statista.com/statistics/206236/resident-population-in-minnesota/*

Figure 5: Estimated volume of wood burned by survey year with 95% confidence interval

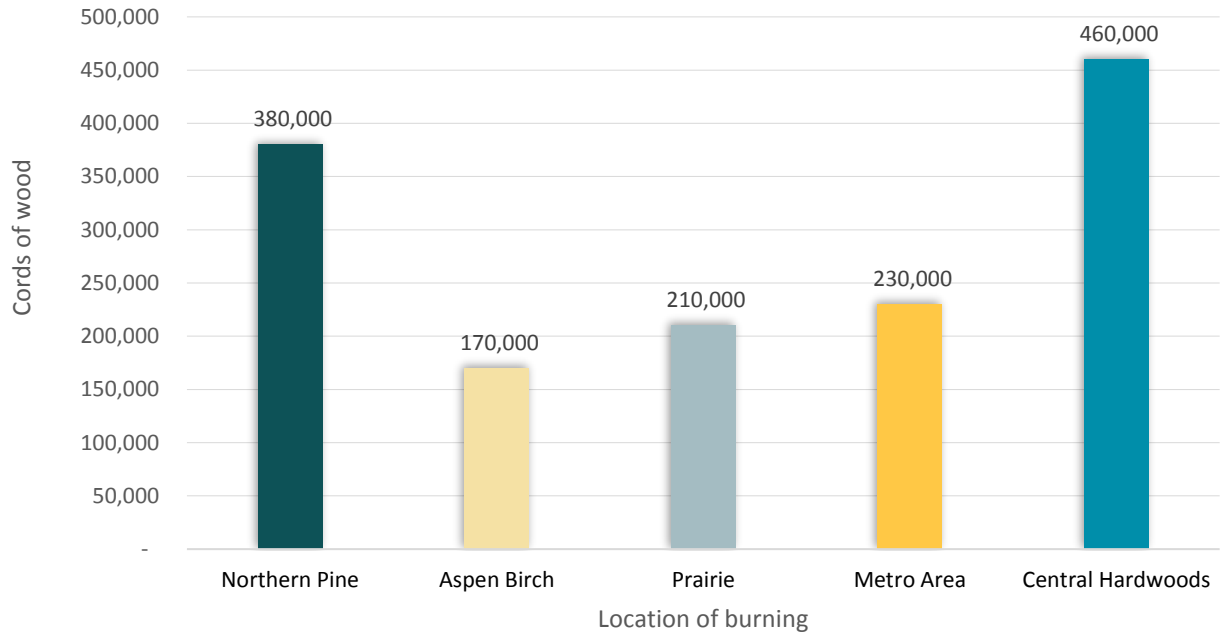


Given changes in survey design and the lower response rate in 2015, comparisons between 2015 and 2018 should be made with caution. Observed trends over multiple survey years may also be affected by changes in survey design, which have not been tested for statistical significance. Survey selection bias, error in respondents' self-reporting, and changes to the survey tool and administration may also affect estimated burning rates and comparisons over time.

Wood burning by region

The greatest amount of wood burned in any of the five regions was in the Central Hardwood region. Of the estimated 1.45 million cords burned statewide, an estimated 32%, about 460,000 cords, was burned in the Central Hardwood region (Figure 6). Despite having just 6% of the state's total occupied households, an estimated 26% of all wood was burned in the Northern Pine region (380,000 cords). The Metro had just an estimated 16% of all wood burned (230,000 cords) despite having the greatest number of households estimated to have burned wood. The fewest estimated number of cords burned were in the Prairie and Aspen-Birch regions, with 15% and 11% of all wood burned, respectively. These totals include all wood burned in each region at primary residences, secondary residences, or campsites.

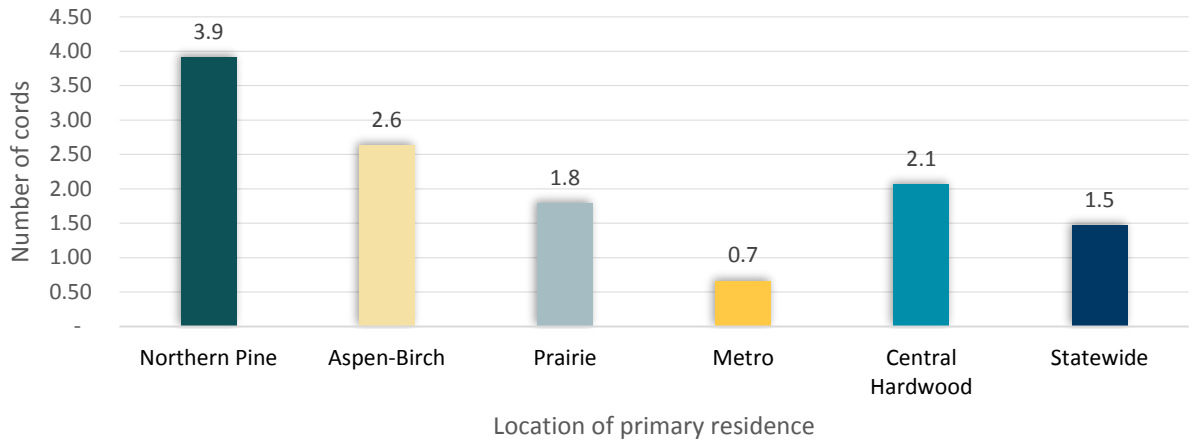
Figure 6: Estimated volume of wood burned in each region[6]



Statewide, households that burned wood burned an estimated average of 1.5 cords of wood per household, regardless of property type (primary or secondary residences or campsites). The average varies considerably, however, between regions. Households with primary residence in the Northern Pine region on average burned the most amount of wood per household, at an estimated almost four cords per household (Figure 7). Households with primary residence in the Aspen-Birch region burned the next highest estimated amount of wood, at 2.6 cords per household. Metro households that burned wood averaged 0.7 cords burned per household. This was the only region in the state that burned less than the statewide average of 1.5 cords per household.

[6] *See Appendix C, Table 9 for unrounded estimated values.*

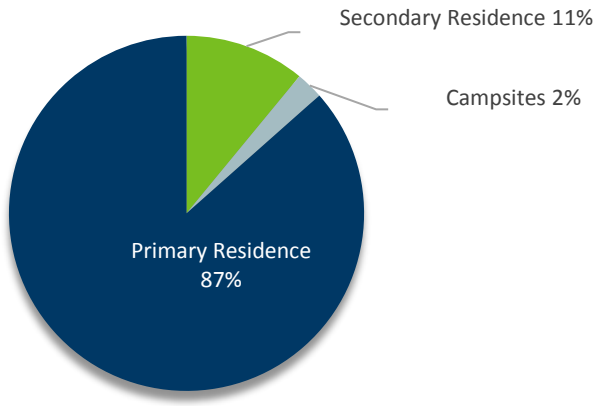
Figure 7: Estimated average volume of wood burned per household anywhere in the state by region[7]



Location of wood burning by region

The majority of estimated wood burned statewide was at primary residences (1.25 million cords, 87%), followed by secondary residences (160,000 cords, 11%), and campsites (36,000 cords, 2%; Figure 8).

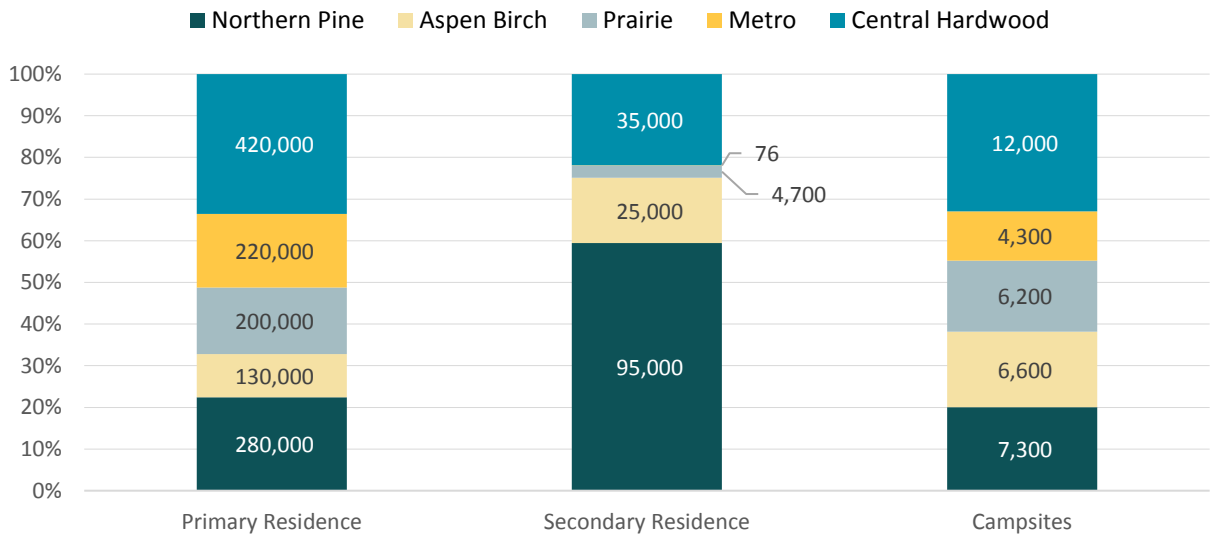
Figure 8: Estimated wood burned by property type



The greatest total estimated volume of wood burned at primary residences was in the Central Hardwood region, with 420,000 cords (Figure 9). An estimated 60% of all the wood burned at secondary residences was in the Northern Pine region (95,000 cords). Of all the wood that was burned at campsites, one-third was burned at campsites in the Central Hardwood region (12,000 cords).

[7] *Evaluated using the total amount of wood burned anywhere in the state by each region's primary residents. See Appendix C, Table 15 for amount of wood burned by a region's primary residents in each region.*

Figure 9: Estimated volume of wood burned by property type and region[8]



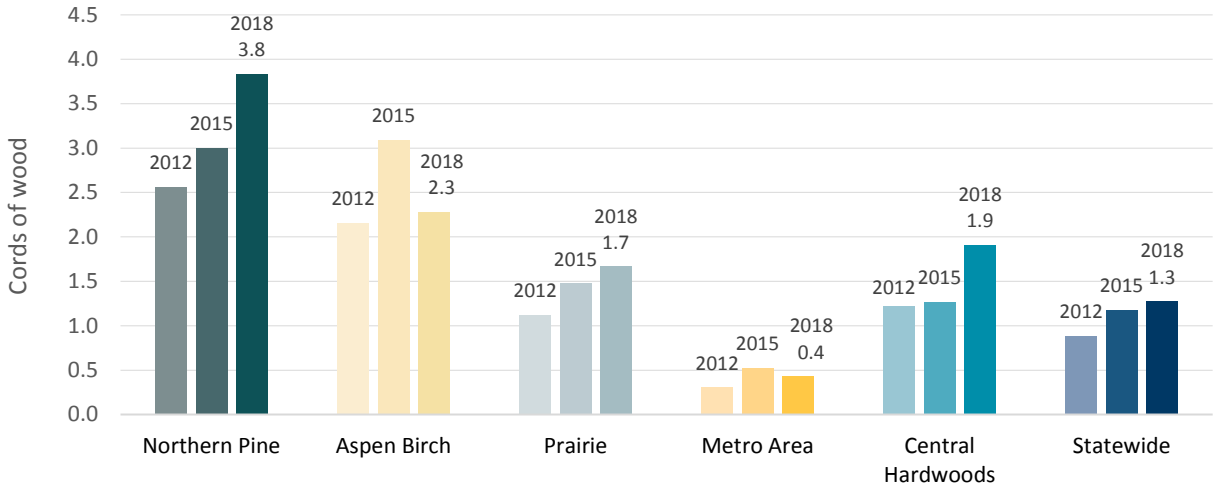
Volume of wood burned per household

The average amount of wood burned at primary residence was evaluated across time to try to understand the large swings in total estimated wood burned from year to year, especially between 2012, 2015 and 2018. This analysis looks at the average amount of wood burned only among households that burned wood.

Between 2012 and 2015, all regional averages appeared to have increased. The averages in three regions, the Northern Pine, Prairie, and Central Hardwood, appeared to consistently increase each survey year since 2012 (Figure 10). The Northern Pine regional average appears to have been increasing the fastest since 2012, at a rate 1.5 times the Central Hardwood average and more than twice the Prairie average. Between 2015 and 2018, the greatest apparent increase among all regional averages was an estimated 51% increase in the Central Hardwood average. In 2018, the Northern Pine and Prairie estimated regional averages increased from 2015 averages by 28 and 13%, respectively. In contrast, the Aspen Birch and Metro estimated regional averages between 2015 and 2018 decreased by 26 and 18%, but did not fall below 2012 levels.

[8] *See Appendix C, Table 12 for unrounded estimated values.*

Figure 10: Average estimated volume of wood burned at primary residences over time by region[9]



Equipment used for wood burning

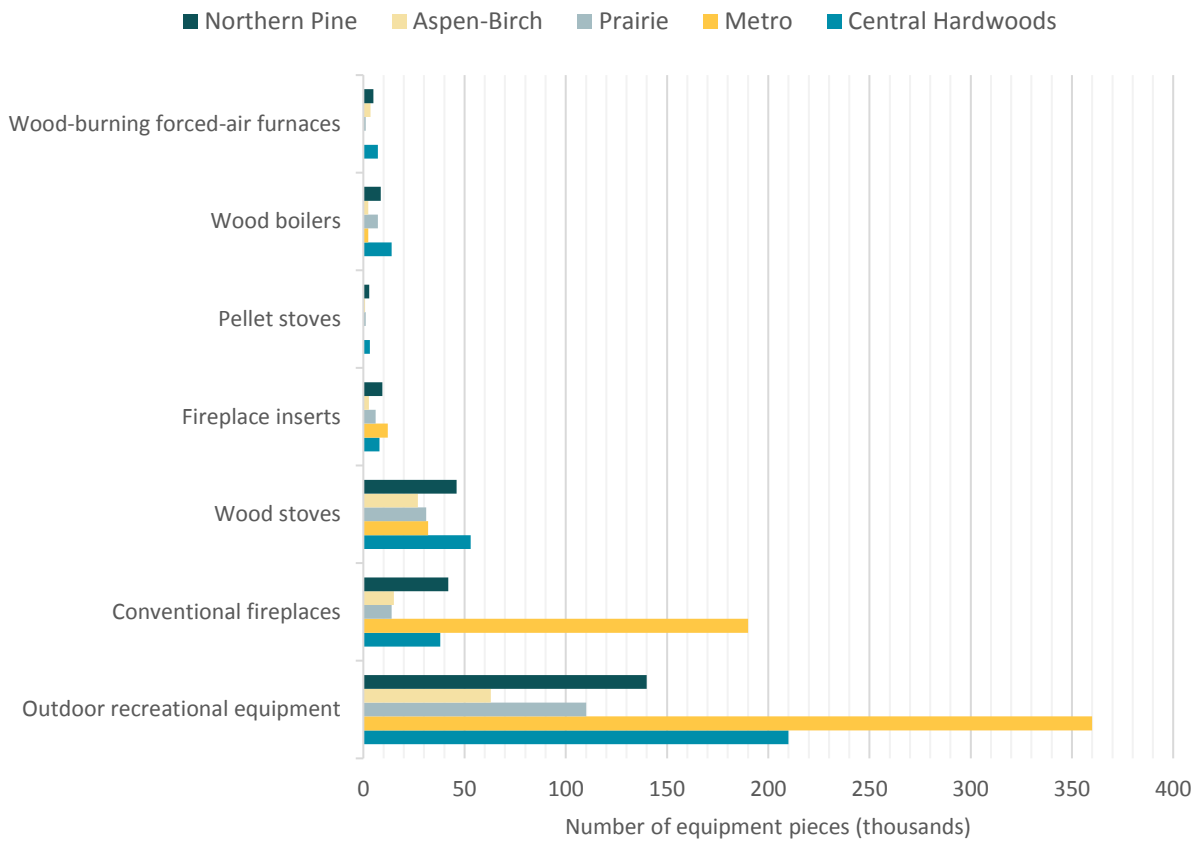
Numbers of equipment pieces used

Between May 1, 2017 and April 30, 2018, Minnesota households used an estimated 1.47 million pieces of wood-burning equipment. The most common type of equipment owned at primary and secondary residences statewide was outdoor recreational equipment (fire pits, fire rings, chimineas, etc.), making up 60% of all equipment pieces used (not including equipment at campsites). The next most common pieces of equipment used were conventional fireplaces (21%) and wood stoves (13%). Less frequently reported equipment included fireplace inserts (3%), wood boilers (2%), wood furnaces (1%) and pellet stoves (0.6%).

Figure 11 shows the estimated number of equipment pieces in each region by equipment type. Forty-one percent of all equipment used was located in the Metro region, due to the region's large household population. The Metro had the most outdoor recreation equipment (360,000), conventional fireplaces (190,000), and fireplace inserts (12,000). Woodstoves were most commonly used in the Central Hardwood (53,000) and Northern Pine (46,000) regions, as were furnaces, boilers, and pellet stoves. An estimated 41 percent of the total wood boilers in the state are located in the Central Hardwood region. There is no estimated number of pellet stoves or boilers in the Metro region because no survey respondents from the region reported owning any.

[9] *Evaluated using only wood burned at primary residence. This could not be evaluated using the total amount of wood burned anywhere (i.e., including secondary sites) in the state by each region's primary residents (as in Figure 7) because this information was not available from 2012 and 2015.*

Figure 11: Estimated number of pieces of wood burning equipment used by region[10]



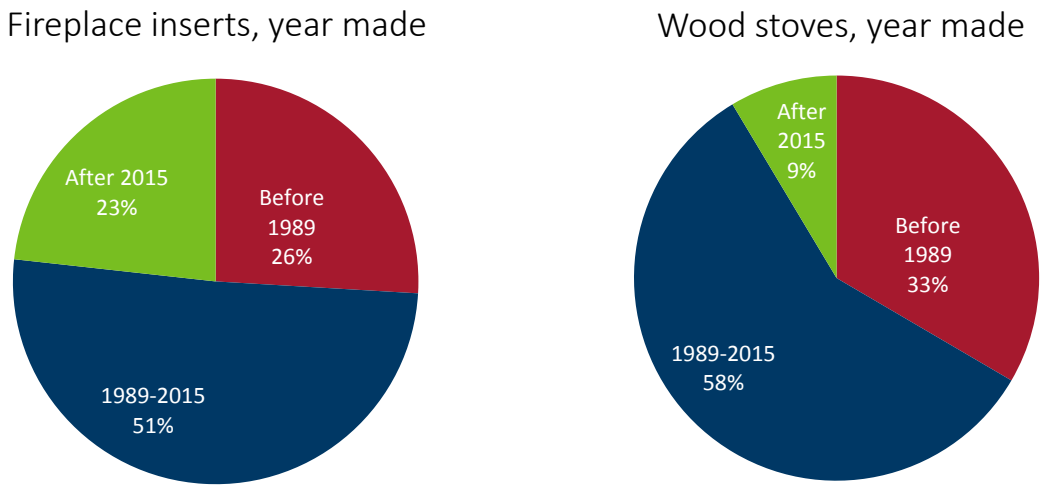
Age of wood stoves and fireplace inserts

Federal standards to limit the allowable amount of air pollution from wood stoves and inserts were initially adopted in 1989. In 2015, the U.S. Environmental Protection Agency (EPA) updated the standards to further reduce air emissions, reflecting emissions and efficiency technology advances in the wood stove industry. Survey respondents were asked to report the age of their wood stoves and whether or not the stoves had a catalyst.

There were an estimated 63,000 wood stoves and 10,000 fireplace inserts used that were manufactured before 1989, compared with 130,000 wood stoves and 29,000 fireplace inserts manufactured since 1989 (Figure 12). These estimates inform an understanding of the potential quality of air emissions and the potential emission reductions that could be achieved from stove replacement programs.

[10] *Does not include outdoor recreation equipment at campsites, since they are not owned by Minnesota households. See Appendix C, Table 10 for unrounded estimated values.*

Figure 12: Equipment age of wood stoves and fireplace inserts[11]



Wood burning by equipment and burn location

Despite comprising only an estimated 15% of active wood-burning equipment, wood boilers and wood stoves accounted for more than half of all the wood burned in the state, since this equipment tends to burn wood in higher quantities. Outdoor recreation equipment, comparatively, burned just a quarter of all wood, despite comprising 60% of all equipment used at primary and secondary households and burning an estimated 36,000 cords at campsites. The greatest estimated amount of wood was burned in wood stoves (420,000 cords, 29% of all wood burned), followed by outdoor recreational equipment and wood boilers (360,000 cords each). More than three-quarters of all the wood burned in the state was estimated to have been burned in these three equipment types.

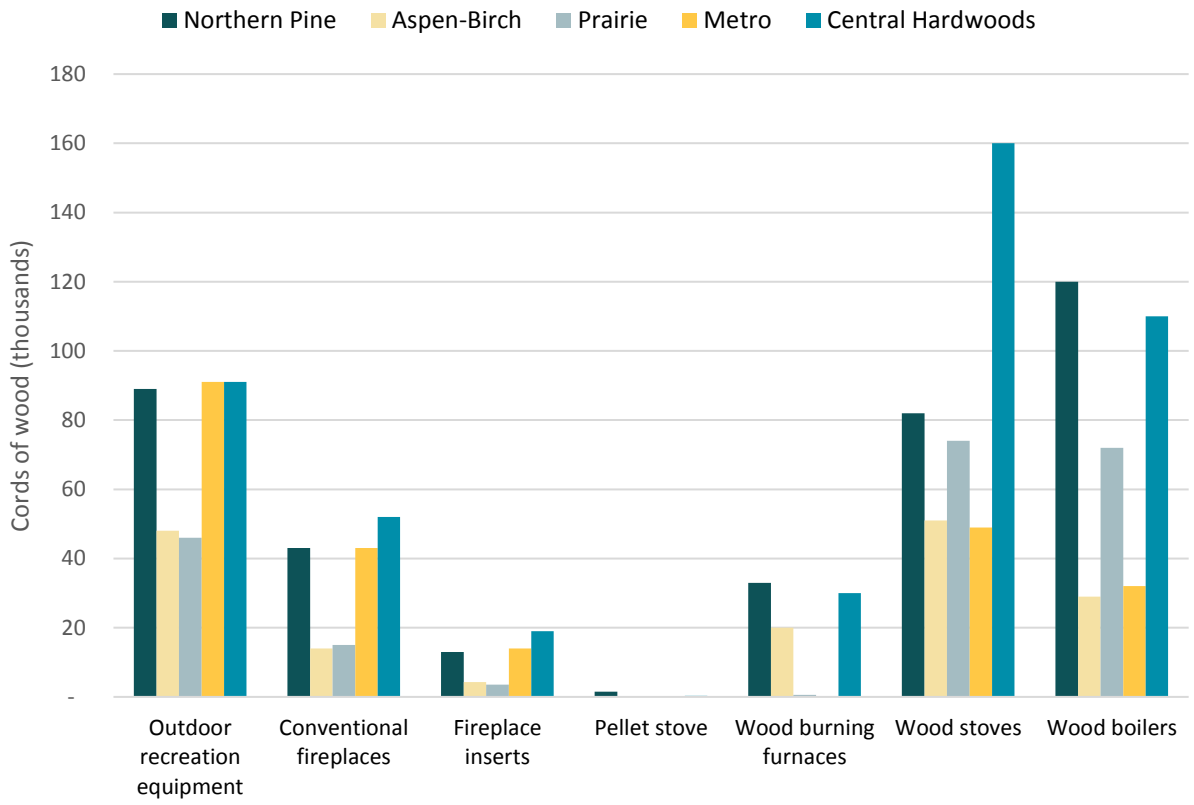
Wood boilers and wood stoves in the Central Hardwood and Northern Pine regions, especially, burned some of the largest estimated amounts of wood burned in all equipment types in all regions. As illustrated in Figure 13, the three largest estimated amounts of wood burned by equipment type and region were:

1. Wood stoves in the Central Hardwood region (160,000 cords)
2. Wood boilers in the Northern Pine region (120,000 cords)
3. Wood stoves in the Northern Pine region (110,000 cords)

These three categories burned more wood than did any region's outdoor recreation equipment. It should be noted that in all equipment categories except outdoor recreation equipment, equipment located in the Central Hardwood and Northern Pine regions each burned either the most or second-most wood among all regions.

[11] *See Appendix C, Tables 17 and 18 for estimated number of equipment pieces by age and location.*

Figure 13: Estimated volume of wood burned by equipment type and region[12]

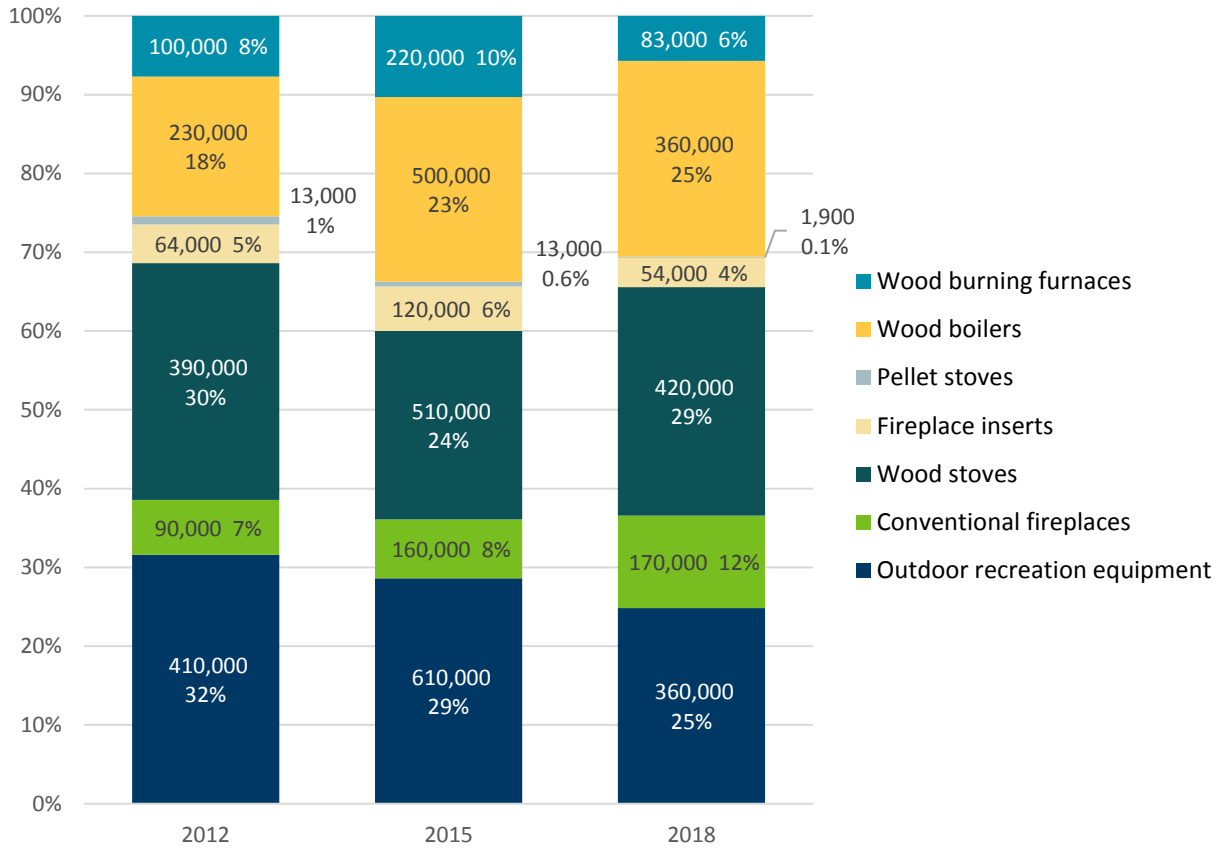


Wood burning by equipment over time

The estimated proportions of all wood burned in each type of equipment have varied slightly between 2012, 2015, and 2018 (Figure 14). As a proportion of all wood burned, wood burned in outdoor recreation equipment appears to be decreasing, while the proportion of wood burned in equipment more typically used for heating purposes, like wood stoves and boilers, appears to be increasing. The largest estimated increase in proportion of wood burned over time has been in conventional fireplaces, which made up 7% of all wood burned in 2012, but increased to 12% in 2018.

[12] *See Appendix C, Table 11 for unrounded estimated values.*

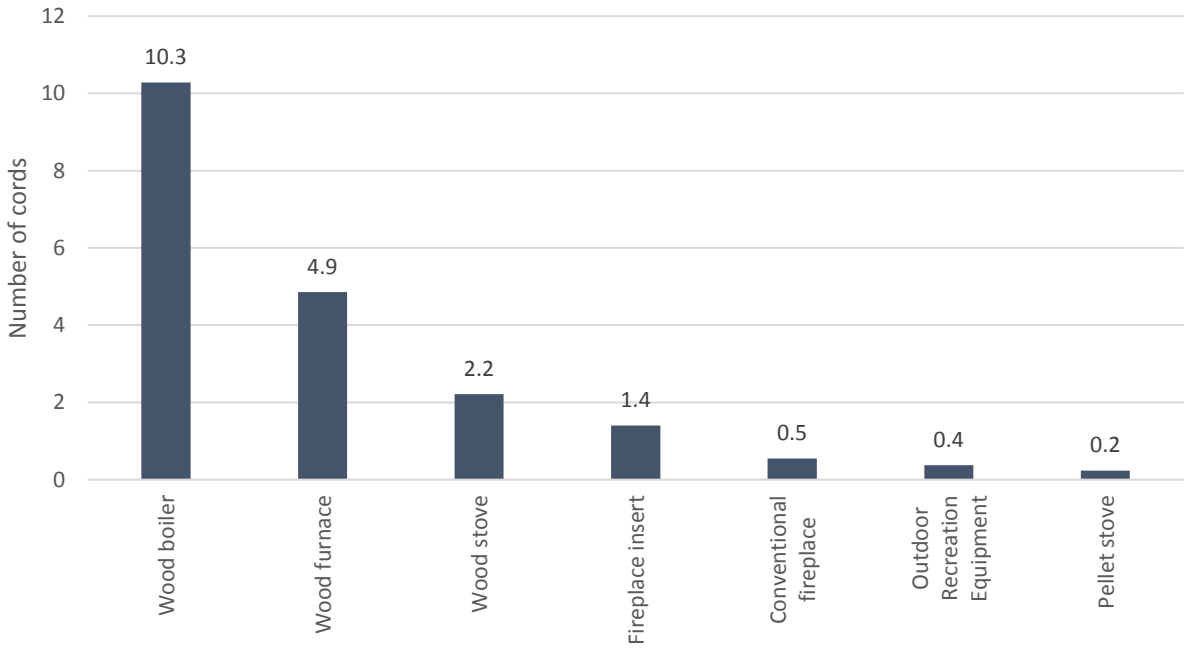
Figure 14: Estimated cords of wood burned by equipment type over time



Wood burning rate by equipment type

As mentioned above, the estimated proportion of wood burned in equipment typically used for heating purposes, such as wood stoves and boilers, has been increasing over the last three surveys. On average, these two equipment types typically burned much higher quantities of wood than other types. Figure 15 shows the estimated average number of cords burned per type of equipment in 2018. Wood boilers burned more wood per unit than all other types. The estimated average amount of wood burned in a wood boiler was large, ranging from about seven cords (Central Hardwood) to almost 14 cords (Northern Pine) annually. The statewide estimated average quantity burned in a wood boiler was about 10 cords per year. Pellet stoves burned the least wood for heat, which is understandable given their higher heating efficiency and that they generally require less wood than other heaters (see conversion factor in Appendix A). Outdoor recreational equipment also burned very small amounts of wood since this type of equipment is generally used for pleasure and disposal of woody yard waste.

Figure 15: Average estimated volume of wood burned annually by equipment type[13]



Characteristics of wood fuel users

Reasons for wood burning

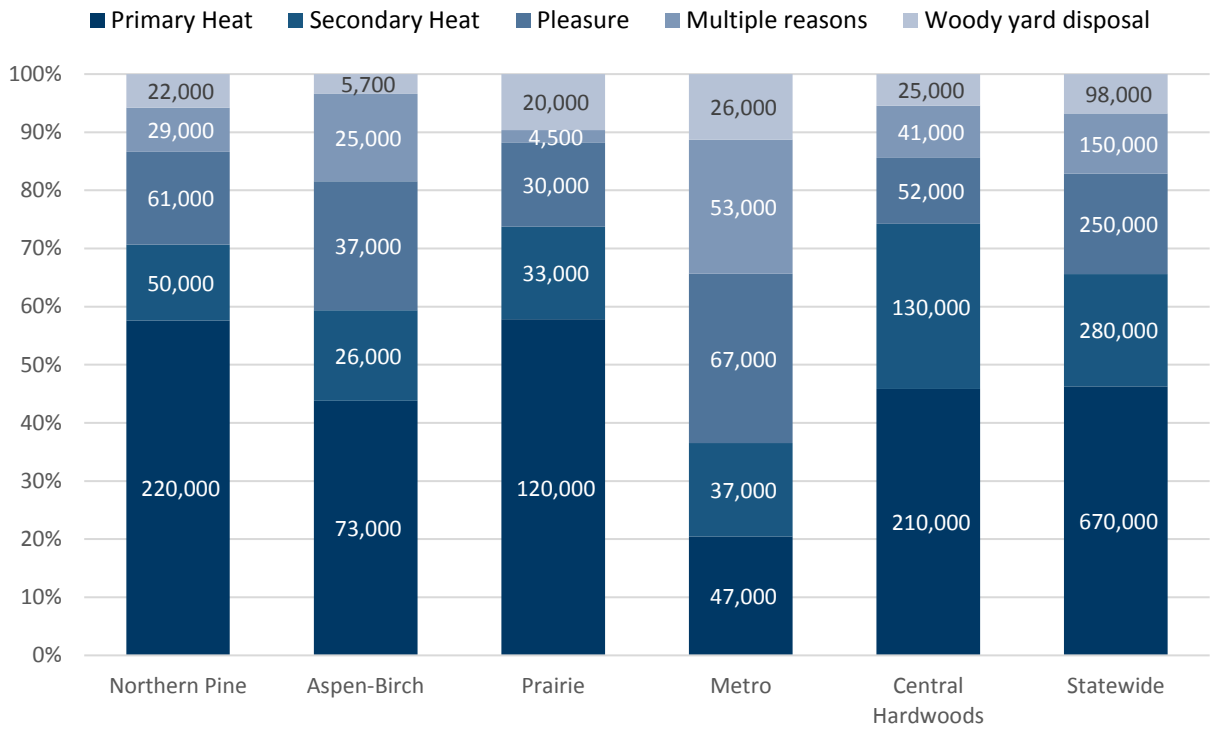
Survey respondents were asked to report their reason(s) for burning wood in each type of equipment they used. For each type, respondents could select from the following five options: pleasure, primary heat source, secondary heat source, multiple reasons, or disposal of woody yard materials.

Statewide, the greatest estimated volume of wood was burned for primary heat (47%), followed by secondary heat (19%), pleasure (17%), and multiple reasons (10%). Disposal of woody yard materials accounted for an estimated 6% of the cords burned.

In 2018, the estimated distribution and amount of wood burned by reason varied between the regions (Figure 16). The greatest estimated volumes and proportions of wood being burned for heat, both primary and secondary, were in the Central Hardwood (340,000 cords), Northern Pine (270,000 cords), and Prairie regions (153,000 cords). The Metro had the greatest estimated volume and proportion of wood burned for pleasure among all regions, accounting for approximately 29% of wood burned in the region. The Metro and Central Hardwood regions both had the greatest estimated volume of wood burned for woody yard disposal.

[13] *Does not include wood burned in outdoor recreation equipment at campsites.*

Figure 16: Estimated cords of wood burned by reason and region[14]



Northern Pine households burned the highest average volume of wood per household for primary heat, at an estimated average of 2.85 cords per household (Figure 17). This is more than two times the next highest average of 1.24 cords of wood burned per household for primary heat, in the Aspen-Birch region. All regions outside the Metro were higher than the statewide average. The Northern Pine and Aspen-Birch regions also had the highest estimated averages per household for wood burned for pleasure. All the non-Metro regions burned more wood for primary heat than for pleasure.

[14] *See Appendix C, Table 13 for unrounded estimated values.*

Figure 17: Average estimated volume of wood burned per household by burn purpose[15]

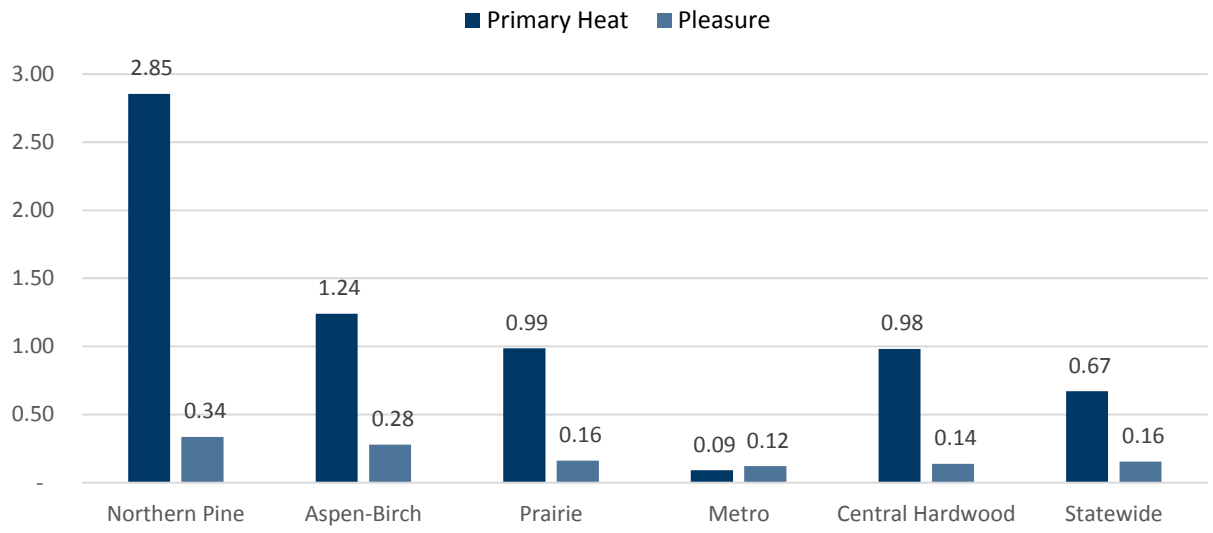
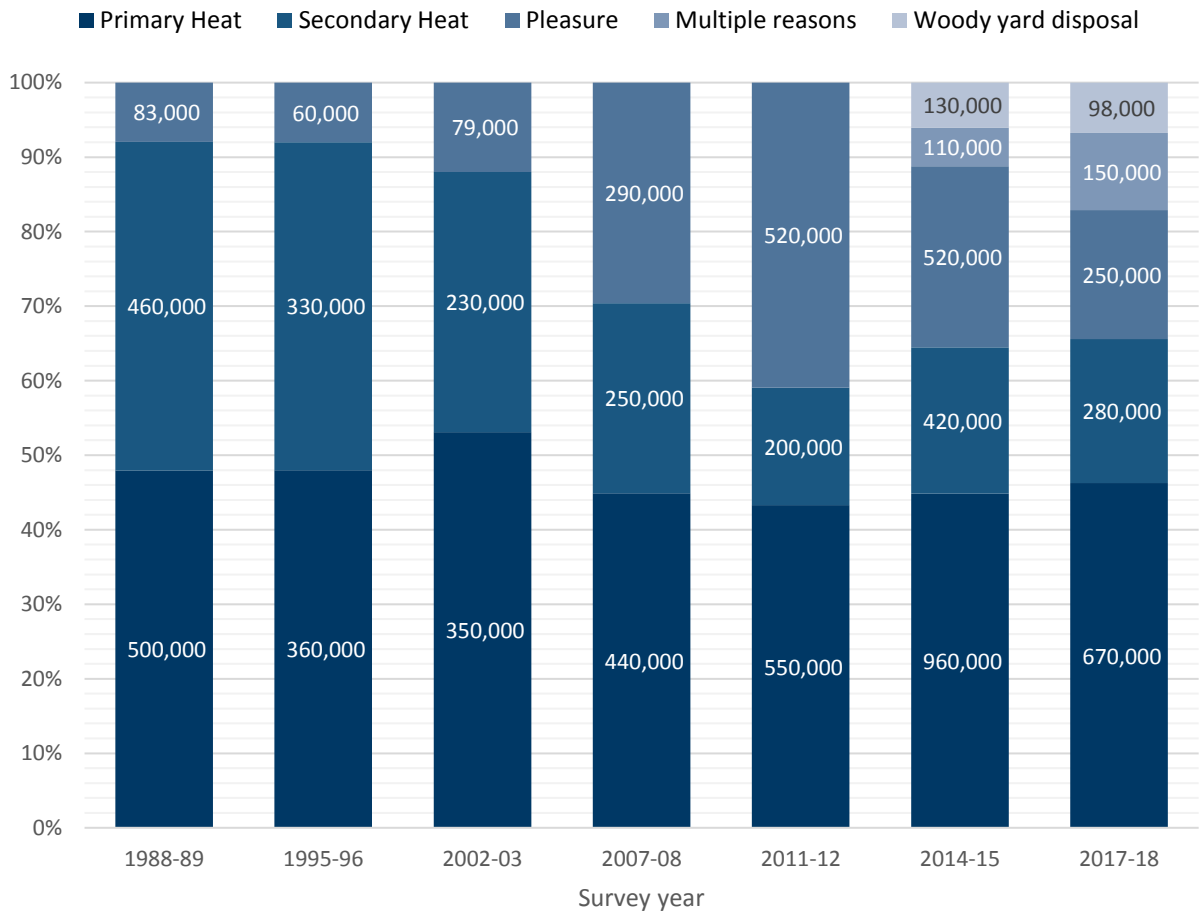


Figure 18 shows this distribution of reasons for burning wood from the last seven surveys conducted. Note that "woody yard disposal" and "multiple reasons" were first added to the survey in 2015. This should be kept in mind when comparing reasons over time. The estimated proportion of wood burned for primary heat has remained relatively consistent over the last three decades, accounting for about half of all wood burned. Beginning after 2000, the proportion and total amount of wood burned for pleasure began to increase rapidly over the following decade, accounting for 12% of wood burned in the 2003 survey and 41% in 2012. While the proportion of wood burned for secondary heat decreased as a result, the overall amount of wood burned for secondary heat remained relatively consistent. In 2015, the total amount of wood burned for pleasure was the same as in 2012 (520,000 cords), but the proportion decreased to about 24% of all wood burned. This coincided with the two new options for burn reason, which together made up 11% of all wood burned. Between 2015 and 2018, the amount of wood burned for pleasure decreased by half but still made up 17% of all wood burned, while the proportion of burning for disposal and multiple reasons increased to 17% of all wood burned.

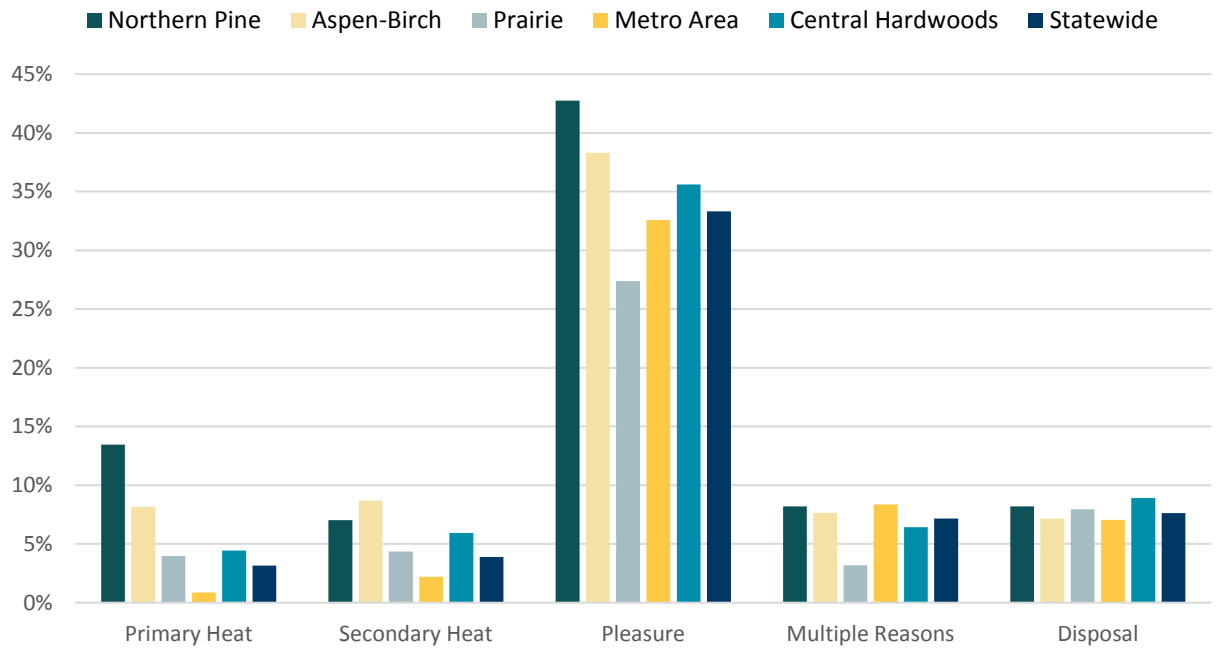
[15] *Based on number of cords burned at primary residences.*

Figure 18: Estimated cords of wood burned by reason for burning over time, as percent of total wood burned



Statewide the greatest estimated volume of wood was burned for primary heat (670,000 cords), but burning for pleasure was the most common reason a household burned wood. As illustrated in Figure 19, this held true across all regions, with the greatest percent of households burning for pleasure (27-43% of total households by region). Statewide, 33% of all occupied households burned for pleasure. Comparatively, only 3% burned for primary heat. As noted previously, wood burned for primary heat made up 47% of all wood burned in the state. The estimated percentage of total households that burned for primary heat varied between regions, however, from 1% of all households in the Metro to 13% of all households in the Northern Pine region.

Figure 19: Estimated percent of total household population in each region that burned by reason[16]

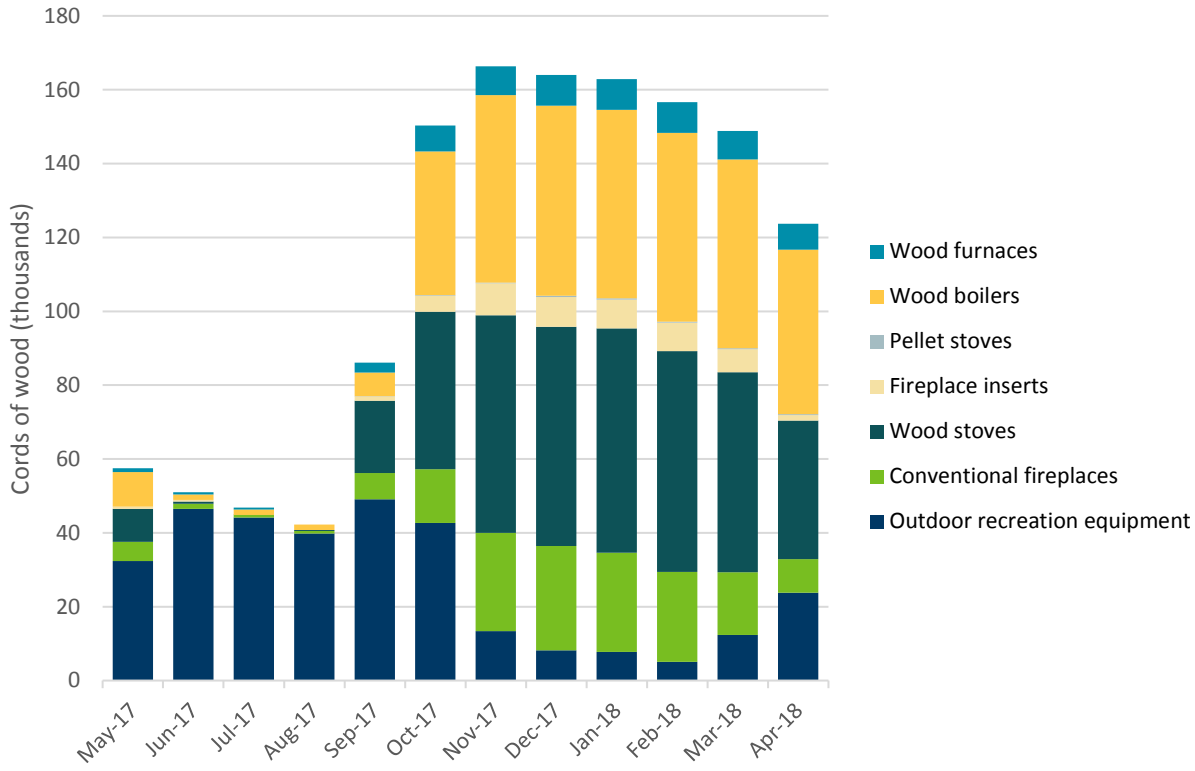


Time of year

Survey respondents were asked to report the months of the year in which they burned wood. Most was burned from September to April, reflecting the use of wood for heating purposes (Figure 20). Outdoor recreational burning occurred throughout the year, but primarily in the summer and fall. Some wood boilers were also operated throughout the year, indicating their use in the summer months for purposes other than space heating, including to heat domestic water supply for washing, cooking, etc. Wood stoves and conventional fireplaces were also operated in all months of the year.

[16] *This figure includes all households that burned for any and all reasons, therefore double-counting houses in some cases. For example: a household in the Metro that burned for pleasure in one type of equipment but for multiple reasons in another is counted in the percentage for both reasons. See Appendix C, Table 14.*

Figure 20: Estimated volume of wood burned each month by equipment type[17]



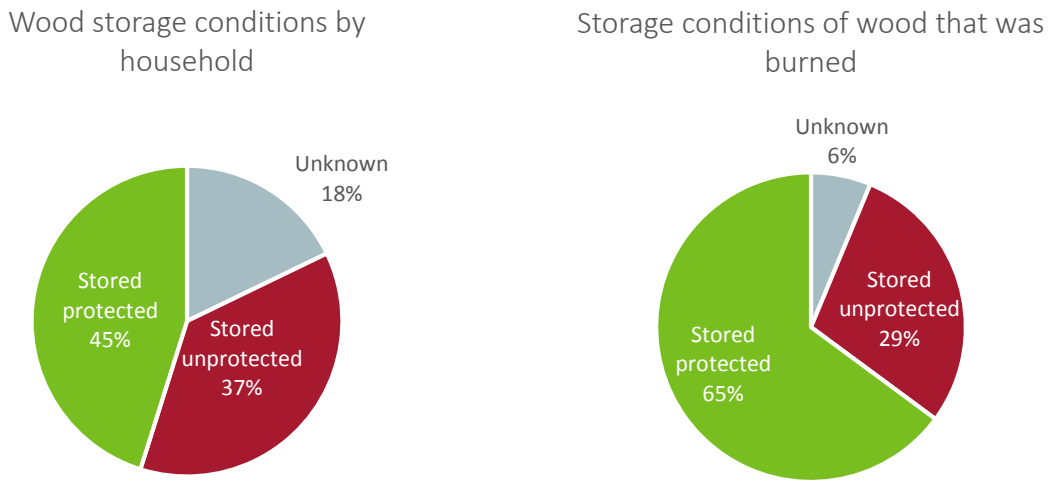
Wood storage practices

Survey respondents were asked to report whether their wood was stored protected from the elements, such as rain, at primary and secondary residences. This aspect of wood use is important in addressing air quality since burning dry wood emits fewer air pollutants than burning wet wood.

While less than half of Minnesota households stored their wood protected from the elements, more than half of the estimated wood burned was stored dry (Figure 21). This was because households that burn large quantities of wood for the purposes of heating are likely more careful about storing their wood protected.

[17] *Does not include wood burned at campsites. Figure shows an aggregate sum of 1.36 million cords, or 96% of all cords burned at primary and/or secondary residences since some respondents did not indicate in which months they used their equipment.*

Figure 21: Wood storage conditions[18]



Types and source of wood burned

Survey respondents reported the volume of wood they burned in units of cords, face cords, bundles, and bags of branches. Depending on the equipment type, they could also report the volume of wood in the form of pallets, slabs, wood pellets, and wax logs. These volumes were converted to full cords for analysis. Nearly all wood burned in the state was in the form of "wood" logs and split wood (93%). Bags of branches (5%), pallets (1%), wood pellets (0.2%), and wax logs (0.1%) accounted for much smaller proportions of all the wood burned. No slabs of wood were reported burned (Table 1).

Table 1: Estimated volume of wood burned by fuel type

Fuel type	Cords	Percent of total
Wood (cords, face cords, and bundles)	1,350,000	93%
Bags of branches	76,000	5%
Pallets	16,000	1%
Wood pellets	3,000	<1%
Wax logs	1,300	<1%
Total	**1,450,000**	

Types of wood burned

The distribution of types of wood burned in 2018 was similar to distribution in previous surveys. The greatest estimated percent of wood burned was oak (22%), followed by birch and ash (10% and 9%). Less elm, maple or aspen were burned statewide, while there was a small estimated increase in the percent of pine relative to previous surveys (Table 2). Trends are difficult to determine because of the addition of "other hardwoods",

[18] *Only includes wood burned at primary and secondary residences, not campsites. See Appendix C, Table 16 for regional percentages.*

"other softwoods" and "unknown type" in the 2015 survey, along with the deletion of other wood types as response selections.

Table 2: Estimated percent of wood burned by type

	Percent of statewide total						
Type	**1988-89**	**1995-96**	**2002-03**	**2007-08**	**2011-12**	**2014-15**	**2017-18**
Oak	32%	27%	38%	29%	29%	27%	22%
Pine	N/A	N/A	N/A	N/A	6%	7%	11%
Birch	13%	14%	13%	9%	11%	11%	10%
Ash	8%	4%	10%	17%	11%	11%	9%
Maple	8%	4%	8%	10%	9%	6%	9%
Other Hardwoods	N/A	N/A	N/A	N/A	N/A	5%	6%
Aspen	7%	10%	8%	12%	7%	9%	5%
Elm	14%	3%	5%	9%	6%	5%	5%
Other Softwoods	N/A	N/A	N/A	N/A	N/A	3%	4%
Basswood	N/A	N/A	N/A	N/A	1%	2%	3%
Unknown species	N/A	N/A	N/A	N/A	N/A	14%	17%
Cedar	N/A	N/A	N/A	N/A	<1%	N/A	N/A
Mixed species	N/A	N/A	N/A	N/A	16%	N/A	N/A
Other species	3%	6%	9%	10%	4%	N/A	N/A
Slabs and scrap lumber	15%	32%	8%	4%	N/A	N/A	N/A

Note: Changes over time should be interpreted with caution due to changes in the survey design, methodology, response rate, and conversion rates for different types of wood.

N/A: Minimal or not asked on the survey

Procurement of wood for burning

The survey asked respondents to report how and where they procured the wood they burned. About 56% of the wood Minnesota residents burned was self-harvested by the household or an immediate family member, while 32% was purchased or received for free (Table 3). A large portion came from an unknown sources (12%). The total cords of wood harvested does not include wood gathered during yard clean-up or maintenance.

Table 3: Estimated amount and percent of wood burned by procurement method

Procurement method	**Percent of state total**	**Cords**
Self-harvested	56%	810,000
Purchased or received for free	32%	460,000
Unknown	12%	180,000
Total		**1,450,000**

Wood Harvesting

The survey asked respondents how much firewood they harvested for the purpose of burning over the course of the year, not including wood gathered during yard clean-up or maintenance.

Amount of wood harvested

Results of the survey indicated an estimated 1 million cords of wood were harvested by Minnesotans between May 2017 and April 2018[19]. This is greater than the 810,000 total cords reported as self-harvested in Table 3 because the total in Table 3 refers to amount of wood burned that was procured via harvesting. This may be because respondents harvested more wood than they ended up burning, accounting for the discrepancy between these two values.

Types of wood harvested

Similar to the distribution of wood burned, the greatest percent of wood harvested was oak (26%), followed by ash (12%) and birch (10%) (Table 4).

Table 4: Estimated percent of wood harvested by type

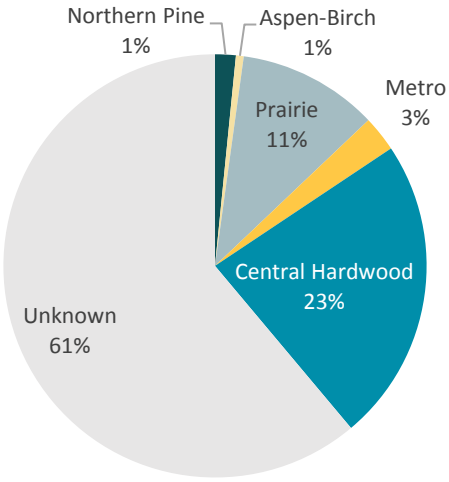
Type	Percent of total
Oak	26%
Ash	12%
Birch	10%
Maple	8%
Pine	8%
Elm	7%
Other Hardwoods	7%
Aspen	6%
Other Softwoods	5%
Basswood	1%
Unknown species	9%

Location of wood harvesting

Many survey respondents did not report or know the region in which they harvested wood, so an estimated 61% of the wood harvested was from an unknown region. Excluding wood harvested from unknown locations, the Central Hardwood region had the greatest reported amount, with 23% of the total (Figure 22).

[19] *See Appendix C, Table 19 for unrounded estimated value, and amount harvested by each region's residents.*

Figure 22: Estimated percent of wood harvested by region[20]



The majority of harvested wood was from private land (96%). Small proportions were harvested from county land (<1%), state land (1%), national forestland (1%), and unknown (2%). (Table 5)

Table 5: Estimated amount and percent of wood harvested by property type

Harvest location	Cords	Percent of total
Private land	960,000	96%
State land	11,000	1%
National Forestland	9,600	1%
County land	9,200	<1%
Unknown	15,000	2%
Total	**1,000,000**	

An estimated 43% of the wood harvested came from live or dead trees from yards inside city limits, or other non-forest land; almost 30% came from dead trees from forest land; 12% came from live or dead trees from pasture land and/or cropland; 8% from live trees from forestland; and 4% from cut trees and/or tops and branches after a timber harvest. Three percent came from unknown harvest sources (Table 6).

[20] *See Appendix C, Table 20 for estimated values.*

Table 6: Estimated amount and percent of wood harvested by type of harvest source

Harvest Source	Cords	Percent of total
Live or dead trees from yards, inside city limits, or other non-forestland	430,000	43%
Dead trees from forestland	290,000	29%
Live of dead trees from pasture land and/or cropland	120,000	12%
Live trees from forestland	80,000	8%
Cut trees and-or tops and branches after a timber harvest	44,000	4%
Unknown	32,000	3%
Total	**1,000,000**	

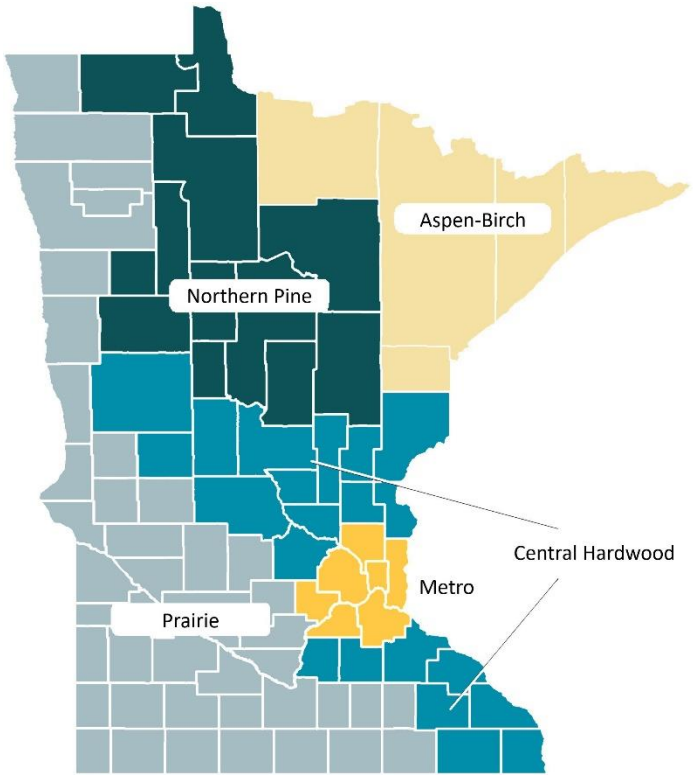
Methods

Survey methods

Study regions

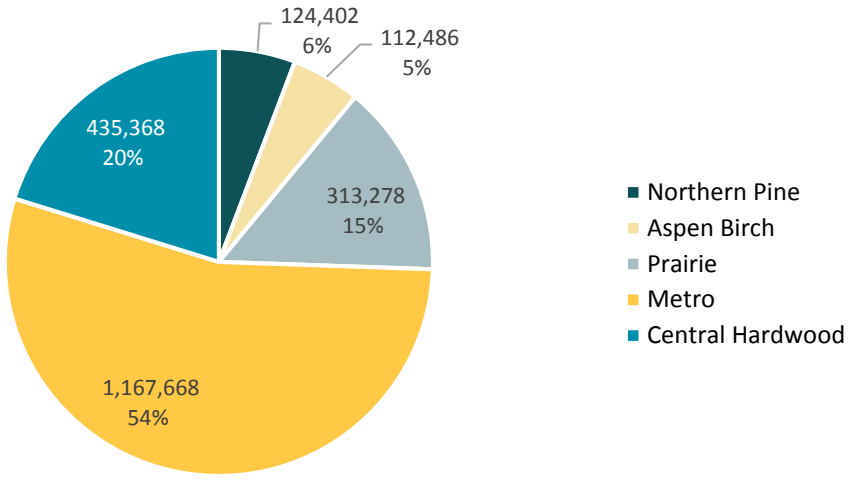
As in prior surveys, the survey was conducted in five geographic regions. Surveys stratify the population into subgroups expected to have similar behaviors as a way to cost-effectively improve the precision of the estimates. These five survey regions, depicted in Figure 23 below, are based on four U.S. Forest Service survey units for Minnesota forests. The seventeen northern counties that make up the Aspen-Birch and Northern Pine survey regions contain most of the state's boreal forest. The Aspen-Birch region has Minnesota's largest area of reserved forestland, including the Boundary Waters Canoe Area Wilderness and Voyageurs National Park. Hardwoods dominate the 21-county Central Hardwood survey region. The more densely populated seven-county Twin Cities Metro region was sampled separately from the less densely populated portion of the Central Hardwood region. The Prairie survey region, comprising 42 counties from northwest to south central Minnesota, is dominated by croplands.

Figure 23: Survey regions for stratified sample



Based on recent census data, the Metro region is geographically the smallest region, but contains just over half of Minnesota's occupied households. The Aspen-Birch and Northern Pine regions are the least densely populated. The Prairie and Central Hardwood regions are also much less densely populated than the Metro region (Figure 24).

Figure 24: Occupied households by region[21]



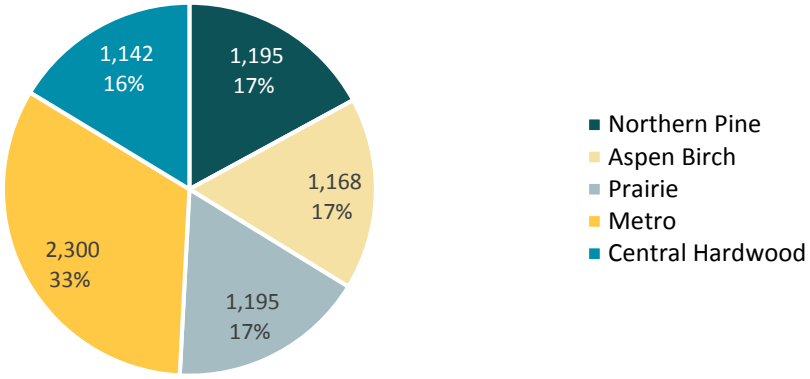
Sample selection

A sample of 7,000 addresses were selected at random from each region, with the number of surveys in each region conforming to the constraints of the stratified sampling design described below. The addresses were purchased from Marketing Systems Group, a company specializing in sampling services. Vacant, seasonal, PO boxes, and drop points (single addresses that are for multiple residences) were excluded from the sample.

These Minnesota households were included in the sampling frame using a *disproportionate stratified sampling design*. Households in the Northern Pine and Aspen-Birch regions had a five times greater chance of being invited to take the survey than did those living in the Metro region. The chance that any one Prairie and Central Hardwood household was surveyed was 1.9 and 1.3 times higher, respectively, than a household in the Metro region. Based on the number of households in each region, this resulted in the Metro region receiving about twice as many surveys as each of the other regions (Figure 25). This is consistent with the sampling method and survey totals used in the 2012 and 2015 survey design. The pre-2012 surveys invited equal numbers of households to take the survey from each region. Beginning with the 2012 survey, the Metro area received twice as many surveys as each of the other regions for several reasons. First, because more than half of the households in Minnesota are in the Metro area, residential wood smoke from the relatively dense population in the Metro area has a larger localized air quality impact due to a denser population than the rest of the state. Secondly, the survey has had slightly lower response rates from the Metro. Even though it received twice as many surveys as other regions, Metro households were least likely to be surveyed because the region's population was more than twice that of any other region. The Metro received the fewest surveys of any region as a proportion of its population, making it the most under-represented region in the survey sample relative to its population.

[21] *Number of occupied housing units is from the 2013-2017 5-year U.S. Census American Community Survey, table DP04.*

Figure 25: Number of surveys sent and percent of total by region[22]



Changes from previous survey administration

The 2018 survey research design was changed slightly to try to increase the response rate. The first change from 2015 was to revert back to only using paper surveys, as opposed to an additional web version of the survey. This decision was made for three primary reasons. First, the web response option for the 2015 survey to the survey yielded a lower response rate than the paper option. Second, the added resources required for programming, monitoring, and reconciling data from the web version with the paper version were not worthwhile without an increase in response rate. Finally, Wilder recommended a first round of data cleaning on the paper forms, and this would not have been feasible with the mixed-method approach.

Another change made to the 2018 survey was to move the primary question of "In the last year, have you burned any wood?" to the front cover of the survey booklet, and clearly requested respondents to submit the survey even if they did not burn any wood. This change was made as a result of a concern that the 2015 survey design may have made it more likely for non-wood-burning households to disregard the survey, thus leading to an overrepresentation of wood-burning households and an overestimation of total wood-burning rates and amounts. This does not mean the 2015 results should be disregarded.

Wilder pilot-tested the survey by sending it to eight people who burned wood at their primary and/or secondary residence. Five completed the test survey and were then asked a series of questions to gather their feedback on the survey. Based on these results, question language and flow were revised to make the survey easier to complete.

Survey administration

The week of May 14, 2018, all addresses in the sample were mailed an invitation letter with a survey and an addressed, postage-paid envelope. About a week later, a reminder postcard was sent to the full sample. Addresses for materials returned completed or undeliverable were then removed from the sample and the remaining addresses were sent a final full survey packet on June 15, 2018.

[22] *Based on primary residence of respondents.*

There were no requirements on whom within a household could respond, so any resident of a household could complete the survey. Presumably, the household member who was willing or who knew the most about the household's wood burning practices completed the survey.

Each survey had a unique number printed in the upper right hand corner that corresponded to an address in the sample. As surveys were completed, the unique survey numbers were checked off a master list. Over 1,500 surveys were returned (Table 7), with at least 262 from each region (Figure 26). A "refusal" was defined as a household that returned a blank survey with a message that they did not want to participate.

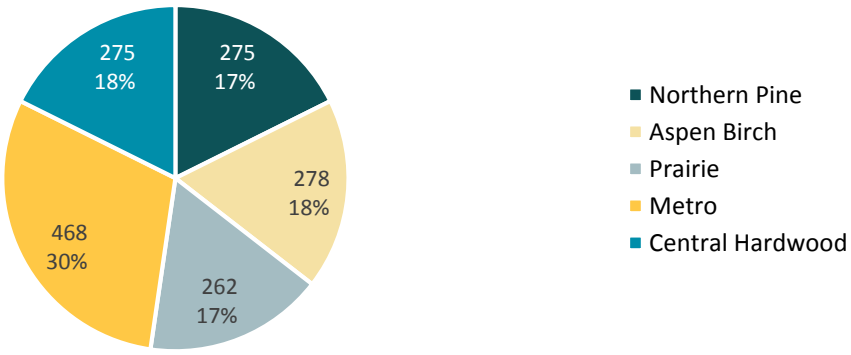
Table 7: Survey mailings and response rates

	Northern Pine	Aspen-Birch	Prairie	Metro Area	Central Hardwood	Statewide
Number of occupied housing units*	124,402	112,486	313,278	1,167,668	435,368	**2,153,202**
Number of addresses in sample	1,195	1,168	1,195	2,300	1,142	**7,000**
Number of addresses returned as undeliverable	59	52	49	54	32	**246**
Number of refusals	1	1	1	-	-	**3**
Total surveys returned	283	278	262	457	278	**1,558**
Response rate	24.9%	24.9%	22.9%	20.3%	25.0%	**23.1%**
Survey respondents, by location of primary residence	275	278	262	468	275	**1,558**
Regionally-adjusted scaling weight**	452	405	1,196	2,495	1,583	***N/A***

**Number of occupied housing units is from the 2013-2017 5-year U.S. Census American Community Survey, table DP04*

***Number of households represented by one survey respondent from the region (total occupied households divided by survey respondents, by location of primary residence)*

Figure 26: Total number of surveys completed and returned by region of primary residence



Paper survey results were entered into an electronic database so all the data could be compared easily using Excel software. Once all responses were entered and checked for quality, the unique numbers were disassociated from the addresses to maintain privacy of the respondents. The data could still be tracked by city, county, ZIP code, and survey region.

Data analysis methods

Preparation of data for analysis

The first step to prepare data for analysis was to import the paper survey responses into the statistical software program SPSS, review responses for quality, and recode responses into formats appropriate for analysis. To ensure data quality, manually entered data from the paper surveys was rechecked to make any necessary corrections. Additional review of the data set was done to ensure data validity and to discard any unusable surveys. Discarded surveys included those with duplicate entries, those returned blank, and those with invalid survey numbers (rendering it impossible to determine the location of their reported activities or to be certain that they were not duplicate surveys). Once the data were checked and quality ensured, the resulting total was 1,558 responses.

Correction of missing, invalid, or contradictory responses

Dealing with missing, invalid, and contradictory responses was a lengthy process that involved a combination of inference, imputation, and common sense. Many of the key assumptions that were made are documented below. Throughout this process, any questionable responses were checked with the actual paper surveys to ensure that data were recorded correctly. If a questionable response was verified, it was reclassified as invalid and a replacement value for the response was imputed based on the assumptions and methods listed below.

Missing location information

A first step in the data analysis was to determine the location, by survey region, of every reported wood burning activity. Wood burning could occur at three location types: primary residence, secondary residence, or campsite. For respondents who filled out the survey completely and accurately, survey region and county for all of these activities were entered into the database. However, in some instances this information was missing or incomplete. In all cases in which respondents did not provide the location of their primary residence, it was assumed that the primary residence was the address to which the survey was mailed. In most cases where respondents *did* provide the location of their primary residence, it matched our information on where the survey was mailed. In the few cases where there was not a match, the location in the survey response overrode the survey region where the survey was mailed.

When respondents indicated wood burning at a secondary residence, but did not provide location information for a secondary residence, its location was inferred based on probabilities for all respondents who did provide secondary residence information. (This is known as a *random hot deck method.*) As a hypothetical example, suppose that for all Northern Pine residents who provided secondary residence information, data showed the following probabilities for the location of its secondary residence (hypothetical example with made up numbers):

Primary residence:	Northern Pine
Secondary residence:	Northern Pine: 70%
	Aspen-Birch: 10%
	Prairie: 5%

Metro: 0%

Central Hardwood: 15%

Then, for all households with a primary residence in the Northern Pine region that did not provide the location of their secondary residence, their secondary residence location was randomly chosen according to these probabilities.

The final location type for wood burning was campsites. Survey respondents were instructed to select the regions in Minnesota in which they burned wood at campsites. Respondents could select more than one of the five regions. When respondents indicated more than one camping location, the total wood burned while camping was allocated equally to all regions listed. In cases where respondents did not provide campsite locations, the location was inferred based on the modal response of all other responses from households with primary residences in the same region. For example, if among all households with a primary residence in the Metro region the most common camping location was in the Aspen-Birch region, then all respondents from the Metro region that did not provide campsite locations were assumed to have camped in the Aspen-Birch region.

Missing or invalid wood burning quantities

There were many instances when respondents indicated owning particular wood burning equipment, but they did not enter the quantity of wood burned. Quantities were inferred or imputed in the following ways. In the majority of cases, a missing quantity was inferred to indicate that the respondent did not use the particular wood burning equipment, and thus the quantity burned was assumed to be zero. Only in cases where other responses made it clear that the household did indeed burn wood were missing quantities inferred or imputed. Such responses included indicating the months of the year in which the particular equipment was used. In these cases, simple regression models were used to impute missing quantities based on all those that did provide quantities for that particular equipment. For all households that did provide burning quantities for use of equipment, their reported number of equipment pieces and the number of months in which they used the equipment were used to estimate the following regression equation:

$$\textit{Quantity Burned} = \alpha + \beta_1\ \textit{Number of Equipment} + \beta_2\ \textit{Number of Months Equipment Used}$$

Thus, using the responses of all other households that did provide burning quantities, the coefficients in the above equation (α, β_1, β_2) were estimated and used to impute the amount of wood burned by any household that did not provide quantities based on the number of pieces of equipment the household reported to have and the number of months[23] for which burning activity was reported. Note that a separate version of the equation above was estimated and applied for each different type of equipment, and separate equations were estimated for primary and secondary residences.

In the case of campfires, when respondents reported having campfires but did not provide the quantity of wood burned, the median campfire burning amount for all respondents was assumed.

Other missing information

In several cases, respondents indicated having and using wood burning equipment, but did not give complete information. When respondents failed to indicate how many pieces of a particular type of equipment they had, it was assumed they had only one piece of equipment (which was the modal response for all the equipment types for the households that did provide this information). When respondents did not provide their main purpose for using a piece of equipment, the guidelines from the 2012 and 2015 studies were followed by replacing missing data with the most typical burning purpose of a particular equipment type—"pleasure" for fireplaces and outdoor wood burning equipment; "secondary heat source" for wood stoves, fireplace inserts,

[23] *Missing numbers of months were replaced with the median response.*

and pellet stoves; and "primary heat source" for wood burning boilers or furnaces. For all but wood burning boilers or furnaces, the purpose question was changed into a multiple response question in the survey. In order to impute the purpose in the analysis, respondents who gave more than one response were placed in a "multiple answers" category. For all four of the “purpose” questions, respondents who said “None” were left as “None.”

For each type of equipment, variables were created indicating whether the respondent had the equipment and, if so, whether that equipment was used. Having the equipment was determined from all of the questions in the equipment section of the survey. If the respondent said they had the equipment (for instance, a fire pit), or if any of the follow-up items indicated the equipment existed (for instance, they reported using it for pleasure), then it was presumed that the respondent had that type of equipment. Using the equipment was defined as having the equipment and reporting any one of the following: a purpose for burning, months during which there was burning, or amount of wood burned.

Other responses revealed clear contradictions that suggested respondents either did not thoroughly understand the survey or did not know the specific type of equipment that they had. For example, in the section on wood burning furnaces and boilers, some respondents indicated that they had wood furnaces, but also indicated that the equipment’s function was to heat water, which is clearly a characteristic of a wood boiler (not a furnace). In cases of obvious contradictions such as this, corrections were made to best represent the actual behaviors of responding households.

The questions on type of wood burned and firewood harvesting directed respondents to give percentages that would sum to 100%. In some cases, that did not happen. If a question’s percentages summed to less than 100%, the residual was placed in an "unknown" category. Similarly, respondents who harvested wood were asked to list the counties (up to four) from which the wood came and the percentage of wood that came from each county. For some cases, the percentages did not sum to 100%. When that occurred, a fifth, "unknown county" was added, and the residual was placed there. There were also cases where the percentages summed to more than 100%. For those, all percentages were proportionately reduced to make them sum to 100%.

A total of 28 respondents indicated they used wood stoves, fireplace inserts or pellet stoves, but did not know (or did not provide a response) when their most commonly used equipment was made. These missing values were imputed using data from those households with valid data points by means of a *hot deck method*, similar to the procedure used for imputing missing secondary residences (described above).

Additional technical details regarding data preparation

- If a secondary residence was not in Minnesota or an open-end response indicated that the residence was not actually a residence (e.g., a campground), all responses for secondary residence burning were dropped.
- If information written on a form indicated that wood burning reported for secondary residence was actually for the primary residence (e.g., survey questions 20 to 23), the responses were moved to primary (Q16 to Q19).
- If a respondent failed to answer campfire burning activity or said "no" (survey question 5) but provided an answer for amount of wood burned (survey question 6) or region(s) in which burning took place (survey question 7), then the response to survey question 5 was assumed to be "yes".
- Missing burning amounts for wood stoves were imputed collectively, without regard to the specific equipment sub-type (conventional, non-catalytic, and catalytic). This was also done for fireplace inserts.
- If the only burning reported in a survey was of yard waste, all items in the harvesting section (survey questions 50 through 55) were recoded to be not applicable (NA).

- If a respondent reported they did not burn any wood, and they finished the survey without reporting their county of primary residence, location was assumed based on the mailing address to which the survey was sent.
- It was assumed that respondents that did not indicate a secondary residence but did not check the check box next to "I do not have a secondary residence" actually did not have one.
- For wood burning boilers or furnaces, if there was evidence of burning and survey question 32 or 37 was blank, code Q32 or Q37 = "yes, unknown device."
- In cases where respondents put identical information in multiple sections (for instance, in fireplaces and fireplace inserts) the duplicate was deleted.
- If a respondent answered "yes" to burning wood but indicated they did not own any of the listed equipment in the survey or amounts of wood burned, it was assumed the burning took place outside in an undesignated, non-permanent burning location on or near the property. An outdoor recreation piece of equipment was therefore imputed. The fuel amount assigned was the average amount of wood burned by respondents from the same region in the same type of equipment piece.

Concurrent to the completion of analysis for this report, the quality-assured data with all the inferences and imputations described above was transferred into a relational database, which is publicly available.

Aggregation of survey responses

Based on locations of primary and secondary residences and provided (or inferred) locations for campsite burning, every burning activity reported in the survey was assigned to one of the five regions. All wood burning quantities were converted into common units of cords. Some survey units (cords, face cords, and bundles) were converted based on standard conversion factors.[24] Other wood burning units (wax logs, pallets, pounds of pellets) were converted into cord equivalents using the conversion factors listed in Appendix A.

Extrapolation of survey sample totals to population-wide estimates

Estimates of the total wood burned, as well as subtotals by equipment type and burning purpose, were extrapolated to estimate wood burning amounts for the entire population for each region. This extrapolation was based on the number of households in each survey region, according to the 2013-2017 5-year U.S. Census American Community Survey, table DP04. For example, there were 468 survey responses from the Metro region, and there are 1,167,668 households in the region. Thus Metro-region totals for the survey sample were scaled up by a factor of $\frac{1,167,668}{468}$ = 2,495[25] to estimate total burning activities for the region. Scaling survey region-wide estimates in this manner corrects for the unequal probability of selection caused by *disproportionate stratified sampling* (i.e., the fact that the proportion of completed surveys from any individual survey region was unequal to that region's proportion of the total state household population).

The regionally-adjusted scaling weight for each respondent was based on the location of their primary residence, not the location of their reported burning. Regionally-adjusted scaling weights for the Northern Pine, Aspen-Birch, Prairie, Metro and Central Hardwood regions were 452, 405, 1,196, 2,495, and 1,583, respectively, for respondents living in those regions.

[24] *Three face cords or 171 bundles equal one full cord.*

[25] *This is equivalent to saying that each household responding to the survey from the Metro region represents 2,495 households in the population as a whole.*

The regionally-adjusted scaling weights (unrounded) were applied for all analyses throughout the main body of this report, to estimate the total quantities across the state and within each of the five regions.

Calculation of regional and statewide total amounts

Survey results were tallied using the populated relational database and reported as state totals and for the five regions based on the region in which the burning took place. The wood burning equipment and burning activities were grouped into seven categories -- outdoor recreational equipment, conventional fireplaces, wood stoves, fireplace inserts, wood pellet stoves, wood boilers (hydronic heaters), and forced-air furnaces. Wood burned in each equipment category was grouped according to the main purpose for which the household reported burning the wood.

Calculation of average annual growth rate

Average annual growth rates in volume of wood burned and population over time were calculated by solving for the compound annual growth rate.

Calculation of the confidence interval for the total wood burned statewide

A confidence interval was calculated for the estimate of the total cords of wood burned statewide. This indicates the range where the true statewide amount burned was expected to be, with a 95% level of confidence. This reflects the inherent variability in how much wood a household burns and the fact that all population-level estimates derived from survey responses have an inherent degree of uncertainty. This uncertainty arises from many causes, including the survey sampling method and size.

Confidence intervals for statewide wood-burning totals were calculated in the following manner. First, a regionally-adjusted non-scaling weight was calculated. Out of 1,558 total completed surveys, 468 were from respondents with primary residences in the Metro region. Thus, the percentage of surveys in the total survey sample from the Metro region was $\frac{468}{1{,}558}$ = 30%. The overall number of households in the Metro region is 1,167,668, while there are 2,153,202 households in the state. Thus, the percentage of the state's households in the Metro region is $\frac{1{,}167{,}668}{2{,}153{,}202}$ = 54.2%. Therefore, Metro region households make up 54% of the state population but only 30% of the survey sample population, so the Metro region was under-represented in the survey sample. Similarly, other regions were either under- or over-represented in the survey sample. As was appropriate for the calculations of the regionally-adjusted scaling weights above, because wood-burning behaviors may vary across regions of primary residence, giving equal weight to all surveys regardless of residence location could introduce bias in the total estimates for statewide burning. Weights for surveys from over-represented survey regions were given regionally-adjusted non-scaling weights less than one (i.e., the contribution of their wood burning activities to state totals was adjusted down), while under-represented regions were given regionally-adjusted non-scaling weights greater than one (their contribution to total estimates was adjusted up). Continuing the Metro region example, responses from this region were given weights of $\frac{54\%\ of\ population}{29\%\ of\ survey\ sample}$ = a weight of 1.85. Weights across the five regions ranged from 0.29 in the most over-represented regions (Aspen-Birch) to 1.85 in the most under-represented region (Metro). Specifically, the regionally-adjusted non-scaling weights for the Northern Pine, Aspen-Birch, Prairie, Metro and Central Hardwood regions were 0.32, 0.29, 0.87, 1.85 and 1.13, respectively, for respondents living in those regions.

These weights are generally termed “post-stratification weights” and their use is fairly common in survey analysis where response rates are not equivalent across different subgroups within the survey sample or when some subsets of the population are sampled more than others.

A regionally-adjusted non-scaling weight was assigned to each of the 1,558 responding households. Next, the mean and standard deviation of the individually reported unweighted total wood burned by the households was calculated for each region. For each household respondent, this calculation used the total number of cords of wood (and wax logs) they burned in all types of equipment anywhere in the state, including zeros for the households who did not report burning any wood or wax logs. The standard deviation of the amounts of wood burned for each region was divided by the square root of the number of surveys in the sample to estimate the standard error (SE) of the sample for each region. (See Figure 26 for the sample sizes of each region based on location of primary residences). For 95% confidence intervals, a critical value (t*) was obtained from tables of the t distribution with a significance level (α) of one minus the 95% confidence level, or 0.05. The SE of the sample was multiplied by t* to obtain a margin of error around each region’s sample mean. Finally, to correct for the design effect, which entails greater variance in the data and thus greater uncertainty in population-wide wood burning estimates due to the weighting described above, the following correction was made to each region’s margin of error. The design effect was calculated as

$$1 + \left(\frac{\sigma}{\mu}\right)^2$$

where σ is the standard deviation of the regionally-adjusted non-scaling weight parameters and μ is the mean of the regionally-adjusted non-scaling weight parameters across all 1,558 households in the survey sample. Each region’s confidence interval was scaled up by the square root of the design effect, which served to widen the confidence intervals by roughly 17%. Each confidence interval was then multiplied by the total number of households in the respective region to scale the interval to the region. The confidence intervals from all five regions were summed together to apply a confidence interval around the statewide estimate of total cords of wood burned, to obtain overall estimates of a 95% confidence interval for statewide wood burning quantities.

Limitations

There are some important limitations to this study that should be considered when interpreting the results. First, of the 6,754 households invited to participate in the survey, 1,558 completed the survey for a response rate of 23%. The response rate by region varied from 20 to 25%, with the Metro region having the lowest response rate (see Table 7). Despite getting higher response rates than the 2015 survey, estimated results from this year’s survey should still be interpreted with caution, since there are margins of error surrounding the extrapolation of survey results to whole populations.

The survey also relied on retrospective self-reporting of burning and wood harvesting behaviors. These retrospective reports are likely to be strong approximations of actual behaviors, but they should be treated as estimates, as opposed to precise measurements.

It is difficult to confidently compare survey years and examine trends. Each survey administration has involved changes to the survey instrument and collection methods, which may change the results. For example, one change to this year’s survey was asking, “In the last year, have you burned any wood?” on the front cover of the survey packet. Respondents could either check a box labeled “Yes” or “No”, and were encouraged to return the survey regardless of if they burned wood or not. This change was made in response to a concern that the design of the 2015 survey may have made it more likely for those who did not burn wood to disregard the survey, which may have led to a higher estimated rate of burning in each survey region and amount of wood burned than had actually occurred. Despite survey design changes, some comparisons and trends across survey years

were examined in this report, but it should be recalled that all results are estimations, as opposed to precise measurements.

Similarly, because of the design of this year's survey, respondents who indicated they burned no wood immediately ended the survey. Therefore, any wood-burning equipment they may have owned (but did not use) was not accounted for, since they did not continue the survey to indicate what equipment they may or may not have owned. In cases where a respondent reported owning more than one piece of wood-burning equipment but did not use all of them during the survey period, only the used pieces of equipment were coded into the relational database used to analyze results. This report, therefore, unlike past reports, only captures the number of pieces of wood-burning equipment *in use* in the state, as opposed to the number of pieces of equipment owned.

Estimated rates of equipment ownership of wood stoves and outdoor recreational equipment, which are common in all regions, are likely more reliable than estimates for less frequently reported equipment.

The survey did not ask respondents if their conventional fireplaces were wood or gas fueled. It is likely that respondents may have reported a gas-burning conventional fireplace as what would have then been interpreted as a wood-burning fireplace during data analysis. Likewise, the survey did not ask respondents about burning done in any undesignated, impermanent locations, outside of any formal pieces of equipment (say, in an unofficial "spot" in a yard).

Additional weighting by household type, which has been explored in past surveys, was not possible because households that reported no burning activity immediately ended the survey prior to the household type question.

This survey report is limited to residential wood burning. It does not include or discuss commercial or industrial wood burning in Minnesota to any degree.

In spite of these limitations, the survey results contain an abundance of information that can be used by a variety of interested parties.

Conclusions

Key findings

Residential wood burning appears be increasing over time. An estimated 1.45 million cords were burned between May 1, 2017 and April 30, 2018. While this is a decrease from the estimated total amount of wood burned in 2015, residential wood burning estimates overall have been increasing since 2003.

Roughly 980,000 households, or about 46% of all Minnesotan households, burned wood in some amount during this time period. This proportion varies between the five survey regions. The Northern Pine region had the highest estimated proportion of households that burned wood, at 59% of the region's total households, while the Prairie region had the lowest, at 40%.

Statewide, the greatest volume of wood burned was for primary heat, but burning for pleasure was the most common reason a household burned wood. Statewide, an estimated 47% of all wood burned was burned for primary heat. However, only 3% of households statewide burned for primary heat, while 33% of households burned for pleasure.

Wood stoves burned the largest amount of wood of all equipment types, but wood boilers burned the largest amount of wood per unit. In all regions, wood boilers had the highest estimated rates of wood burning of all wood-burning equipment, four times greater than wood stoves. The average estimated number of cords burned per wood boiler ranged from 7.5 – 13.8 cords across the five survey regions. About one-quarter of all wood burned in the state was burned in wood boilers.

Less than half of Minnesota households stored their wood protected from the elements. Wet wood burns less efficiently than dry wood and releases more smoke.

Most woodstoves and fireplace inserts used were made after 1989, and were therefore subject to the 1989 federal performance standards. However, an estimated 33% of wood stoves and 26% of fireplace inserts used were built before 1989; this equipment is much less efficient and emits more pollutants than newer models.

Implications

The Metro region covers a much smaller geographic area than any other region, but its households burned a comparable amount of wood. On average, **the Metro region burns more cords of wood per acre than any other region**.

More wood burning translates to more air pollution. The amount of air pollution released from the different types of wood-burning equipment varies depending on the air pollution controls. Outdoor recreational residential fires, which have no controls, account for 40% of the wood burned in the Metro region and 25% of the wood burned statewide, suggesting that information campaigns about how to build clean-burning backyard fires will be useful throughout Minnesota, especially in more densely populated neighborhoods. These data will inform the MPCA's partners in Clean Air Minnesota[26] who are working on voluntary measures to reduce air pollution from sources such as residential wood burning.

[26] *Clean Air Minnesota* https://environmental-initiative.org/work/clean-air-minnesota/

Estimates from this study indicate residents use their backyard recreational equipment to dispose of woody materials from their yards. If other methods for disposing of branches and brush from residential properties were convenient and widely available, this air pollution source could be reduced.

A large proportion of wood was burned in conventional fireplaces, and the amount of wood burned in them has been increasing over the years. Conventional fireplaces tend to pollute more than other types of wood-burning equipment. What's more, many fireplace owners reported using them for heating purposes. Because fireplaces are in fact very poor at space heating, education can and should be done to ensure conventional fireplace-owners understand the drawbacks of attempting to use a conventional fireplace for heat.

Opportunities still exist for wood-burning equipment change-out programs. Information about the number, location, and types of old, dirty wood burning equipment still being used will be useful for efforts such as Environmental Initiative's Project Stove Swap[27] in designing those incentive programs.

Additional analysis and possible future research

This report provides initial data analyses. The data set is robust, allowing the MPCA to conduct additional analyses of the data. For example, further analysis is in progress on the increasing trend of wood burning especially compared to population, external factors such as propane and other fuel prices, and better understanding of the reasons for use of specific equipment. The data set will be available from MPCA on request.

In February 2015, EPA revised the standard for new wood stoves and fireplace inserts and added standards for previously unregulated boilers (hydronic heaters) and forced-air furnaces. As the survey data show, we are already seeing more households using these cleaner-burning units. The MPCA will be evaluating how to incorporate the increasing use of these newer devices into its emissions inventory estimates.

The MPCA could consider ways to better understand the use of wood burning in commercial establishments such as restaurants as, at least anecdotally; use of wood-burning ovens seems to be increasing in popularity.

[27] *Environmental Initiative* https://environmental-initiative.org/work/project-stove-swap/

Appendix A

Sources of secondary calculations of wood fuel volumes

Wood slabs. A conversion factor of 1.0368 tons per cord was used for sawmill slabs and edgings, based on: Bell, G. E., & Brooks, E. (1955). *Cord-cubic volume of relationship of slabwood and edgings* [Release No. 232]. American Pulpwood Association. New York, NY.

Wood pellets. A conversion factor of 2.752 tons per cord was used for wood pellets, based on information from Jason Berthiaume, Pellet Fuels Institute (PFI). Current standards require a minimum density for PFI-graded pellets of 40lbs/cu ft. Under newly approved standards, implemented in 2009, density for super-premium and premium pellets are 40-46lbs/cu ft, with standard and utility grades at 38-46lbs/cu ft. As super-premium and premium make up the vast majority of residential heating pellets, it makes sense to use the 40-46 range. Mid-range of 43 X 128 cubic feet per cord = 2.752 tons per cord.

Wax logs. A conversion factor of 1.0989 tons per cord was used for wax/manufactured fireplace logs, based on: Houck, J. E. (July 2002). OMNI Consulting Services, Inc. Beaverton, Oregon. He determined 444 typical logs make up a cord. The weighted average mass of wax/sawdust fireplace logs is 4.95 pounds (2.5 pounds, 3.2 pounds, 5 pounds, and 6 pounds logs are sold). The average mass of densified logs sold is 5 pounds.

Wood pallets. A conversion factor of 0.5184 tons per cord was used for wood pallets and crates, based on: WikiAnswers: “How much does a pallet weigh?” and “What is the standard size of a wooden pallet?” It was assumed the Grocery Manufacturers' Association pallet was 48" x 40" and each weighed 45 pounds.

30-gallon bag of branches. A conversion factor of 63 “30 gallon bags of tree branches and wood brush collected from your yard” per cord of wood was used. This is based on a commonly used estimate of 300 pounds per cubic yard of loose yard waste branches from the National Recycling Measurement Standards and Reporting Guidelines, based on information from John Springman, Ramsey County Minnesota Yard Waste Program (2016). This estimate falls within the 250 to 350 pound per cubic yard of loose brush range referenced in Resource Recycling, November 1991.

Appendix B

Glossary and definitions for this report

Bundle: A unit measure for wood volume that measures about 16 inches by 9 inches by 9 inches (0.75 cubic feet). One hundred and seventy one bundles is equivalent to one cord. Note that in prior surveys a bundle was defined as 2 cubic feet or 64 bundles per cord.

Confidence interval: A range of values centered on the sample estimate that is known to contain the true value with a given degree of confidence (usually 95%).

Conventional fireplace: Conventional fireplaces are generally used for aesthetic purposes rather than for heat. They are often open but may have non-sealed glass doors. The survey did not distinguish whether the fireplaces were located inside or outside the residence.

Cord: A unit of measure for a volume of wood. It measures four feet high by four feet wide by eight feet long and has a volume of 128 cubic feet (Figure 1). Cords do not describe how much the wood weighs, so a cord of one species of wood may weigh more than a cord of a less dense wood.

Design effect: An adjustment used in some statistical studies, which inflates the variance of parameter estimates, to allow for the design structure. In this case, it is an adjustment for the population weighting that was done to address the disproportionate stratified sampling and response rates. The weighting of the data increases its variance, and the design effect is used to adjust confidence interval estimates to account for the increased variance.

Differential response rates: These refer to the situation where the response rate was (substantially) different in different subgroups of the population (e.g., in households from different survey regions or from different demographic groups).

Disproportionate stratified sampling: Conducting a survey where the sizes of different groups (in this case, number of surveys sent to each survey region) vary and do not represent the percentage of any particular group within the larger population.

Estimate: The value obtained from a sample, which is used with a known margin of error, as an approximation for a population characteristic.

Face cord: A unit of volume that is four feet high by eight feet long by 16 inches wide, equal to one-third of a cord.

Fireplace insert: An enclosed space-heating device, similar in function to a wood stove that is designed to fit into the opening of an existing fireplace. These are designed to be more energy efficient than most conventional fireplaces.

Household: The person or persons occupying a housing unit.

Margin of error: The statistic, which describes the amount of random sampling error in a survey's results. When the margin of error is great, there is less confidence that the results of the survey correctly represent what would have been found by surveying the entire population.

Methodology: A description of the way in which data are collected and analyzed in a research project.

Outdoor recreational burning: In this study, outdoor recreational burning includes burning in outdoor fire pits, chimineas, or fire rings. They may be used for recreational backyard burning or at campgrounds.

Outlier: An extremely small or extremely large value in a set, compared with the mean of all values in the set.

Primary residence: The dwelling where a person or persons usually live, typically a house or an apartment. The survey questionnaire defined the primary residence as "your main home."

Response bias: Inaccuracy of data collected caused by participant error. This could be caused by misunderstanding or misinterpreting survey questions or in some cases could be deliberate misrepresentation of one's actions.

Response rate: The number of completed surveys divided by the number of eligible units (i.e., households) in a sample. In other words, this is the number of completed surveys returned divided by the number of surveys sent that successfully reached the households. The surveys sent out that were returned by the post office are not included.

Sample: A subset of the population from which data are collected to be used in estimating actions or behaviors of the total population. In this case, the "survey sample" is all the households who completed and submitted a survey.

Secondary residence: This includes all dwellings that are not the primary place where a person or persons live. In this study, it includes second homes, cabins, trailers, or other vacation properties. Camping locations were not included.

Selection bias: A type of non-sampling error that occurs when participants who chose to participate in some research (i.e., who choose to fill out and submit a survey) are systematically different than the intended sample. This type of bias is caused by certain types of participants replying to a survey invitation more than others or when participants put themselves into groups to which they aspire but do not currently belong. For this study, a potential source of selection bias could be that households who burn wood are more likely to answer a survey about residential wood burning than households who do not burn wood. As a result, the survey analysis could overestimate wood burning activity in the overall population. Similar to "non-response error," which is error caused by some sub-groups of the sample responding less often than the rest of the sample.

Slab: Rounded edges of wood typically sawn from a log face when squaring a log.

Statistical significance: Refers to whether some research results genuinely reflect a population of interest in some way or whether the results could occur by chance. Statistical significance is determined by comparing the research results with the values defined by the confidence interval.

Survey regions: The key geographic unit for this analysis. The five survey sampling regions have been used in past Minnesota residential wood fuel use surveys. Minnesota is comprised of five regions that roughly correspond to the state's ecoregions. An ecoregion is an area of land with similar ecological characteristics. The five survey regions of Minnesota—Northern Pine, Aspen-Birch, Prairie, Metro Area, and Central Hardwoods—were delineated based on forest cover and predominant tree types.

Wood boiler: A wood burning central heating device that heats a liquid (generally water or glycol) as the medium to transfer the heat to where it is needed. Hydronic heater is the more technical term for this equipment as they do not actually boil the water. Wood boilers are generally, though not exclusively, located outside the main building. The heated liquid may provide space heat through radiators, in-floor heating, or to the air by the use of a heat exchanger. In residential settings, they may also be used to heat multiple buildings, the domestic water supply swimming pools, etc. Because some wood "boilers" (hydronic heaters) are called

"outdoor wood furnaces", this survey distinguished the boilers from the forced-air furnaces using descriptive characteristics including brand or model information and whether it used water to transfer the heat.

Wood furnace: A wood burning central heating device in which the heat in the combustion chamber directly heats air that is transferred through ducts to provide space heat to the home or building. In this survey, the term "furnace" was specifically used for the forced-air furnaces that heat air, not those that use water as the heat transfer medium.

Wood pellet stove: A room heating device similar to a wood stove, designed to burn wood pellets.

Wood stove: An enclosed free-standing heating appliance capable of burning wood fuel generally connected by ventilating stove pipes to a suitable chimney or flue. A wood stove can generally be used to burn wood, or wood-derived biomass fuel, such as wood pellets. It is generally designed to heat the air in a few rooms or a smaller home.

Appendix C

Data Tables with unrounded estimates

Table 8. Total estimated number of households that burned wood

Northern Pine	72,832
Aspen Birch	57,457
Prairie	124,355
Metro	513,974
Central Hardwood	215,309
Total	**983,926**

Table 9. Total estimated number of cords of wood burned in each region

Northern Pine	379,114
Aspen Birch	165,484
Prairie	210,251
Metro	228,990
Central Hardwood	463,699
Statewide	**1,447,538**

Table 10. Estimated number of active pieces of wood burning equipment by region where located[28]

Type of equipment	Northern Pine	Aspen-Birch	Prairie	Metro	Central Hardwood	Statewide
Outdoor recreational equipment	144,194	62,670	105,986	358,371	210,737	**881,958**
Conventional fireplace	42,051	15,003	14,349	194,611	37,565	**303,579**
Wood stoves	46,296	26,801	31,089	32,435	53,156	**189,777**
Fireplace inserts	9,352	2,832	5,979	12,475	7,916	**38,554**
Pellet stoves	2,940	809	1,196	-	3,166	**8,112**
Wood boilers	8,595	2,428	7,174	2,495	14,248	**34,941**
Wood burning furnaces	4,976	3,642	1,196	-	7,244	**17,058**
Total	**372,393**	**214,396**	**232,790**	**689,525**	**481,557**	**2,218,992**

Table 11. Total estimated cords burned in each equipment type by region[29]

Type of equipment	Northern Pine	Aspen-Birch	Prairie	Metro	Central Hardwood	Statewide
Outdoor recreational equipment	88,759	48,016	46,007	91,015	90,593	**364,391**
Conventional fireplace	42,702	13,638	14,549	42,852	51,764	**165,504**
Wood stoves	82,016	50,605	73,647	48,550	164,759	**419,577**
Fireplace inserts	12,627	4,282	3,521	14,138	19,450	**54,018**
Pellet stoves	1,481	88	17	-	302	**1,888**
Wood boilers	118,974	29,133	71,913	32,435	106,863	**359,318**
Wood burning furnaces	32,556	19,722	598	-	29,969	**82,845**

[28] *Does not include 516,683 estimated uses of outdoor recreation pieces of equipment at campsites, since they are not owned by Minnesotan households and any piece of campsite equipment has the potential to overlap between two or more households.*

[29] *Includes wood burned at campsites.*

Table 12. Total estimated cords burned by survey region and place of burning

		Primary Residence		Secondary Residence		Camping	
Region wood burned	**Total cords burned**	**Cords burned**	**Percent of total cords burned**	**Cords burned**	**Percent of total cords burned**	**Cords burned**	**Percent of total cords burned**
Northern Pine	379,115	277,317	73%	94,535	25%	7,260	1.9%
Aspen-Birch	165,485	134,348	81%	24,570	15%	6,565	4.0%
Prairie	210,251	199,424	95%	4,677	2%	6,150	2.9%
Metro Area	228,991	224,632	98%	75	0.03%	4,282	1.9%
Central Hardwood	463,700	417,078	90%	34,908	8%	11,712	2.5%
Statewide	**1,447,542**	**1,252,799**	**87%**	**158,765**	**11%**	**35,969**	**2.5%**

Table 13. Total estimated cords burned by primary reasons for burning

	Northern Pine	Aspen-Birch	Prairie	Metro	Central Hardwood	Statewide
Primary Heat	217,873	72,992	122,731	46,524	213,615	**673,735**
Secondary Heat	50,366	25,500	33,179	36,923	131,457	**277,425**
Pleasure	60,588	36,529	30,250	67,312	51,985	**246,664**
Multiple reasons	28,507	24,722	4,468	52,730	41,301	**151,727**
Woody yard disposal	21,780	5,741	19,625	25,501	25,342	**97,989**

Table 14. Estimated percent of households burning wood for one or more reasons in each region

Location of burning	Estimated total households burning	For primary heat	For secondary heat	For pleasure	Multiple reasons	For woody yard disposal
Northern Pine	72,832	23%	12%	73%	14%	14%
Aspen-Birch	57,457	16%	17%	75%	15%	14%
Prairie	124,355	10%	11%	69%	8%	20%
Metro Area	513,974	2%	5%	74%	19%	16%
Central Hardwood	215,309	9%	12%	72%	13%	18%
Statewide	**983,926**	**7%**	**9%**	**73%**	**16%**	**17%**

Table 15. Total estimated cords burned by each region's residents by location of burning

	Location of burning				
	Northern Pine	**Aspen-Birch**	**Prairie**	**Metro**	**Central Hardwood**
Northern Pine residents	282,190	1,900	14	20	1,011
Aspen-Birch residents	1,881	149,205	93	4	38
Prairie residents	14,248	382	203,284	238	4,851
Metro area residents	74,519	11,609	6,055	228,562	22,201
Central Hardwood residents	6,276	2,388	805	167	435,598

Table 16. Estimated percent of households' wood storage conditions by household location

	Stored Dry	**Not Stored Dry**	**Unknown**
Northern Pine	55%	35%	11%
Aspen-Birch	59%	28%	13%
Prairie	38%	44%	18%
Metro	47%	31%	22%
Central Hardwood	37%	48%	14%
Statewide	**45%**	**37%**	**18%**

Table 17. Estimated number of wood stoves by age and location

	Equipment Age		
	Before 1989	1989-2015	After 2015
Northern Pine	5,881	14,023	1,357
Aspen-Birch	4,856	20,232	1,619
Prairie	7,174	23,914	3,587
Metro	24,950	24,950	4,990
Central Hardwood	20,581	26,914	4,749
Statewide	**63,442**	**110,033**	**16,302**

Table 18. Estimated number of fireplace inserts by age and location

	Equipment Age		
	Before 1989	1989-2015	After 2015
Northern Pine	1,809	1,357	-
Aspen-Birch	809	1,214	809
Prairie	2,391	4,783	-
Metro	4,990	7,485	4,990
Central Hardwood	-	4,749	3,166
Statewide	**10,000**	**19,588**	**8,966**

Table 19. Estimated number of wood cords harvested by each region's residents

Region of primary residence	Cords Harvested
Northern Pine	143,447
Aspen-Birch	61,645
Prairie	170,760
Metro	258,584
Central Hardwood	370,316
Statewide	**1,004,752**

Table 20. Estimated number of wood cords harvested by location

Location	Cords Harvested
Northern Pine	15,878
Aspen-Birch	6,006
Prairie	107,831
Metro	27,386
Central Hardwood	233,641
Unknown	614,009

Appendix D

Start Here ▶ **In the last year, have you burned any wood?**

☐ NO. Please return the survey with this box checked. You do not need to answer any other questions.

☐ YES. Please continue.

Help us understand how

MINNESOTANS USE FIREWOOD

Residential Wood Fuel Survey

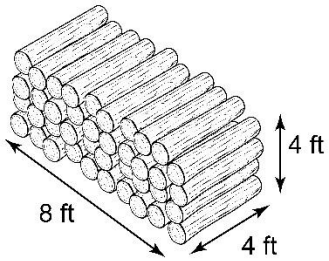
Minnesota, May 2017-April 2018

Conducted by the Minnesota Pollution Control Agency in partnership with the Department of Natural Resources and the US Forest Service

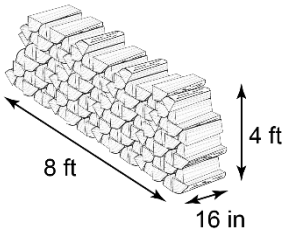
Section A: Key

ESTIMATING HOW MUCH FIREWOOD YOU USE.

A full cord is a large amount of wood. It measures 4 feet high by 4 feet wide by 8 feet long (4’ x 4’ x 8’) and has a volume of 128 cubic feet.



A full cord

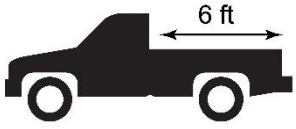


A face cord

A face cord of wood is 4 feet high by 8 feet long and is as wide as the individual firewood pieces, but averages 16 inches wide. A 16-inch wide face cord (sometimes called **a fireplace cord**) is equal to one-third of a full cord.

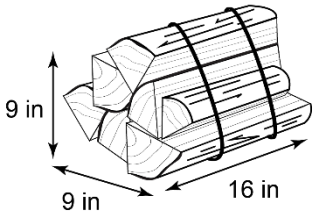
x2

Two full-size pick-up truck loads (8 foot box) equals **one full cord**, whether the wood is stacked carefully so it is about level with the truck box sides, or is thrown into the truck box with the top of the pile about as high as the cab.



x4

Four compact pick-up truckloads (6 foot box) equals **one full cord**, whether the wood is stacked carefully so it is about level with the truck box sides, or is thrown into the truck box with the top of the pile about as high as the cab.



X170

Bundles of wood sold at gas stations, hardware stores and state parks are often 0.75 cubic feet. They often measure about 16 inches x 9 inches x 9 inches. 170 bundles equals **one full cord**.

Section B: Residence

The survey asks about the **wood-burning equipment** you use. **Wood-burning equipment** includes wood-burning fireplaces, fireplace inserts, wood stoves, wood furnaces, wood boilers, outdoor fire pits, chimeneas, etc.

The survey also asks about how much you burn at your primary and secondary residence in Minnesota. We are using the following definitions for these residences:

- **Primary residence** includes your main home, including garages and outbuildings.
- **Secondary residence** includes your or your family's second home, cabin, trailer, rented cabin, or other residential property. If you have more than one secondary residence, please consider only the most frequently used secondary residence.

1. Where is your **primary** residence located? (Your main home, including garages and other outbuildings.)

   Primary residence location:

   County

   _____

   City/Township

   _____

   Zip Code

   _____

2. Which of the following best describes your ***primary*** residence?
   - ☐1 Single-family house (detached)
   - ☐2 Townhouse or twinhome (attached)
   - ☐3 Multi-family building (such as condominiums, apartments, or cooperatives)
   - ☐4 Mobile home or trailer

☐ **I do not have a secondary residence in Minnesota.**

If you do not have a secondary residence in Minnesota skip all questions about secondary residence.

3. If you have a **secondary** residence, where is it located? (A second home, cabin, trailer, rented cabin, or other residential property that is located in Minnesota. If your secondary residence is not in Minnesota do not include it.)

   Secondary residence location:

   County

   _____

   City/Township

   _____

   ZIP

   _____

4. Which of the following best describes your ***secondary*** residence, cabin, trailer, rented cabin, or vacation property?
   - ☐1 Single-family house (detached)
   - ☐2 Townhouse or twinhome (attached)
   - ☐3 Multi-family building (such as condominiums, apartments, or cooperatives)
   - ☐4 Mobile home or trailer
   - ☐5 Cabin

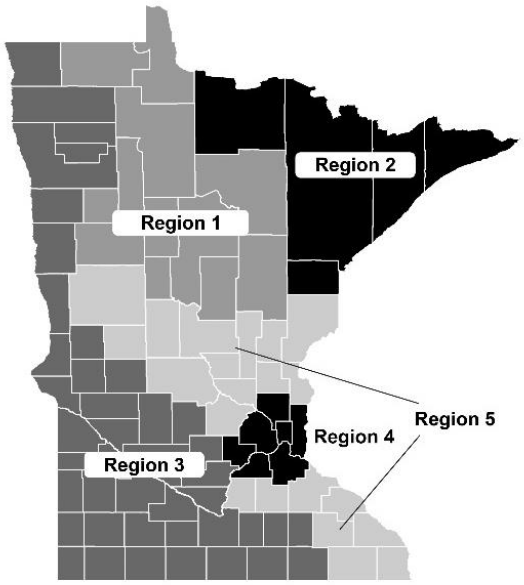
Section C: Campsites and campgrounds

5. Did you burn firewood at a campsite or campground in Minnesota between May 2017 and April 2018?
   - ☐1 No. **Skip to Q8.**
   - ☐2 Yes. Please continue.

6. If you burned firewood at a campsite between May 2017 and April 2018, please estimate the total amount of wood burned.

   _____ Estimated total amount (in bundles) of wood burned at all campsites

7. Please check all of the regions in which you burned wood at a campsite between May 2017 and April 2018, based on the following map.
   - ☐1 Region 1
   - ☐2 Region 2
   - ☐3 Region 3
   - ☐4 Region 4
   - ☐5 Region 5



Section D: Outdoor wood burning fire pits, chimeneas or fire rings

Chimenea

Fire pit

Chimeneas, fire pits, fire rings, etc.

Can be above the ground or dug into the ground
Are located outside the house

Please answer only for those that burn wood rather than propane

PRIMARY RESIDENCE

8. Do you have a fire ring, fire pit, chimenea or similar type of equipment at your primary residence?
   - ☐1 No. **Go to Q12.**
   - ☐2 Yes.

9. In the past 12 months, did you use this equipment ***mainly*** for:
   - ☐1 Pleasure
   - ☐2 Disposal by burning of woody yard materials (e.g. fallen branches, trees and twigs, brush/trees collected from property)
   - ☐3 None. Please check if you did not burn wood in this equipment during the last year and **Skip to Q12.**

10. Please check which months you used this wood-burning equipment at your home over the last year.

2017								2018			
MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
☐1	☐2	☐3	☐4	☐5	☐6	☐7	☐8	☐9	☐10	☐11	☐12

11. Please indicate how much wood or wax logs you burned in the past 12 months in your fire ring, fire pit, chimenea or any similar type of equipment. (Respond to as many as you need to collectively best describe how much wood was burned.)
    - 1 _____ Bundles of wood (0.75 cubic feet each)
    - 2 _____ Bags of tree branches and woody brush collected from your yard (Estimate how many 30 gallon bags – typical size of yard waste bags sold)
    - 3 _____ Full cords (answer to the nearest tenth of a cord)
    - 4 _____ Face cords (answer to the nearest tenth of a face cord)
    - 5 _____ Number of wax logs (such as Duraflame, Emuiro Log, Pine Mountain, etc)
    - 6 _____ Number of wood pallets

If you do not have a secondary residence in Minnesota skip all questions about secondary residence.

SECONDARY RESIDENCE

12. Do you have a fire ring, fire pit, chimenea or similar type of equipment at your secondary residence?
    - ☐1 No. **Go to Q16.**
    - ☐2 Yes.

13. In the past 12 months, did you use this equipment ***mainly*** for:
    - ☐1 Pleasure
    - ☐2 Disposal by burning of woody yard materials (e.g. fallen branches, trees and twigs, brush/trees collected from property)
    - ☐3 None. Please check if you did not burn wood in this equipment during the last year and **Skip to Q16.**

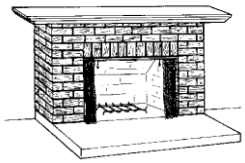
14. Please check which months you used this wood-burning equipment at your home over the last year.

2017								2018			
MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
☐1	☐2	☐3	☐4	☐5	☐6	☐7	☐8	☐9	☐10	☐11	☐12

15. Please indicate how much wood or wax logs you burned in the past 12 months in your fire ring, fire pit, chimenea or any similar type of equipment. (Respond to as many as you need to collectively best describe how much wood was burned.)
    - 1 _____ Bundles of wood (0.75 cubic feet each)
    - 2 _____ Bags of tree branches and woody brush collected from your yard (Estimate how many 30 gallon bags – typical size of yard waste bags sold)
    - 3 _____ Full cords (answer to the nearest tenth of a cord)
    - 4 _____ Face cords (answer to the nearest tenth of a face cord)
    - 5 _____ Number of wax logs (such as Duraflame, Emuiro Log, Pine Mountain, etc)

6 _____ Number of wood pallets

Section E: Conventional wood burning fireplaces



DEFINITION: A CONVENTIONAL FIREPLACE

Often for aesthetic use rather than primarily for heating
May have hot air grilles
May either have no doors or glass doors without gaskets (not airtight)
Doors can be double or bifold doors
Includes fireplaces known as "heatilators" and fireplaces with tubular grates or other devices intended to increase heat flow
Includes freestanding fireplaces
Does not have an insert (if your fireplace has an insert **go to Section F, page 6**)

PRIMARY RESIDENCE

16. Do you have a conventional wood burning fireplace at your primary residence (including outbuildings such as pole barns or garages)?
    - ☐1 No. **Go to Q20.**
    - ☐2 Yes → How many? _____

17. During the past 12 months, did you use this equipment ***mainly*** for:
    - ☐1 Pleasure
    - ☐2 Primary heat source for my residence
    - ☐3 Supplemental heating for my residence
    - ☐4 None. Please check if you did not burn wood in your fireplace and **Skip to Q20.**

18. Please check which months you used this wood-burning equipment in your home.

2017								2018			
MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
☐1	☐2	☐3	☐4	☐5	☐6	☐7	☐8	☐9	☐10	☐11	☐12

19. If you used your fireplace please indicate how much wood or wax logs you burned in your fireplace(s) in the past 12 months.
    - 1 _____ Full cords of wood (If necessary, you can answer in fractions of full cords, such as 1/2, 1.5)
    - 2 _____ Face cords of wood
    - 3 _____ Bundles of wood (0.75 cubic feet each)
    - 4 _____ Number of wax logs (such as Duraflame, Emuiro Log, Pine Mountain, etc)

If you do not have a secondary residence in Minnesota skip all questions about secondary residence.

SECONDARY RESIDENCE

20. Do you have a conventional wood burning fireplace at your secondary residence (including outbuildings such as pole barns or garages)?
    - ☐1 No. **Go to Q24 Section F on page 6**.
    - ☐2 Yes → How many? _____

21. During the past 12 months, did you use this equipment ***mainly*** for:
    - ☐1 Pleasure
    - ☐2 Primary heat source for my residence
    - ☐3 Supplemental heating for my residence
    - ☐4 None. Please check if you did not burn wood in your fireplace and **Skip to Q24.**

0

22. Please check which months you used this wood-burning equipment in your home.

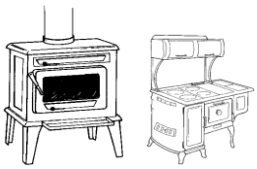
2017								2018			
MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
☐1	☐2	☐3	☐4	☐5	☐6	☐7	☐8	☐9	☐10	☐11	☐12

23. If you used your fireplace please indicate how much wood or wax logs you burned in your fireplace(s) in the past 12 months.
    - 1 _____ Full cords of wood (If necessary, you can answer in fractions of full cords, such as 1/2, 1.5)
    - 2 _____ Face cords of wood
    - 3 _____ Bundles of wood (0.75 cubic feet each)
    - 4 _____ Number of wax logs (such as Duraflame, Emuiro Log, Pine Mountain, etc)

Section F: Wood stoves, wood burning fireplace inserts, and pellet stoves

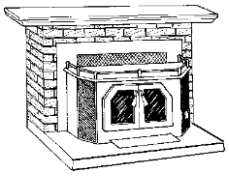
DEFINITION: WOOD STOVES, WOOD BURNING FIREPLACE INSERTS, AND WOOD PELLET STOVES

Wood stoves



Wood stoves are freestanding space heaters often used to heat a small house or zone of the house.

Wood burning fireplace inserts



Wood burning fireplace inserts are space heaters designed to fit into an existing fireplace opening.

Wood pellet stoves

Wood pellet stoves burn small compressed wood pellets. A pellet-burning appliance has a hopper to hold the fuel and can burn for a long time without reloading.

PRIMARY RESIDENCE

24. Do you have this equipment in your primary residence (including outbuildings such as pole barns or garages)?
    - ☐1 No. **Go to Q27**
    - ☐2 Yes.

25. In the past 12 months, did you use this equipment ***mainly*** for:
    - ☐1 Pleasure
    - ☐2 Primary heat source for my residence
    - ☐3 Supplemental heating for my residence
    - ☐4 None. Please check if you did not burn wood in your wood stove, fireplace insert, or wood pellet stove, and **Skip to Q27.**

26. Check the months in which you used this wood-burning equipment in your home over the last year.

2017								2018			
MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
☐1	☐2	☐3	☐4	☐5	☐6	☐7	☐8	☐9	☐10	☐11	☐12

If you do not have a secondary residence in Minnesota skip all questions about secondary residence.

SECONDARY RESIDENCE

27. Do you have this equipment in your secondary residence (including outbuildings such as pole barns or garages)?
    - ☐1 No. **Go to Q30.**
    - ☐2 Yes

28. In the past 12 months, did you use this equipment ***mainly*** for:
    - ☐1 Pleasure
    - ☐2 Primary heat source for my residence
    - ☐3 Supplemental heating for my residence
    - ☐4 None. Please check if you did not burn wood in your wood stove, fireplace insert, or wood pellet stove, and **Skip to Q30.**

29. Check the months in which you used this wood-burning equipment in your home over the last year.

2017								2018			
MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
☐1	☐2	☐3	☐4	☐5	☐6	☐7	☐8	☐9	☐10	☐11	☐12

Section F: Wood stoves, wood burning fireplace inserts, and pellet stoves

Before 1989, most wood stoves and fireplace inserts sold did not have pollution control technology. Beginning in 1989, wood stoves and fireplace inserts sold were required to have EPA-certified pollution control technology. In 2015, wood stoves sold were required to meet tighter emission standards. Some EPA-certified woodstoves and fireplace inserts have a ceramic or metal honeycomb catalyst.

PRIMARY RESIDENCE

30. Fill in the grid below for each piece of equipment you have at your primary residence.

	EQUIPMENT			TOTAL AMOUNT OF FUEL WOOD BURNED IN ALL UNITS between May 2017 and April 2018				
Type of equipment	**How many units did you use in the past 12 months?**	**For your most commonly used unit, when was it made?**	**For your most commonly used unit, does it have a catalyst?**	**# Full cords**	**# Face cords**	**# Wood bundles**	**# Wax logs**	**Pounds of wood pellets**
Wood Stove	_____	☐1 Before 1989 ☐2 1989 - 2015 ☐3 After 2015 ☐-8 Don't know	☐1 Yes ☐2 No ☐-8 Don't know	_____	_____	_____	_____	_____
Wood Burning Fireplace Insert	_____	☐1 Before 1989 ☐2 1989 - 2015 ☐3 After 2015 ☐-8 Don't know	☐1 Yes ☐2 No ☐-8 Don't know	_____	_____	_____	_____	_____
Pellet stove	_____	☐1 Before 1989 ☐2 1989 - 2015 ☐3 After 2015 ☐-8 Don't know	☐1 Yes ☐2 No ☐-8 Don't know	_____	_____	_____	_____	_____

If you do not have a secondary residence in Minnesota skip all questions about secondary residence.

SECONDARY RESIDENCE

31. Fill in the grid below for each piece of equipment you have at your secondary residence.

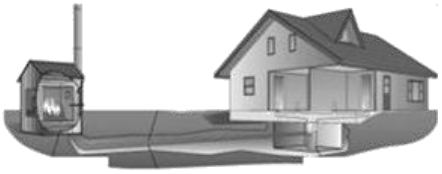
	EQUIPMENT			TOTAL AMOUNT OF FUEL WOOD BURNED IN ALL UNITS How many units did you use in the past 12 months?				
Type of equipment	**How many units did you use in the past 12 months?**	**For your most commonly used unit, when was it made?**	**Does your equipment have a catalyst?**	**# Full cords**	**# Face cords**	**# Wood bundles**	**# Wax logs**	**Pounds of wood pellets**
Wood Stove	_____	☐1 Before 1989 ☐2 1989 - 2015 ☐3 After 2015 ☐-8 Don't know	☐1 Yes ☐2 No ☐-8 Don't know	_____	_____	_____	_____	_____
Wood Burning Fireplace Insert	_____	☐1 Before 1989 ☐2 1989 - 2015 ☐3 After 2015 ☐-8 Don't know	☐1 Yes ☐2 No ☐-8 Don't know	_____	_____	_____	_____	_____
Pellet stove	_____	☐1 Before 1989 ☐2 1989 - 2015 ☐3 After 2015	☐1 Yes ☐2 No ☐-8 Don't know	_____	_____	_____	_____	_____

☐-8 Don't know

Section G: Wood burning boiler or furnace

DEFINITION: WOOD BURNING BOILER OR FURNACE

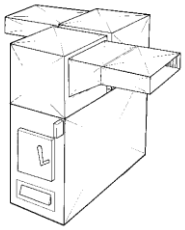
Outdoor wood boiler



Wood boilers

- Wood boilers are usually installed outside and may look like a small shed
- Wood boilers heat water that moves in pipes to where the heat is used

Indoor wood furnace



Wood furnaces

- Wood furnaces are usually installed in basement or utility rooms
- Wood furnaces heat air directly and are connected to ducts that move the hot air around the building

PRIMARY RESIDENCE

32. Do you have any of this equipment at your primary residence (including outbuildings such as pole barns or garages)?
    - ☐1 No. **Go to Q37.**
    - ☐2 Yes a forced air furnace
    - ☐3 Yes a wood boiler

33. Brand and model (if known)

    _____

34. Is the equipment inside or outside the house?
    - ☐1 Inside
    - ☐2 Outside

35. The boiler or furnace
    - ☐1 Heats water to heat my home
    - ☐2 Heats water to heat my other building(s) (workshops, garages, greenhouse)
    - ☐3 Heats water to heat my domestic water supply (for washing, showering, cooking, etc.)
    - ☐4 Heats water to heat my swimming pool
    - ☐5 Heats air; has no liquid

36. In the past 12 months did you use this equipment ***mainly*** for:
    - ☐1 Primary heat source at my residence
    - ☐2 Supplemental heating at my residence
    - ☐3 None. Please check if you did not burn any wood in your heater or boiler, then **Skip to Q37.**

If you do not have a secondary residence in Minnesota skip all questions about secondary residence.

SECONDARY RESIDENCE

37. Do you have any of this equipment at your secondary residence (including outbuildings such as pole barns or garages)?
    - ☐1 No. **Go to Q42.**
    - ☐2 Yes a forced air furnace
    - ☐3 Yes a wood boiler

38. Brand and model (if known)

    _____

39. Is the equipment inside or outside the house?
    - ☐1 Inside
    - ☐2 Outside

40. The boiler or furnace
    - ☐1 Heats water to heat my home
    - ☐2 Heats water to heat my other building(s) (workshops, garages, greenhouse)
    - ☐3 Heats water to heat my domestic water supply (for washing, showering, cooking, etc.)
    - ☐4 Heats water to heat my swimming pool
    - ☐5 Heats air; has no liquid

41. In the past 12 months did you use this equipment ***mainly*** for:
    - ☐1 Primary heat source at my residence
    - ☐2 Supplemental heating at my residence
    - ☐3 None. Please check if you did not burn any wood in your heater or boiler, then **Skip to 42.**

Section G: Wood burning boiler or furnace

42. Please check which months you used your wood burning boiler or furnace in your home.

2017								2018			
MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
☐1	☐2	☐3	☐4	☐5	☐6	☐7	☐8	☐9	☐10	☐11	☐12

43. If you used your boiler or furnace, please indicate how much wood you burned in your furnace or boiler in the past 12 months (If necessary, you can answer in fractions of full cords, such as 1/2, 1.5).

1 _____ Full cords of wood
2 _____ Full cords of slabs (the round parts of a log cut off to make milled wood)
3 _____ Face cords of wood
4 _____ Number of wooden pallets

If you do not have a secondary residence in Minnesota skip all questions about secondary residence.

SECONDARY RESIDENCE

44. Please check which months you used your wood burning boiler or furnace in your home.

2017								2018			
MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
☐1	☐2	☐3	☐4	☐5	☐6	☐7	☐8	☐9	☐10	☐11	☐12

45. If you used your boiler or furnace, please indicate how much wood you burned in your furnace or boiler in the past 12 months (If necessary, you can answer in fractions of full cords, such as 1/2, 1.5).

1 _____ Full cords of wood
2 _____ Full cords of slabs (the round parts of a log cut off to make milled wood)
3 _____ Face cords of wood
4 _____ Number of wooden pallets

Section H: Complete this section if you burned wood in the past 12 months

46. At your ***primary*** residence, is your wood stored in a way that is protected from the elements, such as rain?
    - ☐1 Yes
    - ☐2 No

47. At your ***secondary*** residence, is your wood stored in a way that is protected from the elements, such as rain?
    - ☐1 Yes
    - ☐2 No

48. Of all the firewood you **burned** at your ***primary*** residence this past 12 months, what percent was burned of each species (if known)? (Percentages should add up to 100%.)

Hardwoods								**Softwoods**		Unknown species
Oak	Birch	Ash	Elm	Maple	Aspen	Basswood	Other Hardwoods	Pine	Other Softwoods	
____%	____%	____%	____%	____%	____%	____%	____%	____%	____%	____%

49. Of all the firewood you **burned** at your ***secondary*** residence, what percent was burned of each species (if known)? (Percentages should add up to 100%)

Hardwoods								**Softwoods**		Unknown species
Oak	Birch	Ash	Elm	Maple	Aspen	Basswood	Other Hardwoods	Pine	Other Softwoods	
____%	____%	____%	____%	____%	____%	____%	____%	____%	____%	____%

Section I: Complete this section if you burned or harvested wood in the past 12 months

For the following questions, please use the following definitions:

- **Harvested** includes all live or dead whole trees harvested primarily for the purpose of firewood anywhere in Minnesota.
- Harvested wood excludes **yard waste**, which is wood produced from the care and maintenance of landscaped areas, gardens, and lawns. Yard waste includes material such as: pruned branches and stems, brush, Christmas trees, mulch, stumps and roots. Wood yard waste also includes the removal of unwanted live trees and dead or diseased trees or any wood cleared for construction in a maintained area.

50. Of all the wood your household burned between May 2017 and April 2018, indicate the percent(s) you harvested or obtained from the following sources:

    1_____ % Purchased or free slabs from sawmills

    2_____ % Purchased from a firewood dealer or logger

    3_____ % Purchased from a store or campground

    4_____ % Free or purchased from other sources

    5_____ % Harvested by you or a member of your immediate family **Note: If 0% harvested, skip to end.**

51. Indicate the total amount of firewood that was ***harvested*** by you or a member of your immediate family between
    May 2017 and April 2018: (If necessary, you can answer in fractions of full cords, such as 1/2, 1.5. If none enter "0")

    _____ Full cords

52. If you or a member of your immediate household ***harvested*** firewood between May 2017 and April 2018, indicate the percent that came from the following locations: (Percentages should add up to 100%)

    1_____ % Private land

    2_____ % State land

    3_____ % County land

    4_____ % Municipal land

    5_____ % National forestland

    6_____ % Unknown location

53. If you or a member of your immediate household ***harvested*** firewood between May 2017 and April 2018 please indicate what percent came from the following sources: (Percentages should add up to 100%)

    1_____ % Live trees from forest land

    2_____ % Dead trees from forest land

    3_____ % Cut trees and/or tops and branches after a timber harvest

    4_____ % Live or dead trees from pasture land and/or cropland

    5_____ % Live or dead trees from yards, inside city limits, or other non-forest land

    6_____ % Unknown location

Section I: Complete this section if you burned or harvested wood in the past 12 months

54. If you or members of your immediate household ***harvested*** firewood in the past 12 months please indicate what percent came from the following species: (Percentages should add up to 100%)

Hardwoods								Softwoods		
Oak	Birch	Ash	Elm	Maple	Aspen	Basswood	Other Hardwoods	Pine	Other Softwoods	Unknown species
____%	____%	____%	____%	____%	____%	____%	____%	____%	____%	____%

55. If you or a member of your immediate household harvested firewood in the past 12 months, indicate the counties from which the firewood came and the percent from each county:

☐1 I do not know

County name: 1. _____ Percent: _____ %

2. _____ _____ %

3. _____ _____ %

4. _____ _____ %

Thank you for completing this survey.
Please place the survey in the postage paid envelope provided and mail it promptly.

Survey sponsored by
Minnesota Department of Natural Resources
Minnesota Pollution Control Agency
U.S. Forest Service

Thanks to John Gulland of Gulland and Associates, Killaloe, CA, for allowing the use of parts of his survey.