Alaska Department of Environmental Conservation

Amendments to: State Air Quality Control Plan

Vol. III: Appendix III.D.7.06

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 7. Fairbanks North Star Borough PM2.5 Control Plan, Serious Requirements}

Adopted November 19, 2019

Amendments Adopted November 18, 2020

Michael J. Dunleavy
Governor

Jason W. Brune
Commissioner

This appendix document consists of the Serious SIP Requirements adopted November 19, 2019, and the 2020 Amendments to the Serious SIP Requirements adopted November 18, 2020. The 2020 Amendments have been added to the end of the original document. The Serious SIP requirements start from page Appendix III.D.7.6-1 to Appendix III.D.7.6-273, while the 2020 Amendments start from page Appendix III.D.7.6-274 to Appendix III.D.7.6-506.

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Appendix III.D.7.06

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Emission Inventory Document

Estimating FNSB Home Heating Elasticities of demand using the Proportionally-Calibrated Almost Idea Demand System (PCAIDS) Model: Postcard Data Analysis

Memo on the Analysis of Fairbanks 2016 Home Heating Postcard Survey by Carlson et al.

The following document is included as part of the Appendix, however due to its electronic nature, it may be found posted separately at:
http://dec.alaska.gov/air/anpms/communities/fbks-pm2-5-serious-sip/

Fairbanks PM2.5 Serious SIP Emissions by Source Sector and SCC Code; Emission Inventories Final Excel Spreadsheet.

Appendix III.D.7.6

INTRODUCTION

This technical appendix provides detailed documentation of the data sources, issues considered and methodologies and workflow applied in developing the baseline emission inventories developed to support the episodic attainment modeling in the Fairbanks North Star Borough (FNSB or Fairbanks) $PM_{2.5}$ Serious SIP. The intent of this documentation is to explicitly describe the approaches used in calculating episodic emissions. Thus, the documentation is organized by source sector as follows:

- Episodic Point Sources;
- Home Heating Area Sources;
- Other Area Sources;
- On-Road Mobile Sources; and
- Non-Road Mobile Sources.

(Biogenic emissions do not occur in Fairbanks during the snow and ice-bound winter $PM_{2.5}$ season.)

Following the sector specific documentation, an inventory summary section is included that contains sector-specific tabulations of the 2013 Baseline, 2019 Projected Baseline, 2019 Control and 2029 Control inventories. These tabulations include reporting of separate filterable and condensable components for $PM_{2.5}$ for those source sectors for which these components are available as explained therein.

For all inventory sectors, episodic modeling emissions were generally calculated using a "bottom-up" approach that relied heavily on an exhaustive set of locally measured data used to support the emission estimates.

Within the Home Heating sector, separate sections are provided that detail key underlying data sources and components of the approach used to estimate episodic home heating emissions, given their importance within the entire inventory as follows:

- Development of Energy Model – describes local instrumented data collection and analysis used to develop a home heating energy demand model calibrated to episodic wintertime conditions in Fairbanks;

- Residential Surveys – documents the structure, content and approach used to collect key activity, source mix and behavior pattern data in a series of home heating surveys of locally sampled residential households;

- Fairbanks Wood Energy and Moisture Content – explains the data sources used to identify the local mix and energy content of wood species used in home heating and the methods used to account for the effect of wood moisture content on emissions;

- OMNI and AP-42 Emission Factors – discusses the emission factors used to estimate home heating emissions in Fairbanks by device type and includes factors developed from laboratory testing local heating devices and AP-42-based rates; and

- Emission Calculation Details – explains how each of the data sources and upstream methods were combined to estimate gridded hourly estimates of home heating emissions.

EPISODIC POINT SOURCE DATA

Given the potential for strong seasonal variations in facility activity and demand, point source emissions to support the episodic modeling were developed on a day- and hour-specific basis for each of the key point source facilities within the modeling domain. This section of the technical appendix describes how episodic activity data were collected by DEC and emission estimates calculated for these point sources. It also explains how these data were reviewed for quality assurance before being loaded into the SIP modeling inventory.

BASE YEAR EPISODIC POINT SOURCE DATA

For the 2013 Baseline SIP inventory, DEC queried facilities from its permits database to identify major and minor point source facilities within the modeling domain. DEC uses the definition of a major source under Title V of the Clean Air Act (as specified in 40 CFR 51.20) to define the "major source" thresholds for reporting annual emissions. These thresholds are the potential to emit (PTE) annual emissions of 100 tons for all relevant criteria air pollutants. Natural minor and synthetic minor facilities (between 5 and 99 TPY) reporting emissions under either New Source Review (NSR) or Prevention of Significant Deterioration (PSD) requirements were also in the query identify facilities down to the 70 TPY threshold required to classify stationary point sources under Serious Area inventory requirements.

A total of 14 facilities were identified. Of these, DEC noted that three of the facilities, the Golden Valley Electric Association (GVEA) Healy Power Plant and the heating/power plants at Fort Greely (near Delta Junction) and Clear Air Force Base (near Anderson) were excluded from development of episodic emissions. These facilities were excluded because of their remoteness relative to Fairbanks (all are between 55 and 78 miles away)[1] or the fact that they were located generally downwind of the non-attainment area under episodic air flow patterns (Healy Power Plant and Clear AFB). Three others were identified as minor/synthetic minor sources: 1) Fort Knox Mine (26 miles northeast of Fairbanks), 2) Usibelli Coal Preparation Plant (in Healy), and 3) CMI Asphalt Plant (in Fairbanks) and were excluded from treatment as individual episodic point sources because they were either located outside the non-attainment area (Fort Knox and Usibelli) or exhibited insignificant wintertime activity (CMI Asphalt Plant).

(These excluded facilities were treated as stationary non-point or area sources within the inventory.)

The names and primary equipment and fuels of the eight remaining facilities for which episodic data were collected and developed are summarized in Table 7-6-1. One facility, Eielson Air Force Base is located just outside the non-attainment area boundary on the southeast edge. All other facilities listed in Table 7-6-1 are located within the non-attainment area.

[1] Individual point source plume modeling conducted by DEC in support of the SIP using the CALPUFF model found that under the episodic meteorological conditions, emissions from facilities located outside the Fairbanks PM2.5 non-attainment area exhibited negligible contributions to ambient $PM_{2.5}$ concentrations in the area.

Table 7-6-1
Summary of SIP Modeling Inventory Point Source Facilities

Facility ID	Facility Name	Primary Equipment/Fuels
71	Flint Hills North Pole Refinery	11 crude & process heaters burning process gas/LPG (9 operated during episodes), plus 2 natural gas-fired steam generators, gas flare
109	GVEA Zehnder (Illinois St) Power Plant	Two gas turbines burning HAGO[a], two diesel generators burning Jet A
110	GVEA North Pole Power Plant	Three gas turbines, two burning HAGO, one burning naphtha (plus an emergency generator and building heaters not used during episodes)
236	Fort Wainwright	Backup diesel boilers & generators (3 each) - none operated during episodes
264	Eielson Air Force Base	Over 70 combustion units - six coal-fired main boilers only operated during episodes
315	Aurora Energy Chena Power Plant	Four coal-fired boilers (1 large, 3 small), all exhausted through common stack
316	UAF Campus Power Plant	Two coal-fired, two oil-fired boilers (plus backup generators & incinerator not operated during episodes)
1121	Doyon Utilities (private Fort Wainwright units)	Six coal-fired boilers

[a] Heavy Atmospheric Gas Oil. HAGO is a crude distillate at the heavy end of typical refinery "cuts" with typical boiling points ranging from 610-800°F. Due to geographic proximity, GVEA seasonally used HAGO during winter, a by-product from Flint Hills Refinery until Flint Hills shutdown refinery operations after 2014.

As noted in Table 7-6-1, some of the equipment is not normally operated during wintertime modeling episodes. This infrequently operated equipment includes backup boilers and emergency generators.

In December 2010, DEC sent letters of request and spreadsheet templates to each of the eight point source facilities listed in Table 7-6-1, requesting additional actual day- and hour-specific activity and emissions data from each facility (as available) covering the two 2008 historical modeling episodes:

- Episode 1 (E1) – January 23 through February 10, 2008; and
- Episode 2 (E2) – November 2 through November 17, 2008.

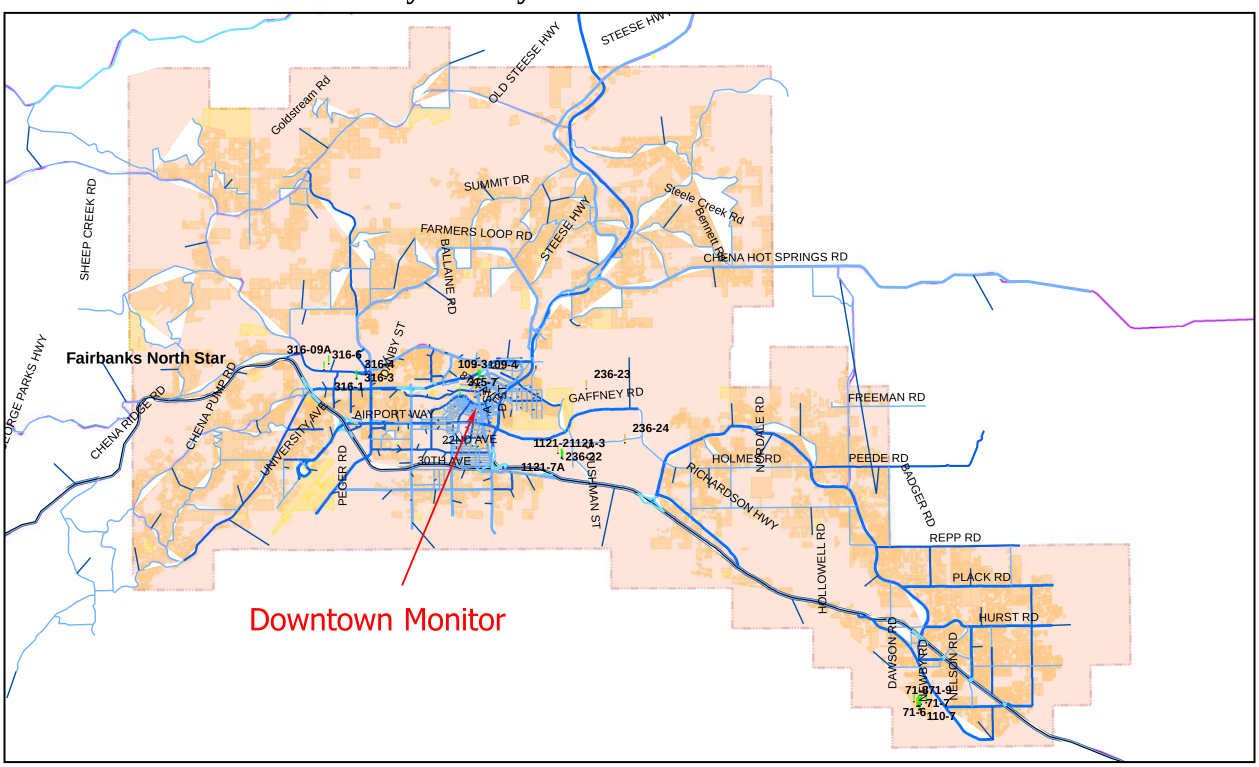
The spreadsheet template contained individual sheets organized in a structure similar to that use to collect and submit stationary point source data to EPA under National Emission Inventory (NEI) reporting requirements. Information was requested for both combustion and fugitive sources. Requested data elements included emission units, stack parameters (height, diameter, exit temperature and velocity/flow rate), release points (location coordinates), control devices (as applicable), seasonal and diurnal fuel properties and throughput.

If available (e.g. through continuous emissions monitoring systems) facilities were also directed to submit additional spreadsheets with day and hour-specific data for the two historical modeling episodes.

Episodic 2008 actual data were provided by seven of the eight facilities listed earlier in Table 7-6-1. (Episodic data were not provided for Fort Wainwright (Facility ID=236) since as its backup diesel generators and boilers were not in operation during the two 2008 modeling episodes as noted in Table 7-6-1.) The facilities provided fuel use, sulfur content, emission factor, and/or emissions data. The pollutants of interest included $PM_{2.5}$, sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOC).

Figure 7-6-1 shows the locations of each of the point sources contained within the $PM_{2.5}$ nonattainment area (the tan shaded area), by facility ID and stack ID. The green dots represent locations of combustion point sources while the orange dots signify fugitive VOC sources. The location of the downtown ambient $PM_{2.5}$ monitor is also shown in Figure 7-6-1.

Figure 7-6-1
Location of Point Sources by Facility ID Within Fairbanks $PM_{2.5}$ Non-Attainment Area



Quality Assurance Review

DEC's contractor, Sierra Research, Inc. (Sierra), then assembled and reviewed the submitted data for completeness, consistency and validity prior to integrating the episodic data into the SIP inventories. Given the differences in structure and content of the submitted episodic data, the data were individually reviewed for each facility before being assembled into a consistent inventory structure.

Generally, most facilities provided hourly $PM_{2.5}$ and SO_2 emission rates by individual emission unit. As explained in greater detail below, Sierra then developed estimates of NO_x and VOC emission rates from AP-42[2] based emission factors (where fuel use data were explicitly provided) or from fuel-specific emission factor ratios.

The actual episodic data obtained from each facility are summarized below. Any corrections made to the data during the review are specifically noted.

Flint Hills Refinery (#71) - The Flint Hills Refinery (FHR) provided DEC with hourly emissions data for $PM_{2.5}$/ SO_2/NO_x/ VOC for five release points encompassing 12 emission sources. Flint Hills Refinery did not differentiate the hourly emissions among the underlying emission sources. Flint Hills Refinery did not provide the underlying fuel usage rates, process throughput rates, or the emission factors associated with these emissions. Flint Hills Refinery did not provide the basis for the emissions data; it only provided the hourly emissions. Emissions from one of the four release points – the flare – are insignificant compared to the emissions from the four release points. Flint Hills Refinery did not provide stack temperature, stack flow rate, or stack velocity data for the flare.

GVEA Zehnder Power Plant (#109) - GVEA provided DEC with hourly fuel consumption and PM/SO_2 emissions data for two liquid-fired gas turbines and two liquid fired generators. The gas turbines (Units 1/2) burn HAGO/Jet A. GVEA calculated hourly PM/SO_2 emissions from the hourly fuel usage and emission factors. Sierra similarly calculated hourly NO_x/VOC emissions from the hourly fuel usage and emission factors.

For Units 1/2, GVEA used a source test-derived filterable PM emission factor; Sierra assumed that PM comprised 100% $PM_{2.5}$ since AP-42 does not distinguish PM emissions by particle size. Sierra further assumed that the condensable PM fraction was negligible compared to the filterable PM fraction. GVEA derived the HAGO/Jet A SO_2 emission factors from the averaged measured HAGO/Jet A sulfur contents and HAGO/Jet A higher heating values (HHV). Sierra obtained the NO_x/VOC emission factors for an uncontrolled gas turbine from Tables 3.1-1 and 3.1-2a, respectively, of AP-42 (April 2000).

For the generators (Units 3/4), GVEA obtained the $PM_{2.5}$ emission factor from Table 3.4-2 of AP-42 (October 1996). GVEA derived the diesel SO_2 emission factor from the averaged measured Jet A sulfur content and Jet A HHV. Sierra obtained the NO_x/VOC emission factors for an uncontrolled engine from Table 3.4-1 of AP-42 (October 1996). Sierra corrected some

[2] "AP-42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources," Environmental Protection Agency, January 1995.

errors it discovered while reviewing GVEA's calculations. Units 3/4 SO_2 emissions were overstated by a factor of 100 because the fuel sulfur content was not divided by 100 in the calculation. Unit 4 SO_2 emissions during November were further overstated. The combined emissions from Units 3/4 were calculated rather than apportioning the fraction attributable to Unit 4. Emissions from the two generators are insignificant compared to the emissions from the two gas turbines. GVEA did not provide stack temperature, stack flow rate, or stack velocity data for the generators.

GVEA North Pole Power Plant (#110) **-** GVEA provided DEC with hourly fuel consumption and PM/SO_2 emissions data for three liquid-fired gas turbines comprising five release points (two turbines each discharge to two separate stacks). Units 1/2 burn HAGO while Unit 5 burns a combination of naphtha and Jet A. GVEA calculated hourly PM/SO_2 emissions from the hourly fuel usage and emission factors. Sierra similarly calculated hourly NO_x/VOC emissions from the hourly fuel usage and emission factors.

For Units 1/2, GVEA used a source test-derived PM_{10} emission factor; Sierra assumed that PM_{10} comprised 100% $PM_{2.5}$ since AP-42 does not distinguish PM emissions by particle size. GVEA derived the SO_2 from the averaged measured HAGO sulfur content and HAGO HHV. Sierra obtained the NO_x/VOC emission factors for an uncontrolled gas turbine from Tables 3.1-1 and 3.1-2a, respectively, of AP-42 (April 2000). Sierra corrected an error it discovered while reviewing GVEA's calculations. Units 1/2 emissions were inadvertently calculated using the Jet A HHV rather than the HAGO HHV.

For Unit 5, GVEA obtained the PM emission factors (filterable and condensable) from Table 3.1-2a of AP-42 (April 2000); Sierra assumed that PM comprised 100% $PM_{2.5}$ since AP-42 does not distinguish PM emissions by particle size. The AP-42 PM emission factor used for Unit 5 is over an order of magnitude lower than the source test-derived PM_{10} emission factor used for Units 1/2. GVEA derived the naphtha/Jet A SO_2 emission factors from the averaged measured naphtha/Jet A sulfur contents and naphtha/Jet A HHVs. The naphtha/Jet A SO_2 emission factors used for Unit 5 are nearly an order of magnitude lower than the HAGO SO_2 emission factor used for Unit 5 because the sulfur content of HAGO is much higher than that of naphtha/Jet A. Sierra obtained the NO_x/VOC emission factors for a water injected gas turbine from Tables 3.1-1 and 3.1-2a, respectively, of AP-42 (April 2000).

Eielson Air Force Base (#109) **-** Eielson Air Force Base provided DEC with combined hourly $PM_{2.5}$ and SO_2 emissions data for six release points, each comprising one coal-fired spreader stoker boiler. Eielson did not differentiate the hourly emissions among the underlying boilers but did provide the underlying hourly steam production rates associated with each boiler. Eielson did not provide the basis for the hourly $PM_{2.5}$ and SO_2 emissions data; it only provided the combined hourly emissions. Sierra allocated hourly $PM_{2.5}$ and SO_2 emissions among the six boilers proportional to hourly steam production relative to the total steam production.

Sierra calculated hourly NO_x and VOC emissions from the hourly $PM_{2.5}$ emissions using the ratio of NO_x/VOC emission factors to an assumed $PM_{2.5}$ emission factor. Sierra obtained the assumed total $PM_{2.5}$ emission factor, representing the sum of filterable and condensable emission factors, for a spreader stoker boiler equipped with a baghouse and firing sub-bituminous coal (or bituminous coal when sub-bituminous coal emissions data were not available) from Tables 1.1-5 and 1.1-9 of AP-42 (September 1998). Sierra obtained the NO_x/VOC emission factors for a water injected gas turbine from Tables 1.1-3 and 1.1-19, respectively, of AP-42 (September 1998).

Emission factors for spreader stoker boilers firing sub-bituminous coal (or bituminous coal when sub-bituminous coal emissions data were not available). Sierra similarly allocated hourly emissions among the six boilers proportional to hourly steam production relative to the total steam production.

Aurora Energy, LLC (#315) **-** Aurora Energy, LLC provided DEC with hourly average $PM_{2.5}$/SO_2 emissions data, which Aurora derived from daily emissions, for one release point encompassing 4 emission sources (i.e., coal boilers). Aurora did not differentiate the daily emissions among the underlying emission sources. Aurora did not provide the basis for the $PM_{2.5}$/SO_2 emission calculations. Aurora did not provide any hourly fuel usage or steam production data to enable Sierra to allocate daily emissions on an hour basis proportional to hourly plant production.

Aurora also provided Sierra directly with daily coal usage data from which Sierra used emission factors (in lb/mmBTU) to calculate daily NO_x/VOC emissions. Aurora provided Sierra permitted NO_x emission rates and maximum heat input rates for each boiler, from which Sierra derived NO_x emission factors (in lb/mmBTU). Sierra obtained the VOC emission factor for a coal-fired spreader stoker boiler from Table 1.1-19 of AP-42 (September 1998). Since Aurora did not provide any hourly fuel usage or steam production data to enable Sierra to allocate daily emissions on an hour basis proportional to hourly plant production, Sierra calculated the average hourly NO_x /VOC emissions from the daily NO_x /VOC emissions.

University Of Alaska, Fairbanks (#316) **-** The University of Alaska, Fairbanks (UAF) provided DEC with hourly fuel use data for four boilers – two coal-fired and two oil-fired – comprising four separate release points. UAF subsequently confirmed with Sierra that the fuel oil usage units of measure are actually gallons per minute, though initially reported as gallons per hour. UAF did not provide hourly emissions data. Sierra calculated hourly $PM_{2.5}$/SO_2/ NO_x /VOC emissions using emission factors and fuel usage. UAF provided fuel sulfur content data and a source test-derived coal $PM_{2.5}$ emission factor. Sierra obtained SO_2/ NO_x /VOC emission factors for overfeed stoker boilers burning sub-bituminous coal from Tables 1.1-3 and 1.1-19 of AP-42 (September 1998). Sierra obtained $PM_{2.5}$/SO_2/ NO_x /VOC emission factors for industrial boilers burning #2 fuel oil from Tables 1.3-1, 1.3-2, and 1.3-3 of AP-32 (May 2010).

Doyon Utilities (#1121) **-** Doyon Utilities provided DEC with daily emissions data for $PM_{2.5}$ and SO_2 for six release points, each comprising one coal-fired spreader stoker boiler. Doyon did not provide the hourly emissions for each boiler but did provide the underlying hourly steam production rates associated with each boiler. Doyon calculated daily $PM_{2.5}$/SO_2 emissions from the daily coal usage, daily coal sulfur content, and emission factors. Doyon obtained the $PM_{2.5}$/SO_2 emission factors for spreader stoker boilers equipped with a baghouse and firing sub-bituminous coal (or bituminous coal when sub-bituminous coal emissions data were not available) from Tables 1.1-3, 1.1-5, and 1.1-9 of AP-42 (September 1998). Sierra similarly calculated daily NO_x / VOC emissions from the daily coal usage and emission factors. Sierra obtained the NO_x /VOC emission factors for spreader stoker boilers firing sub-bituminous coal from Tables 1.1-3 and 1.1-19 of AP-42 (September 1998). Sierra allocated hourly emissions among the six boilers proportional to hourly steam production relative to the daily steam production.

Doyon was unable to provide hourly steam production data for January 24th. Sierra allocated daily emissions by assuming that the hourly emissions were proportional to the average of the hourly emissions from the preceding and following day (i.e., January 23rd and 25th). Hourly steam production was also missing for Hours 14 through 16 on November 15th. Sierra assumed that hourly steam production for these missing hours equaled the average of the preceding and following hours (Hour 13 and 17).

Cross-Facility Fuel Properties Review – As an additional data validation check, a comparison of key fuel properties across all of the point source facility data was performed. Although fuel property data submitted by facilities were based on actual fuel measurements, the intent was to ensure there were no inadvertent transcription errors in the submitted data by confirming that these data fell within accepted ranges. Table 7-6-2 summarizes the results of sulfur and ash content comparisons by fuel type across all facilities using each fuel.

Table 7-6-2
Comparison of Key Point Source Fuel Properties

Fuel	Sulfur Content (%)	Ash Content (%)
LPG/Natural gas	~0.001	0
Naphtha	0.018 - 0.024	0
Jet A	0.083 - 0.093	0
Coal	0.12 – 0.34	7-15
Distillate Oil	0.39 – 0.44	0
HAGO	0.69 – 0.71	0

Source Coordinates Review – Coordinates for stack/vent release point locations obtained from each facility were also reviewed by Sierra. The transmittal spreadsheets requested latitude and longitude coordinates and the geodetic datum on which they were based for the source release points of each facility.

To validate the source coordinate data submitted by each facility, the latitude/longitude data and datum (when provided) were loaded into GIS software (ArcGIS). As-received coordinates were given based on a combination of WGS84, NAD1983 and NAD1927 datums. Thus the first step in validating the coordinate data consisted of converting them all to a single standardized datum (WGS84) within ArcGIS. WGS84 was chosen since it is the datum upon with the Google Earth mapping utility is based. The unified datum coordinate data were then exported to a “KMZ” spatial data file for plotting and viewing within Google Earth.

Several coordinate inconsistencies were found for one or two of the facilities and were straightforward to visually identify using Google Earth. They generally appeared to be the result of either transcription errors in the latitude/longitude data provided or related to uncertainty about the datum upon which they were based. A list of facility-specific coordinate inconsistencies was prepared for DEC which was used to follow-up with and obtain corrected data from affected facilities. In one instance, revised location coordinates still did not accurately match comparisons of zoomed in Google Earth views and source locations on a building sketch map. For this instance, it was assumed that the datum with which the coordinates were associated was incorrect and the latitude/longitude coordinates were identified directly from the zoomed in Google Earth view.

Scaling of Episodic Emissions from 2008 to 2013 – Annual actual emissions by emission unit for each facility in calendar years 2008 and 2013 were obtained from the DEC permit database (including facility operating reports and permit fee assessments). Actual annual emissions by facility and pollutant for each year were tabulated and then used to scale the day/hour specific 2008 episodic data provided by each facility from 2008 to 2013. This approach essentially simulates the levels of facility-specific emissions from the 2008 modeling episodes relative to annual emissions, carried forward to 2013.[3]

Table 7-6-3 compares annual fuel use by facility between 2008 and 2013, including splits of HAGO vs. lighter distillates (distillate #2/#1, Jet A, Naphtha) at the GVEA facilities. As seen, there were generally modest changes (roughly within 10%) in annual throughput/fuel use between 2008 and 2013 for most facilities. The GVEA facilities were the biggest exception, using much less HAGO fuel in 2013 than in 2008 (although HAGO use increased at the Zehnder facility). This is important since HAGO has significantly higher $PM_{2.5}$ and SO_2 emissions per unit of fuel energy than the lighter distillate/Jet A/Naphtha fuels it also uses. Coal use at Doyon was 17% higher in 2013 than 2008.

Generally, each facility provided hourly $PM_{2.5}$ and SO_2 emission rates by individual emission unit. Estimates of NO_x, VOC and NH_3 emission rates were developed from AP-42 based emission factors[4] (where fuel use data were explicitly provided) or from fuel-specific emission factor ratios.

[3] Since day-specific 2013 modeling episodes for the Serious SI baseline year were not developed, there was no reason to obtain day- and hour-specific emissions or fuel use from facility operations in 2013.

[4] AP-42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources,” Environmental Protection Agency, January 1995.

Table 7-6-3
Comparison of 2013 vs. 2008 Annual Fuel Use by Facility and Fuel Type

Facility ID	Facility Name	Calendar Year	HAGO (1000 gal/year)	Light Distillate (1000 gal/year)	Coal (tons/year)
109	GVEA Zehnder	2008	827	8	n/a
		2013	1,200	1	n/a
		% Change	+45%	-87%	n/a
110	GVEA North Pole	2008	5,634	23,054	n/a
		2013	2,764	23,345	n/a
		% Change	-51%	+1%	n/a
315	Aurora Energy	2008	n/a	n/a	222,592
		2013	n/a	n/a	214,961
		% Change	n/a	n/a	-3%
316	UA Fairbanks	2008	n/a	935	73,900
		2013	n/a	848	68,599
		% Change	n/a	-9%	-7%
1121	Doyon (Fort Wainwright)	2008	n/a	n/a	246,250
		2013	n/a	n/a	288,702
		% Change	n/a	n/a	+17%

Note: Fuel data in both years for Flint Hills Refinery and Eielson AFB were not available, only annual emissions.

Emission Comparisons

Episodic vs. Annual Actual Emission Levels - Once the facility data were corrected and validated, a series of emission summaries for each facility were developed comparing emissions across each of the two modeling episodes (from the episodic data) to actual emissions for all of calendar 2013. Emission levels were converted to an average daily basis, to standardize the comparisons of episodic and annual emissions.

Figure 7-6-2 through Figure 7-6-6 provide comparisons of $PM_{2.5}$, SO_2, NO_x, VOC and NH_3 emissions (for facilities reporting NH_3 emissions), respectively, for each source facility for which episodic data were collected. Within each figure, three sets of daily average emissions (in tons/day) are plotted for each facility, as described below.

1. *2013 E1 Avg* – Episode 1 average daily emissions, scaled forward to 2013
2. *2013 E2 Avg* – Episode 2 average daily emissions, scaled forward to 2013
3. *2013 Annual* – 2013 annual average daily actual emissions (from DEC database)

Figure 7-6-2. 2013 $PM_{2.5}$ Episodic vs. Annual Average Point Source Emissions (tons/day)

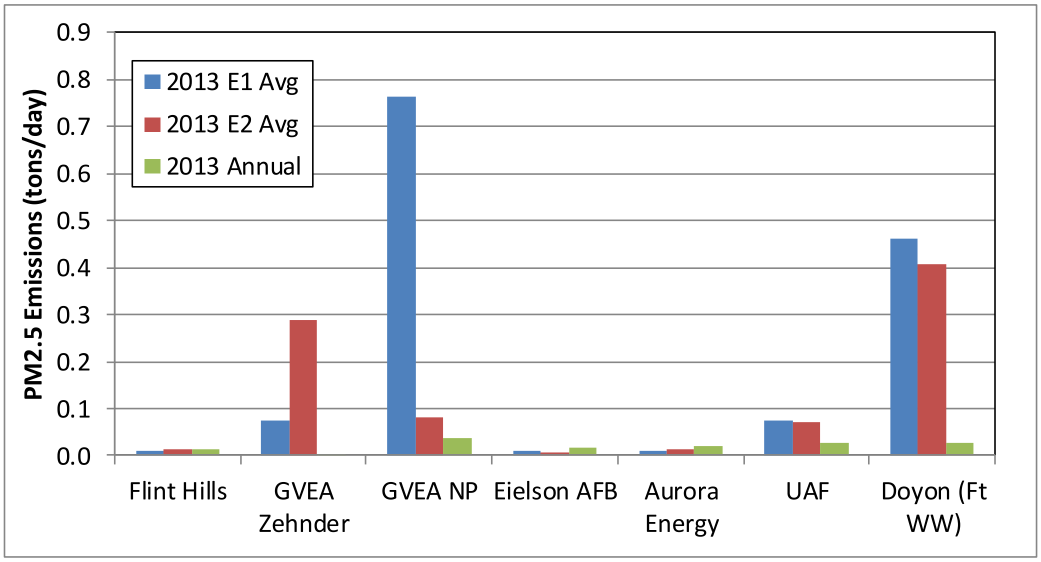
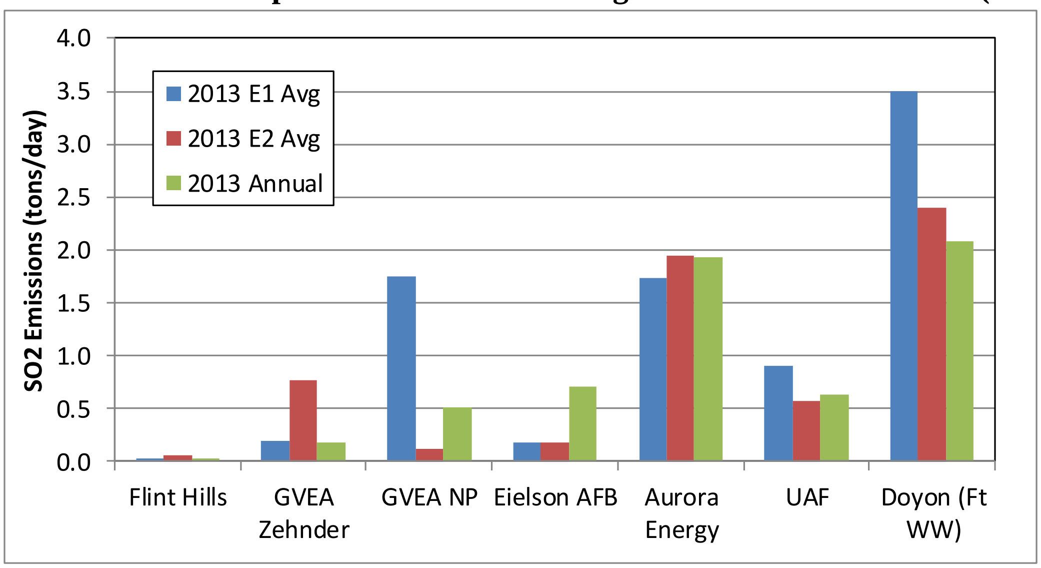


Figure 7-6-3. 2013 SO_2 Episodic vs. Annual Average Point Source Emissions (tons/day)



All five pollutant plots show two elements very clearly. First, the strong seasonal nature of emissions at many of the facilities is evidenced where episodic daily emissions are higher than annual average daily emissions. For example, as shown in Figure 7-6-2 direct $PM_{2.5}$ emissions during the wintertime modeling episodes are much higher than the daily average over the entire year at both GVEA power plants and the Doyon facilities on the Fort Wainwright Army Base. This relates to the fact that more energy is needed for electric heat and power from these facilities during winter when temperatures are colder and nights are longer. Second, each plot shows which facilities are the major point source contributors for each pollutant.

Figure 7-6-4. 2013 NO_x Episodic vs. Annual Average Point Source Emissions (tons/day)

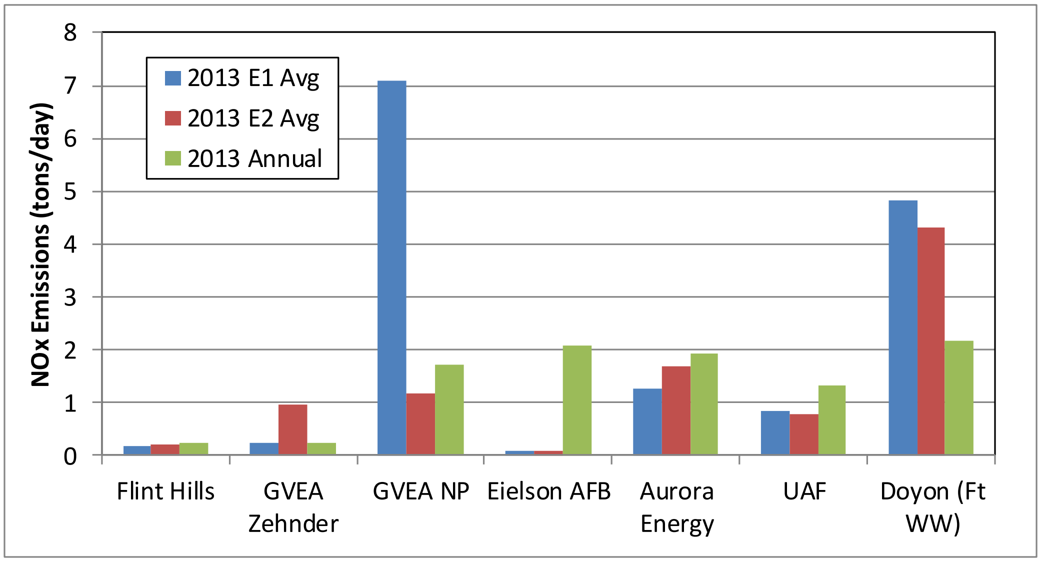
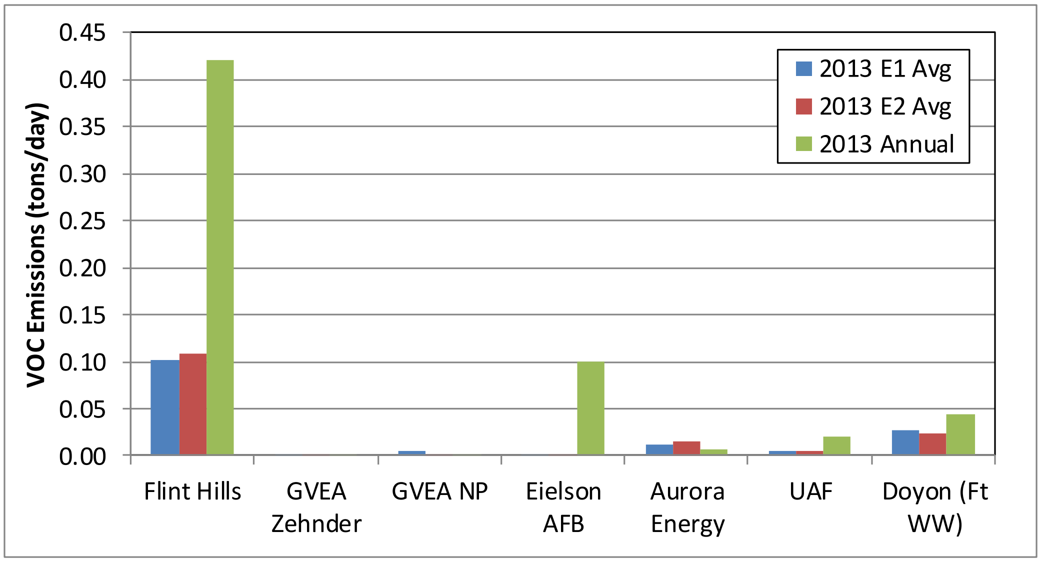


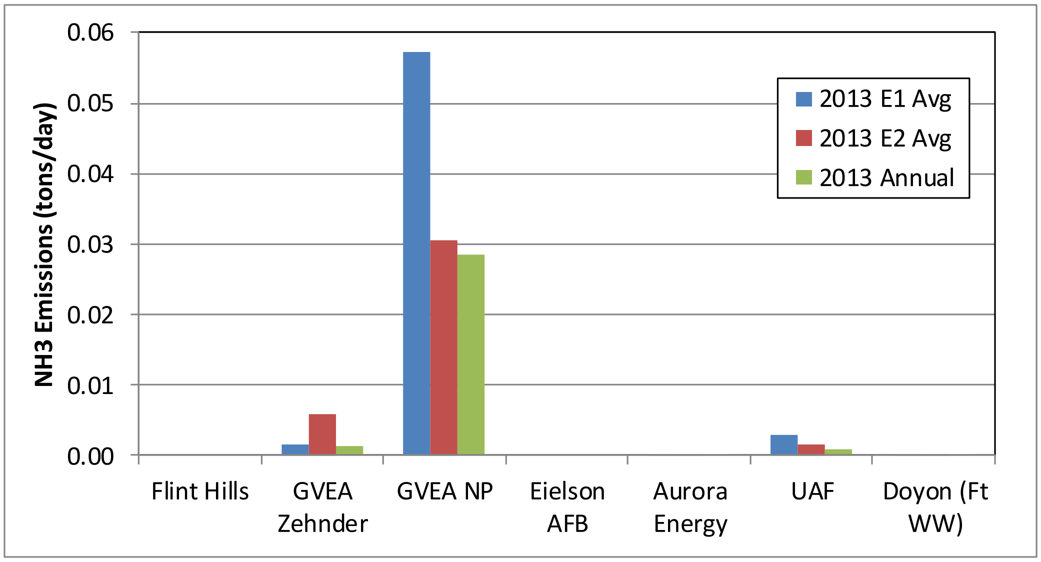
Figure 7-6-5. 2013 VOC Episodic vs. Annual Average Point Source Emissions (tons/day)



Though not shown in Figure 7-6-2 through Figure 7-6-6, a cross-check of the 2008 to 2013 facility emissions scaling updates was performed to verify that scaled 2013 emissions did not exceed annual PTE limits for each facility.

In the modeling inventory, the episodic actual emissions for each point are represented on a day- and hour-specific basis. The E1 and E2 emission levels shown in the plots are averages compiled from the day- and hour-specific emissions across each modeling episode.

Figure 7-6-6. 2013 NH_3 Episodic vs. Annual Average Point Source Emissions (tons/day)



Note: NH_3 emissions were not reported from Flint Hills and Eielson AFB. Those for Aurora Energy and Doyon are too small to see on the scale of the plot.

Hourly Emissions – In addition to examining episodic and annual emissions, comparisons of hourly emissions averaged across all days in each episode were also developed for each facility.

Figure 7-6-7 and Figure 7-6-8 compare average hourly $PM_{2.5}$ emissions for each facility in Episode 1 and Episode 2, respectively. As seen in these two figures, the hourly $PM_{2.5}$ emission profiles vary both by facility within an episode, as well as across each episode for some facilities. The two GVEA facilities show significant variation in hourly average emissions. As seen in Figure 7-6-7 hourly $PM_{2.5}$ emissions at GVEA North Pole (GVEA-NP) vary by nearly a factor of ten, with emissions highest from 10 am through around 10 pm before dropping significantly. The GVEA-Zehnder emissions also vary, but appear more muted when plotted on the same scale because emissions for that facility during Episode 1 are much lower than at GVEA-NP. In contrast, Figure 7-6-8 shows that GVEA-Zehnder $PM_{2.5}$ hourly emissions vary even more dramatically that GVA-NP during Episode 2. Hourly $PM_{2.5}$ emissions for the other five facilities are much more constant throughout the day.

Figure 7-6-9 and Figure 7-6-10 present similar comparisons across Episodes 1 and 2 for hourly SO_2 emissions. Again, the two GVEA facilities exhibit significant variation in diurnal SO_2 emissions, while emissions for the other facilities are generally flat across each hour of the day.

Figure 7-6-7
Episode 1 Average Hourly $PM_{2.5}$ Emissions (lb) by Facility

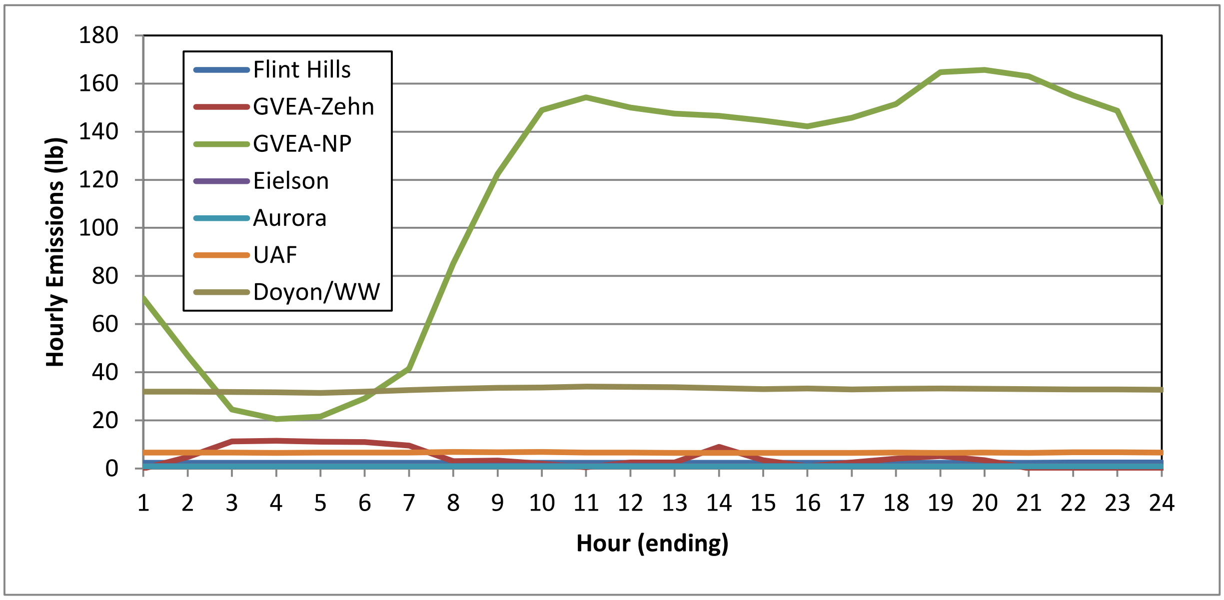


Figure 7-6-8
Episode 2 Average Hourly $PM_{2.5}$ Emissions (lb) by Facility

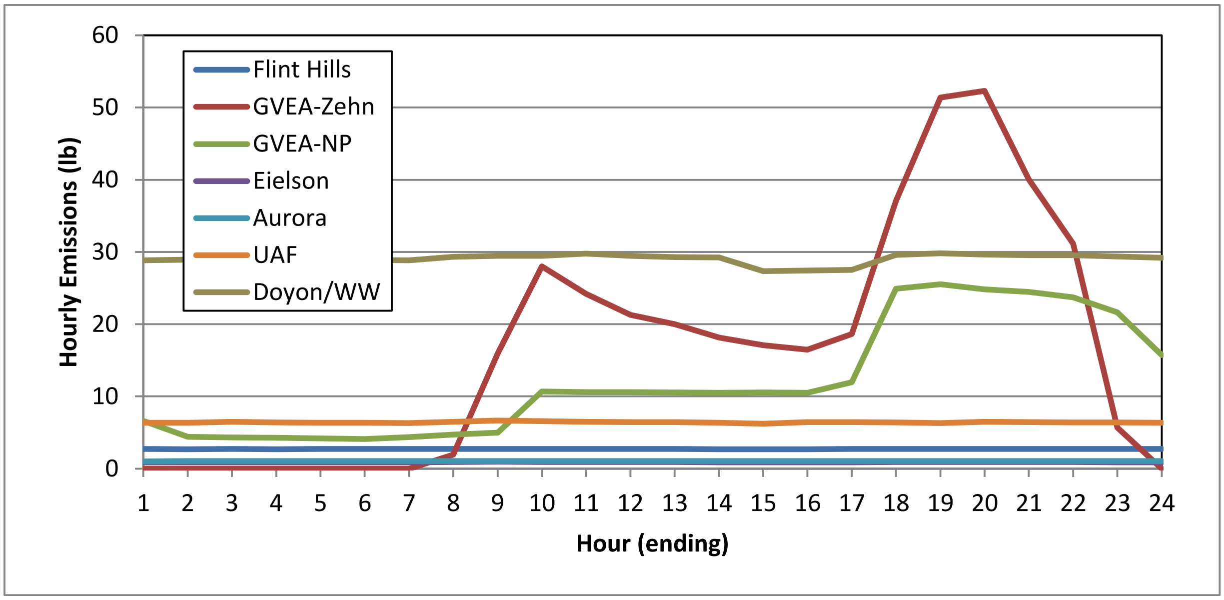


Figure 7-6-9
Episode 1 Average Hourly SO_2 Emissions (lb) by Facility

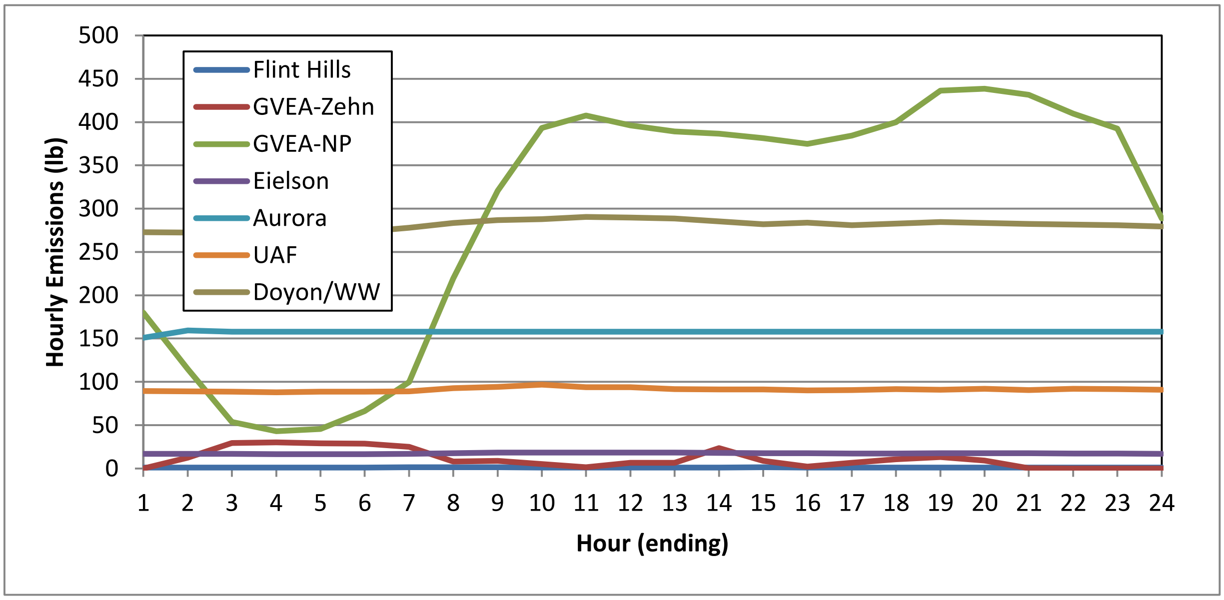
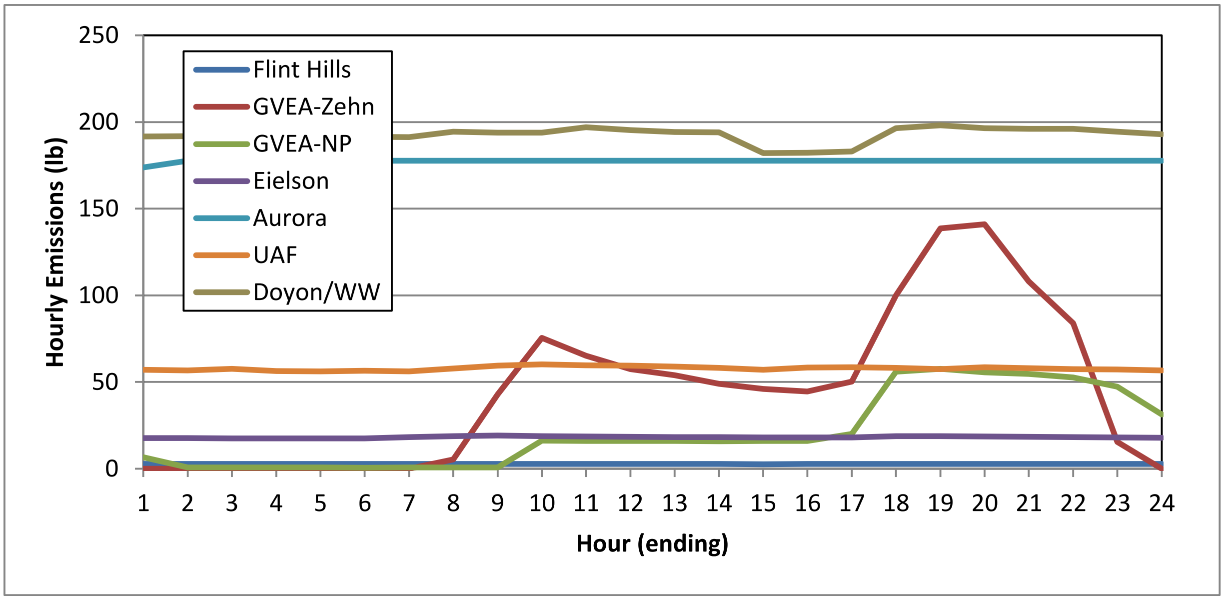


Figure 7-6-10
Episode 2 Average Hourly SO_2 Emissions (lb) by Facility



Projected Baselines

Often, projected baseline emissions for stationary point source facilities are developed based on actual emissions in the baseline year (2013 in this SIP) with activity growth projected using population or employment forecasts or other reasonable growth surrogates, coupled with control factors that reflect effects of emission reductions from phase in or addition of industrial source controls triggered by technology-based regulatory standards (e.g., RACT/BACT[5]) for areas with an existing SIP.

Population-Based Activity Growth Factors – As explained earlier, annual emissions data from each point source facility in calendar years 2008 and 2013 were used to scale/update episodic emissions to 2013. Point source activity in future years beyond 2013 was projected using population growth rates from ADOT/Kittelson socio-economic forecasts for the FMATS 2045 Metropolitan Transportation Plan and covered an area that extended beyond the nonattainment area. Table 7-6-4 presents the population-based activity growth factors by calendar year tabulated from these socio-economic forecasts (which include Eielson F-35 triggered growth). Growth factors are shown relative to calendar year 2013, as well as calendar years 2015 and 2016. The use of growth factors relative to 2015 and 2016 is explained below.

Table 7-6-4
Populated-Based Activity Growth Factors by Calendar Year

Calendar Year	Population Growth Factors		
	2013=1.0	2015=1.0	2016=1.0
2013	1.000	n/a	n/a
2015	1.019	1.000	n/a
2016	1.028	1.009	1.000
2017	1.038	1.019	1.009
2019	1.057	1.037	1.028
2020	1.084	1.063	1.054
2021	1.115	1.095	1.084
2022	1.129	1.108	1.098
2023	1.137	1.116	1.105
2024	1.145	1.123	1.113
2025	1.153	1.131	1.121
2026	1.160	1.139	1.128
2027	1.168	1.147	1.136
2028	1.176	1.154	1.144
2029	1.184	1.162	1.151
2030	1.192	1.169	1.159
2031	1.198	1.175	1.165
2032	1.204	1.181	1.170

[5] RACT – Reasonably Available Control Technologies, BACT – Best Available Control Technologies.

Fuel Switch Effects – DEC also assembled annual emissions from each facility for calendar years 2014 and 2015 and additionally for the two GVEA facilities (North Pole and Zehnder) in 2016 from their permits database to address changes in activity and emissions within the Point Source sector that could not be accounted for simply with population growth factors.

Emissions for 2015 based on annual emissions for each facility were similarly scaled from the 2008 episodic data as was done for 2013 in the Baseline inventory. The reasons for this were twofold: 1) several facilities exhibited variations in annual emissions between 2013 and 2015 that were both upward and downward and outside the range of the modest population growth factors; and 2) Flint Hills shutdown its refinery operations during 2014, so reported annual emissions through 2015 were reviewed to confirm this.

Although annual emissions changes for most facilities from 2013-2015 were typically within ±10%, there were much greater swings for Flint Hills and the GVEA facilities triggered by the refinery shutdown. As noted earlier, both GVEA facilities have historically burned HAGO in their turbines, a heavy distillate fuel produced by the nearby Flint Hills Refinery. With the refinery shutdown, HAGO was no longer produced and the GVEA facilities switched their turbine fuel to lighter and cleaner distillate oil (mostly #2 distillate).

In reviewing the reported 2015 emissions data for GVEA (available by individual emission unit), it was noted that HAGO was still being burned during that year, likely reflecting on-site storage of HAGO that was still in use after 2014. As a result, reported annual 2016 emissions data for the two GVEA facilities were obtained to confirm HAGO use ended in 2015 and to represent "post-HAGO" emissions at these facilities going forward. Annual $PM_{2.5}$ emissions dropped by 96% and 65% at GVEA North Pole and GVEA Zehnder, respectively from 2013 to 2016, largely due to the switch from HAGO triggered by the Flint Hills Refinery shutdown. Conversely, combined SO_2 emissions from the GVEA facilities increased by 24% between 2013 and 2016 as the result of an overall increase in fuel use of 20%, coupled with a larger usage fraction of #2 distillate (3,790 ppm S) relative to lower sulfur jet fuel (970 ppm S) in 2016 relative to 2013. For SO_2, this effectively negated the switch from HAGO.

Thus for all facilities except the GVEA facilities, projected baseline emissions were based on actual 2015 emissions with population based growth factors relative to 2015. For the GVEA facilities growth factor projections were applied to 2016 actual emissions to fully reflect post-HAGO fuel use.

Home Heating – Development of Energy Model

Overview

A spreadsheet-based household space heating "energy model" was developed to support the SIP inventory. This energy model was based on locally-developed home heating energy usage data collected from a stratified sample of residential homes in the Fairbanks area during cold wintertime conditions. The data were collected under a 2011 study[6] conducted by the Cold Climate Research Housing Center (CCHRC).

The primary objective of the study was to collect detailed heating appliance usage pattern data for homes using various combinations of oil and wood heating devices. The approach consisted of instrumentation and collection of fuel usage and device temperature data for a stratified random sample of 30 homes in Fairbanks that used various combinations of oil and wood home heating devices based on pre-study screening surveys. The target sampling matrix consisted of selection of 10 households in each of the following three groups (as identified based on the screening surveys):

1. *Group "O" (Oil Only)* – households heated solely with oil devices that included central oil boilers, oil-fired furnaces or direct-vent (DV) room heating oil devices;

2. *Group "M" (Mixed Oil and Wood)* – households heated with a mixture of oil devices (as listed above) and wood devices that included wood stoves, outdoor wood boilers (OWBs) and fireplaces with wood as the secondary heating source; and

3. *Group "W" (Wood Only/Primary)* – households heated exclusively or primarily with wood-burning devices.

Table 7-6-5 provides a summary of the homes sampled and heating devices within each group. Of the ten "oil" homes, seven used Central Oil boilers, two used direct vent oil heaters, and the tenth used an oil-fired furnace. Ten additional homes using a mix of fuel oil and wood were studied. The final ten homes were identified as primarily wood heating. The wood heating systems included seven wood stoves, one fireplace and two outdoor wood boilers. The rated output (in BTU/hour) of each household's oil device is also listed in Table 7-6-5. (For direct vent oil heaters which have 3-4 fuel rate settings, the maximum output is shown.)

The intent of this stratified sample of households was not to necessarily be a representative self-weighing sample of wintertime residential space heating in Fairbanks, but rather to ensure a sufficient range of the most commonly used residential heating devices were sampled and that the range of usage patterns for households with single and multiple heating devices (and their interactions) were adequately measured.

[6] "Heating Appliance Operation Survey, Phase II Fairbanks, Alaska," Cold Climate Research Housing Center, June 30, 2011.

Table 7-6-5
Home Heating Instrumentation Sample Summary

Residence ID	Heated Area (ft^2)	Oil Appliance	Rated BTU/hour	Wood Appliance
O-01	2,448	Central Boiler	100,000	n/a
O-02	1,500	Central Boiler	147,000	n/a
O-03	2,775	Central Boiler	189,000	n/a
O-04	2,912	Borg Warner Furnace	156,800	n/a
O-05	1,400	Toyo Direct Vent	39,875	n/a
O-06	1,200	Toyo Direct Vent	39,875	n/a
O-07	1,200	Central Boiler	140,000	n/a
O-08	2,200	Central Boiler	189,000	n/a
O-09	2,100	Central Boiler	147,000	n/a
O-10	2,200	Central Boiler	95,200	n/a
M-01	2,464	Central Boiler	147,000	Wood Stove
M-02	2,900	Central Boiler	106,250	Wood Stove
M-03	2,500	Central Boiler	133,000	Wood Stove
M-04	1,770	Central Boiler	95,200	Wood Stove
M-05	1,900	Central Boiler	140,000	Fireplace
M-06	3,000	Central Boiler	252,000	Wood Stove
M-07	1,400	Central Boiler	105,000	Wood Stove
M-08	1,760	Central Boiler	147,000	Wood Stove
M-09	2,600	Central Boiler	118,750	Wood Stove
M-10	2,000	Central Boiler	231,000	Wood Stove
W-01	1,250	Central Boiler	119,000	Wood Stove
W-02	980	Toyo Direct Vent	43,750	Wood Stove
W-03	2,488	OWB preheat	137,500	Outdoor Wood Boiler
W-04	2,100	Central Boiler	140,000	Wood Stove
W-05	5,000	OWB (multi-fuel)	154,000	Central Boiler-oil/wood
W-06	915	Toyo Direct Vent	20,625	Wood Stove
W-07	4,580	Central Boiler	224,000	Outdoor Wood Boiler
W-08	1,400	Toyo Direct Vent	20,625	Wood Stove
W-09	884	Wood Stove only	n/a	Wood Stove
W-10	575	Toyo Direct Vent	20,625	Wood Stove

n/a = Not applicable

The final analysis revealed that during the sampling period, which was characterized by very cold ambient temperatures, three of the homes initially identified as primarily wood burning by the owners actually used oil for more than one-third of the heating energy consumed during the sampling, and could have been characterized as mixed.

Data loggers recording the fraction of time a motor was on were used to monitor central oil boiler and furnace heating appliances (which have a single fuel rate setting). Thermocouples mounted on the surface of the exhaust flue were used to monitor temperatures from wood burning devices and direct vent oil furnaces (which can run at several fuel rate settings). The sampling period extended from early December of 2010 through late February of 2011. Generally speaking, each home was instrumented and fuel usage measurements were collected over a period spanning 6-10 weeks. Written diaries or "logs" of actual fuel use were also kept during the first couple of weeks of sampling in each household. As explained later, these fuel use logs were used to calibrate and validate raw data logger and thermocouple measurements.

Ambient temperature measurements were also collected by CCHRC from a handful of meteorological stations in the Fairbanks area during the winter 2010-2011 sampling period. CCHRC reviewed data from both National Weather Service and Citizen Weather Observer Program sites (CWOP), and selected sites to represent ambient temperatures at each sampled household based on completeness of record and proximity/representativeness of the weather station to each home. CCHRC then temporally merged historical ambient temperature data (recorded every 30 or 60 minutes) from each selected weather station into the appropriate household data file, providing a raw database of hourly oil device operating patterns and wood (and direct vent oil) thermocouple measurements and ambient temperatures.

Sierra then performed a series of data validation and completeness checks on measurements and fuel usage diaries from each sampled household. As discussed later, 4 of the 30 sampled homes were dropped from the analysis because of problems with the measuring equipment as installed in those homes, rendering most if not all of the data for those households invalid.

After reviewing/validating the data, they were analyzed to generate a dataset of household hourly heating energy use (in BTU/hour) by device type and ambient temperature. This winter 2010-2011 energy use dataset was then used to develop a multivariate model of residential household space heating energy use as a function of heated dwelling size, device mix, hour of the day and ambient temperature that could be readily applied within the SIP inventory workflow to generate episodic day-specific and hourly heating energy use and emission estimates. The details of these data analysis and energy model development elements are discussed in the next sub-sections.

Data Processing

Because of the device-specific nature by which usage patterns and fuel measurements were collected, different processing methods were utilized for each type of device. These device-specific methods are described separately below.

Central Oil Boilers/Furnaces – For central oil devices, the process of determining hourly energy usage was straightforward. Data loggers were used to continuously monitor and record the fraction of each hour in the sampling period that the boiler/furnace was operating. Hourly fuel usage rates were determined from the label on the unit (preferred) or from the instruction manual for the particular boiler/furnace model. The energy content (EC) of given volume of fuel was dependent on fuel oil type: 125,000 BTU/gal was used for Fuel Oil #1, while 140,000 BTU/gal was assumed for Fuel Oil #2.

The BTU output for each hour of operation was then simply calculated as:

BTUs/hr = % of Hour Operated × Fuel Usage Rate (gal/hr) × Fuel EC (BTU/gal)

For example, if an oil device burning #2 oil with a fuel usage rate of 0.8 gal/hr was measured to operate for 32.1% of the time during a given hour, the calculated oil energy use for that hour is:

32.1% percent on time × 0.8 gal/hour × 140,000 BTU/gal = 35,952 BTU/hour

Data logger results also included a date and time stamp of the reading. BTU calculations were performed in this manner for all central oil devices and merged into a common database across all households. Results were summarized by residence both as hourly and daily BTUs and inspected for reasonableness.

A log of oil usage was maintained by the homeowners for the duration of the sampling period. At the start and end of sampling and each time a delivery of heating oil was made to their tank, the homeowner used a calibrated dipstick to record the fill level in their oil tank. Tank volume calculations were performed by CCHRC to translate the fill level measurements to volumes and estimates of incremental fuel use between deliveries, although a source of uncertainty for these fill level-based fuel volume estimates occurred for homeowners with underground tanks with unknown capacity and geometry. Notwithstanding this uncertainty for underground tanks, total volume of fuel determined from summing the hourly usage rates was compared to total fuel estimates from storage tank volume logs for consistency/validation.

Wood Burning Devices - Determination of the hourly heat energy obtained from burning wood was less direct. Homeowners recorded the time and weight of all fuel added during an initial "calibration" sampling period. The duration of this period varied from a few days to, in one case, the entire sampling period, but typically averaged 1-2 weeks. The total sampling period within each household was generally two months.

All wood additions were assumed to be White Birch, the predominant wood type in Fairbanks. Using US Forest Products Laboratory tables, at 20% moisture content White Birch is reported to have a weight of 3,179 pounds/cord and an energy content of 20.3 mmBTU/cord, yielding an average energy content of 6,386 BTU/lb.

For the purpose of initially analyzing the wood usage data, the average moisture content of wood from sampled households with wood devices was assumed to be 26.6% based on moisture measurements of wood sampled from those households conducted by CCHRC. After adjusting for this sampled moisture content, the average energy content used to estimate hourly wood-based energy use was 6,053 BTU/lb. (As explained later, a second wood energy content adjustment was performed when using the energy model developed from these data to calculate

SIP inventory emissions based on specific wood species mix and moisture content data collected to support the inventory estimates.)

This energy content was multiplied by the pounds of fuel added from the homeowner wood diaries to arrive at BTUs added from each wood loading. These fuel-loading BTUs were then totaled across the initial instrumentation period during which wood loading diaries were kept.

A thermocouple was used to measure the flue temperature or surface temperature of the wood stoves from a single fixed location throughout the instrumentation period for each device. The thermocouple logger recorded temperature at 5-minute intervals, producing a value that is a relative indicator of the rate of heat release. Under a simplistic ideal case for distributing energy use across the fuel loading period, the flue temperature would be allowed to rise from ambient during combustion until all of the fuel had been consumed, when the temperature would return to ambient. The temperature rise above ambient in each five minute period during the combustion period would then be summed to provide a surrogate for total energy emitted from that fuel load. The ratio of flue temperatures and wood BTUs would then be used to estimate a rate of energy consumption per cumulative degrees per five-minute period using the data logger results.

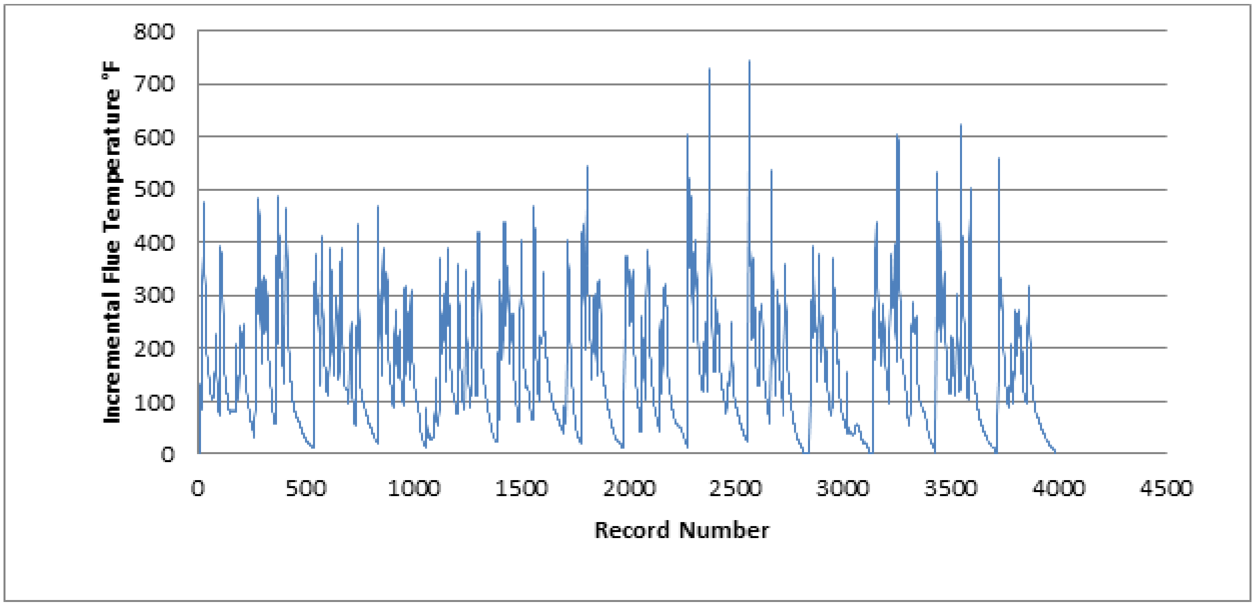
The challenge for wood-burning households was turning the record of wood BTUs added over time into a time series of heat energy (in BTUs) released by the unit. The approach taken was to use the temperature rise recorded by the datalogger to proportion the estimated amount of wood BTUs added to the unit. The temperature rise is the number of degrees Fahrenheit that the recorded temperature is above its baseline. The baseline was determined by locating the lowest temperature level recorded by the datalogger. For indoor devices (stoves, fireplaces) the baseline temperature was based on the indoor room temperature. Outdoor air temperatures were used as baselines for outdoor wood boilers (OWBs).

Some households burned wood sporadically. For these, data points could be determined for each burn event, consisting of the wood BTUs added and the total temperature rise over the time period of the burn. Temperatures were recorded every 5 minutes, so the total temperature rise has units of °F × 5-minute interval. For these households, the calibration determined an average factor (°F per BTU) that can be divided into the observed temperature rise in any 5-minute period to determine the BTUs released. The term "BTUs released" refers to the total BTUs estimated to be released by the fire in the time period, consisting of both BTUs that heat the home and BTUs that are lost to the environment.

Other households burned wood nearly continuously and offered no discrete events that could be used to develop an average calibration factor. The same general approach, however, was applied. The cumulative pounds of fuel added (as BTUs of fuel) were plotted against cumulative rise in flue temperature. A linear slope/intercept equation was fit to the data. This resulting equation was then used to estimate the BTUs produced through the entire sample period from the cumulative degree-minutes recorded by the data logger.

Figure 7-6-11 displays the flue temperature observed during the fuel weighing period for one home from the instrumented sample, mixed oil-wood household M-02, which used wood for about 30% of its heating energy. The 4,000 temperature readings made at 5 minute intervals

Figure 7-6-11
Example Wood Stove Fuel Temperature Trace, Household M-02



represent 14 days during which the owner weighed the fuel and recorded the results in a log. Individual temperature readings were adjusted by subtracting the lowest temperature observed in the study period. Thus, as labeled on the vertical axis of Figure 7-6-11, the plotted flue temperatures are incremental values over this baseline minimum temperature.

Figure 7-6-12 displays the cumulative BTU wood additions and cumulative flue degrees for the M-02 woodstove. During this sampling period, a total of 18 wood loadings were made. (Some contained smaller amounts of wood and cannot be discerned from the plotted scales in Figure 7-6-12.) A total of 630 lb of wood were burned across all 18 loadings, equivalent to 3,813,390 BTUs of fuel energy.

The red line in Figure 7-6-12 displays the fitted relationship used to estimate BTUs from flue temperatures recorded during the more extended data collection period for this specific woodstove. Based on the output for this particular stove and the location of the thermocouple during its instrumentation, the relationship between fuel loading data and flue temperatures (i.e. the fitted slope) was found to be 0.190 DegF-Hrs/BTU.

These same analyses of cumulative flue degree-hours vs. wood BTUs were developed for each of the households with valid wood device measurements. Separate fitted “temperature slopes” were developed for the wood devices in each household and were necessitated by the variation in flue temperature response to BTUs calculated from wood loading. This device-to-device variation was the result of difference in where the thermocouple was placed on or near each device, the size/output of the firebox and the general usage pattern of each device (frequent vs. occasional).

Figure 7-6-12
Cumulative Wood Stove BTUs and Flue Degrees, Household M-02

Table 7-6-6 lists the resulting fitted temperature slopes developed for each of the 16 Mixed and Primary wood device households with valid data. As shown in the highlighted column, the fitted slope (representing the relationship between measured flue temperature and fuel energy) differed across the devices by roughly an order of magnitude due to the aforementioned factors. Also listed for each household are the specific wood devices and sensor locations where the thermocouples were mounted on each device.

(As noted below Table 7-6-6, separate fitted slopes were developed for two distinct portions of sampling in household W-01, that corresponded to validated sampling periods before and after the thermocouple fell off the wood stove and was re-attached in a slightly different location.)

Using the individually fitted relationships for the wood-burning devices in each of these households developed based on that initial portion of the instrumentation period where wood loadings were measured (1-2 weeks), wood BTU usage estimates could be reasonably predicted based solely on the thermocouple-based flue temperature measurements over the entire (6-10 week) sampling period for each household.

As discussed later under “Quality Assurance and Data Validation,” installation/removal diaries, homeowner observations and temperature traces over the entire sampling period for each wood device were carefully examined to ensure validity of the thermocouple data.

Table 7-6-6
Fitted Temperature/Fuel Energy Slopes for Sampled Wood Devices

Res. ID	Heated Area (ft^2)	Device No.	Wood Device	Temp. Slope (°F-hrs/BTU)	Temperature Sensor Location
M-02	2900	1	Wood Stove	0.190	Back of single wall stove pipe
M-03	2500	1	Wood Stove	0.078	Uninsulated flue pipe
M-04	1770	1	Wood Stove	0.072	Under the door
M-05	1900	1	Fireplace	0.142	Left firewall
		2	Wood Stove	0.175	Not recorded
M-06	3000	1	Wood Stove	0.046	Under the door area
M-08	1760	1	Wood Stove	0.120	Below door area
M-09	2600	1	Wood Stove	0.200	On side of firebox under heat shield
W-01	1250	1	Wood Stove	0.039, 0.043[a]	Uninsulated stove pipe
W-03	2488	1	OWB	0.031	Firebox door edge
W-04	2100	1	Wood Stove	0.046	Uninsulated exhaust stove pipe
W-05	5000	1	OWB (multi-fuel)	0.027	Exhaust flue
W-06	915	1	Wood Stove	0.042	On side of firebox under heat shield
W-07	4580	1	OWB	0.013	Fan motor
W-08	1400	1	Wood Stove	0.125	Side of stove
W-09	884	1	Wood Stove	0.130	Back of stove pipe
W-10	575	1	Wood Stove	0.115	Uninsulated stove pipe

[a] Two separately-fitted slopes were developed for this wood stove because the thermocouple fell off during the instrumentation period and as re-attached at a slightly different location for the remainder of the sampling.

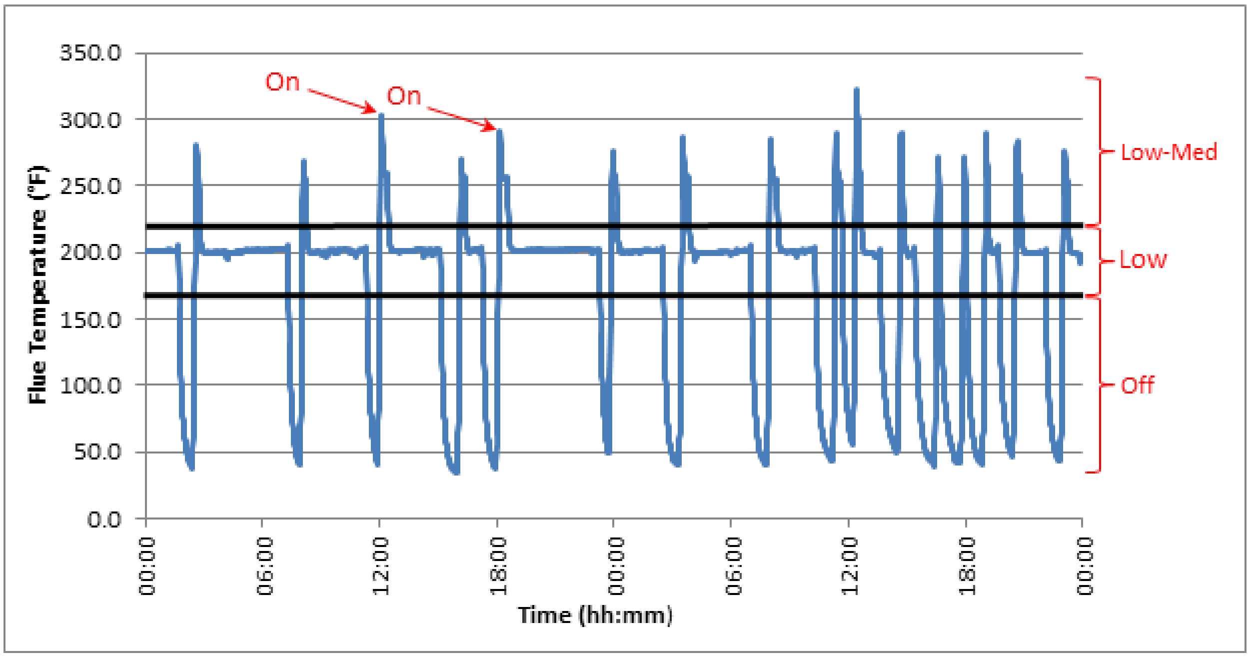
Direct Vent Fuel Oil - Direct Vent fuel oil combustion technology is used for both central home heating and room space heating. Both the large and small units use three or four fuel flow rates which are staged in response to ambient temperature and thermostat setting. This variable fuel flow precludes the use of the simple hourly fraction-on data loggers used with traditional constant-flow on/off centralized oil boilers. Instead, data loggers set to record flue temperatures at one minute intervals were used. At the same time, fuel oil usage was recorded in a diary or log book, providing a cross check of final fuel oil usage estimates.

The control operation and the flue temperature recording position varied between households. The flue temperature patterns similarly varied. Some common patterns, however, emerged. The most common pattern involved a sudden rise from ambient to an elevated level, which would be held from one to several minutes, followed by a reduction to a lower level which could be maintained from a few minutes to an hour or more, followed by a drop back to the initial ambient level. The length of the "hold" period was related to the outdoor ambient temperature, with lower temperatures resulting in longer run times.

Trial and error assignments of fuel usage rates to the different intervals were used to calculate total fuel usage during a period when the total amount of fuel used was known (from the diary logs). In general, the best agreement between recorded and estimated fuel usage was found when the second to lowest fuel usage rate was assigned to the initial startup period, followed by the lowest fuel usage rate for the extended stabilized period.

Figure 7-6-13 presents a representative example of measured flue temperatures from a direct vent heater (in household O-06) that clarifies this approach. Note the flue temperature in this example returns to just below 50°F when the device is off. When the heater starts, the flue temperature rises above 250°F, and holds from one to several minutes. In Figure 7-6-13, these events are marked with red arrows at times around 12:00 and 18:00 on the first day. The temperature then drops to about 200°F and holds from several minutes to several hours. It then shuts off and the temperature returns to below 50°F. The thick horizontal lines demonstrate "cut points" of 170°F and 220°F that were used to identify the fuel flow modes for this specific direct vent heater, a Monitor 2400.

Figure 7-6-13
Sample Direct Vent Oil Heater Fuel Temperature Trace



The Monitor 2400 has the following four fuel rates[7]:

1. High - 0.319 gal/hour;
2. High-Medium - 0.240 gal/hour;
3. Low-Medium - 0.180 gal/hour; and
4. Low - 0.120 gal/hour.

[7] Fuel rate data for each direct vent heater in the sample were looked up from published specifications based on the specific heater models identified in each household and recorded by CCHRC.

Discussions with CCHRC confirmed these direct vent heaters generally operate (under thermostatic control) at their lower fuel rates because they are often used as individual room heaters and are quite efficient. Thus as shown at the right of Figure 7-6-13, temperatures above the 220°F cutpoint established for this specific heater were assumed to reflect operation of the device at its Low-Medium setting. Flue temperatures between 170°F and 220°F were assumed to reflect operation at the Low setting. And temperatures below 170°F were assumed to reflect periods where the thermostatically controlled heater was shut off. For each region, fuel rates were translated into device energy use (in BTUs). Direct vent heaters generally operate on Fuel Oil #1 (125,000 BTU/gal).

The first day of operation in the example corresponds to a day with a low outdoor ambient temperature that results in a high demand and nearly continuous furnace operation. The second day demonstrates the reduced demand on warmer days, with furnace operation in the day time hours cycling on for a short time and then remaining off for longer periods. This pattern of increasing furnace cycling frequency with higher ambient temperatures was typical.

Two higher capacity direct vent oil units and two supplemental direct vent room heating units were included in the study sample.

Quality Assurance and Data Validation

A number of problems were encountered in analyzing and processing the raw data from the instrumentation study. The raw data from CCHRC were provided in individual spreadsheets for each household. In addition to the raw measurements, each household spreadsheet included detailed descriptions of the heating devices and locations within each house, the heated building space, wood/oil usage diaries/logs and most importantly, installer/remover or homeowner observations regarding any operational issues noted during the sampling (e.g., a thermocouple stopped working or fell off). All results were carefully reviewed for completeness and reasonableness in assessing whether all or a portion of the data measured in each sampled household were deemed valid.

The temperature measurement sensors presented the greatest difficulty. The thermocouples were intended to be mounted in contact with the flue surface. It was sometimes noted that the thermocouples detached from the surface, and the recorded results reflected the significant drop in temperatures recorded at those times. In other cases, it appeared as if the thermocouple electrical connection to the data logger was intermittent or failed, as reflected by large negative readings (-328°F was typical). The results, therefore, were carefully reviewed to remove these data from the final results. It was also important that the temperature recorded during the calibration period when the fuel was being weighed be consistent with the temperatures recorded before and after this period. Three wood burning homes were removed from the sample because flue temperature recording problems invalidated the results.

The base time unit of all resulting data streams was adjusted to one-hour intervals. The standard centralized oil-based loggers began with a one-hour time base. The wood burning flue temperature loggers recorded data every five minutes. The direct vent temperature loggers recorded data every minute. In all cases, calculated BTUs for each device were tabulated on an hourly basis (i.e., five-minute and one-minute flue temperature-based BTUs were summed over each hour). Device and ambient temperatures reported for the hour were averaged.

Results from homes with more than one heating source were aligned to start and end at the same time. For example, the data logger used to measure fuel oil usage might have been activated three hours before the logger used to monitor wood stove flue temperature was installed and operating. In this instance, the oil data for those initial three hours were discarded. In other cases, at the end of a sampling period a logger might have been removed and allowed to continue running for several hours. If one logger failed during the trial, the results from loggers for any other heating devices in the household were also discarded to ensure the remaining sample was not biased in accounting for interactions/usage patterns between the two heating sources.

Table 7-6-7 summarizes the household-by-household data validation results from the original 30 household sample. Four of the 30 households (shaded rows in Table 7-6-7) had instrumentation failure or other issues. All the data from these households (M-01, M-07, M-10 and W-02) were invalidated and discarded from further analysis. As summarized in Table 7-6-7, data for portions of the instrumentation duration in some households that were suspect were also discarded. In general, the homes with oil heating ran much more consistently, with no corrections or deletions required for any sampling period. As noted earlier, the wood heating homes required more effort to validate and assemble consistent data sets. All told, roughly 85% of the originally measured data were validated/corrected and utilized as the basis for the Fairbanks home heating energy model.

Separate spreadsheets containing data for each household as received from CCHRC were combined into a single database during the data validation and quality-assurance processing. The final validated database consisted of time-aligned records of <u>hourly</u> energy usage and outdoor ambient temperature by residence.

Each hourly record in the final database contained the household ID, heated space, ambient temperature and the measured/calculated energy use (in BTUs) for each of five device types found in the sample:

1. Woodstoves/Inserts (WS);
2. Fireplaces (FP);
3. Outdoor Wood Boilers (OWB);
4. Central Oil Boilers/Furnaces (COil); and
5. Direct Vent Oil Heaters (DV).

The final database contained over 25,200 valid hourly energy use records. This represented an average sampling duration of 970 hours or 40 days per household for the 26 valid households.

Table 7-6-7
Home Heating Instrumentation Data Validation Summary

Res. ID	Data Validation Results by Household
O-01	This is a 2,448 ft^2 home with central oil heating. The monitor was installed on 12/15/10 and removed 1/26/11. A total of 1,011 hours or 42 days of data were collected from this residence.
O-02	This is a 1,500 ft^2 home with central oil heating. The monitor was installed on 12/23/10 and removed on 2/16/11. A total of 1316 hours or 54 days of data were collected from this residence.
O-03	This is a 3,000 ft^2 home with central oil heating. The monitor was installed on 12/16/10 and removed on 1/27/11. A total of 1,015 hours or 42 days of data were collected from this residence.
O-04	This is a 2,912 ft^2 home with central oil heating. The monitor was installed on 12/16/10 and removed on 1/27/11. A total of 1,014 hours or 42 days of data were collected from this residence.
O-05	This is a 1,400 ft^2 home heated with a main direct vent (DV) oil furnace (40,000 BTU/hr) and a smaller DV bedroom unit (20,000 BTU/hr). The monitors were installed on 12/16/10 and removed on 1/27/11. A total of 1,007 hours or 42 days of data were collected from this residence.
O-06	This is a 1,200 ft^2 home heated with a single DV oil furnace. The monitor was installed on 12/16/10 and removed on 1/27/11. A total of 994 hours or 41 days of data were collected from this residence.
O-07	This is a 1,200 ft^2 home with central oil heating. The monitor was installed on 12/21/10 and removed on 2/04/11. A total of 1085 hours or 45 days of data were collected from this residence.
O-08	This is a 2,200 ft^2 home with central oil heating. The monitor was installed on 12/17/10 and removed on 2/04/11. A total of hours 1,255 or 52 days of data were collected from this residence.
O-09	This is a 2,100 ft^2 home with central oil heating. The monitor was installed on 12/23/10 and removed on 2/02/11. A total of 993 hours or 41 days of data were collected from this residence.
O-10	This is a 2,200 ft^2 home with central oil heating. The monitor was installed on 12/22/10 and removed on 2/09/11. A total of 1,152 hours or 48 days of data were collected from this residence.
M-01	This 2464 ft^2 home is heated by a wood stove and a central oil fired boiler. The results from the home were discarded when it was determined that logging of wood added was performed while there was a poor thermocouple connection, invalidating the temperature vs. BTU calibration.
M-02	This 2900 ft^2 home is heated by a wood stove and a central oil boiler. Recordings were made from 12/14/2010 through 1/27/2011. The wood stove was not used from 12/28/2010 through 1/21/2011. The temperatures recorded after 1/21 were inconsistent with the earlier recordings, and were thus discarded. The oil usage logger performed well through the entire period, but results after 12/28 were discarded to maintain a representative sample for a home with two heat sources. The final data set for both appliances was from 12/14/10 through 12/28/2011, a total of 337 hours or 14 days.
M-03	This 2500 ft^2 is heated by a wood stove and a central-oil fired boiler. Valid recordings were made from 12/15/2010 through 1/18/11 and from 2/3/11 through 2/4/11. The occupants were on vacation in late January so the period was removed from the data set to maintain a representative sample for a home with two heat sources. The final data set included 835 hours or 34 days of valid results.
M-04	This is a 1770 ft^2 residence with a wood stove and oil fired boiler with holding tank. Valid recordings were made from 12/22/10 through 2/4/11, a total of 45 days or 1,080 hours. An interesting inverse relationship between ambient temperature and wood usage was observed during the test period. Wood usage dropped off when the ambient temperature was above 0°F.

Table 7-6-7
Home Heating Instrumentation Data Validation Summary

Res. ID	Data Validation Results by Household
M-05	This is a 1900 ft^2 residence with a central oil fired boiler supplemented with heat from a fireplace and a wood stove. About 22% of the total BTU energy observed in the home was produced by the wood appliances. Data was collected from 12/21/10 through 02/15/11, a total of 55 days or 1,320 hours. The inverse wood fuel usage with ambient temperature seen with M-04 continued with this household.
M-06	Residence M-06 also uses an oil fired central boiler with holding tank and a wood stove. The 2700 ft^2 home includes an additional 300 ft^2 allowance for a basement that is generally maintained about 50°F. Data was collected here from 12/21/10 through 2/03/11, a total of 45 days or 1,080 hours.
M-07	Residence M-07 used an oil fired central boiler as its primary heating source, with a wood stove as a secondary source. The data logger used to monitor oil usage was not initialized during installation. No data was recorded during the study. Multiple problems were noted with the thermocouple used to monitor the wood stove. This residence was not used in analysis. It is a 1400 ft^2 residence. Monitors were installed on 12/23/10 and removed 02/03/11. No usable data was collected.
M-08	Residence M-08 uses an oil fired central boiler as its primary heating appliance (91%) and a secondary wood stove (9%). Wood usage was sporadic. The home has an area of 1,760 ft^2. The monitors were installed on 12/20/10 and removed on 02/04/11. A total of 43 days, or 1,035 hours of data were collected.
M-09	This residence used an oil-fired central boiler as its primary heating appliance (79%) and a wood stove for the remainder. Wood usage was not particularly related to outdoor ambient temperature. The home has an area of 2600 ft^2. The monitors were installed on 12/16/10 and removed 1/28/11. A total of 1033 hours, or 43 days, of data were collected.
M-10	This residence used an oil-fired central boiler and two wood stoves. Thermocouple problems with the wood stoves made the data from this home unusable. It is a 3,000 ft^2 home. Approximately 1,000 ft^2 was shut off during day time hours. The monitors were installed on 12/17/10 and removed 02/03/11. No usable data was collected from this home.
W-01	This residence is primarily heated with a wood stove (83%), with central oil heating as a secondary source (17%). The home has 1,300 ft^2 of area, with a 50 ft^2 unheated artic entry, leaving 1,250 ft^2. The data collection monitors were installed on 12/24/10 and removed 2/9/11. The wood stove thermocouple fell off on 12/26/11 and was restored on 1/3/11. Both the wood and oil data collected in this period was removed from the data. A net total of 946 hours or 39 days of valid data were collected and used in the analysis.
W-02	This residence has a wood stove and direct vent oil heater. The thermocouple on the DV oil heater fell off after installation. A total of 120 gallons of fuel oil were reported as used, but could not be allocated. The wood data collected during the same time period was, therefore, invalidated. The home has 980 ft^2 of heated area. The monitors were installed on 12/17/10 and removed 2/24/11. No data from this home was used in the final analysis.
W-03	This is a 2,488 ft^2 home. Primary heating is from an Outdoor Wood Boiler (OWB). Oil is used to ignite the OWB. A thermocouple monitor was installed on the firebox door on 12/17/10. A separate monitor was installed on the oil burner on 12/28/10. Data collection ended on both systems on 1/31/11. Only results collected when both monitoring systems were functioning were used in the final analysis. A total of 815 hours of data, or 34 days, were collected.

Table 7-6-7
Home Heating Instrumentation Data Validation Summary

Res. ID	Data Validation Results by Household
W-04	This is a 2,100 ft^2 home that uses a central oil boiler and a wood stove. While initially classified as a primarily wood burning home, it was found that 72% of the heating energy during the sample period came from oil, with the remainder from wood. It was treated as a MIXED home in the analysis. Both the oil and wood sensors fell off during the data collection period. All data after the wood sensor came off on 12/31/10 was discarded. The sensors were installed on 12/15/10 and were removed on 2/9/11. Only 15 days of data were used in the final analysis.
W-05	This is a 5,000 ft^2 residence heated with an OWB and an indoor boiler. The OWB provided 96% of the total BTUs consumed during the sample period. The monitor equipment was installed on 12/16/10 and removed on 1/28/11. A total of 1260 hours or 53 days of data were collected.
W-06	This is a 916 ft^2 home heated primarily with a wood stove (99%) and a supplemental direct vent oil heater. The monitoring equipment was installed 12/16/10 and removed 1/28/11. An absence between 1/13/11 and 1/25/11 was noted when the data was examined. Wood usage stopped and oil heat was used to maintain the home during this period. The results for both oil usage and wood usage during the interval were removed from the final data. A total of 9041 hours or 31 days of data were retained.
W-07	This is a 4,580 ft^2 home heated with an OWB and two indoor oil-fired boilers. Oil and Wood were nearly equal in the production of BTU's during the sampled period (50% each). The monitors were installed 12/26/10 and removed on 2/9/11. Valid data was retained for a total of 810 hours or 33 days.
W-08	This is a 1,400 ft^2 home using primarily a wood stove (67%) for heating, with a direct vent oil heater as a secondary source (33%). Sensors were installed 12/30/10 and removed 2/19/11. A total of 1022 hours or 43 days of data were collected from this home.
W-09	This is an approximately 884 ft^2 home. It is heated exclusively with a wood stove. The data logger was installed on 12/21/10 and removed on 2/1/11. A total of 1006 hours or 41 days of data were collected.
W-10	This is a 575 ft^2 residence heated with a wood stove and DV oil heater. A problem was found with the DV temperature sensor, but the oil usage log revealed only 10.5 gallons of fuel oil were consumed during the sampling period. This is equivalent to about 10% of the total BTUs produced by the wood consumed during the same period. The sensors were installed on 12/28/10 and removed on 2/16/11. A total of 31 days of data were used.

Summary of Validated Results

Table 7-6-8 displays the average daily energy consumption (in BTUs) by heating device type for each of the remaining homes with validated data during the sampling period. The valid households are sorted by sampling group (O-Oil Only, M-Mixed/Primary Oil, W-Mixed/Primary Wood). Cells with "n/a" under the daily energy use columns reflect devices that do not exist in that household (e.g., wood devices in the first three columns are not applicable for the group of Oil Only households). Total average daily energy (across all devices in each household) are listed in bold. As shown in the "Total" column of Table 7-6-8, average household energy use ranges from 235,075 BTU/day (O-06) to 1,938,204 BTU/day (W-03), an eight-fold range, with a sample average of 839,622 BTU/day.

Table 7-6-8
Validated Home Heating Instrumentation Sample Summary

Res. ID	Heated Area (ft^2)	Avg. Household Daily Energy Use by Device (BTU/day) Woodstove	Fireplace	OWB	CentOil	DirectVent	**Total**	Wood Use Pct.	BTU/Day per ft^2
O-01	2,448	n/a	n/a	n/a	792,168	n/a	**792,168**	0%	324
O-02	1,500	n/a	n/a	n/a	972,312	n/a	**972,312**	0%	648
O-03	2,775	n/a	n/a	n/a	1,086,937	n/a	**1,086,937**	0%	392
O-04	2,912	n/a	n/a	n/a	918,548	n/a	**918,548**	0%	315
O-05	1,400	n/a	n/a	n/a	n/a	374,537	**374,537**	0%	268
O-06	1,000	n/a	n/a	n/a	n/a	235,075	**235,075**	0%	235
O-07	1,200	n/a	n/a	n/a	654,180	n/a	**654,180**	0%	545
O-08	2,200	n/a	n/a	n/a	1,021,203	n/a	**1,021,203**	0%	464
O-09	2,100	n/a	n/a	n/a	950,833	n/a	**950,833**	0%	453
O-10	2,200	n/a	n/a	n/a	454,368	n/a	**454,368**	0%	207
M-02	2,900	265,559	n/a	n/a	720,968	n/a	**986,528**	27%	340
M-03	2,500	249,740	n/a	n/a	830,137	n/a	**1,079,876**	23%	432
M-04	1,770	205,229	n/a	n/a	394,971	n/a	**600,200**	34%	339
M-05	1,900	See Note a	295,208[a]	n/a	973,542	n/a	**1,268,751**	23%	668
M-06	3,000	449,953	n/a	n/a	773,096	n/a	**1,223,049**	37%	408
M-08	1,760	73,282	n/a	n/a	744,147	n/a	**817,429**	9%	464
M-09	2,600	164,336	n/a	n/a	583,305	n/a	**747,640**	22%	288
W-01	1,250	903,366	n/a	n/a	174,558	n/a	**1,077,924**	84%	862
W-03	2,488	n/a	n/a	1,820,881	117,323	n/a	**1,938,204**	94%	779
W-04	2,100	395,049	n/a	n/a	978,646	n/a	**1,373,696**	29%	654
W-05	5,000	1,172,540	n/a	n/a	41,932	n/a	**1,214,472**	97%	243
W-06	915	284,096	n/a	n/a	n/a	n/a	**284,096**	100%	310
W-07	4,580	n/a	n/a	459,869	427,135	n/a	**887,004**	52%	194
W-08	1,400	201,224	n/a	n/a	n/a	94,377	**295,601**	68%	211
W-09	884	278,445	n/a	n/a	n/a	n/a	**278,445**	100%	315
W-10	575	297,106	n/a	n/a	n/a	n/a	**297,106**	100%	517
Averages	**2,129**	**379,994**	**295,208**	**1,140,375**	**680,515**	**234,663**	**839,622**	**35%**	**418**
Pct. of Energy Use		**23%**	**1%**	**10%**	**62%**	**3%**	**100%**	-	-

n/a = Not applicable.
[a] Energy use for both wood devices (fireplace and woodstove) were combined to better represent fireplace as secondary device.

The rightmost two columns in Table 7-6-8 list the average wood energy percentage and daily energy use per unit area (BTU/Day per ft^2). As shown and discussed earlier, the sample of households exhibit varying amounts of wood vs. oil use for each of the wood and oil devices measured. (All heating devices in each household were instrumented. The selected sample included only those five device types listed earlier and displayed in the table.)

As summarized in a footnote, wood-burning energy use for household M-05 was assigned entirely to its fireplace, even though the home also had a wood stove (and a central oil boiler). Although energy use was measured separately for both the fireplace and the wood stove, it was all assigned to the fireplace. The reason for this adjustment is the belief that few homes have multiple wood-burning devices, based on repeated home heating surveys of several hundred residences each. Since this was the only household with a fireplace in the instrumented study sample, the adjustment provided a "cleaner" approach for development of the fireplace-specific components of the resulting energy model.

In assessing this "all-as-fireplace" adjustment of wood energy use in household M-05, diurnal patterns of wood use in both devices was examined and within this household, found to be generally similar. Both wood devices were used on most days and typically fueled in the early morning and evening hours. By assigning all of the wood energy to the fireplace, this household was recast in a manner that matched the overwhelming majority of homes where fireplaces are used as a secondary heating source.

Daily energy use by device averaged across the household sample is shown in the "Sample Averages" row at the bottom of Table 7-6-8. These values are averaged over only those households with the given device (e.g., the OWB average is based on OWB household averages for W-03 and W-07).

The last row of Table 7-6-8 shows energy use percentage splits by device and is based on averages across all households, irrespective of whether they have each device. As shown, oil vs. wood energy use was split at 65% oil (62% CentOil + 3% DV) and 35% wood (10% stoves, 1% fireplaces, 24% OWBs). This is consistent with the oil/wood splits seen in local heating surveys, but not identical since these instrumented households were a targeted, not random sample.

Comparison of Measured Energy Use to Independent Source

Although the instrumented households represented a stratified (oil/mixed/wood), targeted sample, the results were compared to an independent estimate of winter residential space heating energy use in Fairbanks. In a November 2013 report[8] prepared for the Interior Gas Utility (IGU), Northern Economics assembled results from local residential survey data and found average household space heating in Fairbanks to be 154 mmBTU/year. (In the report, it is shown on a natural gas energy basis of 151 Mcf[9], with gas energy content of 1.023 mmBTU/Mcf.)

To account for the strong seasonal variation in energy use and enable a direct comparison to the instrumented data collected between December 2010 and February 2011, a monthly space heating demand profile published in a June 2013 natural gas engineering study[10] by Northern Economics was used to allocate the annual usage from the IGU-sponsored survey to a daily

[8] Northern Economics, "Natural Gas in the Fairbanks North Star Borough: Results from a Residential Household Survey, prepared for the Interior Gas Utility, November 2013.
[9] Mcf = Thousand cubic feet.
[10] L. Cuyno and P. Burden, Estimated Natural Gas Demand for NS LNG Project memorandum, June 21, 2013.

average over a December-February period. From Figure 5 of that study, 43.7% of annual space heating demand occurs during those three winter months (Dec-Feb). An independent estimate of daily average energy use during this period was then calculated as:

154 mmBTU/year × 43.7% ÷ 90 days/year = 0.750 mmBTU per average Dec-Feb day.

When accounting for the fact that Dec 2010-Feb 2011 period was cooler than the long-term average for the same three months as measured at Fairbanks International Airport (-10°F vs. -4°F long-term), the 840,000 BTU/day sample average from Table 7-6-8 compares reasonably well to the independent estimate of about 750,000 BTU/day. Although a targeted sample, the instrumented database appears to reasonably approximate average Fairbanks household space heating energy use during winter.

HOME-HEATING ENERGY MODEL

After the data were validated and assembled into a unified database of hourly energy use by household and device, a least-squares regression analysis was performed to develop a predictive model of household space heating energy use, calibrated to Fairbanks practices and wintertime ambient conditions.

Several different forms of regression models and independent variables were evaluated. This evaluation included the following elements:

1. Assessment of the data to examine patterns/dependencies in home heating energy use;
2. Identification of terms or variables with statistically-significant explanatory power; and
3. Examination of equations/model forms that could be readily applied in conjunction with other data in an episodic emissions inventory workflow.

Patterns Revealed from Instrumented Sampling

In support of the first element, scatter plots of the validated data were prepared and examined to evaluate temporal energy usage patterns and both external (ambient) and internal (device usage practices in multi-device households) factors. Figure 7-6-14 through Figure 7-6-16 present time series plots of hourly space heating energy use by household for Oil Only, Mixed (Oil & Wood) and Primary Wood households, respectively. In each plot, hourly energy use for each household is plotted using distinct symbols/colors on the left axis. Ambient temperatures recorded for each hour are plotted in blue against the right axis. (The right axis is appropriately scaled to locate the ambient temperature series at the upper portion of the panel so it can be more clearly compared to the energy use data located largely toward the bottom.)

Figure 7-6-14
Hourly Instrumented Energy Usage (BTU/hour), Oil Only Households

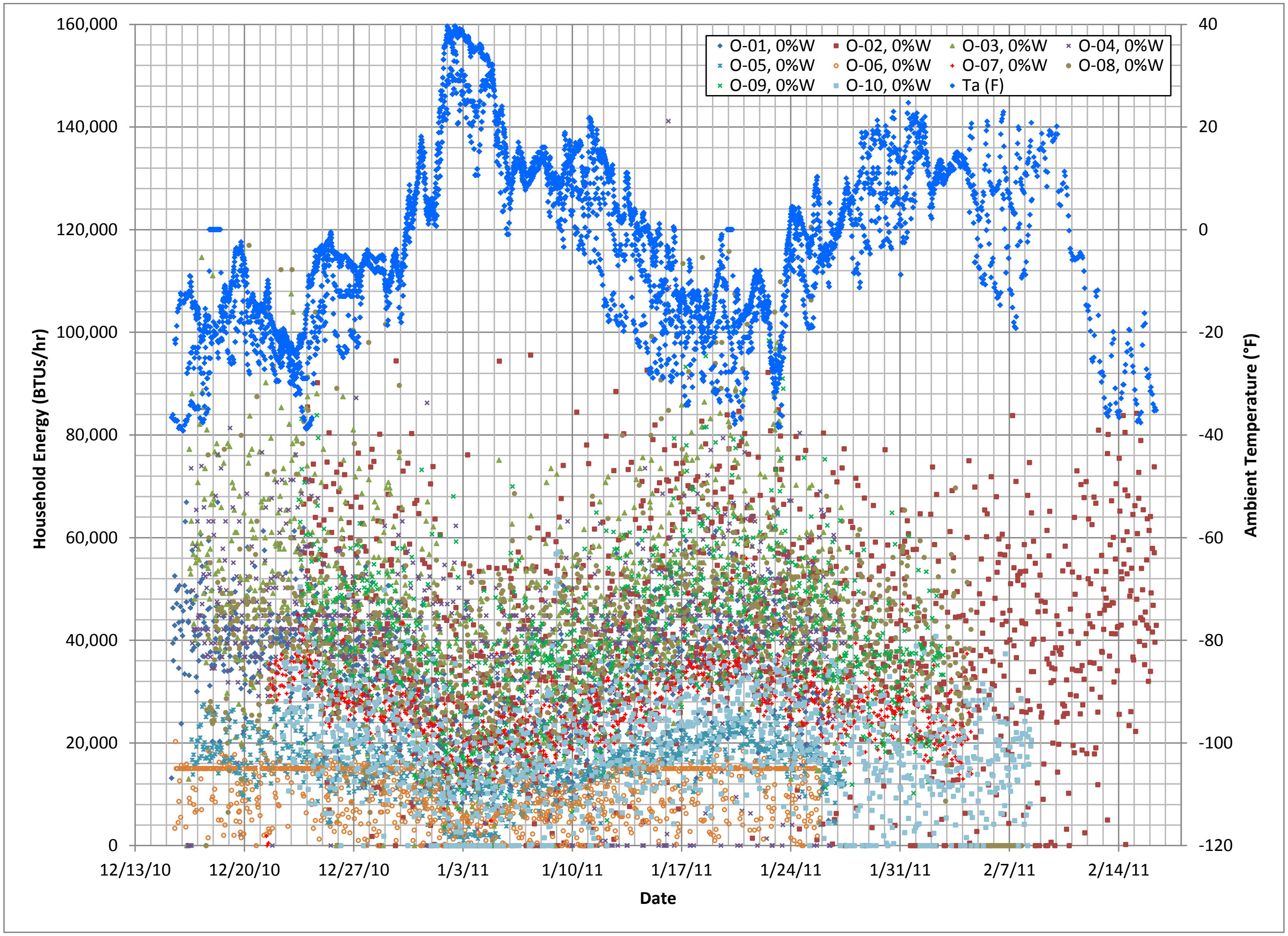


Figure 7-6-15
Hourly Instrumented Energy Usage (BTU/hour), Primary Wood Households

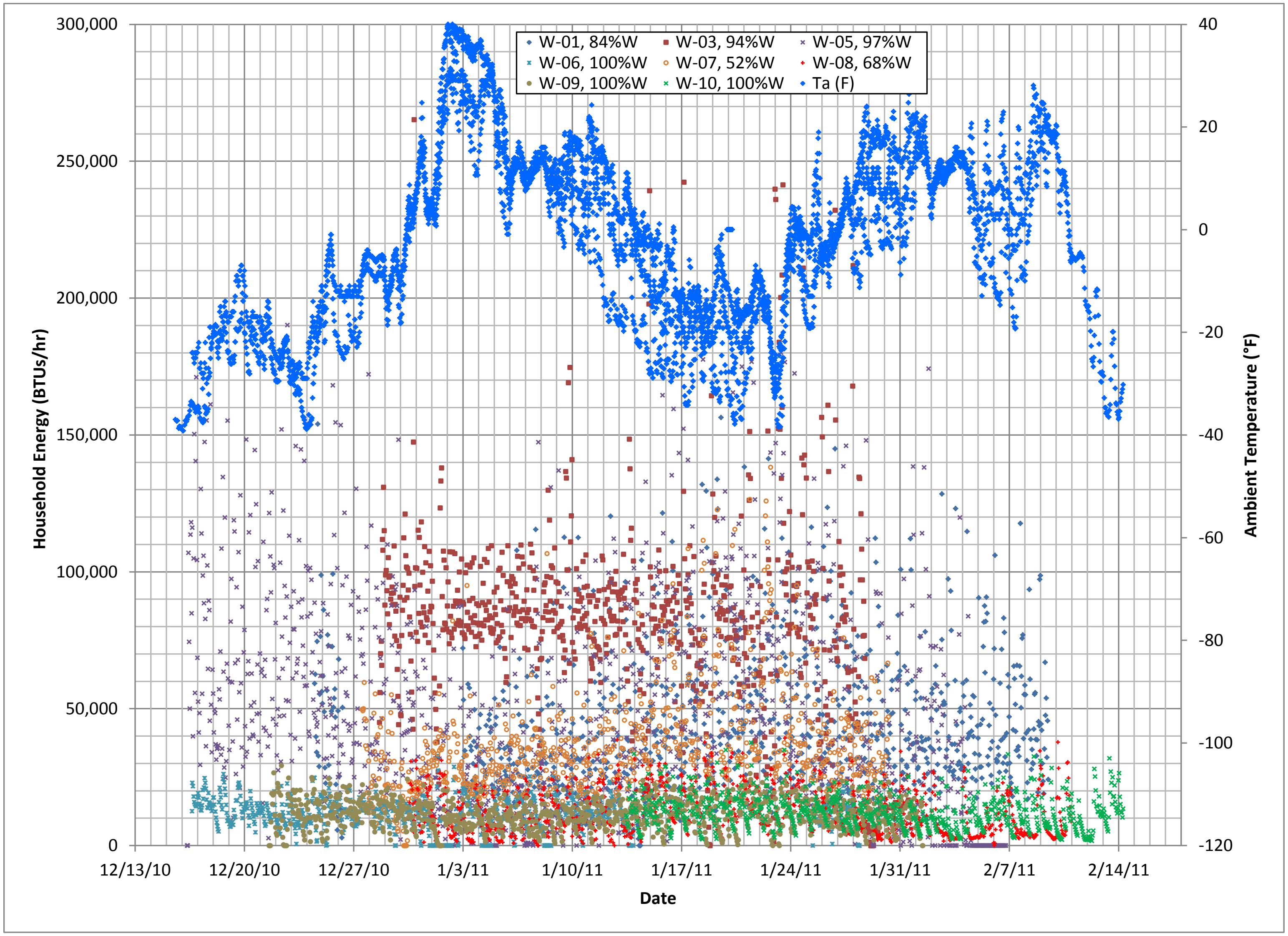
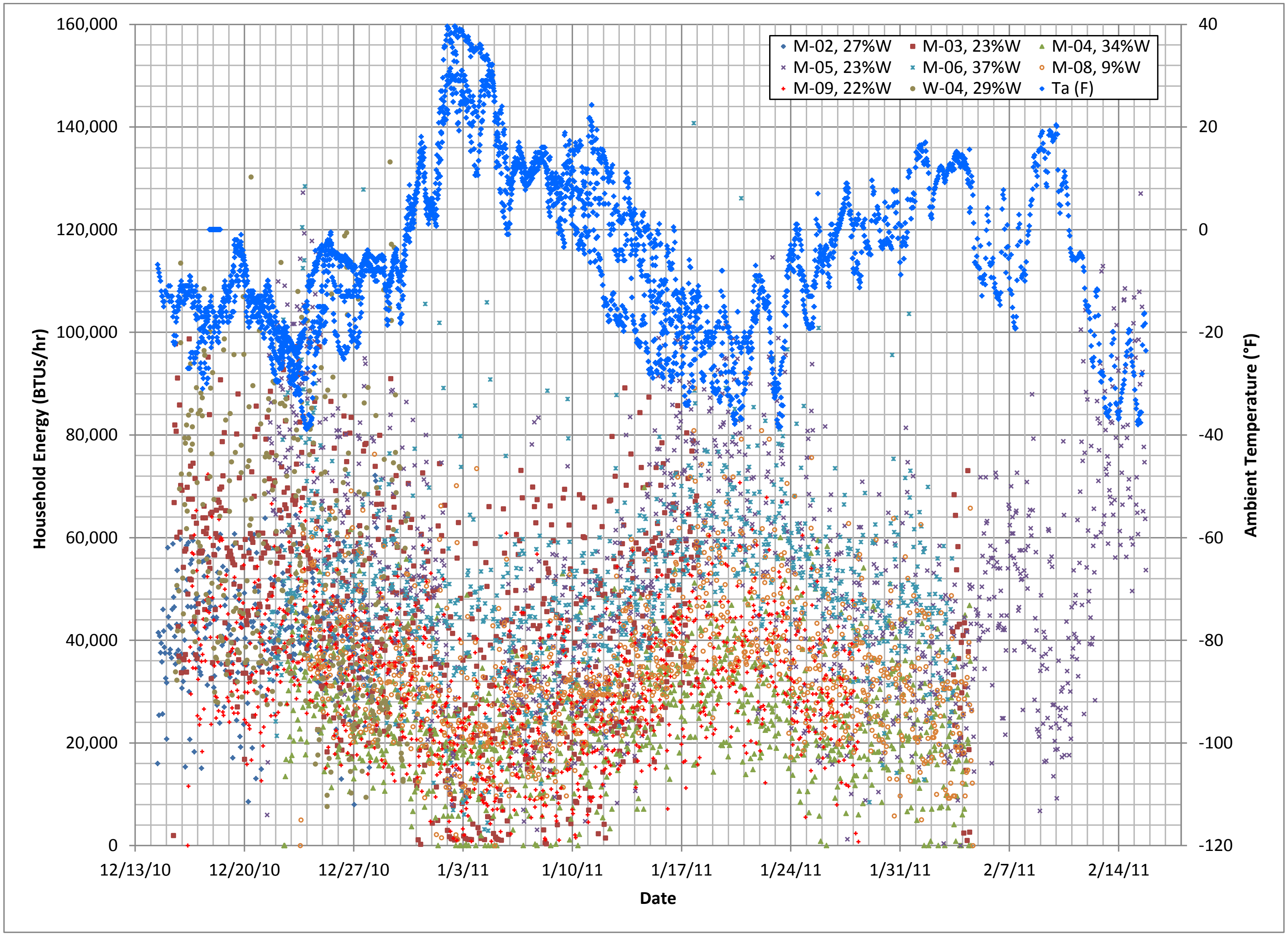


Figure 7-6-16
Hourly Instrumented Energy Usage (BTU/hour), Mixed Households



In Figure 7-6-14, ambient temperatures are shown to hover near the -20°F range at the start of the instrumentation period (mid-December) before rapidly warming to over +40°F in early January. Temperatures then head back near -20°F (and drop as low as -40°F) by mid-January, then rise to around +10°F at the end of the month before dropping toward -20°F again at the end of the instrumentation period in mid-February. Not surprisingly, plots for each Oil household's energy use tend to track variations in ambient temperature, but in the opposite direction.

Some other interesting patterns can also be seen. Comparing household sizes (shown earlier in Table 7-6-8) there is loose correlation between heated area and average energy use (R^2=0.41), although some homes exhibit disproportionally higher or lower energy use than reflected by their size (e.g. O-02 is higher, O-10 is lower). These size vs. energy use variations are also likely due to differences in construction/insulation and thermostat settings between households. As shown in Figure 7-6-4, the oil households exhibit differences in the magnitude of temporal variations over their sampling periods and generally show high degrees of scatter when plotted on an hourly basis, with one exception. Household O-06 (plotted with tan markers) is a small home (1,000 ft^2) heated entirely with a single direct vent heater. Based on its thermostat settings and heat output of the unit, the heater often operates at a steady rate of about 15,000 BTU/hour (which shows up as a horizontal line near the bottom of the plot). (The other direct vent oil home, O-05, has two direct vent units which operated together and are less steady in their output.)

Despite the high degree of visible scatter for the Oil households shown in Figure 7-6-14, temporal variation or scatter in hourly energy use was much higher in the Primary Wood households. As shown in Figure 7-6-15 (note the larger scale for energy use on the left axis), there tends to be much more scatter in hourly energy use, both within and across households that primarily burn wood. And at least on an hourly basis, energy use in Primary Wood households (R^2=0.05) is less correlated with ambient temperature than in Oil Only (R^2=0.19) homes. This lower correlation (on an hourly basis) is likely due to the fact that wood devices are not thermostatically controlled like oil devices. In addition, the Primary Wood group includes some households using oil as a secondary heating source, which affects total household energy use and hourly patterns.

Figure 7-6-16, the final plot in this series, shows hourly energy use for the Mixed households (those primarily heated using oil with wood as a secondary heating source). As shown earlier in Table 7-6-4, Wood household W-04 exhibited only 29% wood use, even though it was pre-screened as a primary wood home. Thus, it was plotted with the Mixed Households group in Figure 7-6-16.

Comparing Figure 7-6-16 (Mixed) to Figure 7-6-14 (Oil), the variation in energy use with ambient temperature appears more pronounced for Mixed households than Oil homes. A likely explanation for this is that in Mixed households, wood is used as supplemental or secondary heat, with oil providing a "base load" of heat energy. Given the relative heating efficiency of wood devices (40%-70%) compared to oil devices (over 80%), use of wood devices with lower efficiency, especially on colder days would result in more household energy use on those days compared to a case when the home is entirely oil-heated.

Since a portion of the scatter in this set of plots results from variation in hourly use, a second set of daily energy use plots were also developed and examined. Figure 7-6-17 shows total daily household energy use for each home in the Mixed group. Solid lines (with different colors and markers are used to show total daily energy use for each household. Similar to the earlier plots, daily average ambient temperature is plotted in Figure 7-6-17 using blue “diamond” markers against the right axis.

Comparing daily energy use across the Mixed households, day-to-day variations in energy use for all homes tend to work in reverse to ambient temperature variations. Homes M-05, M-06, M-03 and W-04 tend to exhibit higher energy use than others in the group (although the valid sample duration for W-04 was shorter than the rest). These four homes tended to be larger in size (M-06, M-03), use lower efficiency wood devices (M-05 used fireplace) or use a higher wood-based heating fraction (M-06=37%) than the rest of the group.

To better understand interactions in energy use for these multi-device households, Figure 7-6-18 presents daily energy use by device (oil, wood and total) for a selected set of Mixed households, M-04 and M-06. It illustrates two common patterns exhibited in multi-device homes even though their wood heating fractions are similar (~35%). For each household, total energy is plotted using a solid line and marker points; oil and wood energy are plotted using dashed and dotted lines, respectively. (Again, daily ambient temperature is also plotted against the right axis).

Shown in green lines in Figure 7-6-18, daily energy use in household M-04 exhibits a typical pattern, especially in smaller or more efficient/insulated homes. On colder days, both oil and wood are used (e.g. during the first week of sampling, from 12/22/10 through 12/30/12 and again from 1/10/11 and 1/24/11.) On warmer days (e.g. from 1/1/11 through 1/9/11 and again on 1/26/11) wood use actual dropped to zero and all heat was supplied by the oil device.

On the other hand, household M-06 displayed a different pattern in day-to-day interaction between oil and wood heating as shown in the three blue lines in Figure 7-6-18. Both devices were used to supply heat on every day of the sampling period, and with one exception around 12/29/10, the ratio in supplied heat between the oil and wood devices was fairly steady (roughly 2:1 oil-to-wood).

Figure 7-6-17
Daily Instrumented Energy Usage (BTU/day), Mixed Households

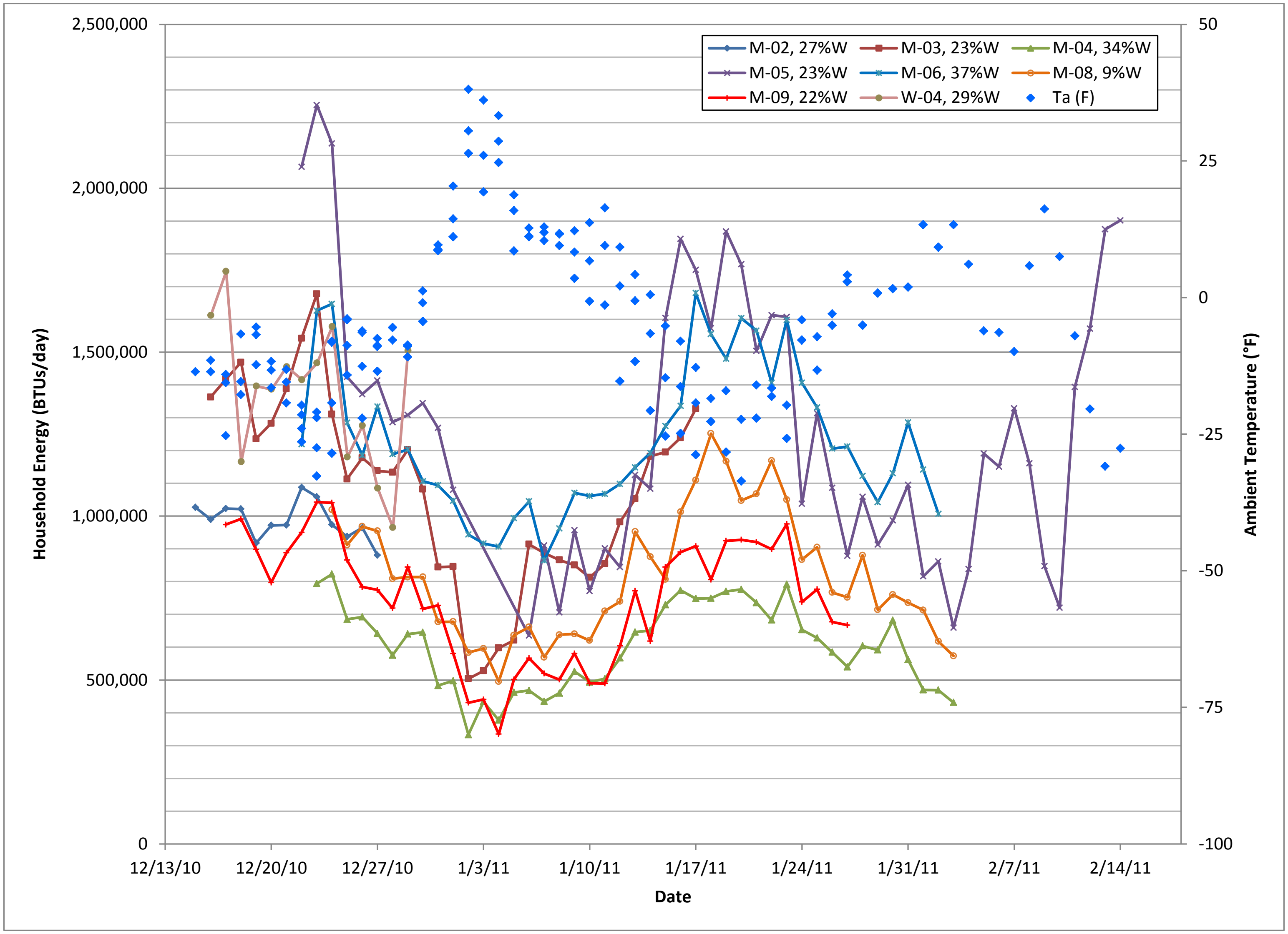
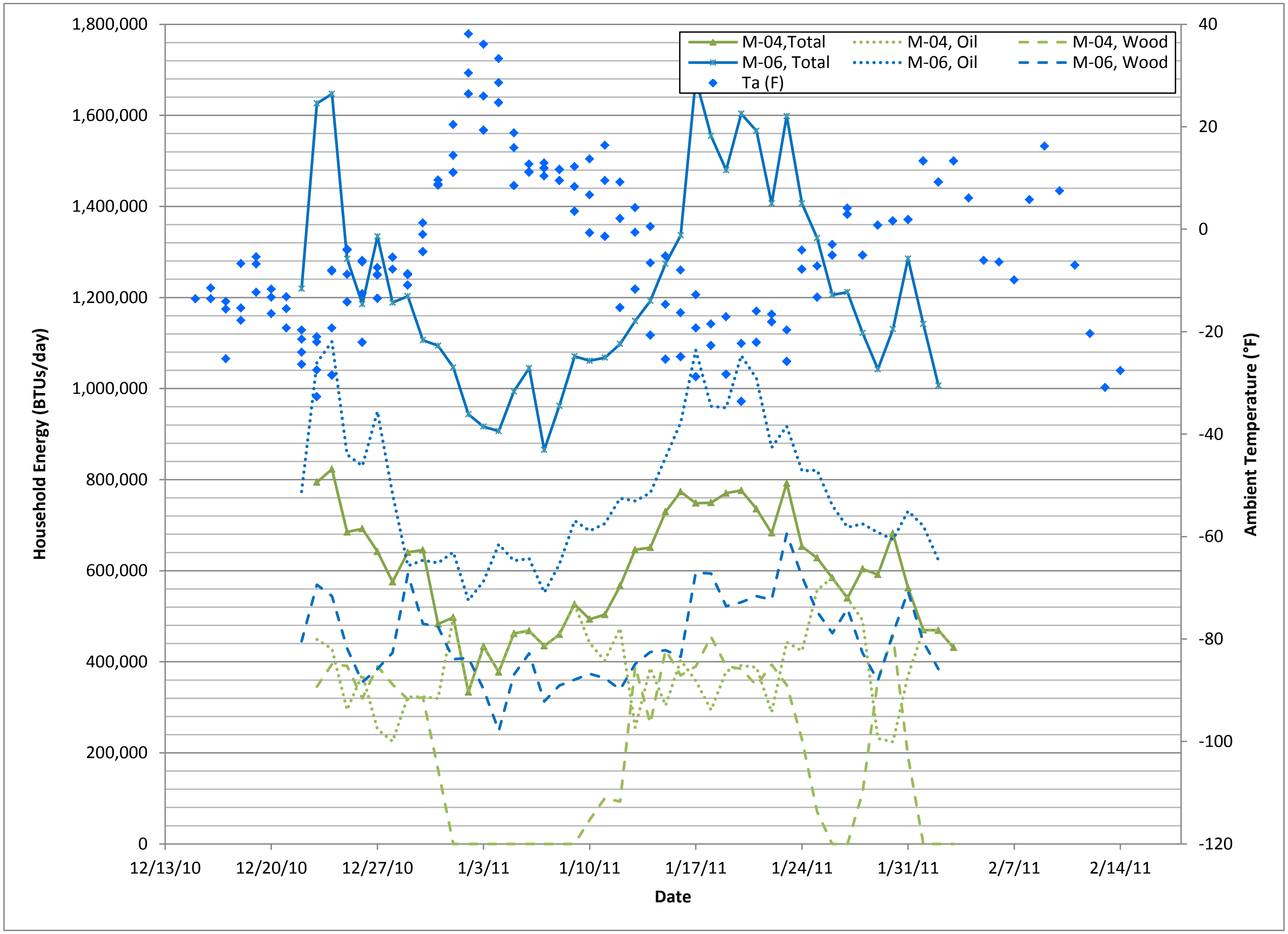


Figure 7-6-18
Daily Instrumented Energy Usage (BTU/day) by Fuel Type, Mixed Households M-04 and M-06



Identification and Selection of Explanatory Variables

Based on the review of space heating energy use patterns and examination of plotted results, several factors or variables were considered in building the regressions supporting the energy home heating model. These factors included:

- *Ambient Temperature* - Ambient temperature, as the primary measure of heat loss from the structure. An effort was made to determine if the energy use coefficient for temperature varied in different parts of the day, but there is insufficient data to make the determination.

- *Building Size* – Heated dwelling space was used as a marker of heat demand for each structure; the more heated area, the higher the heating demand.

- *Hour of Day* - Denoted by the beginning of the hour (the 00 hour is midnight-1 am). Dummy variables indicating the 24 individual hours of the day provide a diurnal profile of energy use (with other factors held constant) that reflects a combination of human behavior, particularly the times of day when the dwelling is occupied, and environmental contributions, such as the influence of daylight and dark on heat loss from the structure.

- *Device(s) Used* – The mix of devices used in each household was also considered. Examination of the patterns of variance in instrumented data suggested that both the type (in single-device homes) and the interaction (in multi-device homes) was a factor in explaining both total household energy use and diurnal usage patterns. Since wood devices are generally less efficient than oil devices, it is expected that all other factors being equal, homes primarily burning wood would exhibit higher energy use. In addition, the ability to thermostatically control the usage rate of oil-fired devices results in a different diurnal profile than for wood-burning devices, which are generally not thermostatically controlled (except hydronic heaters) and require manual fuel loading.

- *Day Type* - Weekday versus weekend days were distinguished, represented as a dummy variable for weekends, to capture overall differences in energy use that correspond to different occupancy and behavioral patterns between weekdays and weekends. An effort was made to determine if weekend-related differences could be related to time of the day, but there was insufficient data to make the determination. Thus, the weekend factor represents the average amount by which energy use is different on a weekend day versus a day during the work week.

The analysis was guided by the statistical significance of the estimated terms (at 95 percent confidence), but it did not require statistical significance in all cases because of the relatively small sample size available for study, especially for fireplace and direct vent oil devices. Terms have been retained where they appeared to be both important to capture and plausible, even if the desired level of statistical significance was not universally reached.

Inventory-Driven Regression Models – Given the review of the energy use patterns and selection of a set of factors believed to account for observed variations in the measured data, a series of multivariate regression models were considered and tested. In addition to statistical significance, a key element that guided the selection of appropriate model forms/equations was the applicability of the model for use in representing residential energy use (and device specific emissions) to support wintertime episodic modeling of space heating emissions in the SIP inventories. After trying a number of different models/forms, the final Fairbanks residential space heating energy use model consisted of two separate but serially-applied regression models that are listed below:

1. Daily Model – a single model predicting daily household space heating energy use (in BTUs) as a function of the average mix of the device usage in the home and its heated area; and

2. Hourly Device Models – a suite of device-specific models predicting diurnal usage patterns and unique responses of each device to daily ambient temperature variations and day of week effects.

Daily Model – The Daily model was a least-squares regression fitted model predicting daily household space heating energy as a function of heated living area and the fraction of each heating device type for each of the five device types represented in the instrumented sample:

1. Wood Stove (WS);
2. Fireplace (FP);
3. Outdoor Wood Boiler (OWB);
4. Central Oil (CO); and
5. Direct Vent Oil (DV).

These five device types account for over 95% of wintertime residential space heating energy use according to multiple residential home heating surveys performed in Fairbanks.
For each sampled day the total BTUs for each device type within a household were summed to find the total BTUs. The fraction of the total for each heating device type was then calculated by dividing the BTUs for the type by the total household BTUs for that day. A conventional multiple factor linear regression was performed on the resulting dataset. A total of 1,018 heating days were included in the regression.

The Daily model accounts for energy use effects of home size and heating device efficiency devices used within the home and their interactions on a given day. The Daily model predicts household energy per day (BTUs/day) using the following multivariate equation:

$$HH\ DayBTU = C_0 + C_1A + C_2\%WS + C_3\%FP + C_4\%OWB + C_5\%CO + C_6\%DV \quad (1)$$

Where:

HH DayBTU = predicted daily household space heating energy use (BTU/day);
A = heated dwelling area (ft^2);
%WS = percentage of average winter household energy use by wood stoves;
%FP = percentage of average winter household energy use by fireplaces (no inserts);
%OWB = percentage of average winter household energy use by outdoor wood boilers;
%CO = percentage of average winter household energy use by central oil devices;
%DV = percentage of average winter household energy use by direct vent heaters; and
C_0 - C_6 = least squares-fitted coefficients (C_0 is the intercept).

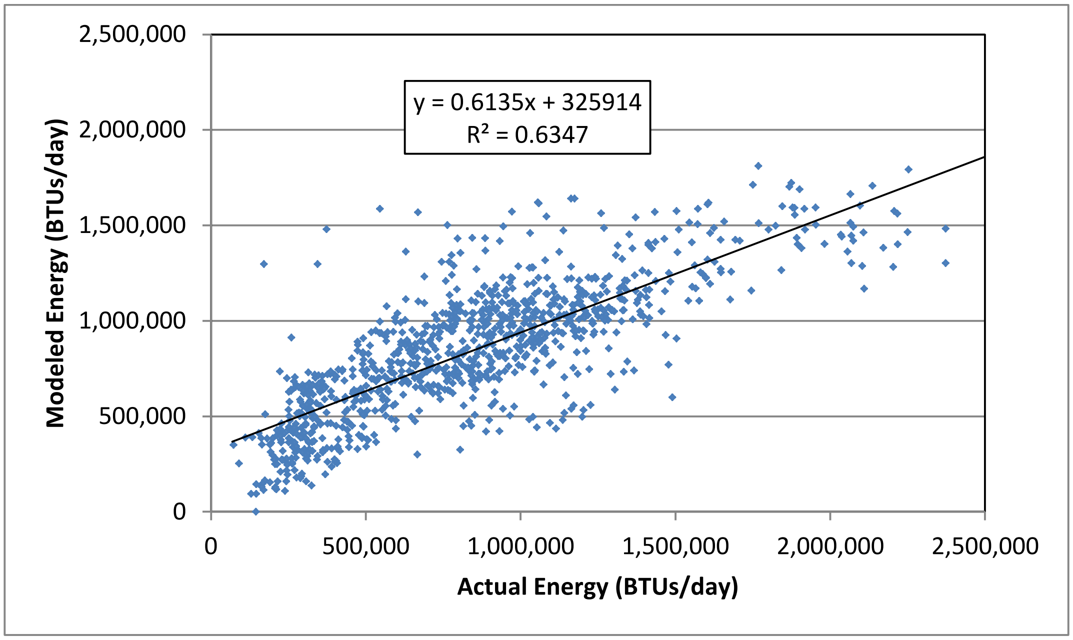
As discussed later in the "Emission Calculation Details" section of this appendix, heated dwelling area and fractions of device energy use over an entire winter season are elements that can be obtained from sources such as FNSB Assessor parcel database (building size) and home heating survey results (energy use splits over an entire winter season). Thus, for use in subsequent inventory calculations, these are known independent variables. Table 7-6-9 lists the resulting least squares-fitted coefficients used for the Daily model.

Table 7-6-9
Daily Model (Device Distribution and Area Model) Coefficients

Coefficient - Term	Value
C_0 - Intercept	-392560
C_1 – Heated Area	133.07
C_2 - % Wood Stove	799199
C_3 - % Fireplace	2462593
C_4 - % Outdoor Wood Boiler	1576799
C_5 - % Central Oil	987823
C_6 - % Direct Vent Oil	504552

Figure 7-6-19 presents a scatter plot of predicted daily household energy using the Daily regression model against actual measurements from the instrumented study database. Predicted estimates were generated by inputting the size and average device energy use splits of each household in the study. The plotted trend line and its equation box show that total daily BTUs in each household (predicted as a function of its size and device mix) are fairly well correlated with measured values (R^2=0.63), although the positive intercept for the trend line and the slope below unity indicate a bias toward over-prediction at the low end of measured daily energy and under-prediction at the high end. Given that ambient temperature dependence has yet to be factored in, this Daily model performs reasonably.

Figure 7-6-19
Modeled vs. Actual Household Energy by Day - Total Daily BTUs



To see how well the Daily model represents day-to-day energy use for each specific heating device, a set of similar scatter plot comparisons were developed showing predicted vs. measured energy use for each device in the household.

In Figure 7-6-20, predicted daily energy use from household wood stove use is also reasonably well correlated with measurements (R^2=0.66). Since the predictions here are being driven by the average energy split for wood stoves across all sampling days (for households equipped with wood stoves, the Daily model generally performed well in representing day-to-day and household-to-household wood stove energy use.

Figure 7-6-21 presents predicted vs. measured household energy use for fireplaces. As it shows, predicted energy use for fireplaces is not as well correlated as for wood stoves and tends to over-represent measured values. These relatively poor predictions are largely due to the fact that the instrumented study sample consisted of only a single household that used a fireplace and it was used intermittently as a secondary heating source. Evidence of this can be seen in Figure 7-6-21; there are several data points on the y-axis, meaning the model is predicting some fireplace energy use (based on average splits) on given days when the fireplace was not operated. The regression model would certainly benefit from additional sampling of fireplaces.

Figure 7-6-20
Modeled vs. Actual Household Energy by Day - Daily Wood Stove BTUs

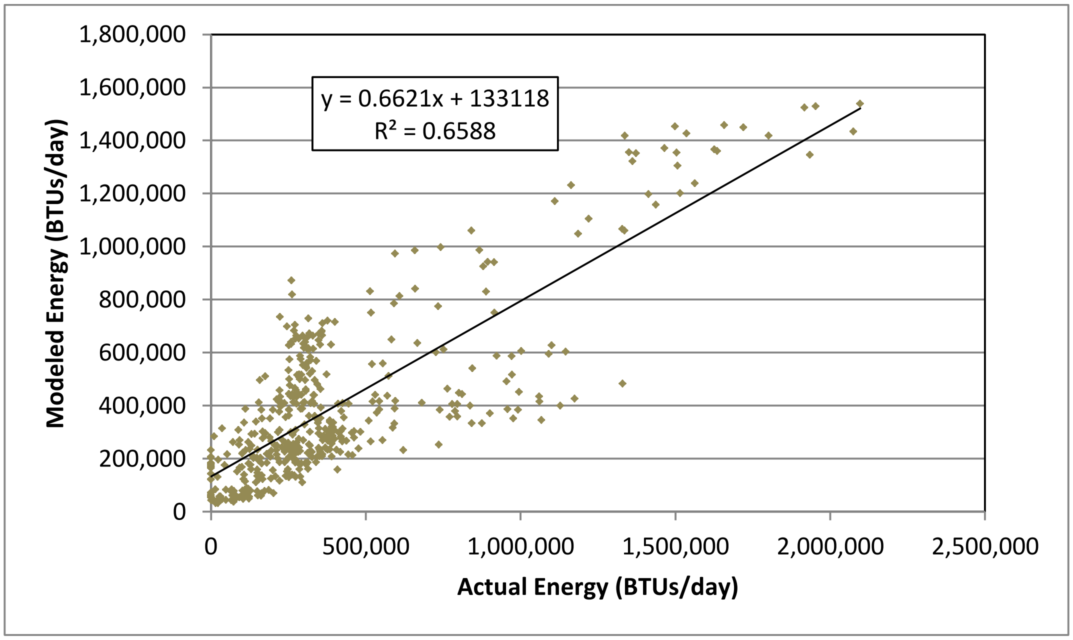
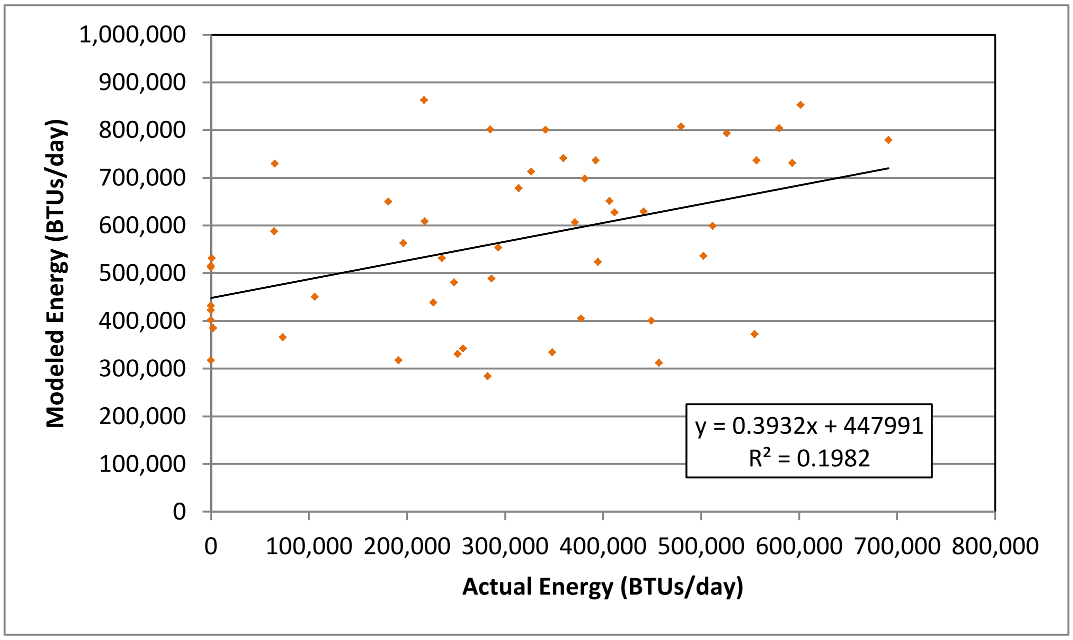
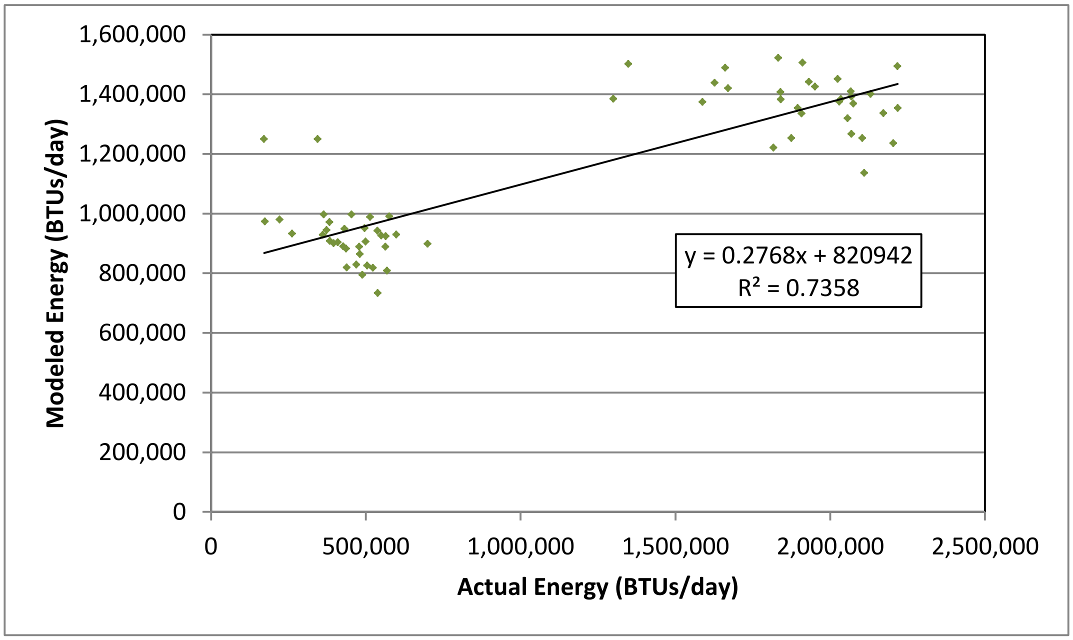


Figure 7-6-21
Modeled vs. Actual Household Energy by Day - Daily Fireplace BTUs



Predicted vs. measured daily household energy use for outdoor wood boilers (OWBs) is presented in Figure 7-6-22. Although it shows predicted results are better correlated with actual measurements (R^2=0.74), its two "clusters" of data represent the only two households with OWBs in the study sample. And the usage patterns exhibited by these two OWBs appear to span a wide range of actual practice. In the first OWB household (W-03), the OWB supplied 94% of the household heat energy over its measurement period, while in the second (W-07) there was a more even balance between OWB and central oil heating (52% vs. 48%).

Figure 7-6-22
Modeled vs. Actual Household Energy by Day - Daily Outdoor Wood Boiler BTUs



As shown in the preceding three plots, it is mildly problematic to accurately predict daily energy use for wood-burning devices on an individual device and household basis, because of their somewhat intermittent use. In contrast, predicted oil device household energy use better matched measured values.

Figure 7-6-23 and Figure 7-6-24 show predicted vs. measured household energy use for central oil devices and direct vent heaters, respectively. Predicted estimates for both oil device type are very well correlated with daily measurements ($R^2 \geq 0.8$), partially reflecting the fact that oil devices generally provide "base load" heat from day to day.

Figure 7-6-23
Modeled vs. Actual Household Energy by Day - Daily Central Oil Device BTUs

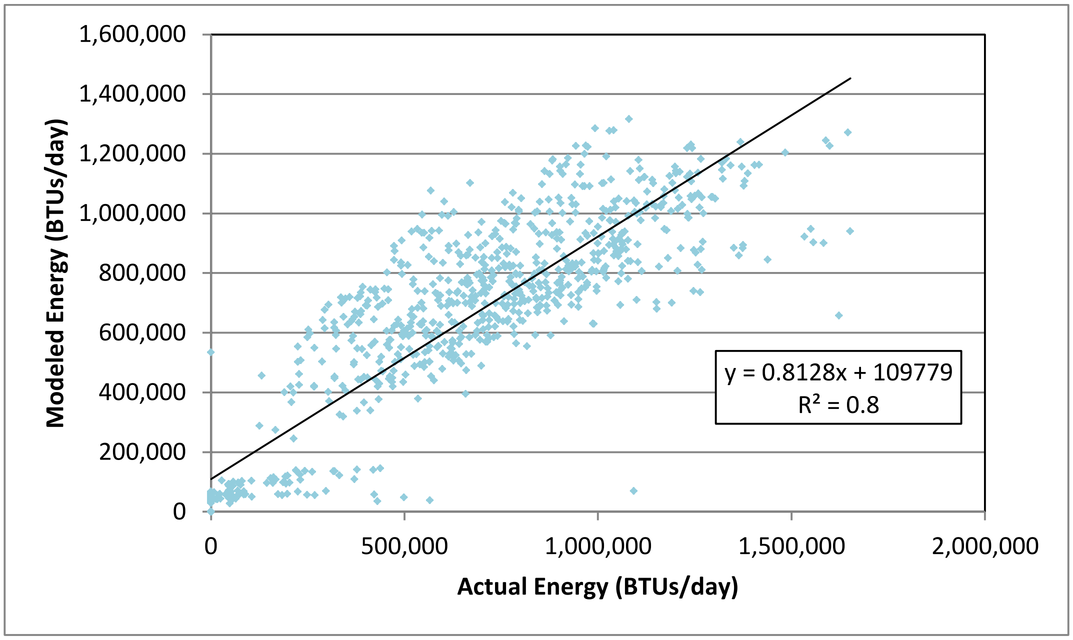
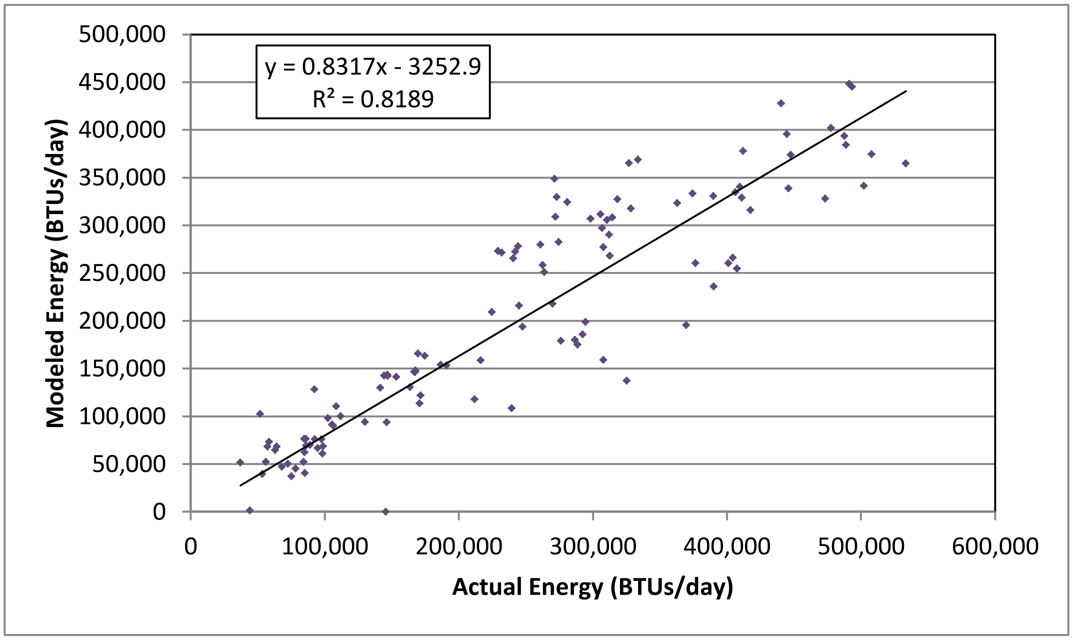


Figure 7-6-24
Modeled vs. Actual Household Energy by Day - Daily Direct Vent Heater BTUs



Hourly Model – The second and final component of the complete home heating energy model consisted of the development of a separate set of least-squares regression models of hourly energy use (one for each device type) that incorporated ambient temperature, weekday/weekend and diurnal variation influences unique to each device.

Since most wood-burning devices are not thermostatically controlled and require "manual" loading of fuel, their diurnal (and weekday/weekend) energy use patterns would be dictated by someone being home (and loading wood into the firebox). Depending on the size and burn duration range of each type of wood device, one might expect a different set of statistically fitted diurnal and weekday/weekend profiles than for oil devices.

Ambient temperature, an obvious explanatory variable for residential space heating energy use was incorporated into the Hourly model. (Incorporation of ambient temperature dependence was tested in both the Daily and Hourly models. It was determined that by incorporating it into the Hourly model rather than Daily model, device-specific responses to variations in ambient temperature could be better modeled.)

Thus, the set of Hourly models (one for each device type) was developed using the following equation form:

$$\boldsymbol{HH\ HrBTU_i = C_0 + C_{1,i} + C_2T + C_3DayType} \qquad \textbf{(2)}$$

Where:

$HH\ HrBTU_i$ = predicted hourly household space heating energy use (BTU/hr) in hour *i* (ranging from 0 to 23);
T = daily ambient temperature (in °F);
DayType = a dummy variable for weekday (value 0) and weekend (value 1) days and
$C_0 – C_3$ = least squares-fitted coefficients (C_0 is the intercept).

Daily, rather than hourly ambient temperature was found to produce marginally better fitted results for the set of Hourly regression models. This was attributed to the high degree of overall variance in the hourly measurement data (especially at the individual device level) and the fact that wood device are generally not thermostatically controlled and depending on the device and its settings, have a wide range in burn duration (over 12 hours for some devices) for a single fuel load. This diminishes correlation with hourly temperatures. Therefore, the set of Hourly models were fitted using daily ambient temperatures (i.e. averaged over 24 hours) developed from the hourly ambient temperature data.

Table 7-6-10 lists the set of Hourly model coefficients for each of the five heating devices determined using least-squares fitted regressions. The "intercept" coefficients (C_0) for each device reflect a baseline, or average hourly energy use for that device. The series of 24 C_1 coefficients (hourly index from 0 to 23) reflect fitted hour-specific adjustments to the baseline (C_0) level unique to each device type. In the fitted regression, the baseline was assigned to Hour 0 (midnight to 1 AM). This is why the C_1 value shown for Hour 0 in Table 7-6-10 is zero.

Table 7-6-10
Hourly Model (Temperature, Day, Diurnal Variation Model) Coefficients

Coefficient	Hour Index	Coefficient Values by Device				
		Woodstove	Fireplace	OWB	CentOil	DVOil
C_0 – Hourly, base	n/a	14952	11085	49737	29322	6047
C_1 - Hourly	0	0	0	0	0	0
	1	130	-1425	-1388	547	79
	2	-606	-2559	-1893	1108	130
	3	-2111	-3779	-1299	2050	89
	4	-3205	-4731	-2308	3351	421
	5	-4699	-4183	-3496	3849	-44
	6	-3477	-4026	-4218	5173	-95
	7	-1527	-3447	-4510	6640	-548
	8	-869	-1650	-2484	5774	-494
	9	1359	-1013	-1247	4562	-431
	10	1855	-1135	-257	4069	-157
	11	2702	-1383	-292	2979	-165
	12	1836	70	218	3001	185
	13	593	2822	1869	1774	-245
	14	1156	3418	-1223	2311	-21
	15	1531	2359	-2377	1762	-214
	16	2617	116	-5490	2411	-339
	17	1964	498	-6101	1719	-546
	18	3940	619	-7770	1328	-1676
	19	3561	-262	-8067	81	-1668
	20	5282	-19	-7050	359	-596
	21	3117	284	-5169	-1507	-1165
	22	571	1370	-3537	-817	-628
	23	1056	947	-1756	-457	-242
C_2 - Ambient Temp.	n/a	-263	-244	-175	-434	-170
C_3 - DayType	n/a	406	-655	-3548	-82	79

n/a – Not applicable

At the bottom of Table 7-6-10, the C_2 and C_3 coefficients are shown for each device reflecting daily ambient temperature and weekday/weekend differences, neither of which is modeled as varying by hour, but rather as an offset term that is constant over the day. As expected, the ambient temperature coefficients (C_2) are all negative, reflecting increasing energy use with decreasing outdoor temperature. The ambient temperature coefficient for Central Oil is the largest (negative) value compared to those for the other devices. This makes sense since central oil devices are the predominant source of “base level” or entire heating in a large majority of the instrumented sample (as well as Fairbanks residences in general) and thus reflect the greatest response to ambient temperature.

Finally, the DayType (C_3) coefficients in the bottom row of Table 7-6-10 reflect a mixture of positive and negative values across the range of instrumented devices. Since the DayType dummy variable is 0 for weekdays and 1 for weekends, a positive value indicates greater predicted energy use for that device on weekend days relative to weekdays. The two oil devices show a weaker variation between weekend and weekday energy use than the wood devices, likely due to the fact that the oil devices are thermostatically controlled.

Combined Application of Fitted Regression Models - The final step in the development of the home heating energy model consisted of serially combining the two models into a "composite" model as follows.

First, the Daily model is applied to generate estimates of daily household energy use by device as a function of dwelling size and the device use fractions in a household (or group of households as described later in the "Emission Calculation Details" section of the appendix. Next, the Hourly model is applied (with separate sets of coefficients for each applicable device) to estimate hourly energy use by device, factoring in ambient temperature, day of week and diurnal usage pattern effects.

In order to properly impose the variations addressed by the Hourly model, a reference temperature and a reference day type must be assumed to allow normalization of the second model results when combined with the Daily model predictions. The overall average temperature during the instrumented study sampling period was chosen as the reference temperature (-3.5°F), while weekdays were chosen as the reference day type.

Once daily energy use estimates have been generated using the Daily model and daily estimates are divided by 24 to represent an average hourly value, the Hourly model is then applied twice (for each device type), first using the selected input ambient temperature and day type and next with the reference ambient temperature (-3.5°F) and reference day type (weekday). Ratios of actual day to reference day energy use for each device in each hour are then calculated for each set of Hourly model estimates.

Finally, the results from the Daily and Hourly model regressions are combined by summing the product of the Daily model energy for each type, the Daily model device fraction for each type, and the ratio of the Hourly model energy for each type at the desired conditions and the Hourly model energy for each type at the reference conditions as shown in the following equation:

$$\boldsymbol{HH\ BTU_{d,i,t} = {}^{DayBTU_d}\!/_{24} \times {}^{HrBTU\ Actual_{d,i,t}}\!/_{HrBTU\ Ref_d}} \qquad \textbf{(3)}$$

Where:

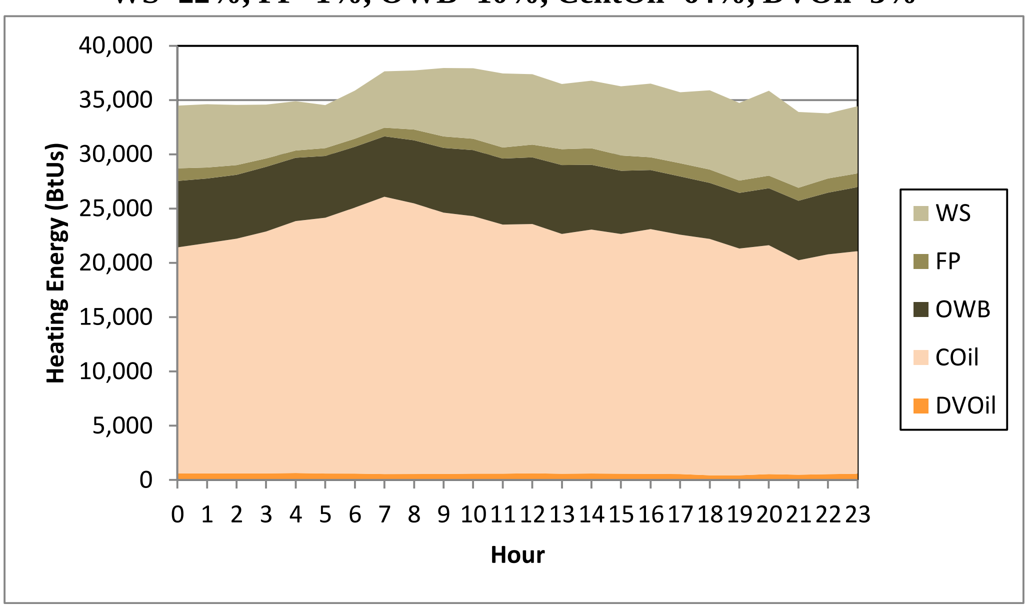
$HH\ BTU_{d,i}$	= Calculated household hourly energy use (BTU) for device type *d* and hour *i*;
$Day\ BTU_{d}$	= Daily model-predicted household energy use (BTU) for device type *d*;
$HrBTU\ Actual_{d,i,t}$	= Hourly model-predicted household energy use (BTU) for input ambient temperature (in °F) and day type (weekday or weekend);
$HrBTU\ Ref_{d}$	= Hourly model-predicted household energy use (BTU) averaged over all 24 hours for the reference temperature (-3.5°F) and reference day type (weekday); and

Device Type 1=Woodstove, 2=Fireplaces, 3=Outdoor Wood Boilers, 4=Central Oil, 5=Direct Vent Heaters, Hour *i* refers to the hour ending (1=midnight to 1 AM, 2=1 AM to 2 AM, etc.) and *t* is ambient temperature in °F.

Figure 7-6-25 through Figure 7-6-28 present estimates of hourly energy by device and hour for several sets of example conditions to illustrate how the combined space heating energy model responds to each of its input variables. In each figure, predicted household hourly energy use (in BTUs) is plotted by hour of the day (0 represents midnight to 1 AM) for each device type in a hypothetical household.

First, Figure 7-6-25 shows a case that represents a typical mix of household device usage splits identified in local home heating surveys, reflecting primary oil use and secondary wood use. It assumes a daily average ambient temperature of 0°F.

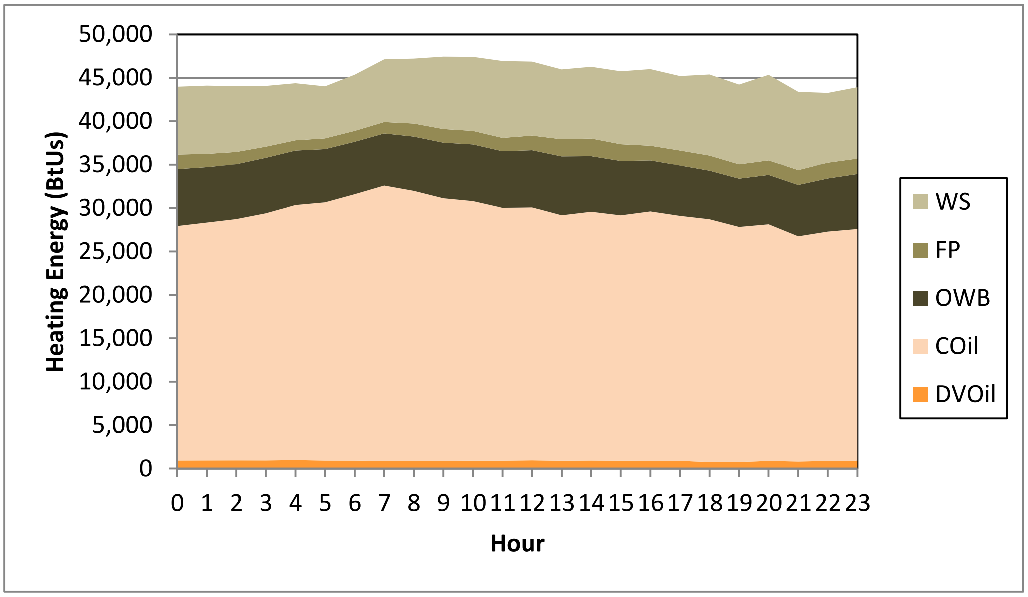
Figure 7-6-25
Combined Model Energy Use Case:
Dwelling Size = 2,129 ft^2, Temp = 0°F, Day Type = WD,
WS=22%, FP=1%, OWB=10%, CentOil=64%, DVOil=3%



(Although a single home is not likely to employ all five of these devices, the energy model was designed for use in space heating inventory calculations which as explained later in the "Emission Calculation Details" section of the appendix, is applied for large groups of households. The energy model can also look at more simplistic one- and two-device per home scenarios, but it was designed for the broader inventory use explained above.)

Figure 7-6-26 shows predicted household energy use for the same device mix as in Figure 7-6-25, but at a colder -20°F daily ambient temperature. Expectedly, predicted energy use is over 20% higher (note the difference in vertical axis scales between the two figures).

Figure 7-6-26
Combined Model Energy Use Case:
Dwelling Size = 2,129 ft^2, Temp = -20°F, Day Type = WD,
WS=22%, FP=1%, OWB=10%, CentOil=64%, DVOil=3%



Next, Figure 7-6-27 illustrates a case representing a household primarily heated by wood, again at -20°F. In this example, wood burning devices collectively comprise 70% of the average winter season household energy use with oil used for the remaining 30%. Compared to Figure 7-6-26, this shows higher overall energy use (due to the relative inefficiency of wood devices compared to oil) and a different diurnal pattern.

Finally, Figure 7-6-28 shows the typical "primary oil" device mix case from Figure 7-6-26, but for a smaller dwelling size (1,500 vs. 2,129 ft^2). Comparing its results to those in Figure 7-6-26, a reduction in overall energy use of about 10% is predicted for the smaller home.

Thus, this series of plots demonstrates how the space heating energy model works and responds reasonably to changes in its inputs.

Figure 7-6-27
Combined Model Energy Use Case:
Dwelling Size = 2,129 ft^2, Temp = -20°F, Day Type = WD,
WS=55%, FP=5%, OWB=10%, CentOil=28%, DVOil=2%

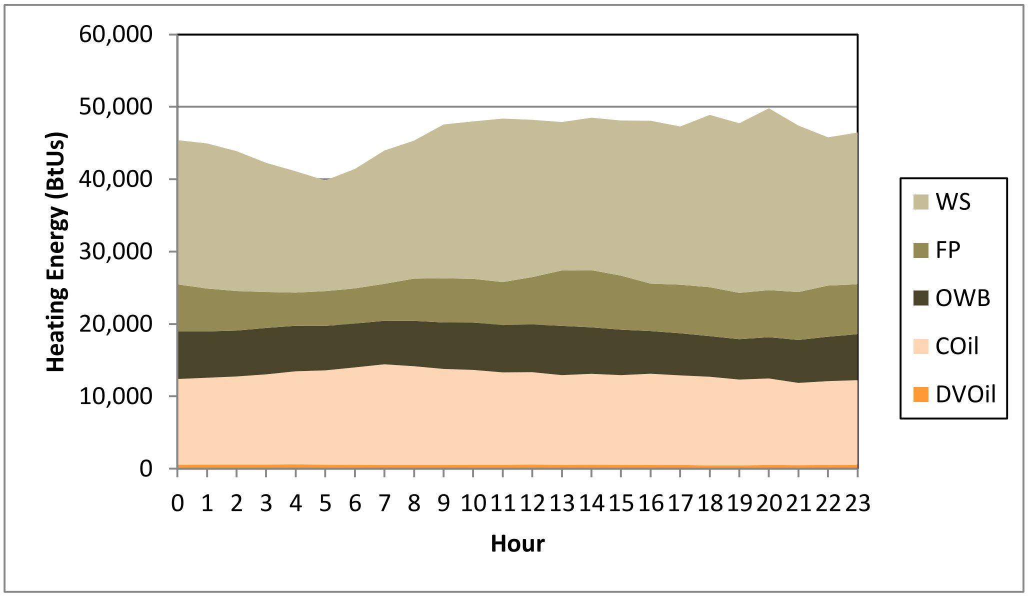
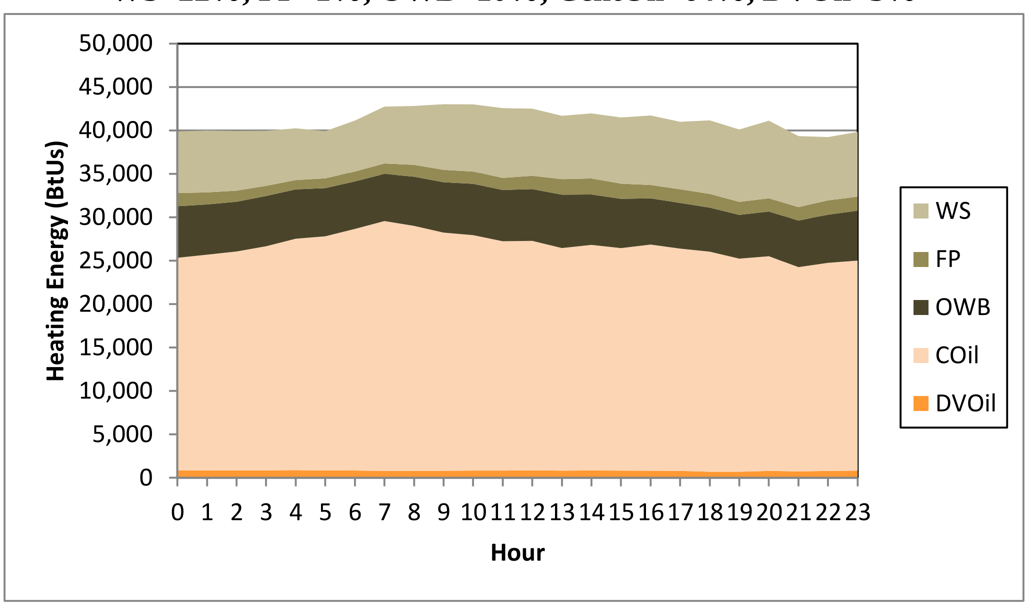


Figure 7-6-28
Combined Model Energy Use Case:
Dwelling Size 1,500 ft^2, Temp = -20°F, Day Type = WD,
WS=22%, FP=1%, OWB=10%, CentOil=64%, DVOil=3%



HOME HEATING – SPACE HEATING SURVEYS

One of the key sources of data use to drive the residential heating energy model was information developed from a series of residential "Home Heating" (HH) telephone surveys regularly conducted by DEC. These surveys have been conducted in 2006, 2007, and 2010-2015 and have been used by DEC and Borough to determine the mix of residential home heating devices and practices within the Fairbanks $PM_{2.5}$ nonattainment area.

In addition to these broader HH surveys, the agencies also funded and coordinated two special surveys in 2013 specifically targeting wood-burning households, one in which more details were obtained on rated emission levels for certified devices, the other which further examined wood purchase and usage practices.

This section of the Emission Inventory Technical Appendix describes each of these two sets of survey instruments and summarizes the key data extracted from these surveys and processing performed for use in calculating space heating emissions within the SIP inventories.

RESIDENTIAL HOME HEATING SURVEYS

Purpose – The primary purpose of these HH surveys was to collect up-to-date information on residential heating practices in Fairbanks during the winter season when extremely cold ambient temperatures cause a significant seasonal increase in fuel combustion for residential heating. Since the first surveys were conducted during the 2006 and 2007 winter seasons, DEC has continued to fund similar annual surveys beginning again in early 2010. The rationale behind these continued surveys is to ascertain whether trends in the devices/fuels used to heat homes have changed over time. DEC and the Borough also use the surveys to gauge public awareness about local air quality and control programs.

Basic Approach - The HH surveys were conducted by a specialized research survey firm, Hays Research Group (Hays), based in Alaska. Hays was directed to randomly sample residential households within the Fairbanks $PM_{2.5}$ non-attainment area, perform the telephone surveys and deliver the detailed, electronically recorded survey data results to DEC. The telephone surveys were generally toward the end of each winter (e.g., the 2010 survey was conducted during February 2010) to get responses about heating patterns/practices while fresh in the minds of the respondents.

Targeted sample sizes for the first three HH surveys (2006, 2007 and 2010) were set at 300 households for each survey. For the 2011-2015 surveys, the targeted sample size was more than doubled, to 700 households. Within each survey, ZIP code-specific sampling targets were established based on household data from the 2010 U.S. Census and used to select stratified samples of residential households by ZIP code. (For the 2010 and earlier HH surveys, stratified ZIP code sampling was based on 2000 Census data, then later re-weighted to be consistent with the 2010 Census weightings. Composite metrics tabulated across ZIP codes from all surveys could then be compared in an unbiased manner.)

In addition, the 2011 and later surveys utilized a different Fairbanks telephone database that included mobile phones. Given the growing use of cell phones, in some households as a replacement for land-line phones, concern emerged that the approach used to sample households using a land-line only phone number database may have unintentionally biased the resulting samples. As a result, the household selection process for the 2011 and later surveys was revised to include cell-sampled respondents. The cell phone respondents were contacted using known Fairbanks cell prefixes, and then verified to be within the boundaries of the survey. Sample sizes for the cell phone respondent subsets within each survey were "self-selecting." Hays simply used a combined list of phone numbers (land and cell) and randomly dialed from the list. Cell vs. land line phone status was later confirmed by the Hays interviewer during the survey of each respondent. The cell phone respondent fractions ranged from 5% to 12% across the three (2011 and later) HH surveys. No ZIP code or address location data were collected for these cell-based respondents, except within the 2012 survey[11]. For the other surveys, cell respondents were proportionally distributed across the non-attainment area ZIP codes based on the 2010 Census weightings.

Survey Content – The surveys focused on identifying the types and usage practices of different home heating devices used in residences within the nonattainment area during winter months. It was organized into a hierarchical series of roughly 70 separate questions that respondents were asked to answer based on the types of heating devices available and used within their homes. Key questions included the following:

- identifying the types of heating devices present in the household (including the specific type of wood-burning device if used);

- providing rough usage percentages for each device on both a winter season and annual basis; and

- estimating the amount of fuel used in each device (e.g., cords of wood or gallons of heating oil) both during winter and on an annual basis.

The survey questions were organized in a "branching" structure. An initial set of focused questions were asked to identify the types of heating devices present and used in the home. Then for each device applicable to the household, separate branches of further questions were asked about each device. The residential heating device types tracked under the surveys (for which separate question branching was conducted) are listed in Table 7-6-11. The surveyor navigates the homeowner through specific branches of the survey related to those devices that exist in the household. In addition to those devices explicitly listed in Table 7-6-11, the survey allows other types of heating devices to be identified and recorded into a generic "Other" group for which "verbatim" descriptions of the device provided by the homeowner were recorded into a separate file. Generally, the most common type of heating device in the Other category is portable electric heaters, which produce upstream or indirect emissions.

[11] For the 2012 HH survey only, address data were obtained by Hays, but not released. Hays used the addresses to locate the surveyed households within ZIP codes in material provided to DEC.

Table 7-6-11
Fairbanks Home Heating Survey Device Types

Fuel Group	Device Type
Wood-Burning	Fireplaces
	Woodstoves/Inserts
	Outdoor Wood Boilers
Oil-Burning	Central Oil Boilers/Furnaces
	Portable Fuel Oil/Kerosene Heaters
	Direct Vent Heaters
Gas	Natural Gas Heaters
Coal	Coal Heaters
Steam	Municipal (District) Heat[a]

[s] Municipal or District heat refers to steam heat circulated in underground pipes generated from the Aurora Energy coal plant.

After the branching portions of each survey are completed for the specific devices present in the home, a general section of questions are included at the end that were asked of all respondents. These questions typically focused on planned changes in heating devices/practices and also included elements related to Borough education and control programs. Summarized separately below are the key types of questions contained in each survey branch or section:

- *Initial Section* - types of devices present in the house and the homeowner's rough estimate of the percentages each device was used during winter (and annually in some surveys), later surveys also asked for dwelling size (heated space);
- *Fireplace Section* – winter season and annual wood use estimates; whether wood used is cut by the homeowner or purchased commercially, seasoning period before burning, estimated wood moisture content and annual wood expenditure;
- *Stove/Insert Section* – estimated age and installation date of device, winter season and annual wood use estimates, cordwood or pellet device, whether wood used is cut or bought, seasoning period before burning, estimated wood moisture content and annual wood expenditure;
- *Outdoor Wood Boiler Section* - winter season and annual wood use estimates, use of cordwood or pellets, whether wood used is cut or bought, seasoning period before burning, estimated wood moisture content and annual wood expenditure;
- *Central Oil Section* – size of fuel tank, gallons of heating oil used during winter and annually, yearly cost of fuel oil;
- *Portable Fuel Oil/Kerosene Heater Section* - similar to Central Oil section, plus questions asking whether the device burns fuel oil or kerosene;

- *Direct Vent Heater Section* – similar to Central Oil section;

- *Gas Section* – estimated winter season and annual expenditures for natural gas;

- *Coal Section* – estimated winter season and annual coal use and expenditure, whether used in indoor stove or outdoor boiler;

- *Municipal Heat Section* - estimated winter season and annual expenditures for municipal (i.e. District) heat; and

- *General/Future Use Section* – this final section included questions about future home heating practices, such as estimating the heating oil price that would trigger each respondent to stop burning wood, as well as questions designed to gauge public awareness about air quality in Fairbanks and wood-burning in particular.

Attachment A contains the interviewer survey script for the 2011 Home Heating survey which lists each of the questions and shows their order and the section branching summarized above. (The structure/content for the 2012 and later surveys was similar to that for the 2011 survey.)

Survey Data Assembly and Quality Assurance Review – Once the telephone surveys were completed by Hays Research (the survey firm used to conduct the surveys and assemble the response data) the survey data were then provided to DEC in a series of electronic files[12] for processing and quality assurance review as described below.

Assembly & Processing – For each survey, the as-received data were imported into a single spreadsheet; the primary response data were loaded into one sheet and the verbatim responses in a secondary sheet, with those responses organized into tables specific to each question of that form (verbatim rather than categorical/numeric responses). Each record in the primary data corresponded to completed and coded responses to all questions for a household. Each column contains the responses to a specific question. Respondent IDs, survey dates, and residence ZIP codes were also listed for each record. (Respondent IDs were also recorded for the verbatim responses so they could be properly linked to the primary data. Other basic processing steps included converting number values to numeric types and reassigning '999' missing data codes used by Hays to blank values within the spreadsheets so they would be properly treated during subsequent statistical tabulations performed in the spreadsheets.

Quality Assurance Review – Before response data were analyzed and tabulated into metrics used within the SIP inventories, a detailed set of data consistency and range checks were performed on the as-received data as provided by Hays. Examples of data consistency checks included comparing devices used in the household recorded in the initial section of the survey with

[12] The primary file contains categorical/numeric responses to most of the survey questions. Separate files were used to collect and provide "verbatim" responses to specific questions which did not involve categorical responses. For example, respondents were asked to briefly describe the types of devices that landed into the generic "Other" device category discussed earlier.

completed, valid responses in the appropriate device-specific "branch" sections, or checking that annual fuel use was always greater than or equal to winter season (Oct-Mar) fuel use. Range checks were also applied to responses for questions that involved numerical, rather than categorical responses. Plausible or theoretical limits were used to flag "outlier" values for specific questions (e.g., wood stove fuel use). Where possible, flagged values were compared to other related responses for corroboration. For example, fuel use entries (e.g., cords of wood or gallons of oil burned) were compared to responses in the initial section where the homeowner provided roughly percentage distributions of device usage for each equipped device. If there was a large inconsistency between the two elements, the usage data were invalidated. For example, if a respondent said they burned 10 cords of wood in the winter (a large amount) but listed their wood device providing only 20% of total winter usage, the wood use entry was marked invalid.

Most of the response data (generally 80% or higher) passed these consistency and range checks. For those that didn't, inconsistencies were reported to Hays. In some cases, transcription or survey logic errors were discovered. Transcription errors were then corrected. Survey logic errors (where the surveyor forgot to ask device specific questions for devices present in a household) were addressed by performing callbacks to specific respondents (or calling additional households when the initial respondents were not available) in order to develop valid samples that met sample size targets of the survey (300 households in 2010 and earlier surveys, 700 households in 2011 and later surveys).

<u>Surveys Used for Serious SIP</u> – For this Serious SIP, area-specific wintertime heating device usage fractions and practices were developed from the more robustly-sampled 2011-2015 HH survey data, which encompassed a combined sample of over 3,500 households, and were used to develop space heating emissions for the 2013 baseline inventory. These combined 2011-2015 survey results were used to develop estimates of the types and number of heating devices used during winter by 4 km square areas[13] within the nonattainment area. The survey data were also used to cross-check the energy model-based fuel use predictions as well as to identify and apportion wood use within key subgroups (certified vs. non-certified devices and purchased vs. user-cut wood, the latter of which reflects differences in moisture content that affects emissions).

"Special purpose" surveys were also conducted in support of the Serious SIP and included:

1. 2013 "Wood Tag" and "Wood Purchase" surveys of wood-burning households that collected further detail on EPA-certified devices and wood sources;

2. a 2016 Postcard survey that sought to assess changes in wood use related to heating oil price decreases; and

3. a 2017 Commercial Business survey intended to identify and estimate solid fuel device space heating for commercial businesses within the nonattainment area.

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[13] Modeling grid cells were 1.33 km square. Device and fuel usage distributions from the 2011-2015 survey data were calculated by 4 km square areas (which consist of 3 × 3 sets of modeling grid cells) in order to achieve a minimum statistically sufficient sample size of a least 50 households per 4 km square area across the majority of the nonattainment area.

(These specialized surveys are discussed in the "Specialized Wood Burning Surveys" sub-section that follows.)

The combined 2011-2015 HH survey sample was used to represent residential space heating device and fuel use for the 2013 Baseline inventory, as opposed to the 2013 survey data. The rationale behind this decision was twofold:

1. Calendar year 2013 was centered within the 2011-2015 survey period, and any trends over the period (e.g., wood use, uncertified device fractions would be reasonably represented by the combined average over the period); and

2. Use of the combined data provided a roughly five-fold increase in sample size, which as shown later in this sub-section provided much higher statistical confidence in the device/fuel usage fractions developed from the survey data, especially for smaller proportion device/fuel combinations such as Outdoor Wood Boilers.

And although useful for trends analysis, data from the more sample-limited 2010 and earlier HH surveys were not used to represent residential space heating patterns for the 2013 Baseline inventory.

Tabulation of Key 2011-2015 HH Survey Results – A series of basic cross-tabulations were prepared to examine results of the responses to each question in the surveys. Key results from these tabulations are presented separately below for the combined 2011-2015 HH survey data.

Households Sample Sizes and Multi-Device Usage - The first step in the analysis consisted of translating the cross-tabulated record counts into fractional or percentage distributions by device or fuel type so the survey results could be applied to update the emissions inventory. As described earlier, the initial section of the survey asked respondents to identify all of the specific type(s) of heating devices used in the household. Thus, the survey accounted for use of multiple heating devices within each household. These instances of multiple device use within a household had to be properly accounted for in tabulating the results to ensure that surveyed usage is correctly extrapolated to the entire population of Fairbanks households.

Table 7-6-12 shows the sample sizes by ZIP code (including cellphone households that could not be located by ZIP) in the first two rows. The number and percentage of sampled households are shown. In the highlighted row below, weighting factors developed from the percentage of households within each ZIP code based on the 2010 U.S. Census are shown. Comparing these weighting factors to the sample percentages just above, the sample percentages are in nominal, but not perfect agreement with the Census-based weightings. As described later, these weightings were used to adjust the sampled response data by ZIP (and unknown ZIP for the cellphone households) to generate Census-weighted composites in addition to sample self-weighted averages.

Table 7-6-12
2011-2015 HH Survey Sample Size and Multiple Use Types

Parameter	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**
Sample Size, Households	183	906	114	787	1,150	359	15	3,514
Sample Size, % of Sample	5.2%	25.8%	3.2%	22.4%	32.7%	10.2%	0.4%	100.0%
2010 Census Household Weightings	-	24.6%	4.7%	23.9%	34.3%	12.0%	0.5%	100.0%
Multi-Type Household Factor	1.60	1.32	1.47	1.60	1.55	1.65	1.60	1.51
Multi-Type Household Use %	46.4%	27.5%	38.6%	51.6%	47.8%	55.2%	46.7%	43.8%

[a] Also includes Birch Hill area

Next, Table 7-6-12 lists the multiple device usage factors that were calculated from the validated survey data. This "Multi Type Household Factor" represents the ratio of the total number of devices used divided by the number of households. (For example, a factor of 2.0 would indicate an average of two devices in each household.) As seen in Table 7-6-12, there is a fairly consistent multi-type factor across all ZIP codes, with an average for the entire sample of 1.51. Finally, Table 7-6-12 shows the percentages of households with more than one heating device. As shown, nearly 44% of all surveyed households use multiple heating devices.

Device Counts and Usage Distributions – Table 7-6-13 summarizes the counts (number of households) of heating devices by device type and ZIP code from the survey sample. As seen in Table 7-6-13, central oil furnaces (2,803 total households) and wood-burning devices (1,339 total households) were the most commonly found home heating devices in the combined 3,514 household survey sample. The totals of all devices reported at the bottom of Table 7-6-13 reflect the fact that many households use more than one type of home heating device. These totaled counts, when divided by the number of households surveyed listed earlier in Table 7-6-12, match the Multi-Type Household Factors also reported in Table 7-6-12 (for example, within the Downtown area, 1,193 ÷ 906 = 1.32).

Table 7-6-14 presents the distributions of device usage percentages by ZIP code during the winter months (October-March). These usage percentages were determined from the survey responses to Q9a-Q9h where the respondents were asked to roughly estimate the percentage of time each household device is used during winter. The usage percentages in Table 7-6-14 are not based on either the counts of household devices or the amounts of fuel used queried in later sections of the survey. The usage percentages have been properly normalized to account for multiple device use within a household as described in the preceding sub-section. As shown in Table 7-6-14, central oil furnaces are used between 46% and 76% of the time across all ZIP code areas, with an average across the entire sample of 65.5%. Wood-burning devices represent 19.2% of total wintertime device usage across the entire sample, with higher percentages in the outlying areas (North Pole, Airport and Steese) than in those nearer the city center (Downtown, Wainwright). As seen in Table 7-6-14, households in the Wainwright/Birch Hill area have a much greater usage of District heating because of access to this underground infrastructure.

Table 7-6-13
2011-2015 HH Survey Counts of Heating Device Types
(Number of Surveyed Households with Device)

Heating Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**
Wood Burning	71	168	26	379	514	175	6	**1,339**
Central Oil Furnace	133	751	64	662	906	278	9	**2,803**
Portable Heat Device	11	23	3	23	27	12	2	**101**
Direct Vent Type	39	64	20	84	185	63	2	**457**
Natural Gas	7	37	25	10	23	5	3	**110**
Coal Heating	4	8	7	18	3	8	0	**48**
District Heating	6	43	17	4	11	3	0	**84**
Electric Heat	11	53	3	34	50	19	2	**172**
Other	10	46	3	45	61	30	0	**195**
TOTALS	**292**	**1,193**	**168**	**1,259**	**1,780**	**593**	**24**	**5,309**

[a] Also includes Birch Hill area

The rightmost column of Table 7-6-14 highlights composite average device usage percentages using the 2010 Census household ZIP code weightings listed earlier in Table 7-6-12. These weighted averages were calculated using the Census-based household fractions (rather than the survey sample fractions) by ZIP code. Cell households with no known ZIP code were weighted into the Census composite based on their proportion with the sample (i.e., they were assumed to be proportionally distributed into each ZIP code based on the Census weightings).

Table 7-6-14
2011-2015 HH Survey Distributions of Respondent-Estimated Winter Heating Usage Percentages by Device Type

Heating Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd.**
Wood Burning	20.0%	8.9%	11.9%	27.7%	20.2%	23.3%	26.3%	19.0%	**19.2%**
Central Oil Furnace	57.4%	75.6%	46.6%	62.5%	65.7%	61.6%	50.0%	66.0%	**65.5%**
Portable Heat Device	1.9%	0.8%	0.2%	0.5%	0.4%	0.9%	2.3%	0.7%	**0.6%**
Direct Vent Type	13.8%	3.8%	9.9%	4.7%	9.1%	10.4%	4.0%	7.1%	**7.2%**
Natural Gas	2.3%	3.6%	15.1%	0.8%	1.4%	0.7%	16.7%	2.3%	**2.4%**
Coal Heating	0.0%	0.5%	3.6%	1.3%	0.2%	0.5%	0.0%	0.7%	**0.7%**
District Heating	3.3%	4.1%	12.1%	0.2%	0.4%	0.2%	0.0%	1.8%	**1.8%**
Electric Heat	0.7%	1.2%	0.5%	0.8%	0.7%	0.8%	0.7%	0.9%	**0.9%**
Other	0.6%	1.6%	0.2%	1.6%	1.9%	1.7%	0.0%	1.6%	**1.6%**

[a] Also includes Birch Hill area

Wood-Burning Device Breakdowns – Despite the fact that the survey indicates wood-burning devices are used less than 20% of the time, they are a significant contributor to wintertime ambient $PM_{2.5}$ levels. Table 7-6-15 lists the breakdowns in the types of wood-burning devices used within each surveyed ZIP code area. As shown, woodstoves represent an overwhelming majority of wood-burning devices in Fairbanks. Over 86% of the wood burning devices according to the Census-weighted survey sample are woodstoves. This is not surprising given their heating efficiency and the ability to locate the stove within the interior of a residence.

Table 7-6-15
2011-2015 HH Survey Distribution of Wood-Burning Devices (% of Households Sampled)

Wood-Burning Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd.**
Fireplace	5.8%	8.0%	16.0%	3.2%	5.9%	9.1%	0.0%	6.0%	**5.4%**
Fireplace with Insert	4.3%	9.2%	8.0%	4.8%	5.1%	6.3%	16.7%	5.8%	**5.2%**
Woodstove	84.1%	79.8%	76.0%	87.4%	86.8%	79.4%	66.7%	84.7%	**86.3%**
Outdoor Wood Boiler	5.8%	3.1%	0.0%	4.5%	2.2%	5.1%	16.7%	3.6%	**3.0%**

[a] Also includes Birch Hill area

As also shown in Table 7-6-15, fireplaces represent most of the remaining wood-burning usage. Those with inserts constitute 5.2% of the overall sample. Fireplaces without inserts, which are extremely energy inefficient for space heating purposes, represent 5.4% of household wood devices. Outdoor boilers were only found in some areas and represent 3.0% of the weighted survey sample.

Table 7-6-16 provides a further breakdown of the splits between un-certified and certified fireplace inserts or woodstoves. It shows that uncertified stoves/inserts represent less than 20% of the overall sample. Though not shown, the uncertified stove/insert percentage has dropped consistently between the 2011 and 2015 surveys, from 25.7% in 2011 to 13.9% in 2015, which reflects on-going effects of the Borough's Wood Stove Change Out program.

Table 7-6-16
2011-2015 HH Survey Splits Between Uncertified and Certified Fireplace Inserts/Woodstoves (% of Households Equipped)

Insert/Woodstove Certification Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd.**
Un-Certified (<1988)	9.8%	18.4%	15.8%	15.9%	21.3%	14.6%	20.0%	17.8%	**19.1%**
Certified (≥1988)	90.2%	81.6%	84.2%	84.1%	78.7%	85.4%	80.0%	82.2%	**80.9%**

[a] Also includes Birch Hill area

These splits were compiled based on the responses to Q10a of the survey: "*Was your woodstove or insert installed before or after 1988?*" Beginning in 1988, EPA set mandatory New Source Performance Standards (NSPS) [14] for new woodstoves and inserts. Smoke emission levels of 1988 and newer stoves meeting these EPA limits are generally 50-80% lower than from older un-certified units, so the split between un-certified and certified stoves has a significant effect on particulate emissions.

This survey question based on the device installation date may not truly represent the split between EPA-certified and uncertified devices. Even though EPA established these NSPS, regulatory implementation still enabled device manufacturers to sell "woodstove-like" devices that were not subject to the NSPS. As described in the following sub-section, a specialized survey was conducted in 2013 to identify and quantify the fractions of these additional stove-like devices in use in Fairbanks that avoided NSPS certification.

Fuel Usage Rates and Costs - Table 7-6-17 summarizes average fuel usage rates (i.e., the amount of fuel used per season or year) and heating costs by device type for households equipped with or using each device/fuel. These are not averaged across all households.

As shown in Table 7-6-17, households using either fireplaces with inserts or woodstoves burn an average of 3.85 cords annually and 3.48 cords of wood during winter months (October through March) across the weighted survey sample. (These averages were compiled from a sample size of 1,194 households using fireplaces with inserts or stoves.) As also shown in Table 7-6-17, households equipped with fireplaces (without inserts) burned less, using 2.54 and 2.07 cords annually and in winter, respectively. This is not surprising given the significantly lower net heating efficiency of standard fireplaces compared to those with inserts or woodstoves. In contrast wood usage for outdoor wood boilers (OWBs) was much higher, averaging over 8 cords during winter. Although the sample size of OWBs in this survey was small (47 households), higher wood usage for these devices is consistent with the fact that they are generally used as a primary, rather than supplemental heating source.

As reported in Table 7-6-17, households using central oil furnaces consumed an average of 1,130 gallons of heating oil annually and 882 gallons during winter months alone. (These averages are based on a total of 2,803 central oil furnaces identified in the survey.)

Table 7-6-17 also lists similarly tabulated average fuel amounts or costs for portable/kerosene heaters, direct vent heaters, natural gas-based heating, and municipal heating. The sample sizes these device-specific averages were tabulated from were generally much smaller than for wood-burning and central heating devices. As such, they should be interpreted with caution.

[14] EPA certified woodstove smoke emission limits under the original 1988 NSPS were 7.5 grams/hour and 4.1 grams/hour for non-catalytic and catalytic stoves/inserts, respectively (http://www.epa.gov/burnwise/woodstoves.html). Under the new 2015 NSPS, these limits were dropped to 2.0 grams/hour or 2.5 grams/hour using cord wood, effective in 2020 and new limits were added for other wood burning devices.

Table 7-6-17
2011-2015 HH Survey Wood, Heating Oil and Other Fuel Usage Rates and Heating Costs per Equipped Household

Device Type	Usage Period	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd.**
Stove/Insert Wood Use (cords)	Annual	3.25	3.52	3.94	4.69	3.59	3.83	5.08	3.91	**3.85**
	Winter	2.96	3.14	3.32	4.20	3.32	3.49	4.67	3.55	**3.48**
Stove/Insert Wood Use (pellets, tons)	Annual	2.78	3.00	4.17	3.80	2.74	4.81	0.51	3.37	**3.33**
	Winter	2.41	2.66	3.33	3.29	2.44	3.04	0.46	2.86	**2.78**
Fireplace Wood Use (cords)	Annual	1.67	1.80	5.00	3.20	2.29	2.95	n/a	2.57	**2.54**
	Winter	0.75	1.60	4.75	2.40	2.02	2.11	n/a	2.07	**2.07**
Outdoor Wood Boiler Use (cords)	Annual	20.00	3.29	n/a	8.98	10.60	7.80	20.00	9.97	**8.62**
	Winter	17.33	2.70	n/a	8.58	10.52	7.00	15.00	9.21	**8.10**
Central Oil Use (gal)	Annual	1,038	1,130	1,067	1,121	1,160	1,144	730	1,133	**1,130**
	Winter	844	874	856	878	903	888	607	884	**882**
Portable Heater Fuel Use (gal)	Annual	270	442	28	261	342	277	n/a	315	**322**
	Winter	243	293	28	172	289	130	n/a	223	**231**
Direct Vent Heater Fuel Use (gal)	Annual	440	496	124	413	359	505	193	409	**413**
	Winter	371	430	112	363	310	471	154	359	**362**
Coal Heater Use (tons)	Annual	$2,733	$4,085	$2,132	$1,967	$2,692	$1,350	$1,320	$2,850	**$2,671**
	Winter	$2,277	$2,846	$1,675	$1,283	$2,156	$1,129	$915	$2,103	**$1,982**
Natural Gas Fuel Cost (dollars)	Annual	1.63	3.24	1.38	10.34	7.33	5.64	n/a	6.68	**6.30**
	Winter	1.08	3.19	0.71	8.18	5.67	5.64	n/a	5.52	**5.20**
District Heat Fuel Cost (dollars)	Annual	$1,429	$3,143	$801	$721	$4,000	$200	n/a	$2,412	**$2,342**
	Winter	$803	$1,811	$574	$505	$3,875	$200	n/a	$1,633	**$1,897**

[a] Also includes Birch Hill area
n/a – Not applicable (i.e., indicates where a device was not found in the sample for a specific ZIP code)

Extrapolation of Survey Sample to Nonattainment Area – An important element of the analysis consisted of extrapolating heating device counts and usage rates from the sample of 712 surveyed households to the entire household population within the Fairbanks $PM_{2.5}$ nonattainment area. The extrapolation was based on the 2010 U.S. Census-based occupied household counts by ZIP code within the nonattainment area. These Census-based household counts within the nonattainment area are listed in the first row of Table 7-6-18. Based on the share of Cell households in the survey sample, these Census counts were proportionally re-distributed to reflect this Cell share as shown in the second row of Table 7-6-18.

Table 7-6-18
2011-2015 HH Survey Extrapolated Survey Heating Device Counts to $PM_{2.5}$ Nonattainment Area

Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	$PM_{2.5}$ NA Area ZIP Sum	$PM_{2.5}$ NA Area Extrap
Census-Based Households	*n/a*	*7,412*	*1,490*	*7,560*	*11,430*	*4,199*	*2*	***32,093***	***32,093***
Cell-Distributed Households	*3,876*	*6,517*	*1,310*	*6,647*	*10,049*	*3,692*	*2*	***32,093***	***32,093***
Extrapolation Factor	*9.36*	*8.48*	*12.72*	*9.47*	*9.31*	*10.44*	*9.45*	***n/a***	***9.36***
1 - Wood-Burning Device	665	1,424	331	3,590	4,788	1,827	57	**12,682**	**12,537**
1a - Fireplace without insert	39	114	53	115	283	167	0	**770**	**750**
1b - Fireplace with insert	29	131	26	173	245	115	9	**729**	**722**
1c - Woodstove	559	1,136	251	3,139	4,156	1,451	38	**10,731**	**10,619**
Stoves & Inserts (1b+1c)	588	1,267	278	3,312	4,401	1,566	47	**11,459**	**11,341**
Stove/Ins, Uncertified	132	394	79	946	1,495	427	15	**3,488**	**3,606**
Stove/Ins, Certified	455	873	199	2,366	2,906	1,139	32	**7,971**	**7,735**
Stove/Ins, Cord Wood	519	1,122	249	2,809	4,148	1,491	28	**10,366**	**10,364**
Stove/Ins, Pellets	69	145	29	503	254	76	19	**1,094**	**976**
1d - Outdoor Wood Boiler	39	44	0	163	104	94	9	**453**	**446**
2 - Central Oil Furnace	1,245	6,367	814	6,271	8,439	2,903	85	**26,124**	**26,245**
3 - Portable Heater	103	195	38	218	251	125	19	**950**	**946**
4 - Direct Vent Heater	365	543	254	796	1,723	658	19	**4,358**	**4,279**
5 - Natural Gas Heating	66	314	318	95	214	52	28	**1,087**	**1,030**
6 - Coal Heat	37	68	89	171	28	84	0	**476**	**449**
7 - District Heat	56	365	216	38	102	31	0	**809**	**787**
8 – Electric Heat[b]	103	449	38	322	466	198	19	**1,596**	**1,610**
9 - Other	94	390	38	426	568	313	0	**1,830**	**1,610**
All Heating Devices	2,734	10,114	2,138	11,927	16,580	6,192	227	**49,911**	**49,494**

[a] Also includes Birch Hill area
[b] Electric Heat households and extrapolated device counts developed from processing verbatim responses with "Other" generic device group in survey responses. The "Other" counts shown below this row reflect all non-electric heat devices listed as Other in the survey.

Extrapolation factors or multipliers were then calculated from the number of households in an area (either an individual ZIP code or the entire area) from the Cell-Distributed counts divided by the surveyed households for the same area. For example, the Downtown ZIP code (99701) area contains 6,517 households as listed in Table 7-6-18. Since a total of 906 households within that ZIP code were surveyed as reported earlier in Table 7-6-12, the calculated extrapolation factor is 8.48 (6,517 ÷ 181). The combined 2011-2015 survey sample represents roughly one-tenth of all occupied households within the nonattainment area.

Table 7-6-18 presents these extrapolated estimates of the number of heating devices by ZIP code area and across the entire Fairbanks $PM_{2.5}$ nonattainment area. The first row in the table lists the extrapolation factors calculated for each area to expand the survey sample to the entire population of households for each area. The remaining rows of the table present estimated counts of the number of devices by device type and ZIP code. The "short code" designations in the Device Type column of Table 7-6-18 identify each unique device type and clarify the sub-categories and sub-totals reported within the wood-burning sector. As explained in the note below Table 7-6-18, Electric Heat device counts were also broken out from the Other category.

The extrapolation of device counts from the survey sample to total households across the entire nonattainment area was performed two different ways: (1) by individual ZIP code and then summed; and (2) for the entire self-weighted sample. Table 7-6-18, these total device counts for the nonattainment area are reported in the two rightmost columns labeled "ZIP Sum" and "Extrap," respectively. As seen in comparing these columns, the counts differ slightly. This is likely due to propagation of round-off error from small sample sizes within each ZIP code when summed across all ZIP code areas reflected in the survey sample.

On this basis, a total of 12,682 wood-burning devices were estimated to be in use within the nonattainment area. Of these, 10,731 are free-standing woodstoves and 729 are fireplaces with inserts. From the combined total of 11,459 stoves/inserts, 3,488 were estimated to be uncertified (pre-1988). Fireplaces without inserts and outdoor wood boilers represent the remaining wood-burning devices; their counts within the nonattainment area are 770 and 453, respectively, as shown in Table 7-6-18. As addressed below, the precision of device count estimates is not necessarily accurate to the whole integer values listed in Table 7-6-18. The whole integer values are simply shown in this table to illustrate how they were calculated from the sample-to-nonattainment area extrapolation factors.

Statistical Uncertainty Analysis – In extrapolating devices counted in the combined 2011-2015 HH survey sample to the entire nonattainment area, an additional issue that was addressed was the resulting statistical uncertainty. As shown in the preceding tables, very small numbers of households with certain devices were found. Thus, an analysis of the uncertainties associated with proportional extrapolation of the household sample to the entire nonattainment area was performed.

The results of this uncertainty analysis are presented in the next three tables. The estimates in these tables quantify the statistical uncertainty associated with extrapolating the device usage distributions in the surveyed sample represented earlier in Table 7-6-14 through Table 7-6-16 to all the households in the nonattainment area. In each of these tables, the standard error of proportion was used as the measure of statistical uncertainty. It represents the accuracy of each proportional (i.e., usage fraction) estimate in the sample, measured as the standard deviation of that proportion.

First, Table 7-6-19 presents standard errors of proportion associated with the respondent-estimated usage fractions of each major device type reported earlier in Table 7-6-14. The first value in each cell is the usage fraction from Table 7-6-14; the second value represents one standard deviation of this usage fraction.

Table 7-6-19
2011-2015 HH Survey Standard Error of Proportion for Respondent-Estimated Winter Heating Usage Percentages by Device Type

Heating Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd**
Wood Burning	20.0% ±5.8%	8.9% ±1.9%	11.9% ±5.9%	27.7% ±3.1%	20.2% ±2.3%	23.3% ±4.4%	26.3% ±22.3%	19.0% ±1.3%	**19.2% ±1.3%**
Central Oil Furnace	57.4% ±7.2%	75.6% ±2.8%	46.6% ±9.2%	62.5% ±3.4%	65.7% ±2.7%	61.6% ±5.0%	50.0% ±25.3%	66.0% ±1.6%	**65.5% ±1.6%**
Portable Heat Device	1.9% ±2.0%	0.8% ±0.6%	0.2% ±0.7%	0.5% ±0.5%	0.4% ±0.4%	0.9% ±1.0%	2.3% ±7.6%	0.7% ±0.3%	**0.6% ±0.3%**
Direct Vent Type	13.8% ±5.0%	3.8% ±1.2%	9.9% ±5.5%	4.7% ±1.5%	9.1% ±1.7%	10.4% ±3.2%	4.0% ±9.9%	7.1% ±0.8%	**7.2% ±0.9%**
Natural Gas	2.3% ±2.2%	3.6% ±1.2%	15.1% ±6.6%	0.8% ±0.6%	1.4% ±0.7%	0.7% ±0.8%	16.7% ±18.9%	2.3% ±0.5%	**2.4% ±0.5%**
Coal Heating	0.0% ±0.3%	0.5% ±0.5%	3.6% ±3.4%	1.3% ±0.8%	0.2% ±0.3%	0.5% ±0.7%	n/a	0.7% ±0.3%	**0.7% ±0.3%**
District Heating	3.3% ±2.6%	4.1% ±1.3%	12.1% ±6.0%	0.2% ±0.3%	0.4% ±0.3%	0.2% ±0.4%	n/a	1.8% ±0.4%	**1.8% ±0.4%**
Electric Heating	0.7% ±1.2%	1.2% ±0.7%	0.5% ±1.2%	0.8% ±0.6%	0.7% ±0.5%	0.8% ±0.9%	0.7% ±4.1%	0.9% ±0.3%	**0.9% ±0.3%**
Other	0.6% ±1.1%	1.6% ±0.8%	0.2% ±0.9%	1.6% ±0.9%	1.9% ±0.8%	1.7% ±1.3%	n/a	1.6% ±0.4%	**1.6% ±0.4%**

[a] Also includes Birch Hill area
n/a – Not available

For example, the fraction of wood-burning devices used in winter for the entire sample was 19.2% (as listed earlier in Table 7-6-14). Assuming device usage is normally distributed, the value of ±1.3% listed in the upper right cell in Table 7-6-19 means that the actual wood-burning usage fraction lies between 17.9% (19.2 - 1.3) and 20.5% (19.2 + 1.3) with 95% probability.[15]

As expected, the usage fraction estimates within individual ZIP code areas have wider ranges of standard error than the overall estimate across all areas because the standard error estimates are related to sample size. As seen in the rightmost column in Table 7-6-19, the standard errors for heating device usage fraction are less than ±2% across the entire nonattainment area.

Similarly, Table 7-6-20 and Table 7-6-21 present Standard Error of Proportion estimates for proportional device usage <u>within</u> the wood-burning sector and between uncertified and certified woodstoves/inserts, respectively.

[15] 95% probability represents the probability of a normally-distributed sample within two standard deviations of its mean.

Table 7-6-20
2011-2015 HH Survey Standard Error of Proportion for
Distribution of Wood-Burning Devices (Percent of Households Sampled)

Wood-Burning Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd**
Fireplace	2.3% ±3.5%	1.5% ±1.8%	3.6% ±7.2%	1.7% ±1.3%	2.6% ±1.4%	4.5% ±3.1%	n/a	2.3% ±0.8%	**2.1% ±0.8%**
Fireplace with Insert	1.7% ±3.0%	1.7% ±2.0%	1.8% ±5.1%	2.3% ±1.5%	2.3% ±1.3%	3.1% ±2.6%	6.7% ±20.0%	2.2% ±0.8%	**2.0% ±0.7%**
Woodstove	32.8% ±11.0%	14.8% ±5.4%	17.3% ±14.6%	42.0% ±5.0%	38.8% ±4.2%	38.7% ±7.2%	26.7% ±35.4%	32.2% ±2.5%	**33.2% ±2.5%**
Outdoor Wood Boiler	1.7% ±3.0%	0.6% ±1.1%	n/a	2.2% ±1.5%	1.1% ±0.9%	2.5% ±2.3%	6.7% ±20.0%	1.4% ±0.6%	**1.2% ±0.6%**

[a] Also includes Birch Hill area
n/a – Not available.

Table 7-6-21
2011-2015 HH Survey Standard Error of Proportion for
Uncertified and Certified Stove/Insert Splits (Percent of Households Equipped)

Insert/Woodstove Certification Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd**
Un-Certified (<1988)	9.8% ±7.5%	18.4% ±6.5%	15.8% ±16.4%	15.9% ±4.0%	21.3% ±3.8%	14.6% ±5.9%	20.0% ±35.1%	17.8% ±2.3%	**19.1% ±2.3%**
Certified (≥1988)	90.2% ±7.5%	81.6% ±6.5%	84.2% ±16.4%	84.1% ±4.0%	78.7% ±3.8%	85.4% ±5.9%	80.0% ±35.1%	82.2% ±2.3%	**80.9% ±2.3%**

[a] Also includes Birch Hill area
n/a – Not available.

Comparisons Across Surveys – Finally, Table 7-6-22 presents a comparison of key tabulations from each of the historical Fairbanks Home Heating surveys: 2006, 2007, 2010-2015. The tabulations from all the historical surveys were re-weighted by ZIP code using the 2010 Census weightings for consistency when comparing results.

As Table 7-6-22 shows, the normalized fractions of winter device are fairly consistent over time, except for the fact that wood use fractions have headed upward while usage in the generic Other category has trended down. It shows that wood stoves, and recently, outdoor wood boilers have exhibited increased usage within the wood-burning device sector. A large downward trend in the fraction of uncertified stoves/inserts can also be seen in Table 7-6-22.

Table 7-6-22 also shows increasing (but still modest) penetration of pellet-burning stoves, rising from near zero in the 2006 and 2007 surveys to over 10% of total stoves/inserts in the three latter surveys.

Table 7-6-22
Summary of Key Results from Historical Home Heating Surveys (2006-2015)

Statistic	Parameter	Survey Results							
		2006[a]	2007[a]	2010	2011	2012	2013	2014	2015	**2011-2015**
Average Winter Device Use by Type (% of Household Use)	Wood	10.8%	12.4%	18.2%	15.3%	19.2%	20.8%	22.4%	19.2%	**19.2%**
	Central Oil	68.6%	64.8%	67.2%	67.4%	68.1%	66.8%	60.4%	64.1%	**65.5%**
	Portable	0.7%	0.5%	0.1%	0.8%	0.1%	0.8%	0.9%	0.6%	**0.6%**
	Direct Vent	8.1%	7.0%	8.0%	9.5%	6.9%	5.6%	7.4%	7.0%	**7.2%**
	Natural Gas	2.4%	2.0%	4.2%	3.2%	3.0%	1.6%	1.6%	2.3%	**2.4%**
	Coal Heat	n/a	n/a	0.5%	0.6%	0.4%	1.1%	1.4%	0.2%	**0.7%**
	District Heat	2.0%	0.8%	1.1%	1.8%	1.9%	1.7%	0.9%	2.8%	**1.8%**
	Electric Heat	n/a	n/a	n/a	0.5%	0.1%	0.7%	1.7%	1.2%	**0.9%**
	Other	7.5%	12.5%	0.8%	0.9%	0.3%	0.8%	3.2%	2.6%	**1.6%**
Wood Burning Type (% of Wood-Burning Devices)	Fireplace	12.6%	17.1%	7.0%	5.2%	4.2%	5.4%	6.7%	5.2%	**5.4%**
	Insert	8.2%	5.6%	6.1%	4.3%	4.0%	4.7%	4.6%	8.4%	**5.2%**
	Woodstove	79.2%	77.2%	85.3%	87.2%	89.1%	88.9%	84.3%	82.3%	**86.3%**
	Wood Boiler	n/a	n/a	1.6%	3.2%	2.7%	1.0%	4.5%	4.1%	**3.0%**
Wood Stove/Insert Cert Type (% of Woodstoves/Inserts)	Uncertified	52.0%	46.7%	35.7%	25.7%	22.7%	20.1%	14.4%	13.9%	**19.1%**
	Certified	48.0%	53.3%	64.3%	74.3%	77.3%	79.9%	85.6%	86.1%	**80.9%**
Wood Stove/Insert Wood Type (% of Woodstoves/Inserts)	Cordwood	99.8%	100.0%	95.8%	96.9%	95.9%	88.3%	85.2%	89.1%	**91.0%**
	Pellet	0.2%	0.0%	4.2%	3.1%	4.1%	11.0%	13.5%	10.9%	**8.6%**
Wood Stove/Insert Wood Source (% of Woodstoves/Inserts)	Buy	27.0%	28.0%	36.5%	27.0%	36.1%	35.4%	32.3%	37.4%	**33.8%**
	Cut Own	71.1%	60.6%	50.2%	61.9%	49.1%	47.1%	54.3%	47.9%	**51.8%**
	Both	1.8%	11.4%	13.4%	11.0%	14.8%	17.5%	13.4%	14.7%	**14.4%**
Stove/Insert Wood Use (cords)	Winter	3.14	2.84	3.51	3.31	3.62	3.43	3.69	3.20	**3.48**
Fireplace Wood Use (cords)	Winter	0.82	0.81	4.09	3.94	2.51	1.73	1.41	1.87	**2.07**
Central Oil Use (gal)	Winter	n/a	n/a	6.00	17.80	12.01	5.67	2.30	4.56	**8.10**
Portable Heater Fuel Use (gal)	Winter	1,172	1,027	819	979	861	903	828	841	**882**
Direct Vent Heater Fuel Use (gal)	Winter	97.1	241.9	59.1	323.1	89.4	298.0	212.9	175.0	**231.1**
Coal Heater Fuel Use (tons)	Winter	470	514	487	413	367	342	361	337	**362**
Natural Gas Fuel Cost ($)	Winter	n/a	n/a	2.29	1.50	3.79	2.47	11.38	9.35	**5.20**
Municipal Heat Fuel Cost ($)	Winter	$1,414	$1,287	$1,346	$2,164	$1,836	$2,233	$1,713	$1,837	**$1,982**

[a] Winter usage in these surveys encompassed October-May; later survey winter usage spanned October-March.

In addition, the "Wood Source" section of Table 7-6-22 shows how the mix of where households acquire their wood has trended over time. Most wood-burning households cut their own wood (vs. purchasing it commercially), although the "Cut Own" fraction appears to have drifted downward in recent surveys as shown in Table 7-6-22.

Finally, as shown in the lower section of Table 7-6-22 winter season fuel use and heating cost trends are mixed across the list of devices shown. Although both wood stove/insert and fireplace usage in households equipped with those devices have trended upward, there is significant year to year oscillation in the averages compiled from the survey data.

As highlighted in the rightmost column in Table 7-6-22, the combined 2011-2015 survey data were largely used in the 2013 baseline inventory.

And as noted earlier, Table 7-6-22 shows the clear downward trend in the fraction of uncertified wood stoves and inserts, dropping from 52.0% in 2006 to 13.9% in 2015.which is believed to results from a combination of "natural" turnover in stoves from uncertified to newer, certified (and cleaner) stoves in the early survey years combined with the effects of the Borough's Wood Stove Change Out program that began in July 2010. Thus, as described in further detail later in the "Survey Data Use in SIP Inventories" sub-section, this downward trend in uncertified stoves/inserts was developed using data from all available Home Heating surveys.

Specialized Wood-Burning Surveys

2013 Wood Tag and Purchase Surveys - In additional the annual Home Heating surveys described in the preceding section, DEC and the Borough also commissioned two specialized surveys in early 2013 that focused on wood-burning devices and practices. Unlike the Home Heating surveys which randomly sampled all residential households, these specialized surveys targeted only wood-burning households and are summarized as follows:

1. *Wood Tag Survey* – A telephone survey of 216 households in which respondents were asked a series of questions about their wood devices related to establishing whether it was certified or not and if so, what emission rating (in grams/hour) and output (in BTU/hour) were stamped on the device's "tag" or certification label. Information was also collected on the make, model and installation date of the devices (when available) that was used in conjunction with EPA's published lists of certified stoves/inserts[16] and hydronic heaters[17] to look up emission ratings, technology type (catalytic vs. non-catalytic) and energy output. The survey also contained specific questions related to current participation in wood-related emission control programs, including existing Borough programs as well as likelihood of switching to natural gas under expanded availability of natural gas anticipated over the next several years. Finally, the survey also included questions about other devices and usages within the household beyond the wood-burning devices upon which the survey was primarily focused. As with the Home Heating surveys, the sampling was performed in a stratified manner, randomly sampling households within nonattainment area ZIP codes based on targeted sample sizes developed from 2010 Census household weightings by ZIP code.

2. *Wood Purchase Survey* – A separate survey of 217 wood-burning households within the nonattainment area (again with 2010 Census-weighted targeted sampling by ZIP code) was conducted to ascertain more detailed information about patterns in households that commercially purchase their wood and that cut it themselves. Much like the branching elements of the Home Heating surveys, specific sets of questions were asked in households that bought wood from those that cut their own. For wood buyers, questions centered around purchased wood: the supplier and their reasons for using them, whether

[16] http://www.epa.gov/Compliance/resources/publications/monitoring/caa/woodstoves/certifiedwood.pdf
[17] http://www.epa.gov/burnwise/owhhlist.html

wood was split or in rounds or whole logs, etc. For respondents who cut their wood, questions included the source (private or public land), whether a permit was obtained, etc. For both wood source types, respondents were also asked questions related to moisture content and the drying/seasoning period for their wood.

In addition to the specific questions asked within each of these two wood-burning surveys, respondents in both surveys were asked a series of questions about the price premium they would be willing to pay for purchase of pre-dried wood given that dry wood typically produces about 25% more heat per cord than wet wood. These questions were intended to gauge interest and potential participation in a local control program designed to expand use of fully-dry wood.

Attachment A lists the survey script and questions contained in the 2013 Wood Tag and Wood Purchase surveys (following the Home Heating survey script).

<u>Key Findings Across Tag and Purchase Surveys</u> – Before summarizing findings from the unique questions within each specialized wood household survey, tabulations of several key results <u>common</u> to both surveys are presented as follows.

Wood-Burning Device Distributions – Table 7-6-23 presents a side-by-side comparison of the mix of primary wood-burning devices used in sampled households from the Tag and Purchase surveys (each with sample sizes of over 200 households as noted earlier). As shown, distributions of wood devices between the two surveys are in general agreement.

Both surveys show that woodstoves represented well over 80% of primary wood-burning devices. (Pellet and cordwood stoves from the Tag survey totaled 87.8%, these splits were not available from the Purchase survey.). This is consistent with woodstove fractions from the Home Heating surveys shown earlier in Table 7-6-15 and Table 7-6-22. However, the 17.7% pellet stove fraction from the 213 Tag survey was noticeably higher than that observed in more recent Home Heating surveys (which averaged roughly 4%).

Both the Tag and Purchase surveys also exhibited slightly higher fractions of fireplaces, 7.8% and 9.5%, respectively than those seen in recent Home Heating surveys (roughly 5%), although higher fireplace fractions were seen in earlier surveys prior to 2010 as reported in earlier Table 7-6-22.

Table 7-6-23
2013 Wood Survey Wood-Burning Device Distributions
(Percent of Households Sampled, Census Weighted)

Wood-Burning Device Type	Wood Tag Survey	Wood Purchase Survey
Woodstove (cordwood)	70.1%	82.1%
Woodstove (pellet)	17.7%	
Fireplace Insert	0.4%	3.4%
Fireplace (no insert)	7.8%	9.5%
Outdoor Wood Boiler	3.6%	3.2%
Other	0.5%	1.7%

Wood Source Mix - Table 7-6-24 compares the splits in the source of household wood between the Tag and Purchase surveys. As shown, these splits are very consistent, with households that cut their own wood outnumbering those that purchase their wood commercially by about a 3-to-1 margin, with roughly 15-20% of sampled homes using a mixture of purchased and personally harvested wood. This relative 3-to-1 ratio of Cut vs. Buy group households represents a higher split of Cut households than reported from recent Home Heating surveys. As shown earlier in Table 7-6-22, the Cut vs. Buy household splits ranged from 1.5 to 2-to-1 in the 2010-2012 Home Heating surveys.

As explained later in the “Fairbanks Wood Energy and Moisture Content” section of this appendix, the Buy vs. Cut wood source splits are important because of evidence that indicates homeowners that cut their own wood tend to season (and dry) it longer than those who buy their wood. Thus this split affects the overall wood moisture level.

Table 7-6-24
2013 Wood Survey Wood Source Mix
(Percent of Households Sampled, Census Weighted)

Wood Source Group	Wood Tag Survey	Wood Purchase Survey
Buy	22.4%	19.9%
Cut Own	63.1%	57.7%
Both (Buy & Cut Own)	14.5%	22.3%

Cost of Firewood – In both the Tag and Purchase surveys, respondents in the Buy group (those that purchased some or all of their firewood) were also questioned about the price they paid (excluding any delivery fee). The results were very consistent across both surveys and are listed as follows.

Survey	Avg. Price ($/cord)	Range	Sample Size
Tag	$233	$100-$400	50
Purchase	$227	$89-$400	60

In these 2013 surveys, the average price paid for firewood was about $230 per cord (excluding delivery fee). Under the Purchase survey, Buy group respondents were also asked about delivery fees. About 72% paid no delivery fee (or picked up the wood themselves). For the remaining 28% that paid a fee, the average was $293 although values varied from $40 to $700 and the phrasing of the question was vague in specifying the price per cord, delivery or season.

Willingness to Pay More for Dried Wood – Both wood surveys also included a series of questions intended to measure willingness to spend more on commercially-purchased wood that is fully dried before being sold. The questions were identically phrased in both surveys and were directed to those households that buy all or a portion of their firewood. They were asked in a staged manner as follows: *"Knowing that dry wood provides 25 percent more heat than wet wood, would you pay $25 more per cord for dry wood?"* For those who answered yes, the question was then repeated with the threshold raised to $50, then $75, and finally $100.

Responses are summarized in Table 7-6-25. For each staged question, the percentage who responded affirmatively is shown. In parenthesis next to each percentage is the ratio that was used to calculate it (number answering "yes" divided by total definitive answers). The table shows that the percentage of people willing to pay each specified amount for dry wood was fairly consistent between both the Tag and Purchase surveys, but in no case was the difference statistically significant at the 95% confidence level.[18] Thus, the data from two surveys were combined in the rightmost column of Table 7-6-25 to provide the most robust estimate of the surveyed responses (129 combined households that buy wood).

[18] In general, large sample sizes are necessary to detect small differences between two percentages (see, for example, Snedecor et al, Statistical Methods, 1980).

Table 7-6-25
2013 Wood Survey Willingness to Pay for Dry Wood
Distribution of Wood-Burning Devices (Percent of Households Sampled)

Pay More for Dry Wood?	% Willing to Pay (#yes/total)		**Willingness to Pay Combined Surveys**
	Wood Tag Survey	Wood Purchase Survey	
$25/cord more	73.5% (36/49)	72.5% (58/80)	**72.8%**
$50/cord more (if 'yes' to above)	38.6% (17/44)	46.5% (33/71)	**43.5%**
$75/cord more (if 'yes' to above)	16.3% (8/44)	13.6% (9/66)	**15.5%**
$100/cord more (if 'yes' to above)	14.6% (7/43)	4.6% (3/65)	**9.3%**

Key Tag Survey Findings – As noted earlier, the Tag survey sampled 216 wood-burning households in the Fairbanks nonattainment area. The primary objective of the survey was to obtain a reasonably size subset of households with certified woodstoves/fireplace inserts (or Phase 1 or 2-qualified outdoor wood boilers) and have respondents provide certification information about the device such as its smoke rating (particulate emission rate in grams/hour), heating efficiency and heat output (BTU/hour) by reading these data from the certification label or "Tag" stamped on the device. Table 7-6-26 lists the distribution of primary wood-burning devices from the surveyed sample in the "All" column. For each device, it also shows the breakdown between devices identified as uncertified/unknown or EPA-certified based on the respondents' answers to the question: *"Is your device certified, or does it have a certification label?"* (Certification label information was only solicited for woodstoves, inserts and outdoor wood boilers. As noted with "n/a" in the "Certified" column of Table 7-6-26, certification data was not applicable to fireplaces or other devices not explicitly identified.)

Table 7-6-26
2013 Tag Survey Wood-Burning Device Distributions
(Number of Households)

Wood-Burning Device Type	Sample Size			
	All	Uncertified/ Unknown	Certified	**Certified, Label Read**
Woodstove (cordwood & pellet)	189	92	97	**18**
Fireplace Insert	1	1	0	
Fireplace (no insert)	17	17	n/a	**n/a**
Outdoor Wood Boiler	8	3	5	**1**
Other	1	1	n/a	**n/a**
Totals	216	114	102	**19**

As shown in the highlighted "Certified, Label Read" column in Table 7-6-26, once respondents were asked to actually read information from the device certification label (or provide via follow-up postcard solicitations) few could or did. Label visibility or access were likely the primary factors for getting few "Label Read" responses.

Fortunately, respondents were also asked to provide make, model and model year of their woodstoves, inserts or outdoor wood boilers. A total of 95 respondents were able to provide this information. These responses (where available) were then compared to EPA's published lists[19] of certified woodstoves/inserts and outdoor hydronic heaters (i.e. outdoor wood boilers). For devices that could be matched to EPA's lists (and are therefore certified), emission rate, efficiency and heat output data were looked up. Using this approach, the initial sample of 19 devices for which complete label data were available was expanded to a total of 68 certified devices (67 stoves/inserts, 1 outdoor wood boiler) with compiled emission rate, efficiency and heat output data.

Certified Woodstove/Insert Levels - Table 7-6-27 presents tabulated emission rates (in grams/hour) and heat output ranges (in BTU/hour) for those woodstoves/inserts for which certification data were available. Separate sample sizes and averages are shown by technology type (catalytic vs. non-catalytic). As shown, the analysis sample was split roughly 60%/40% for catalytic and non-catalytic certified woodstoves/inserts. Average particulate emission rates (i.e. certified smoke rating) are highlighted in the middle column. Across the entire sample, the average PM emission rate was found to be 2.48 grams/hour as shown at the bottom of Table 7-6-27. Based on this sample, Fairbanks certified woodstoves/inserts are quite clean compared to EPA's existing certified woodstove emission standards of 7.5 grams/hour and 4.1 grams/hour for non-catalytic and catalytic devices, respectively.

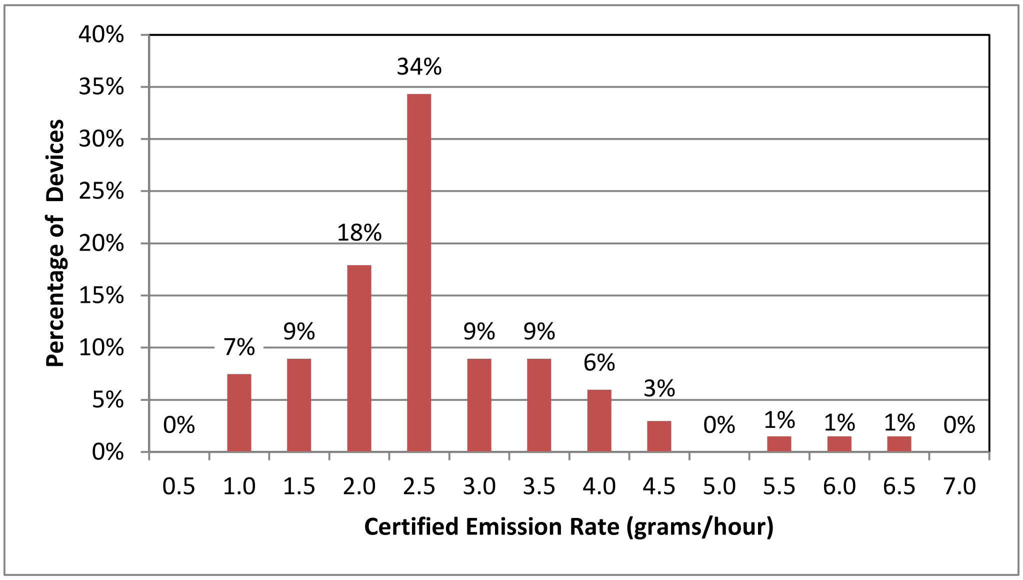
Table 7-6-27
2013 Tag Survey Certified Woodstove/Insert Emission Rates and Output by Technology Type

Technology Type	Sample Size		**Avg. Emission Rate (grams/hour)**	Avg. Output (BTU/hour)	
	N	Pct.		Minimum	Maximum
Catalytic	40	59.7%	**2.23**	10,740	36,541
Non-Catalytic	27	40.3%	**2.86**	10,871	34,714
Totals/Averages	67	100.0%	**2.48**	10,793	35,805

Figure 7-6-29 shows the distribution of emission rates for the certified stoves/inserts from the Tag survey sample. Each interval shows the percentage of devices in the survey sample between the indicated rate and that to its immediate left. For example, 34% of the devices (23 out of 67) had certified emission rates of 2.0 to 2.5 grams/hour. Summing the frequencies from Figure 7-6-29 cumulatively, 31% and 66% of the stoves/inserts were below 2.0 gram/hour and 2.5 gram/hour levels, respectively.

[19] http://www.epa.gov/burnwise/appliances.html, circa January 2013.

Figure 7-6-29
Distribution of Tag Survey Certified Stove Emission Rates (grams/hour)

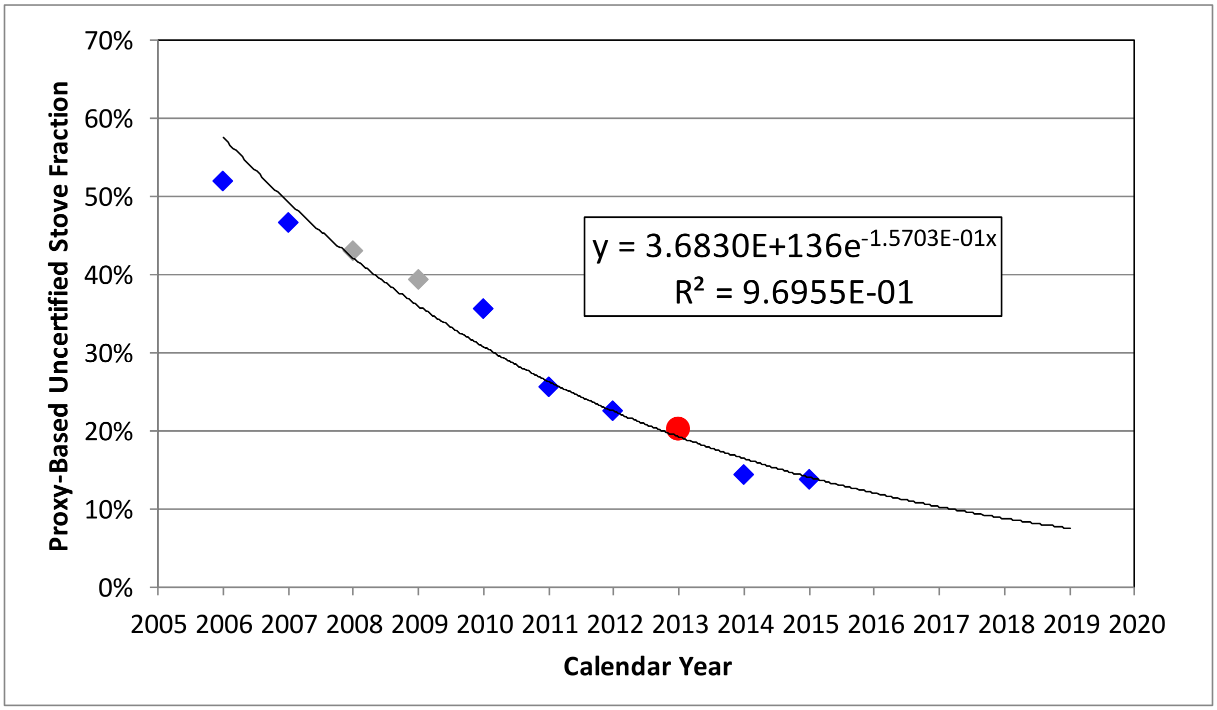


True Uncertified Device Fraction – Responses to specific questions from the Tag survey were also used to evaluate what is believed to be a biased (low) estimate of the percentage of uncertified woodstoves/inserts from the Home Heating surveys. As discussed earlier, the Home Heating surveys do not attempt to get respondents to examine their wood devices for the presence (or absence) of an EPA certification label. The installation date question (1988 and earlier vs. post-1988) from the Home Heating surveys is used as a “proxy” to estimate the fractions of woodstoves/inserts that are not EPA-certified, but as discussed earlier “woodstove-like” devices that are excluded from EPA’s wood heater regulations have been observed for sale in Fairbanks retail outlets. Thus, the more definitive label information (or lack thereof) from the Tag survey presented an opportunity to estimate a true uncertified woodstove/insert fraction.

Out of 129 definitive responses (i.e. removing “don’t know” responses) from Tag survey woodstove/insert households, 90 were found to have a certification label or tag (although as noted earlier not all could be read by the respondents). The remaining 39 when ZIP code Census-weighted represented a “true” uncertified stove/insert fraction of 31.8%.

As shown earlier in Table 7-6-22, the proxy-based uncertified stove fraction estimates from the Home Heating surveys have been on a steady downward decline (in part based on the fixed installation date cutoff). Thus in order to make an equivalent comparison to the true uncertified fraction from the 2013 Tag survey, this Home Heating proxy trend was fitted using a exponential curve approach illustrated in Figure 7-6-30. The diamond shaped marker points are the proxy-based uncertified stove fractions from Table 7-6-22. (Values for 2008 and 2009 shown as gray markers in were interpolated from the 2007 and 2010 survey fractions.)

Figure 7-6-30
Curve-Fitted Forecast of 2006-2015 Proxy-Based
Home Heating Survey Uncertified Stove/Insert Fraction



A least-squares exponential curve was fitted to these data as shown by the line. The proxy-based uncertified fraction from the 2013 survey is shown as a red marker in Figure 7-6-30. This 2013 proxy-based uncertified stove fraction was 20.1%.

The difference between the two 2013 estimates (true vs. proxy) of the uncertified stove fraction was 12.7% (31.8% - 20.1%) and was assumed to represent the "offset" that accounted for the underreported uncertified stoves in the Home Heating proxy-based approach. (How this offset was used in the SIP inventory is discussed in the next sub-section.)

The 39 Tag survey responses used to represent the true uncertified stove/insert fraction were also further examined to cross-check the approach used to calculate this proxy offset. 34 of the 39 "true" uncertified device respondents provided installation/age information for their stoves/inserts; 18 (53.4%) were installed on or before 1988; 16 (46.6%) after 1988. The post-1988 split was then multiplied by the true uncertified stove fraction of 31.8% to produce a "proxy-equivalent" estimate of 14.8% (31.8% × 46.6%), which compares reasonably with the 12.7% offset estimated above.

Natural Gas Expansion – Two questions were included in the Tag survey to gauge willingness of existing wood-burning households to switch to using natural gas under a planned expansion of natural gas availability being guided by the Alaska Industrial Development and Export Authority (AIDEA).

The first question asked respondents to estimate the retail price gas would need to be offered at to get them to switch from wood (and heating oil). To make the question easier to understand and the answers more meaningful, the price question was asked on a heating oil equivalent basis: *"If natural gas becomes available, what gas price would get you to stop burning wood (in $/gal equivalent of heating oil)?"* Out of 140 definitive responses, the average gas price was $2.17 per gallon on an oil equivalent basis. 102 of the 140 respondents, or 72.8% indicated willingness to switch to gas if offered at $2.00/gallon equivalent, about half of the current heating oil price.

The second question dealt with the potential need of wood-burning households that switch to gas to continue to burn wood on extremely cold days (less than -30°F) for reasons such as ensuring particular rooms or areas of the house stayed warm. Of the 185 definitive responses to this question, 37.9% (71 respondents) indicated they may still feel the need to use their wood devices on cold days, even after switching their house to natural gas.

Wood Species Mix – Finally, responses were also tabulated from the question asking homeowners to identify the predominant species of firewood they burned. Out of a total of 191 valid responses, the ZIP code Census-weighted composite fractions (by volume) were as follows:

- Birch (paper birch) – 46.4%;
- Spruce (white spruce) – 34.1%; and
- "Aspen" (black/white poplar) – 18.5%.

These translate to mass fractions of 54.6%, 30.3% and 15.1%, respectively based on the unit mass[20] of each local wood specie published by the Alaska Department of Natural Resources.

<u>Key Purchase Survey Findings</u> – Beside results summarized earlier in conjunction with the Tag survey, a key finding from the Wood Purchase survey was the mix of whole logs (or round) versus pre-split logs purchased. At the time of purchase the 81 responses were split as follows:

- Split – 31 or 38.3%;
- Whole/Rounds – 40 or 49.4%; and
- Both – 11 or 12.3%.

A follow up question was asked of those purchasing whole logs/rounds about when they split their wood, 'as needed' or 'on delivery.' Roughly 44% said 'as needed', the remaining 56% responded 'on delivery.'

Normalizing these tabulations to remove the 'Both' responses and account for splitting by the homeowner after delivery, the mix of split vs. whole/round logs was calculated to be roughly 75% vs. 25%.

[20] "Purchasing Firewood in Alaska," Alaska Department of Natural Resources, Division of Forestry, http://forestry.alaska.gov/pdfs/firewood.pdf

2016 Postcard Survey - A postcard (rather than telephone) survey was conducted in 2016 to assess whether large drops in heating oil prices from 2013 to 2015 had any impact on wood use. Unlike the earlier telephone-based surveys under which a random sample was drawn from all residents in the nonattainment area, the 2016 Postcard survey targeted household respondents who had participated in the 2014 and 2015 HH surveys. Use of a postcard-type survey enabled respondents to more thoughtfully collect and estimate wood and heating oil usage data for winter 2015-2016 space heating that could be directly compared to similar data for the same set of households as sampled in the earlier 2014 and 2015 surveys. An analysis directed by DEC[21] found that winter season residential wood use dropped 30% on average in the 2016 survey for the same set of households sampled in the 2014 and 2015 surveys, and that most of this drop could not be explained by differences in heating demand due to year-to-year variations in winter temperatures.

DEC's Staff Economist then coordinated a study by University of Alaska Fairbanks[22] that evaluated the 2016 Postcard data to determine if a cross-price elasticity could be quantified between wood use and heating oil use and prices in Fairbanks. That economic study found a median cross-price elasticity between wood and heating oil of -0.318, meaning wood use drops by 0.318% for every 1% decrease in the price of heating oil. This wood vs. cross-price elasticity was then used to estimate changes in wood vs. oil use in projected baseline inventories relative to the difference between the forecasted oil price in the projection year vs. the 2013 Baseline.

2017 Commercial Business Survey – In 2017, DEC conducted a study of commercial businesses within the nonattainment area to determine which businesses, if any had and used solid fuel burning devices (wood or coal) during winter months. The first element of the study consisted of acquiring a spreadsheet database[23] of over 1,700 businesses within the nonattainment area from the Borough's Planning Department. The database included the name and type of each business as well as its location. Based on the business types, the data were then classified into a total of 12 categories spanning two groups, Possible Solid Fuel (SF) and Not Likely SF as follows:

- Possible SF – churches, dining/bars, hotels/motels, retirement centers, other;
- Not Likely SF – banks, fast food, grocery stores, gas stations, hospitals/medical, schools/day care, other.

A total of 608 out of 1,774 businesses were categorized within the Not Likely SF group. It was assumed that businesses categorized within this group did not operate solid fuel devices and were not further evaluated. For the remaining 1,116 classified within the Possible SF group, 140 were classified as either churches, dining/bars, hotels/motels or retirement centers. Each of these were surveyed by a combination of telephone and on-site inquiries. A total of 1,026 were classified as Other within the Possible SF group and a random survey of 50 business from this category was similarly conducted.

[21] T. Carlson, M. Lombardo, Sierra Research, R. Crawford, Rincon Ranch Consulting memorandum to Cindy Heil, Alaska Department of Environmental Conservation, January 17, 2017.
[22] "Estimating FNSB Home Heating Elasticities of Demand using the Proportionally-Calibrated Almost Idea Demand System (PCAIDS) Model: Postcard Data Analysis," prepared by the Alaska Department of Environmental Conservation in collaboration with the University of Alaska Fairbanks Master of Science Program in Resource and Applied Economics, December 10, 2018.
[23] Email from Kellen Spillman, FNSB Community Planning Department, October 12, 2016.

Figure 7-6-31 shows the survey form used by DEC to enter information regarding solid fuel devices, usage and related activity from these phone and on-site surveys.

Figure 7-6-31
Commercial Business Solid Fuel Survey Form

FAIRBANKS NON-RESIDENTIAL BUSINESS SPACE HEATING SURVEY

Business Name: ____ PAN: __________

Business Address: ____ Date: __________

1) Do you have a wood, coal or other solid fuel burning device that is used for space heating?
(Yes, No, Not Sure/Don't Know) ____________________

YES BRANCH

Y2) What is/are the device(s) and fuel(s)?

____

____

Y3) How many cords of wood or bags/tons of coal do you use:

In winter (October through March)

_______ cords of wood

_______ bags / tons of coal

Annually (entire year)

_______ cords of wood

_______ bags / tons of coal

Y4) What's a rough estimate of how much heating during winter is from this/these solid fuel device(s)?

__________ %

Y5) What's the size of the building space that's heated?

_________ square feet

NO (or Don't Know) BRANCH

N2) What fuel is your primary source of space heating during winter (October through March)?

☐ – Heating Oil
☐ – Natural Gas
☐ – Municipal/District Heat
☐ – Waste Oil
☐ – Electric
☐ – Other (not listed above)

Notes/Observations: ____
____
____

The resulting response data were entered into a spreadsheet and used to represent solid fuel-burning space heating emissions for commercial businesses. Out of over 1,700 businesses a total of ten were found to operate wood or coal burning devices and their usage estimates were applied within the baseline inventory. (Commercial solid fuel space heating accounted for about 0.01% of total $PM_{2.5}$ emissions within the nonattainment area.)

Survey Data Use in SIP Inventories

As pointed out in the preceding sections, a variety of telephone-based residential surveys have been conducted in Fairbanks dating as far back as early 2006 in order to ascertain information about local space heating practices, as well as their trends over time. This sub-section clarifies two specific elements of these surveys that were utilized to calculate space heating emissions within the SIP inventories. It also describes how they were applied as inputs in these calculations. Except where explicitly noted, these inputs were based on the combined 2011-2015 Home Heating survey data.

Device Energy Usage Splits by 4 km Grid Cell – As discussed earlier, the Home Heating survey data included tabulations of the mix of heating devices in sampled homes and rough estimates of wintertime use percentages provided by the respondent at the beginning of the telephone survey. Later in the device-specific sections of the survey, respondent provided estimates of winter season (and annual) fuel use (e.g., cords of wood or gallons of heating oil) or costs (amount spent per winter month on natural gas or District heat).

A key input to the home heating energy model as discussed earlier under the "Development of Energy Model" section of this appendix was the seasonal average device energy use mix in the household. In the SIP inventory application of the energy model, this winter average household device energy use split was developed and applied from ZIP code-specific tabulations of device energy use splits developed from the 2011-2015 HH survey data. However, instead of using the roughly estimated splits provided by respondents at the beginning of the survey, more robust splits were calculated from the seasonal fuel use data provided later in the survey.

These calculations were performed by converting average seasonal fuel use (for each equipped device in the household) into energy use by multiply by each fuel's specific energy content. Table 7-6-28 lists the energy contents assumed for each fuel and their data sources.

Multiplying by these fuel energy contents, average winter season fuel use estimates from the 2011-2015 HH surveys were then translated into winter season energy use estimates. These calculations were performed by 4 km square grid cell (each of which contains nine 3×3 1.33 km modeling grid cells). Average fuel use for each fuel and device type for all households within each 4 km cell was converted to average winter season energy use estimates by cell. For device categories such as natural gas and electric heat, fuel cost rather than fuel use data was collected in the survey since it was easier for respondents to provide cost rather than usage data for these categories. Table 7-6-28 lists the unit costs for these fuels that were used to translate the survey data into seasonal fuel use.

Table 7-6-28
Assumed Energy Contents of Space Heating Fuels in Fairbanks

Fuel	Energy Content	Units	Source/Notes
Wood, baseline moisture	12.1	mmBTU/ton	Alaska Department of Natural Resources http://forestry.alaska.gov/pdfs/firewood.pdf, Wood density = 1.683 tons/cord
Heating Oil #1	125,000	BTU/gal	Cold Climate Housing Research Center (energy content for #1 oil in heating appliance survey)
Heating Oil #2	138,500	BTU/gal	North American Combustion Handbook, from http://en.wikipedia.org/wiki/Heating_oil
Fairbanks #1 & #2 Blend	135,000	BTU/gal	Fairbanks Community Research Quarterly, http://www.co.fairbanks.ak.us/cp/Pages/crq.aspx
Kerosene	135,000	BTU/gal	http://generatorjoe.net/html/energy.asp
Natural Gas	1,010	BTU/ft^3	Fairbanks Community Research Quarterly, http://www.co.fairbanks.ak.us/cp/Pages/crq.aspx Gas cost = $2.34 per 100 ft^3
Coal	15.2	mmBTU/ton	http://www.usibelli.com/Coal-data.php
Electric	3,413	BTU/kWh	Fairbanks Natural Gas, http://www.fngas.com/calculate.html Electricity cost = $0.180 per kilowatt-hour (kWh)

The results of these energy use calculations are presented in Table 7-6-29**Error! Reference source not found.Error! Reference source not found.**. Actual energy use (winter season BTUs per household) has been translated into normalized percentages in the table. Based on the availability of separate emission factors for specific device/fuel combinations, splits from the survey data were stratified into the categories shown in Table 7-6-29. **Error! Reference source not found.**4 km based on their share of the survey sample and 2010 Census weightings.)4 km based on their share of the survey sample and 2010 Census weightings.)

The first six rows of Table 7-6-29**Error! Reference source not found.** show calculated HH survey-based heating energy use splits by device/fuel for key 4 km grid cells within the Fairbanks portion of the nonattainment area, stretching from the area around Fairbanks International Airport (FAI) and the Chena Pump/Geist Road to the west to the downtown Fairbanks/Nordale and Southeast Fairbanks areas to the east.

The next four rows in Table 7-6-29**Error! Reference source not found.** provide similar splits for the 4 km cells that comprise most of the North Pole area. As seen in Table 7-6-29**Error! Reference source not found.**, the usage splits for woodstoves/inserts and outdoor wood boilers in these North Pole cells are notably higher than those across most of Fairbanks cells, with the area southeast of the Richardson Highway as the exception.

Use of the combined 2011-2015 survey sample enabled the development of these more spatially resolved usage splits. (The Moderate SIP was based on a single survey and only resolved usage splits by ZIP code.)

Table 7-6-29
2011-2015 Home Heating Survey Winter Season Heating Energy Use Splits by Key 4 Km Grid Cell

Area Description	4 Km Grid Cell	Pct. Of Winter Season Heating Energy Use by Grid Cell									
		Wood			Heating Oil			Nat Gas	Coal	Steam	
		Stove/ Insert	Fireplace	Outdoor Boiler	Central Oil	Direct Vent	Portable	Natural Gas	Coal Heat	Muni. Heat	Total
FAI	137,136	25.32%	1.47%	2.08%	66.30%	1.89%	0.00%	0.00%	2.93%	0.00%	100%
Chena Pump/Geist	137,137	8.70%	1.36%	0.58%	84.63%	1.22%	1.72%	0.98%	0.08%	0.72%	100%
Mitchell/S. Fairbanks	138,136	17.88%	0.00%	1.07%	69.76%	2.17%	0.00%	8.26%	0.42%	0.44%	100%
W of Downtown	138,137	11.33%	0.27%	0.53%	80.92%	1.19%	0.37%	3.75%	0.00%	1.64%	100%
Mitchell/SE Fairbanks	139,136	11.51%	0.21%	0.44%	73.75%	2.37%	2.50%	7.08%	0.17%	1.96%	100%
Downtown/Nordale	139,137	9.14%	0.54%	0.23%	84.16%	1.83%	0.27%	0.73%	0.42%	2.69%	100%
NP/SE of Richardson	143,134	20.75%	1.03%	1.39%	72.57%	1.55%	0.07%	0.00%	2.64%	0.00%	100%
NP/N of Hurst	143,135	26.84%	0.35%	3.30%	62.82%	2.78%	0.93%	0.62%	2.35%	0.00%	100%
NP/S of Hurst	144,134	29.82%	0.71%	3.55%	63.00%	1.12%	0.92%	0.67%	0.22%	0.00%	100%
NP/Badger	144,135	24.53%	0.00%	1.88%	71.29%	0.85%	0.24%	0.00%	0.87%	0.35%	100%
Cells <50 Households	Low SS	28.89%	0.59%	1.46%	60.89%	5.90%	0.36%	0.35%	1.45%	0.10%	100%

However, even with five years of combined HH survey data, a number of 4 km cells in the outlying portions of the nonattainment area had sample sizes less than 50 households. As noted at the bottom of Table 7-6-29**Error! Reference source not found.**, all the data for these areas were combined and used to represent device/fuel usage in all of the outlying cells. The 50-household minimum was developed based on balancing explicit splits for more cells with a minimum statistically viable sample.[24]

Highlighted columns in Table 7-6-29**Error! Reference source not found.** refer to those devices for which in-use measurements were collected under the aforementioned CCHRC study, and which were used to construct the home heating energy model. Emissions for those devices not represented in the CCHRC study (those not highlighted in Table 7-6-29**Error! Reference source not found.**) were calculated from their HH survey-based proportional energy use outside the energy model.

Forecasted Trends in Uncertified Stoves/Inserts – As discussed earlier in summarizing the key findings from the 2013 Wood Tag survey, EPA certification data obtained for devices sampled under that effort enabled development of an offset or correction factor to upwardly revise underreported fractions of uncertified stoves/inserts from the Home Heating surveys.

Table 7-6-30 illustrates how this offset was used in conjunction with development of trends in the split between certified and uncertified stoves/inserts over time that were applied in

[24] Alternative minimum sample sizes of 30 and 100 households were also evaluated. A 30-household minimum did not appreciably increase the number of 4 km cells meeting the requirement and for those that did, exhibited greater variations due to the smaller sample size. A 100-household minimum would have resulted in several of the cells shown in Table 7-6-29 not meeting the criteria and therefore not reflecting neighborhood-specific patterns.

representing their effects in both the baseline (2013) and projected baseline inventories.

Table 7-6-30
Corrected Splits and Trends in Uncertified and Certified Stoves/Inserts

Calendar Year	Home Heating Survey-Based Uncertified Pct.	Tag Survey Offset	Corrected Percentages			
			Uncertified	Certified, Non-Catalytic	Certified, Catalytic	Total
2006	52.0%	+12.7%	64.7%	26.3%	9.0%	100.0%
2007	46.7%		59.4%	31.0%	9.6%	100.0%
2008	43.1%		55.7%	31.1%	13.2%	100.0%
2009	39.4%		52.1%	30.7%	17.2%	100.0%
2010	35.7%		48.4%	29.9%	21.7%	100.0%
2011	25.7%		38.4%	37.4%	24.2%	100.0%
2012	22.7%		35.4%	40.3%	24.3%	100.0%
2013	20.1%		32.8%	36.6%	30.6%	100.0%
2014	14.4%		27.1%	40.3%	32.6%	100.0%
2015	13.9%		26.6%	42.3%	31.2%	100.0%
2016			*24.6%*	*47.1%*	*28.3%*	*100.0%*
2017			***22.9%***	***48.1%***	***29.0%***	***100.0%***
2018			*22.9%*	*48.1%*	*29.0%*	*100.0%*
2019+			*22.9%*	*48.1%*	*29.0%*	*100.0%*

The second column in Table 7-6-30 lists the uncorrected fractions of uncertified stoves/inserts tabulated from the annual Home Heating surveys dating back to the inaugural survey in 2006. (2008 and 2009 fractions were interpolated from 2007 and 2010 survey results.) The 12.7% correction factor determined from the Tag survey is shown in the next column and was assumed to be a constant offset over time. (In the absence of additional corroboratory data other than that collected in the 2013 Tag survey and given that the law under which uncertified woodstove-like devices was not changed through 2015, it was believed that a constant offset adjustment over time was reasonable.)

The remaining columns of Table 7-6-30 show the corrected splits between uncertified and certified (both non-catalytic and catalytic) stoves/inserts from the historical Home Heating surveys after applying the offset adjustment to the uncertified fractions. The shaded cells in the table highlight the corrections to the uncertified fractions from the Home Heating survey data over time. For example, in 2013 the Home Heating survey-based estimate of 20.1% was increased by 12.7% to yield a corrected estimate of 32.8%. After applying this correction for each historical calendar year, the splits for the remaining certified non-catalytic and catalytic were proportionally renormalized as shown in the next two columns of Table 7-6-30.

As shown in the *italicized* lower section of Table 7-6-30, estimates of uncertified stove/insert fractions over time out to 2019 (the latest inventory projection year) were forecasted to continue their natural downward trend observed from 2006 through 2017 survey data using the exponential curve and equation presented earlier in Figure 7-6-30 and the constant 12.7% additive adjustment.

However, as highlighted for calendar year 2017, the projected downward trend based on the exponential curve fit shown in in Figure 7-6-30 was capped, or held constant in subsequent years. The reason for this relates to the on-going effects of the Borough's Wood Stove Change Out (WSCO) program.

Under the Moderate SIP, available data at the time suggested that the downward trend in uncertified stoves/inserts had two components: 1) the WSCO Program (which started in July 2010); and 2) "natural" turnover of older uncertified devices that preceded, and continued to occur outside the WSCO program. This analysis and its findings were revisited under the Serious SIP.

WSCO program transaction data for calendar years 2013 through 2016 were obtained from the Borough and tabulated to determine if the Home Heating survey-based exponential trend curve continued to show greater drops in uncertified device fractions over time than explained by WSCO data for uncertified-to-certified wood device change outs.[25] A greater decrease in the uncertified device fractions than explained by the WSCO data over the same period would identify and provide an estimate for the natural turnover in uncertified devices occurring outside the WSCO program. However, analysis of the 2013-2016 WSCO uncertified-to-certified device change-outs showed a <u>nearly identical decrease</u> to that projected from the Home Heating survey data to 2017.

Therefore, it was estimated that little, if any natural turnover was continuing outside the WSCO program. The Home Heating survey-projected downward trend in uncertified devices was held constant in 2017 and later years to reflect WSCO program activity through calendar year 2016 within projected baseline inventories to be consistent with controls included in the Moderate SIP that are now treated as part of the baseline in 2017 and later years.

The corrected splits and trends in Table 7-6-30 were applied to represent stove/insert uncertified/certified fractions in the baseline and projected baseline SIP inventories. As explained later in this appendix, separate analysis of WSCO program data for later years beyond 2016 was conducted to estimate on-going effects from the WSCO program in later years that program control benefits under the Serious SIP.

[25] During the 2013-2016 and beyond, the WSCO program includes several types of incentivized change-outs including: 1) uncertified-to-certified wood device change-outs, 2) high-to-low emitting certified wood device change-outs, and 3) solid fuel (wood or coal) to liquid/gaseous fuel device conversions. Only the first of these change out-types impacts the uncertified device fractions over time.

Home Heating – Fairbanks Wood Energy and Moisture Effects

For biofuels such as wood, the moisture level has a significant effect on the net heating energy when the fuel is burned as well as on resulting emission factors (mass emissions of pollutant per unit mass of fuel). Energy content of the locally-available firewood species must also be accounted for. This section of the Emission Inventory Technical Appendix describes how Fairbanks-specific wood energy and moisture effects were accounted for within the Residential Space Heating sector of the SIP inventories.

The section begins by summarizing the sources and methods used to estimate the energy content of Fairbanks-specific wood used in home heating. It also contains a discussion of basic concepts in representing and accounting for heating energy effects of wood as a function of its moisture content. Next, the data and sources used to estimate baseline moisture levels across the spectrum of Fairbanks wood burners are described. The final sub-section documents how these elements were combined to calculate effects of moisture content on wood-burning emissions within the SIP inventories.

Fairbanks Wood Energy Content

The energy content per unit volume of firewood varies by over a factor of two[26], depending on the species of the wood. Although energy content per unit mass shows much less variation across wood species, firewood is cut, purchased and stacked/stored on a volumetric basis (e.g., in cords) and therefore understanding the types/mix of Fairbanks firewood species is important.

Common woods in the conterminous U.S. typically exhibit an average energy content of roughly 8,500 BTU/lb on an oven dry (i.e. bone dry) basis. In EPA's AP-42 emission factor database, residential wood burning emission factors are based on an energy content of 17.3 mmBTU/ton[27] (equal to 8,650 BTU/lb).

(As discussed in the detail in following sub-section, wood moisture also has a significant effect on its effective energy content or heating value. Therefore, wood energy content is generally reported on a fully-dried basis, or at a reference moisture level. This sub-section deals solely with energy content variations by wood species, irrespective of moisture level.)

To better represent the energy content of firewood burned for space heating in Fairbanks, information on the relative usage of local wood species used in residential heating was collected from the 2013 "Wood Tag" survey of 216 randomly-selected wood-burning households located within the Fairbanks NAA. The three predominant local firewood species are: 1) Birch; 2) White Spruce; and 3) Aspen. Local firewood called "Aspen" is actually a mix of white poplar (American Aspen) and black poplar (Cottonwood) species that grow in the area.

[26] "Firewood BTU Content Charts," Chimney Sweep Online, http://www.chimneysweeponline.com/howood.htm.
[27] http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s10.pdf

Table 7-6-31 lists the relative usage fractions for each of the three primary local wood species (Birch, Spruce and Aspen) tabulated from the 2013 Wood Tag survey responses. It shows that Birch and Spruce are the most commonly used firewood species.

Table 7-6-31
Fairbanks Firewood Usage Splits and Energy Content by Species

Parameter	Local Wood Species			Composite
	Birch	Spruce	Aspen	
Usage Fraction, by volume	46.4%	35.1%	18.5%	100%
Usage Fraction, by mass	54.6%	30.3%	15.1%	100%
Energy Content (BTU/lb)[a]	8,126	8,518	8,252	**8,264**

[a] Assuming 0% moisture or oven dry basis.

Table 7-6-31 also shows energy contents assumed for each specie (on an oven dry basis), based on Alaska-specific data[20] published by the Alaska Department of Natural Resources (ADNR). The energy contents shown in Table 7-6-31 are adjusted to an oven-dry basis from the ADNR values, which reflect 20% moisture content, or "air dry" conditions. As highlighted in the rightmost column of Table 7-6-31, the composite energy content of Fairbanks firewood (weighted by the specie-specific usage percentages) was estimated to be 8,264 BTU/lb on an oven dry (OD) basis.

Wood Moisture and Energy Relationship

When harvested, wood has a certain amount of water or moisture suspended within its mass. The amount of moisture in wood is referred to as its moisture content (MC). Wood moisture content is generally defined on a percentage basis relative to either:

1. the mass of the wood including its water (wet basis, wb); or
2. the mass of the wood excluding the water (dry basis, db).

Wood moisture levels are rigorously measured in the laboratory by measuring the mass of wood before and after placing it in a drying oven (where all its suspended water is evaporated). For example, if a piece of wood had a wet mass (before drying) of 1.25 lb and a dry mass of 1.00 lb, its moisture content on both a wet or dry basis would be calculated as follows:

$$MC\ Wet\ (MC\ wb) = (Mass_{Wet} - Mass_{Dry}) \div Mass_{Wet} = (1.25 - 1.00) \div 1.25 = 0.20 \text{ or } 20\%$$
$$MC\ Dry\ (MC\ db) = (Mass_{Wet} - Mass_{Dry}) \div Mass_{Dry} = (1.25 - 1.00) \div 1.00 = 0.25 \text{ or } 25\%$$

Moisture levels also affect how wood energy content is reported, depending on what state the wood's suspended water molecules are in after being vaporized during combustion. Gross or

Higher Heating Value (HHV) energy content includes energy associated with the latent heat of vaporization of moisture within the wood when condensed after combustion. Net or Lower Heating Value (LHV) energy content excludes this latent heat of vaporization. Under bone dry conditions, both heating values are the same. At moisture levels other than 0%, LHV energy content is lower than that based on the HHV. The equations below, excerpted from the U.S. Department of Energy Biomass Energy Data Book[28] and converted to English units, show how wood HHV and LHV vary by wood moisture content.

$$\boldsymbol{HHV = HHV_{dry} \times (1 - MC_{wb})} \quad \textbf{(4)}$$

$$\boldsymbol{LHV = HHV_{dry} \times (1 - MC_{wb}) - 1050\, MC_{wb}} \quad \textbf{(5)}$$

Where:

HHV = higher heating value (BTU/lb) which includes latent heat of vaporization;
LHV = lower heating value (BTU/lb) which excludes latent heat of vaporization;
HHV_{dry} = laboratory-measured energy content or bone dry HHV (BTU/lb);
MC_{wb} = wood moisture content (%, wet basis); and
1050 = a constant that represents the latent heat of vaporization (at 25°C).

Table 7-6-32 presents calculated Fairbanks wood energy content (on both an HHV and LVH basis) as a function of various moisture levels, expressed on both a wet and dry basis.

Table 7-6-32
Fairbanks Wood Energy Content (BTU/lb) vs. Moisture Content (%)

MC Wet (%)	MC Dry (%)	HHV (BTU/lb)	LHV (BTU/lb)	%HHV Reduction Relative to Oven Dry
0.0%	0.0%	8,264	8,264[a]	0%
5.0%	5.3%	7,851	7,798	5.0%
10.0%	11.1%	7,437	7,332	10.0%
15.0%	17.6%	6,886	6,711	15.0%
20.0%	25.0%	6,611	6,401	20.0%
25.0%	33.3%	6,198	5,935	25.0%
30.0%	42.9%	5,785	5,470	30.0%
35.0%	53.8%	5,371	5,004	35.0%
40.0%	66.7%	4,958	4,538	40.0%
45.0%	81.8%	4,545	4,073	45.0%
50.0%	100.0%	4,132	3,607	50.0%

[a] Based on composite bone-dry energy content for local firewood mix.

[28] B. Boundy, et al., "Biomass Energy Data Book: Edition 4," Oak Ridge National Laboratory, Report No. ORNL/TM-2011/446, September 2011.

The specific value to use depends on the combustion device and application. Wood burning devices used in residential space heating cannot recover latent heat energy from water vapor produced during combustion. Therefore, their heating value or efficiency in the real world would be based on the LHV. This approach is used in Europe. In the U.S. however, residential wood device heating value specifications and efficiencies have traditionally been published on an HHV basis, including data reported through EPA's woodstove certification standards. In order to be consistent with U.S. published data and efficiency ratings (used later in emission inventory and control measure calculations), HHVs were used to account for moisture effects in residential wood burning.

Wood Moisture and Emissions – The energy content vs wood moisture relationship shown in Table 7-6-32 results in a commensurate or proportional impact on wood-burning emissions. Relative to any "reference" moisture level, the amount of additional wood that must be burned is directly related to the difference in energy content between the actual and reference moisture levels. The relative reduction in HHV-based energy content at any moisture level relative to 0% (Oven Dry) moisture content is shown in the highlighted column in Table 7-6-32. The reduction in relative HHV is mathematically equal to the wet-basis moisture content.

Beyond this proportional HHV vs. moisture content impact, emissions from wood-burning devices are also affected by factors that reduce optimum combustion conditions. Wood burning devices are tested for emissions and efficiency performance with "air dry" wood in a moisture content range of about 18% to 28% (15% to 22% wet basis) to represent the normal range most people use or should use. Both higher and lower moisture content can have significant negative consequences[29]. High moisture reduces efficiency and makes it harder to start and sustain good secondary combustion. This is due to its cooling effect that slows down combustion and cools the gases produced by pyrolysis. Very dry wood tends to burn faster and can evolve gases at a rate that outstrips the ability of most heating devices to supply adequate air, resulting in oxygen starvation. This can cause higher emissions, pulsating combustion and overheating.

Available literature that quantifies these moisture-driven combustion effects on resulting device emission levels is extremely limited. In a comparative analysis[30] of wood device testing results from both laboratory measurements and in-home instrumented studies, Houck (2012) observed that any clear relationship that wood moisture alone might have with emissions is clearly obscured by other real-world variables. Earlier studies[31,32] also note the difficulty in isolating the moisture-combustion effect on emission rates in historical test measurements and suggest its

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[29] R. Curkeet, "Wood Combustion Basics," Intertek Worldwide, EPA workshop presentation, March 2, 2011, http://www.epa.gov/burnwise/workshop2011/WoodCombustion-Curkeet.pdf
[30] J. Houck, "A Comparison of Particulate Emission Rates from the In-Home Use of Certified Wood Stove Models with U.S. EPA Certification Emission Values and A Comparison between In-Home Uncertified and Certified Wood Stove Particulate Emissions," prepared for Hearth, Patio & Barbecue Association, February 1, 2012. Docket EPA-HQ-OAR-2009-0734.
[31] R. Curkeet and R. Ferguson, "EPA Wood Heater Test Method Variability Study," prepared for Hearth, Patio and Barbecue Association, October 6, 2010.
[32] J. Houck and P. Tiegs, "Residential Wood Combustion Technology Review Volume 1. Technical Report," prepared for U.S. Environmental Protection Agency, Report No. EPA-600/R-98-174a, December 1998.

magnitude is smaller compared to other sources of variation in the data.

Although the observed literature acknowledges a moisture-combustion effect on device emission rates, a statistically significant relationship isolating this effect does not appear to have been developed. Therefore, wood-burning emissions in the SIP inventories are based solely on the moisture-energy content effect described earlier.

Baseline Moisture Levels

Having developed estimates of local firewood species and their energy content and identifying effects of wood moisture content on effective energy content (or HHV), the next step consisted of assembling baseline wood moisture levels for firewood burned in Fairbanks during winter. Two primary data sources were used:

1. Usage splits developed from Fairbanks home heating surveys on fractions of households that purchase wood sold commercially vs. those that cut their own wood (Cut group);

2. Wood moisture measured from the wood-burning homes in the aforementioned CCHRC Home Instrumentation study (used to the develop the space heating energy model; and

3. Moisture measured in experimental wood piles under a second CCHRC study[33].

Wood Source Groups - In each of the residential home heating surveys, residents were asked to identify the source of wood used in their home categorized as follows:

- Buy - those that they purchased commercially;
- Cut – those that cut their own wood; and
- Both – those using a mixture of wood they cut themselves and purchased commercially.

Table 7-6-33 shows the “Wood Source” results tabulated from the home heating surveys: the combined 2011-2015 HH surveys and the 2013 specialized Wood Purchase and Tag surveys. Data for the 2013 baseline inventory were developed from combined results of the Purchase and Tag surveys. (These survey targeted wood-burning households, had roughly twice the sample of wood burning respondents than in each home heating survey and were less lengthy. As a result, their wood source splits were chosen as better estimates than those from the combined HH survey data.)

Since the fraction of Buy vs. Cut wood sources in households that responded “Both” was not known from the surveys, this response was not used. As highlighted at the bottom of Table 7-6-33, the fractions of Buy and Cut wood source groups from each historical survey were then renormalized.

[33] “Wood Storage Best Practices in Fairbanks, Alaska,” prepared by Cold Climate Housing Research Center, June 27, 2011.

Table 7-6-33
Fairbanks Residential Survey Wood Source Fractions

Wood Source Group	2011-2015 HH Surveys	2013 Purchase Survey	2013 Tag Survey
Buy Wood	35.1%	19.9%	22.4%
Cut Own	60.2%	57.8%	63.1%
Both (Buy & Cut)	4.7%	22.3%	14.5%
Total	100.0%	100.0%	100.0%
Normalized, Buy	**36.8%**	**25.6%**	**26.2%**
Normalized, Cut	**63.2%**	**74.4%**	**73.8%**

Once the household fractions within each wood source group were tabulated, separate data sources were used to estimate average wood moisture levels within each group. This distinction was made to account for the fact that homeowners who cut their own wood tend to be those that have built storage sheds with ample capacity and season or dry their wood for longer periods than those purchasing wood commercially.

Cut Group Moisture – As noted earlier, homeowners who cut their own wood (rather than buying it commercially) tend to be those who pre-plan and generally have constructed wood storage sheds or areas on their property. During the CCHRC Home Instrumentation study, it was observed that a number of the wood-burning participants in that study (the Mixed and Wood households) appeared to fit this profile of homeowners that cut their wood and had on-site storage for it. The moisture content of the wood stacks from each of these Mixed and Wood households in the Instrumented study was measured at the time of the instrumentation (Dec 2010-Feb 2011).

In the absence of any additional detailed data, it was assumed that the average wood moisture content from these 20 households provided a reasonable estimate of the wood moisture for homeowners in the Cut group. Table 7-6-34 lists the measured moisture content (dry basis) from the wood samples taken from each of these households. Moisture levels ranged from a low of 17% to a high of 58%, with an average of 26.6% shown at the bottom of Table 7-6-34.

Half of the measured moisture levels were in the “air dry” range (from 17% to 21%). This is consistent with anecdotal evidence noted earlier that homeowners who cut their own wood tend to properly store their wood and allow for a drying period of at least several months. And since the moisture measurements were taken during mid-winter, they are representative of winter season modeling episodes.

Thus, the average moisture content from this sample of 26.6% was assumed to reasonably approximate wood moisture for the Cut group of households.

Table 7-6-34
Estimated Cut Group Moisture Content
Based on CCHRC Instrumentation Study Wood Samples

CCHRC Household ID	Moisture Content (%, db)
1	25%
2	18%
3	17%
4	27%
5	20%
6	18%
7	33%
8	18%
9	38%
10	20%
21	21%
22	31%
23	24%
24	24%
25	19%
26	32%
27	58%
28	20%
29	21%
30	48%
Sample Average	**26.6%**

Buy Group Moisture – Wood moisture content for the Buy group of wood-burning households was developed from CCHR's "Wood Storage Practices" study. This study consisted of experimental development and testing of moisture content for different types (wood species) and storage/covering practices. Wood was cut and stored at two different points during the year:

1) *Spring Harvest* – wood cut in late May, simulating those homeowners that plan ahead and allow wood to dry over summer; and

2) *Fall Harvest* – wood cut in mid-September, simulating those that wait until fall to cut wood for immediate use in winter.

After each harvest, the wood was stored in different configurations that included a simulated wood shed and tarp covered, and uncovered stacks. Both whole log and split log stacks were prepared. Moisture measurements were then taken from randomly-selected logs within each stack at different durations after each initial harvest at roughly two-month intervals, from immediately after stacking to up to 12 months later.

Table 7-6-35 lists the moisture levels (dry basis) measured by CCHRC for the Spring and Fall harvest cuts by storage method, wood type and seasoning period (in months from cut shown in green shaded cells above the month each moisture measurement was conducted.).

Boldface yellow shaded cells in Table 7-6-35 were originally marked as "Dry" by CCHRC. A moisture level of 15% was assumed for these measurements. *Italicized* tan shaded cells denote moisture levels interpolated from adjacent measurements that we missing in the original data.

These data were used to develop separate estimates of Cut group wood moisture for the January-February and November modeling episodes within the SIP inventories by using measured moisture levels from each harvest in these months. Before doing so, it was necessary to estimate splits in wood use by harvest, log type and storage method.

In consultation with DEC, it was assumed that 25% of wood sold commercially was cut in spring, with the remaining 75% harvested during fall. Greater weight was given to the fall cut due to the short and yearly varying length of the spring wood cutting window, which is affected by the timing of the spring thaw and breakup. Summer months exhibit wet, boggy conditions that can be worsened by thunderstorms, which makes wood harvesting difficult. Early fall is generally when most wood cutting and harvesting occurs, and when commercial wood sellers have a better idea of firewood demand for the upcoming winter months.

Next, the fraction of whole versus split logs was assumed to be evenly divided: 50% whole and 50% split. Not that these are fractions that reflect the state of the logs over duration they are stored in a stack, not the state of logs when burned. (Data collected later under the 2013 Wood Purchase survey roughly corroborate this assumption. The resulting composite moisture level is not strongly sensitive to the mix between whole and split logs based on the CCHRC measurements listed in Table 7-6-35.)

In addition, to represent a composite estimate of storage method-driven difference in moisture content, the "Tarp Covered" values in Table 7-6-35 were used and assumed to represent a mid-range wood storage method in terms of its effectiveness in reducing moisture during seasoning. (For Aspen, moisture levels were based on the "Simulated Wood Shed" measurements since Tarp Covered data were not available for that wood species.)

Table 7-6-35
Moisture Content Measurements from CCHRC Wood Storage Practices Study

Spring Harvest Moisture Content by Sampling Month (%, db)

Storage Method	Seasoning Months →	0	1.5	3	8	10	12
	Wood and Log Type	Late May	July	Late Aug	Jan	March	May
Simulated Wood Shed	Birch – split	52%	20%	18%	**15%**	**15%**	**15%**
Simulated Wood Shed	Birch – whole)	52%	30%	25%	29%	28%	24%
Simulated Wood Shed	Spruce – split	86%	16%	17%	**15%**	**15%**	**15%**
Simulated Wood Shed	Spruce – whole	86%	28%	21%	23%	24%	17%
Simulated Wood Shed	Aspen – split	76%	26%	20%	**15%**	**15%**	**15%**
Simulated Wood Shed	Aspen – whole	76%	49%	44%	40%	*33%*	26%
Tarp Covered	Birch – split	49%	21%	20%	**15%**	**15%**	**15%**
Tarp Covered	Birch – whole	49%	28%	31%	32%	*29%*	25%
Tarp Covered	Spruce – split	86%	22%	22%	35%	*27%*	18%
Tarp Covered	Spruce – whole	86%	67%	30%	29%	*26%*	23%
Uncovered	Birch – split	57%	19%	35%	46%	38%	17%
Uncovered	Birch – whole	57%	29%	32%	52%	39%	25%
Uncovered	Spruce – split	77%	17%	19%	**15%**	**15%**	**15%**
Uncovered	Spruce – whole	77%	29%	27%	47%	29%	17%
Solar Kiln	Aspen – split	59%	24%	16%	**15%**	**15%**	**15%**
Solar Kiln	Aspen – whole	59%	38%	32%	34%	31%	27%

Fall Harvest Moisture Content by Sampling Month (%, db)

Storage Method	Seasoning Months →	0	4	6	8
	Wood and Log Type	Mid Sept	Jan	March	May
Simulated Wood Shed	Birch – split	80%	49%	42%	30%
Simulated Wood Shed	Birch – whole)	80%	55%	56%	47%
Simulated Wood Shed	Spruce – split	85%	63%	40%	37%
Simulated Wood Shed	Spruce – whole	85%	77%	72%	51%
Simulated Wood Shed	Aspen – split	83%	63%	51%	34%
Simulated Wood Shed	Aspen – whole	83%	65%	*57%*	48%
Tarp Covered	Birch – split	78%	63%	70%	49%
Tarp Covered	Birch – whole	78%	67%	*62%*	57%
Tarp Covered	Spruce – split	92%	117%	*101%*	84%
Tarp Covered	Spruce – whole	92%	80%	*85%*	89%

Given these weighting/selection assumptions, **Error! Reference source not found.**Table 7-6-36 presents average moisture levels by specie (birch, spruce, aspen) for January-February and

November, with composites calculated across harvest, log type and storage method. For example, the moisture content for birch during the January-February period was calculated as follows:

$$
\begin{aligned}
MC_{birch,Jan} &= 25\% \times (50\% \times MC_{spring,birch,Tarp,Jan,split} + 50\% \times MC_{spring,birch,Tarp,Jan,whole}) + \\
&\quad 75\% \times (50\% \times MC_{fall,birch,Tarp,Jan,split} + 50\% \times MC_{fall,birch,Tarp,Jan,whole}) \\
&= 0.25 \times (0.50\times15\% + 0.50\times32\%) + 0.75 \times (0.50\times63\% + 0.50\times67\%) \\
&= 54.6\%
\end{aligned}
$$

Table 7-6-36
Average Buy Group Moisture Content by Wood Species and Modeling Episode

Episode	Measurement Month(s)	Moisture Content by Species (%, db)			Wtd. Avg. MC (%, db)
		Birch	Spruce	Aspen	
Jan-Feb	Jan	54.6%	81.9%	54.9%	62.9%
Nov	Interpolation from Aug/Sep and Jan	59.8%	78.7%	62.6%	65.9%

The highlighted column in**Error! Reference source not found.** Table 7-6-36 shows the weighted average moisture content for Buy group wood across all three wood species for each modeling episode. These averages were calculated using the relative usage factors for each species (listed earlier in Table 7-6-31) of 46.4%, 35.1% and 18.5% for birch, spruce and aspen, respectively.

Calculation of Moisture Effects

Once Fairbanks wood-specific energy content and moisture content estimates were developed for each type of wood source (Buy vs. Cut), wood moisture effects were calculated by combining elements from the preceding sub-sections to produce composite estimates for both the 2013 baseline and projected baseline inventories.

The normalized Buy vs. Cut wood fractions from the 2013 Purchase and Tag surveys shown earlier in Table 7-6-33 (24% and 74%, respectively) were used to represent wood source splits during 2013. (As noted earlier, these 2008 splits were interpolated from results tabulated from 2007 and 2010 Home Heating surveys). These wood source splits were combined with separate moisture levels estimated for each source group (Buy vs. Cut), to generate weighted composite moisture level across both source groups as shown below in Table 7-6-37. As seen in Table 7-6-37, the composite wood moisture contents (db) for the 2013 Baseline were 36.1% and 36.9% for the January-February and November episodes, respectively, with a composite average across all episode days of 36.5%. The nominally higher moisture content in November compared to January-February is due to the fact that wet wood cut earlier in the year has less time to season and dry by November compared to the following January-February.

Table 7-6-37
Calculation of Baseline Wood Moisture Effects

Source Group	Usage Fraction (%)	Moisture Content (%, db) by Modeling Episode	
		Jan-Feb	Nov
Buy	26%	62.9%	65.9%
Cut	74%	26.6%	26.6%
Composite	**100%**	**36.1%**	**36.9%**
Energy Content (EC)			
HHV (BTU/lb)		**6,071**	**6,036**
EC Relative to Energy Model (26.6%, db)		**0.930**	**0.925**

The last two rows in Table 7-6-37 show the resulting moisture-affected energy content (as HHV in BTU/lb) and the energy content (EC) relative to the reference EC on which the earlier residential heating energy model is based. The moisture level-specific HHVs were calculated using the energy content vs. moisture relationship shown earlier in Equation (4) and Table 7-6-32. (As explained earlier, the energy model's reference EC is the same as that of the Cut group since that was how the Cut group moisture level was estimated.) These relative ECs highlighted in the bottom row of Table 7-6-37 were applied to the BTU estimates generated by the energy model to adjust effective heating energy to reflect composite wood moisture levels within each episode for 2008 Baseline conditions.

HOME HEATING – OMNI AND AP-42 EMISSION FACTORS

In support of more robust SIP emission estimates, the Borough and DEC have sponsored several local measurement studies designed to better quantify $PM_{2.5}$ and related emissions in Fairbanks in the winter. A key element of this coordinated effort was the FNSB-sponsored study[34] of emission factors from residential space heating appliances and fuels, which was conducted in 2011 by OMNI-Test Laboratories, Inc. (OMNI).

The OMNI study provided the first and most comprehensive systematic attempt to quantify Fairbanks-specific, current technology-based emission factors from space heating appliances and fuels. The laboratory-based emission testing study consisted of 35 tests of nine space heating appliances, using six typical Fairbanks fuels. Both direct PM emissions and gaseous emission precursors of PM (SO_2, NO_x, VOC and NH_3) were measured, along with PM elemental profiles. All emission tests were conducted at OMNI's laboratory in Portland, Oregon. Supporting solid fuel, liquid fuel, and bottom ash analyses were performed by Twin Ports Testing, Southwest Research Institute (SwRI), and Columbia Analytical Services, respectively. PM profiles of deposits on Teflon filters from dilution tunnel sampling were analyzed by the Research Triangle Institute using XRF, ion chromatography, and thermal/optical analysis.

This section focuses on how Alaska-specific emissions data from the OMNI study data were used to complement EPA's more generic AP-42 Compilation of Emission Factors database for space heating sources. As described in detail in the following sub-sections, the overall approach consisted of using the Fairbanks-specific OMNI emission factor data, where available and reasonable. Where OMNI measurement data were not available, AP-42 emission factors were used.

EMISSION FACTORS FOR WOOD-BURNING DEVICES

The main focus of the OMNI study was wood burning appliances and fuels because of their apparent significant contribution to $PM_{2.5}$ in the Fairbanks nonattainment area. Specific wood burning space heaters were selected for testing by OMNI either because they represented popular conventional models in interior Alaska or more advanced models, such as newer EPA-certified wood stoves and EPA-qualified Phase 2 Outdoor Wood Hydronic Heaters (OWHHs), that are expected to be representative of future trends. Additionally, one pellet heater was tested. In all, 20 of OMNI's 35 tests were conducted on wood-fired units.

OMNI's wood burning tests used fuel loadings and test protocols generally as prescribed by EPA Method 28 and related EPA sampling methods. However, to provide the most realistic representation of Alaskan wood burning, split cordwood was used, rather than "crib wood" (i.e., dimensional lumber) as prescribed in the test method. In addition, OMNI used White Spruce and Paper Birch (with bark), the two most common cordwood fuels in Fairbanks, rather than the Douglas Fir prescribed in the test method. Locally produced Alaska wood pellets were used for the pellet heater.

[34] "Measurement of Space Heating Emissions," OMNI-Test Laboratories, Inc., May 23, 2013.

OMNI's emission factor results are expressed in various forms, including emissions per kg of dry wood (similar to AP-42 emissions factors). However, testing was performed using representative Fairbanks fuel samples with as-received moisture levels. More specifically, the cordwood and other solid fuels tested by OMNI were collected in Fairbanks under typical fuel storage conditions and preserved to maintain moisture levels prior to their use in testing. In addition, solid fuels were tested for moisture content by OMNI immediately prior to each test.

EPA test procedures were used as the basis for OMNI's emission testing, with adaptations as needed to improve the representativeness of testing or its practicality. (OMNI's study report provides more details.) EPA Method 28 was followed for solid fuel loadings and test duration. However, Method 28 specifies four different firing rates for each device, in effect requiring four different tests for each appliance/fuel combination and then weighting the results to obtain both annual and heating season average emission values. Unfortunately, this ideal approach of conducting four tests for each appliance/fuel combination was not affordable for Fairbanks due to the size of Alaska's required appliance/fuel test matrix.

The solution for Fairbanks was to conduct Method 28 testing for each appliance/fuel at either "low" firing rate or "low" and "max" firing rates only. The "low" firing rate was defined to be a nominal rate of 35% of maximum load. This load was selected by FNSB for two reasons. First, it is very close to and only slightly above the heating season average weighted load for a Method 28 test, which is 34%. Second, it is very close to, and only slightly below, the center of the range for the most frequent (i.e., most heavily weighted) mode of the Method 28 test, which is Category 3. (This Category has a firing rate of 25–50% of maximum, and it is weighted at 0.450 for the heating season average, i.e. it accounts for nearly half of the firing during the heating season.) By also including a maximum firing rate where practical (corresponding to Category 4 of Method 28), the Borough attempted to capture both the average (g/kg) emission factor (primarily for emission inventory purposes) and the maximum or near maximum (g/hr) emission rate for other evaluation purposes (e.g. estimation of near-field impacts from individual sources).

OMNI's study included limited testing to characterize the effect of cold starts, but to date the results of those tests have not been sufficient to quantify the cold start effect. (Because the data were limited, only an indirect estimate could be made of cold start using results from several runs. These data suggest cold starts may add up to 15% to the total $PM_{2.5}$ emissions, but additional testing with a more direct sampling method would be required to confirm this result.) Therefore, Alaska's wood burning and other space heating emission factors, like AP-42 factors, do not include a cold start effect. Recent survey data from Fairbanks suggest that ignoring this effect may be less serious in Fairbanks than locations outside of Alaska because the vast majority of Fairbanks households that burn wood are more than occasional burners (in a 2012 survey, only 9% of wood burners described their usage as "occasional"); rather, they tend to burn out of economic necessity and very regularly, essentially every day in most cases. In addition, as with cold start test attempts, OMNI performed limited testing to characterize the effectiveness of a solid fuel stove catalytic retrofit device, but those test results too were inconclusive.

<u>Comparison of OMNI and AP-42 Representativeness</u> - In contrast to the appliances and fuels selected for their representativeness of Fairbanks in winter and used in the OMNI study, the emissions studies of residential wood burning that underlie EPA's AP-42 average emission

factors include, by design, a broad spectrum of devices, fuels, and conditions. Among the variables reflected in the more than 150 studies relied upon by AP-42 are appliance types, models, ages, and technologies; fuel types (including many wood, coal, and oil types that are either uncommon or not used at all in Fairbanks); fuel conditions (e.g., moisture content), and form factors (crib vs. cordwood); these reflect test methods and field test conditions that are used throughout North America under a much wider variety of circumstances (not all of which are necessarily appropriate for Alaska). These and other features of the OMNI and AP-42 testing are summarized in Table 7-6-38.

An element not directly compared in Table 7-6-38 is measurement of particle size in reporting PM emission test results. While not correct, total PM, PM_{10}, and $PM_{2.5}$ are often used interchangeably. As noted by Houck[35] (2008), AP-42 states "PM-10 is defined as equivalent to total catch by EPA method 5H train." Most inventories treat the AP-42 values as either PM_{10} or $PM_{2.5}$ and essentially equivalent to each other. Research into the size distribution of particles from a certified catalytic model showed that PM_{10} averaged about 88% of the total particulate catch and $PM_{2.5}$ averaged about 80%; similar research with a certified non-catalytic model showed that PM_{10} averaged about 94% and $PM_{2.5}$ about 92% of the total catch.[36] OMNI's reported test results are size-segregated $PM_{2.5}$ measurements. As noted above, AP-42 published rates do not distinguish particle size.

As a compendium of generic emission factors, AP-42 is both relatively large in scope and a reliable information resource. However, there are several and serious technical challenges to applying the AP-42 average emission factors to Fairbanks wood burning. One of the first problems is lack of geographic specificity. AP-42 does not specify the exact mix of wood types that were used for its testing, but it is known from reviews of AP-42 that they are not dominated by either Paper Birch or White Spruce, the two most common types in Fairbanks. Furthermore, the current woodstove population and technology in Fairbanks and represented in the OMNI study is almost certainly newer than the AP-42 database. This is true not only because the AP-42 database tends to be much older, but also because wood burning in Fairbanks has increased sharply in recent years due to escalating heating oil prices and some of the nation's highest home heating costs (average about $3,700/year). This means (and recent DEC-sponsored telephone surveys tend to support) that the Fairbanks wood burning device population has not only a higher fraction of certified wood burning devices, but also more of the newest (and lowest-emitting) of the certified devices. Finally, while many of the AP-42 wood appliance tests were reportedly conducted under "field conditions," presumably using representative wood moisture levels for those locations and seasons, we do not know whether the fuel moistures and firing rates in those tests were representative of Fairbanks in winter. In the case of OMNI's testing, OMNI and the Borough took steps to ensure the representativeness of Fairbanks fuel samples and the preservation of sample moisture prior to testing. In addition, OMNI measured and reported the fuel moisture levels (except for liquid fuels) before each test, and they used appropriate heating season average (and selected maximum) firing rates.

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[35] J.E. Houck, et al., "Emission Factors for New Certified Residential Wood Heaters," presented at EPA's 17th Annual International Emissions Inventory Conference, June 2008, http://www.epa.gov/ttnchie1/conference/ei17/session4/houck.pdf.
[36] McCrillis, R.C., Wood Stove Emissions: Particle Size and Chemical Composition, U.S. Environmental Protection Agency, Research Triangle Park, NC, 2000, EPA-600/R-00-050.

Table 7-6-38
Comparison of OMNI Heating Device Testing and AP-42 Emission Factors

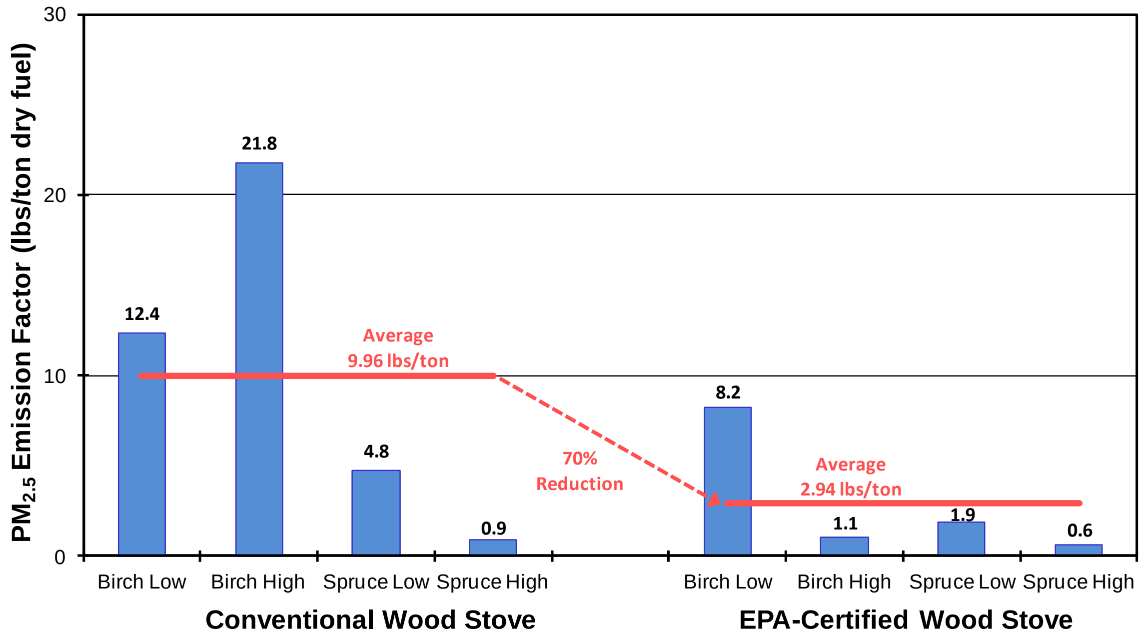
Features	OMNI Test Program	AP-42
Geographic Representation	Testing specific to interior Alaska appliances/fuels/winter conditions;	Testing designed to be representative of average emissions nationwide
Currency	2011 test program, supported by concurrent usage and measurement data (fuel type & moisture, in-use stack temperature monitoring, etc.)	Pertinent sections of AP-42 date from October 1996 or earlier; references dated 1972-2001
Appliances	“Conventional” and “advanced” wood stoves and outdoor hydronic heaters; pellet stove; coal stove; auger-fed coal OHH; fuel and waste oil burners (total: 9 appliances)	Large number and variety of appliances
Sample Size	35 tests conducted	More than 150 studies; hundreds of tests
Fuel Selection	Paper Birch & White Spruce (most common Fairbanks woods); locally produced wood pellets; Usibelli (Alaska) coal; local #1& #2 fuel & waste oil	Wide variety consistent with nationwide averages (hardwood dominates in most states)
Fuel Moisture	Wood fuels sampled in Fairbanks in winter with typical seasoning & moisture; samples preserved for testing; wood sampled for moisture prior to testing; resulting EFs reported “dry basis” (db)	Varies by study (“equilibrium wood moisture” varies by local condition); resulting AP-42 EFs understood to be db, but not reported explicitly; wood heater field studies report 24% avg (db)
Sampling Methods	EPA “Other Test Method 27” for $PM_{2.5}$ (in accordance with EPA proposed changes to method 201A); other EPA methods for gases	Wide variety of primarily EPA methods; most commonly reported as Method 5H or “5H equivalents”
Fuel Loadings: Wood Liquid Fuels Coal	 Method 28 for wood fuel amounts & handling but used Alaskan cord woods rather than Douglas Fir crib wood; No EPA test method; followed manufacturers’ operating instructions; extended test duration to collect sufficient PM for analysis No EPA test method for stoves; followed manufacturers’ operating instructions	Fuel loadings & form factor vary by study (AP-42 predates Method 28)
Firing Rates	OMNI targeted 35% & max firing rates (OMNI’s “low” and “high” firing generally corresponds to Method 28 categories 3&4, respectively; category 3 is predominant mode for “winter season heating”)	Varies by study; may be skewed toward “higher than average in-home burn rate”

One important limitation of the OMNI test program was the number of tests, which was limited by budget constraints to 35. This is far less than the AP-42 sample, which may number in excess of 1,000 tests. However, unlike AP-42, all of the OMNI tests used Alaska-specific fuels and the appliances tested were specifically chosen by OMNI to represent the Alaskan appliance population. Thus, there is a tradeoff between sample size, which favors using AP-42 emission factors, and data specificity, which favors the available OMNI test results.

A second limitation of the OMNI testing was the lack of replicate tests. However, this was partially compensated by the study design, which provided for multiple tests of individual appliances using different fuels and firing rates.

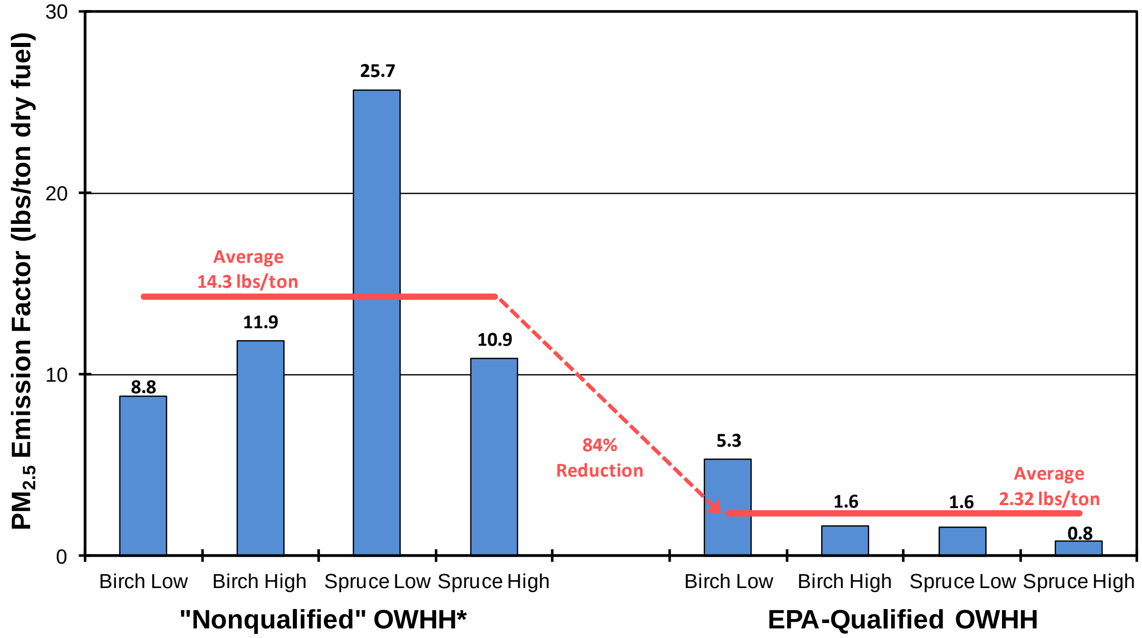
Summary of OMNI Test Results - As shown in Figure 7-6-32 and Figure 7-6-33, the OMNI study design allowed for suspected systematic variations in emissions to be tested and documented, and the observed patterns in the test results give confidence about the repeatability of testing. The figures show not only that EPA-certified wood stoves and EPA-qualified OWHHs emit about 70% less and 84% less $PM_{2.5}$ than their non-certified/nonqualified counterparts, but also that the patterns of reductions are similar for each fuel and firing rate.

Figure 7-6-32
$PM_{2.5}$ Emission Factors from OMNI Testing for
Conventional (left) & EPA-Certified (right) Wood Stoves by Wood Species and Firing Rate



Several apparent deviations from a completely systematic variation, such as higher Spruce vs. Birch emissions for the non-qualified OWHH in Figure 7-6-33, are discussed further in the OMNI report[34]. It should also be noted that the figures each show simple averages across the set of high and low firing rate tests.

Figure 7-6-33
$PM_{2.5}$ Emission Factors from OMNI Testing for
Non-Qualified (left) & EPA-Qualified (right) OWHHs by Wood Species and Firing Rate



Based on the greater specificity and applicability to Fairbanks and the greater amount of current supporting detail available, the OMNI emission factors were selected for use in the Fairbanks $PM_{2.5}$ SIP to represent average emissions from residential wood burning units, except for fireplaces (which OMNI did not test). In particular, the average $PM_{2.5}$ emission factors for "low" firing rate tests of birch and spruce were used to characterize the average emission factors for conventional woodstoves and outdoor hydronic heaters, advanced (i.e., more modern) EPA-certified woodstoves, EPA Phase 2 qualified OWHHs; and results from OMNI testing with locally produced Alaska wood pellets were used to characterize pellet stoves. The low firing rate tests were used to develop the SIP emission factors because the low firing rate (35% of maximum) was close to that of the winter season average Method 28 firing rate of 34% as explained earlier and based on local evidence suggesting wood burning devices tend to have their air dampers set at a low/mostly closed position to extend burn durations of a fuel load (e.g. to avoid waking up at night to add more wood to a stove).

The birch and spruce test results were weighted together based on splits in commercial timber sales within the Borough obtained from the Alaska Department of Natural Resources, Division of Forestry. These relative splits were 52% birch, 6% spruce and 42% aspen. (The normalized relative splits between birch and spruce were 90% and 10%, respectively).

Emission Factors for Oil-Fired Devices

The vast majority of households in Fairbanks have central oil furnaces and, according to recent telephone survey data, about two-thirds of the residential heating in Fairbanks (BTU basis) is by central oil burning systems. Therefore, despite its relatively low PM emissions factor compared to wood, testing of a central heater with Nos. 1 and 2 heating oils (used in Fairbanks in about a 1:3 ratio) and of a waste (motor) oil-fired space heater were included in OMNI's test program.

The same suite of pollutants was sampled for oil burners as for wood, but the key pollutant of interest for oil burners was SO_2, due to both the much higher concentration of sulfur found in oil and the predominance of oil burning in Fairbanks. EPA's emission factor guidance document, AP-42, states: "On average, more than 95% of the fuel sulfur is oxidized to SO_2, about 1 to 5 percent is further oxidized to sulfur trioxide (SO_3), and 1 to 3 percent is emitted as sulfate particulate." According to EPA's $PM_{2.5}$ SIP guidance, SO_2 is presumed to be a precursor of secondary $PM_{2.5}$. Thus, oil burning appliances may contribute to both primary and secondary $PM_{2.5}$ sulfate in the atmosphere.

Samples of Nos. 1 and 2 fuel oil and waste oil sample were collected by FNSB staff, analyzed for OMNI by SwRI, and found to have sulfur contents of 896, 2566, and 3020 ppm by weight, respectively as shown in Table 7-6-39. Also shown in the table are three alternative SO_2 emission factors (Columns 1–3), all of which are in units of grams of SO_2 emitted per kg of oil burned.

Table 7-6-39
Fuel Sulfur and SO_2 Emission Factors for Three Fairbanks Oil Samples

Fuel	ppm Sulfur (by weight) from SwRI	Alternative SO_2 Emission Factors: (grams of SO_2 per kg of fuel burned)		
		Column 1 Range, assuming 95-100% of fuel S emitted as SO_2	Column 2 All fuel S Emitted as SO_2 except as measured in reduced form on $PM_{2.5}$ filters by XRF	Column 3 EF from OMNI SO_2 (and other) measurements
No. 1 Fuel Oil	896	1.70 - 1.79	1.77	1.25
No. 2 Fuel Oil	2,566	4.88 - 5.13	5.12	2.10
Waste Motor Oil	3,020	5.74 - 6.04	5.93	4.76

Column 1 shows the range of emission factors based strictly on the SwRI-measured sulfur contents and on the 95-100% S to SO_2 conversion rate for oil combustion documented in AP-42. Column 2 shows the corresponding emission factor based on 100% oxidation of sulfur but after first subtracting the PM reduced, elemental sulfur contributions on OMNI's PM filter samples (measured by Research Triangle Institute). These data are confirmatory regarding the SO_2 fraction in that they fall within the range anticipated based on AP-42. The third column shows an independent measure of the SO_2 emission factor by OMNI, although in this case, the EFs for all three oils are below the levels anticipated based on fuel sulfur content, suggesting these measurements are suspect. The precise reason for the lower values in OMNI's SO_2 measurement-based factors is not known, but it is recognized that the latter approach is a more complex estimate because it requires accurate calibration and measurement of not only SO_2 in the dilution tunnel, but also the same for a tracer gas in both the hot appliance stack and the dilution tunnel, along with accurate alignment of all measurement traces.

Two final points are worth noting with respect to oil combustion emission factors. First, the emission factors for SO_2 and SO_3 shown in AP-42's Table 1.3-1 imply a slightly higher proportion of fuel S emitted as SO_2 for residential furnaces (98.9%) than for other fuel burning sources. This is consistent with and lends credence to the relatively high SO_2 fractions (i.e., small PM correction) observed from the OMNI/SwRI/RTI measurements. Second, the oil burners were designed for and emission tested by OMNI at a single firing rate (there were no firing rate issues such as occurred with the wood burning appliances).

Based on the above findings, it was concluded that the simplest and most consistent emission factor for SO_2 is that derived from the direct fuel sulfur based method as reflected in AP-42. Accordingly, application of the fuel sulfur based method with 100% SO_2 oxidation and using the SwRI fuel sulfur measurements for oil, has been assumed in developing the Fairbanks SIP emissions inventory. By comparison, the emission factor measurement of SO_2 by OMNI is more complicated and may be less reliable than the above method. Furthermore, considering the closeness of the OMNI PM sulfur adjusted values (column 2) to the 100% S conversion based EFs (upper range limit of Column 1), the latter were used for the SIP-based inventory without adjustment for sulfur in the PM.

Emission Factors for Coal-Burning Devices

In addition to wood and oil fuels, OMNI emission tested Alaskan (Usibelli) subbituminous coal (wet, dry, lump, and stoker) in several residential heaters. Currently, coal is not widely used as a residential heating fuel in Fairbanks, and no EPA source test methods exist for residential coal stoves. The only AP-42 emission factor data available are from testing of much larger coal-fired boilers.

Under contract to OMNI, Twin Ports Testing (TPT) analyzed Alaskan coal samples that had been collected by Borough staff, stored in sealed drums to maintain moisture, and then shipped and stored by OMNI for use in testing. TPT reported that lump and stoker coal have sulfur content of 0.086 and 0.101 weight % S (dry basis), respectively. Fuel moisture contents for the eight coal test charges measured by OMNI immediately prior to testing ranged from 11.20–33.50%.

With regard to $PM_{2.5}$ emissions, coal emission factors were (unlike cordwood emission factors) somewhat variable, depending upon the device tested, wet vs. dry fuel, fuel form factor, firing rate, and other test conditions.

For lack of any information from AP-42 on residential coal burning, emission factors used to develop the Fairbanks inventory were taken from the OMNI test results, using the average of all valid tests at low firing rate (which is close to the expected heating season average firing rate).

Emission Factors for Other Pollutants

In addition to measuring $PM_{2.5}$ and SO_2, OMNI also measured and developed emission factors for VOC, CO, NO, NO_2, NO_x, and NH_3 for all wood-burning devices and oil furnaces. For those cases where the OMNI study has provided more specific and applicable measurements than what is available from AP-42, Sierra has recommended the use of the former, with the two exceptions of SO_2 (discussed above) and VOC. For VOC, OMNI's measurements and emission factor are presented on a carbon mass-basis, whereas AP-42 shows mass emissions for TOC, methane, TNMOC, selected organic species, PAHs, and more. Absent more detailed information about the C-mass fraction of both sources, comparison of the VOC emission factors is problematic. Thus, no attempt was made to compare OMNI's emission factors with those in AP-42, nor consider substitution of the OMNI EF's for those in AP-42.

SIP Inventory Emission Factors

Table 7-6-40 and Table 7-6-41 provide tabulations of the emission factors used to estimate space heating emissions for the SIP inventories. These tables respectively show emission factors for wood-burning (in lbs/ton) and for other heating types (in lbs/1000 gals). The first column in each table lists the device type/technology. The next seven columns list the emission factors for VOC, NO_x, SO_2, primary PM_{10} and $PM_{2.5}$, NH_3 and CO.

The last column in each table lists the data source(s) and, in several cases, provides additional details about the emission factor calculations. Further details are provided in the footnotes to individual emission factor entries. Highlighted cells in each table show emission factor entries that are based on OMNI results. Unshaded cells refer to "default" AP-42 based emission factors that were used where OMNI data were not available or insufficient.

Table 7-6-40
Emission Factors for Wood-Burning Devices (lbs/ton) - EPA Method 5H Except Where Noted (OMNI Factors in Highlighted Cells)

Device and Technology	VOC	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3	CO	Data Source(s)
Fireplace, no insert	229.0	2.6	0.4	34.6	34.6	1.8[37]	252.6	AP-42, Table 1.9-1; for SO2, OMNI fuel S for spruce gave same EF as AP-42
Fireplace insert, non-EPA certified	53.0	2.8	0.4	30.6	30.6	1.7	230.8	Assumed equal to uncertified woodstove EFs
Fireplace insert, EPA-certified, non-catalytic.	12.0[38]	2.0[38]	0.4[38]	12.0	12.0	0.9[38]	140.8[38]	AP-42, Table 3 for PM EFs www.epa.gov/ttnchie1/ap42/ch01/related/woodstoveapp.pdf
Fireplace insert, EPA-certified catalytic	15.0[38]	2.0[38]	0.4[38]	13.0	13.0	0.9[38]	107.0[38]	AP-42, Table 3 for PM EFs www.epa.gov/ttnchie1/ap42/ch01/related/woodstoveapp.pdf
Woodstove, non-EPA certified	53.0	1.4	0.4	11.60[39]	11.60[39]	0.379	115.8	AP-42, Table 1.10-1 for VOC&SO_2; others use avg of OMNI runs 14&15, conventional wood stove, spruce & birch, low firing rate
Woodstove, EPA-certified, non-catalytic	12.0	1.5	0.4	7.57[39]	7.57[39]	0.239	118.1	AP-42, Table 1.10-1,assmd Phase II (1990 stds) for VOC&SO_2; others use avg OMNI runs 5&6 for birch & spruce; EPA (non-cat) woodstove low firing rate
Woodstove, EPA-certified, catalytic	15.0	1.5	0.4	8.40[39]	8.40[39]	0.239	118.1	same as immediately above, except OMNI avgs for PM_{10}&$PM_{2.5}$ scaled by the ratio of cat to non-cat (16.2/14.6)
Pellet Stove, exempt	2.4[40]	4.0	0.32	2.96	2.96	0.072	9.9	AP-42, Table 1.10-1for VOC; all others OMNI run #1, pellet stove, except SO_2 which is based on dry pellet S content from OMNI
Pellet Stove, EPA-certified	2.4[40]	4.0	0.32	2.96	2.96	0.072	9.9	AP-42, Table 1.10-1for VOC; all others OMNI run 1, pellet stove, except SO_2 which is based on dry pellet S content from OMNI
Hydronic Heater, weighted 80/20	*45.4*	*1.5*	*0.4*	9.43	9.43	0.233	*57.9*	80% / 20% weighting of OWB unqualified&OWB-Ph2 qualified
Hydronic Heater, Unqualified	*53.0*	*1.4*	*0.4*	10.55[39]	10.55[39]	0.261	*52.8[41]*	EPA/NY for VOC&SO_2; others use avg of OMNI runs 30&32, OWHH birch &spruce, low firing rate OMNI dry S content for spruce same EF as AP-42
Hydronic Heater, Phase 1	*12.0*	*2.1*	*0.4*	9.303[39]	9.30[39]	0.120	*102.7*	set rates for VOC to those for woodstoves; others from avg of OMNI runs 9&11, spruce & birch, EPA qualified OWHH, low firing rate, but for PM&CO scaled by phase 1&2 ratio;SO_2 based on OMNI content of dry spruce
Hydronic Heater, Phase 2	*15.0*	*2.1*	*0.4*	4.94[39]	4.94[39]	0.120	*78.01*	set rates for VOC to those for woodstoves; others from avg of OMNI runs 9 and 11, spruce & birch, EPA qualified OWHH, low firing rate, but PM & CO scaled by

[37] NH_3 EF from Pechan "Estimating Ammonia Emissions from Anthropogenic Non-Agricultural Sources", Draft Final Report, April 2004.
[38] No separate EF data for this pollutant; assumed equal to corresponding certified woodstove EFs from AP-42.
[39] Entries reflect weighting of spruce and birch EFs from wood-specific OMNI tests based upon spruce vs. birch sales split from US Forest Service timber sales data
[40] From http://www.epa.gov/burnwise/pdfs/EPA_stove_emis_reduct.pdf, converted from kg/tonne to lbs/ton.
[41] CO is lower limit because instrument pegged.

								ratio for phase 1&2;SO_2 based on OMNI S content of dry spruce

Table 7-6-41
Emission Factors for Other Devices (lbs/1000 gal except where noted, OMNI Factors in Highlighted Cells)

Other Heating Types	VOC	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3	CO	Data Source(s)
Central Oil (Wtd #1 & #2), Residential	0.713	11.2	30.71[42]	0.457	0.457	0.024	0.448	AP-42 Table 1.3-1 for VOC; OMNI fuel S content for SO_2; all others OMNI run#17,SwRI for fuel (lower) heating value,AP-42 for fuel oil density
Central Oil (#1 distillate), Residential	0.713	11.2	12.72[43]	0.457	0.457	0.024	0.448	AP-42 Table 1.3-1 for VOC; OMNI fuel S content for SO_2; all others OMNI run#17, SwRI for fuel (lower) heating value,AP-42 for fuel oil density
Central Oil (#2 distillate), Residential	0.713	11.2	36.44[44]	0.457	0.457	0.024	0.448	AP-42 Table 1.3-1 for VOC;OMNI fuel S content for SO_2; all others OMNI run#17, SwRI for fuel (lower) heating value,AP-42 for fuel oil density
Central Oil (Wtd #1 & #2), Commercial	0.713	18	30.71[6]	0.457	0.457	0.024	0.448	AP-42 Table 1.3-1 for NO_x; for all others, assume same as above
Portable Heater: 43% Kerosene & 57% Fuel Oil	0.713	18	30.71[6]	0.4	0.4	0.024	0.4	EFs for portable heaters w. kerosene/fuel oil #2 blend assumed equal to central oil (#2); all except SO_2, NH_3 and CO, assumed same as above
Direct Vent	0.713	11.2	12.72	0.5	0.5	0.024	0.4	EFs for DV w. #1 assumed equal to central oil (on #2) in absence of actual data; except SO_2, NH_3 and CO assumed same as above
Natural Gas-Residential (lb/million ft^3)	5.5	94	0.6	7.6	7.6	20	40	AP-42 Tables 1.4-1 & 1.4-2 for all but NH_3; EPA/Pechan for NH_3
Natural Gas-Commercial, small uncontrolled (lb/million ft^3)	5.5	100	0.6	7.6	7.6	20	40	AP-42 Tables 1.4-1 & 1.4-2 for all but NH_3, EPA/Pechan for NH_3
Coal Boiler (lb/ton)	10	4.7	9.3[45]	8.0	8.0	1.266	130.6	AP-42 Table 1.1-19 for VOC, (w. Usibelli S content) SO_2; OMNI runs 21,23,37&38 for other, coal stove, wet & dry stoker & lump coal, low firing rate
Waste Oil Burning	1	52.2	36.97	5.2	5.2	0.036	12.4	AP-42 Table 1.11-1 for VOC; all others OMNI run#18, SwRI for heating value, AP-42 for No. 2 fuel oil density

[42] Assumes fuel S content of 2,163 ppm by weight; reflects approximate 76/24 split of #2/#1 per information from Polar & Sourdough Fuels; DEC email 1/31/12.
[43] Assumes S content of 896 ppm of #1from SWRI analysis of Fairbanks fuel sample as reported by OMNI Labs.
[44] Assumes S content of 2566 ppm of #2 from SWRI analysis of Fairbanks fuel sample as reported by OMNI Labs.
[45] Assumes coal S content of 0.3% by weight per www.Usibelli.com/coal_data.asp .

Space Heating – Emission Calculation Details

Home heating (and commercial space heating) emissions were calculated in a manner that optimized the use of locally-collected survey data, in-use device activity and fuel use measurements, and emission factor data that were described in detail in the preceding sections of this technical appendix. This section of the appendix explains how these local data were used in conjunction with the Fairbanks space heating energy model to generate estimates of pollutant emissions used in the episodic inventories. Thus, a key element in these emission inventory calculations consisted of utilizing spatially- and temporally-resolved data or relationships based on them to generate gridded, day and hour-specific estimates of space heating emissions over the modeling domain.

These calculations were performed in a series of complex "Space Heating" spreadsheets.

Energy Model Implementation

The first step in building the Space Heating emission calculation spreadsheets consisted of loading in the Fairbanks Home Heating Energy Model in order to compute needed household heating energy as a function of device/fuel mix, building size, average daily ambient temperature and day type (weekday vs. weekend). The *Coeffs* tab in the spreadsheet contains the daily and hourly energy model coefficients listed earlier in Table 7-6-9 and Table 7-6-10.

The energy model is then implemented within the *HtEnergy* tab to calculate heating energy by modeling grid cell for each of the 1.33 km square cells across the modeling domain based on the number of residential households in each cell determined from block-level 2010 U.S. Census data (and grown forward or backward to each inventory year based on population projections). The summed space heating energy over all households in each grid cell was calculated separately by day and hour for each based on 4 km grid cell specific winter season energy use splits by device/fuel type developed the 2011-2015 Home Heating Survey data.

Table 7-6-42 (identical to Table 7-6-29**Error! Reference source not found.** shown earlier) shows these winter season energy use splits for selected 4 km grid cells. Space heating energy use for those device/fuel types not highlighted (Portable Oil Heaters, Natural Gas, Coal and Electric Heat) was estimated from their Home Heating Survey-based splits shown in Table 7-6-42 in proportion to their Survey-based energy use outside the energy model.

In practice, this was applied across the entire nonattainment area with the 4 km cells mapped to the smaller 1.33 km modeling grid cells. Those device/fuel types highlighted in Table 7-6-42 represent those for which space heating energy use is estimated from the energy model.

Table 7-6-42
2011-2015 Home Heating Survey Winter Season Heating Energy Use Splits by Key 4 Km Grid Cell

		Pct. Of Winter Season Heating Energy Use by Grid Cell									
	4 Km	Wood			Heating Oil			Nat Gas	Coal	Steam	
Area Description	Grid Cell	Stove/ Insert	Fireplace	Outdoor Boiler	Central Oil	Direct Vent	Portable	Natural Gas	Coal Heat	Muni. Heat	Total
FAI	137,136	25.32%	1.47%	2.08%	66.30%	1.89%	0.00%	0.00%	2.93%	0.00%	100%
Chena Pump/Geist	137,137	8.70%	1.36%	0.58%	84.63%	1.22%	1.72%	0.98%	0.08%	0.72%	100%
Mitchell/S. Fairbanks	138,136	17.88%	0.00%	1.07%	69.76%	2.17%	0.00%	8.26%	0.42%	0.44%	100%
W of Downtown	138,137	11.33%	0.27%	0.53%	80.92%	1.19%	0.37%	3.75%	0.00%	1.64%	100%
Mitchell/SE Fairbanks	139,136	11.51%	0.21%	0.44%	73.75%	2.37%	2.50%	7.08%	0.17%	1.96%	100%
Downtown/Nordale	139,137	9.14%	0.54%	0.23%	84.16%	1.83%	0.27%	0.73%	0.42%	2.69%	100%
NP/SE of Richardson	143,134	20.75%	1.03%	1.39%	72.57%	1.55%	0.07%	0.00%	2.64%	0.00%	100%
NP/N of Hurst	143,135	26.84%	0.35%	3.30%	62.82%	2.78%	0.93%	0.62%	2.35%	0.00%	100%
NP/S of Hurst	144,134	29.82%	0.71%	3.55%	63.00%	1.12%	0.92%	0.67%	0.22%	0.00%	100%
NP/Badger	144,135	24.53%	0.00%	1.88%	71.29%	0.85%	0.24%	0.00%	0.87%	0.35%	100%
Cells <50 Households	Low SS	28.89%	0.59%	1.46%	60.89%	5.90%	0.36%	0.35%	1.45%	0.10%	100%

These calculations were performed within the context of the gridded modeling inventories in a manner in which space heating energy use is not calculated by individual device (or household), but rather based on the total number of households in each grid cell and the average device/fuel usage splits across all surveyed households within each grid cell. For grid cells not represented in the Home Heating Survey (which sampled households only within the non-attainment area), the Census weighted average splits at the bottom of Table 7-6-42 were used.

Another element considered in calculating space heating energy use by episode day and hour for each grid cell was the use of occupied vs. total (which includes occupied and vacant households) households counts from the 2010 Census. Based on discussions with Borough staff, wood and coal burning energy use was calculated based on occupied households, while energy use for other devices/fuel was based on total (occupied and vacant) households. The central assumption here was that thermostatically-controlled devices (central oil, natural gas) would still be operated at some lower heating level to ensure interior pipes and other infrastructure would not freeze and crack. No adjustment was estimated to account for the lower heating level for these devices in vacant households.

Finally, parcel level GIS data developed by the Borough from tax assessment data was used to calculate the average building size (in heated interior area) separately for both residential and commercial parcels within each grid cell. These average building sizes for each grid cell were required to drive the energy model calculations (along with average daily temperature, device usage mix and day type).

Application of Energy-Specific Emission Factors

The next step in the calculation of space heating emissions consisted of converting the device and technology specific emission factors presented earlier in Table 7-6-40 and Table 7-6-41 from pounds emitted per fuel use unit to pounds emission per unit energy (i.e., pounds per million BTU or lb/mmBTU). This conversion was necessitated by two factors:

1. *BTU-Based Energy Model* - The energy model was configured to predict space heating energy use (in BTUs), rather than fuel use across all of the devices. (This made it easier to utilize relative energy use splits calculated from the Home Heating Survey to augment energy use estimates for device not addressed directly within the energy model.)

2. *Treatment of Wood Moisture Effects* – Unlike other fuels used for space heating, the effective or “heating” energy of wood is directly related to its moisture content as discussed earlier in the “Home Heating – Fairbanks Wood Energy and Moisture Effects” section. The space heating emission calculation workflow (and adjustments for wood moisture) was made much simpler by starting with emission factors for wood devices assuming zero or oven dry moisture content and then applying a multiplicative adjustment that accounted for the heating energy effect as a function of moisture content. (This also made the process for calculating future inventories reflecting either trends in moisture content or effects from planned or adopted control measures more straightforward.)

The emission factor conversions were performed by dividing fuel specific energy content presented earlier in Table 7-6-28 (in BTU/fuel unit) into the pound per fuel unit emission factors in Table 7-6-40 and Table 7-6-41. For example, the $PM_{2.5}$ emission factor for residential heating oil (with mix of #1 and #2 oil) from Table 7-6-41 of 0.457 lb/1000 gal was divided by the energy content for heating oil (with the #1 and #2 mix) of132,000 BTU/gal (or 132 mmBTU/1000gal) listed in Table 7-6-28 to yield an energy-specific emission factor of 0.000346 (3.46×10^{-3}) lb/mmBTU.

Table 7-6-43 and Table 7-6-44 present the results of these emission factor conversions for all wood and non-wood burning devices and technologies, respectively. As noted above, energy-specific wood burning emission factors in Table 7-6-43 are represented on an over dry or 0% moisture basis. In both tables, highlighted cells refer to emission factors based on local device/fuel measurements from the OMNI Labs testing study; AP-42 factors were used for pollutant/device combinations in un-highlighted cells. SCC codes and assumed net heating efficiencies for each device are also shown in both tables. Although the heating efficiencies were not used in calculating baseline emissions, they are used later in Control inventory calculations where efficiency were accounted for in scenarios where heating devices are replaced by other devices, such as switching from wood to heating oil.

Table 7-6-43
Heating Energy-Specific Emission Factors for Wood-Burning Devices (lbs/mmBTU), Oven Dry (0%) Moisture Basis (OMNI-Based Factors in Highlighted Cells)

Device and Technology	SCC Code	Heating Efficiency	Emission Factors (lb/mmBTU)						
			VOC	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3	CO
Fireplace, no insert	2104008100	7%	13.237	0.150	0.023	2.000	2.000	0.104	14.601
Fireplace insert, non-EPA certified	2104008210	40%	3.064	0.162	0.023	1.769	1.769	0.098	13.341
Fireplace insert, EPA-certified, non-catalytic.	2104008220	66%	0.694	0.116	0.023	0.694	0.694	0.052	8.139
Fireplace insert, EPA-certified catalytic	2104008230	70%	0.867	0.116	0.023	0.751	0.751	0.052	6.185
Woodstove, non-EPA certified	2104008310	54%	3.064	0.085	0.023	0.714	0.714	0.023	7.129
Woodstove, EPA-certified, non-catalytic	2104008320	68%	0.694	0.095	0.023	0.466	0.466	0.015	7.274
Woodstove, EPA-certified, catalytic	2104008330	72%	0.867	0.095	0.023	0.517	0.517	0.015	7.274
Pellet Stove, exempt	2104008410	56%	0.139	0.247	0.020	0.182	0.182	0.004	0.612
Pellet Stove, EPA-certified	2104008420	78%	0.139	0.247	0.020	0.182	0.182	0.004	0.612
Hydronic Heater, weighted 80/20	2104008610	43%	2.624	0.095	0.023	0.581	0.581	0.014	3.563
Hydronic Heater, Unqualified	2104008610	43%	3.064	0.087	0.023	0.650	0.650	0.016	3.253
Hydronic Heater, Phase 1	2104008610	43%	0.694	0.127	0.023	0.573	0.573	0.007	6.321
Hydronic Heater, Phase 2	2104008640	43%	0.867	0.127	0.023	0.304	0.304	0.007	4.804

Table 7-6-44
Heating Energy-Specific Emission Factors for Other Devices (lbs/mmBTU) (OMNI-Based Factors in Highlighted Cells)

Device and Technology	SCC Code	Heating Efficiency	Emission Factors (lb/mmBTU)						
			VOC	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3	CO
Central Oil (Wtd #1 & #2), Residential	2104004000	81%	5.40E-03	8.46E-02	2.33E-01	3.46E-03	3.46E-03	1.86E-04	3.39E-03
Central Oil (#1 distillate), Residential	2104004000	81%	5.70E-03	8.94E-02	1.02E-01	3.65E-03	3.65E-03	1.96E-04	3.58E-03
Central Oil (#2 distillate), Residential	2104004000	81%	5.15E-03	8.07E-02	2.63E-01	3.30E-03	3.30E-03	1.77E-04	3.23E-03
Central Oil (Wtd #1 & #2), Commercial	2103004001	81%	5.15E-03	1.30E-01	2.22E-01	3.30E-03	3.30E-03	1.77E-04	3.23E-03
Portable Heater: 43% Kerosene & 57% Fuel Oil	2104004000	81%	5.20E-03	1.31E-01	2.24E-01	2.92E-03	2.92E-03	1.79E-04	3.27E-03
Direct Vent	2104007000	81%	5.70E-03	8.94E-02	1.02E-01	3.65E-03	3.65E-03	1.96E-04	3.58E-03
Natural Gas-Residential	2104006010	81%	5.42E-03	9.26E-02	5.91E-04	7.49E-03	7.49E-03	1.97E-02	3.94E-02
Natural Gas-Commercial, small uncontrolled	2103006000	81%	5.42E-03	9.85E-02	5.91E-04	7.49E-03	7.49E-03	1.97E-02	3.94E-02
Coal Boiler	2104002000	43%	6.54E-01	3.08E-01	6.08E-01	5.22E-01	5.22E-01	8.27E-02	8.53E+00
Waste Oil Burning	2102012000	n/a	7.22E-03	3.77E-01	2.67E-01	3.76E-02	3.76E-02	2.63E-04	8.97E-02

n/a – Not available

In applying these energy-specific emission factors in the Space Heating calculation spreadsheets, it was necessary to apply additional usage splits or allocations for each of the technologies listed in Table 7-6-43 and Table 7-6-44. For example, to calculate separate emission estimates for wood devices burning cordwood versus pellets and to allocate the splits of uncertified and certified wood stoves and inserts Table 7-6-29 and Table 7-6-30 presented earlier in the "Home Heating – Space Heating Surveys" section contain these cordwood/pellet and uncertified/certified device splits.

Notwithstanding wood moisture adjustments discussed separately in the next sub-section, space heating emissions were then calculated within each grid cell (by day and hour) by multiplying the total BTUs by device in the cell by the device and technology-specific energy emission factors listed in Table 7-6-43 and Table 7-6-44.

Wood Moisture Adjustment Calculations

As explained earlier in the "Home Heating – Fairbanks Wood Energy and Moisture Effects" section, wood moisture effects were accounted for using a linear relationship of heating BTUs vs. moisture content. This adjustment was necessary in calculation of 2008 Baseline and 2015 and 2019 Projected Baseline space heating emissions because of trends in average moisture content developed from survey data as described in that earlier section. Thus, with emission factors for wood devices expressed on a lb/mmBTU oven dry basis, it was relatively straightforward to apply the moisture adjustments, given an "input" or assumed average moisture level across all grid cells.

The *Moisture* tab in the Space Heating emission calculation spreadsheets contains the wood moisture content adjustment calculations based on the methods described in the earlier "Home Heating – Fairbanks Wood Energy and Moisture Effects" section. It also accounts for the fact that wood use measurements (and heating energy estimates developed from them embedded in the Home Heating Energy Model are associated with a specific wood moisture content of 26.6% (on a dry basis). Thus, the energy estimates from the model had to be adjusted to an oven dry basis from this 26.6% "reference" moisture level. In addition, the *Moisture* tab also includes an adjustment to account for the difference between the assumed wood energy content when the energy model was developed (6,053 BTU/lb) and that developed later in the SIP inventory process from the aforementioned 2013 Wood Tag Survey (6,413 BTU/lb at the 26.6% reference moisture level).

Commercial Space Heating Emissions

Due to differences in energy efficiency, ceiling heights and overall building size the residential Home Heating Energy Model was not used to estimate space heating energy use and emissions within commercial buildings.

Instead commercial sector heating energy was calculated based on an estimate of commercial building space energy intensity in Alaska provided by CCHRC.[46] CCHRC compared an energy model they developed using the ASHRAE "Energy Standard for Buildings Except Low Rise

[46] Email from Colin Craven, Cold Climate Housing Research Center, April 27, 2009.

Residential Buildings" Standard 90.1. Using the ASHRAE minimum standard (referred to as ECB) our Research Testing Facility, which is primarily office space, CCHRC found an energy intensity of about 89,000 BTU/ft^2/yr for its office building in Fairbanks.

Looking at the 2003 US Commercial Building Energy Consumption Survey (CBECS) published by the U.S. Energy Information Administration, commercial building energy loads in Climate Zone 1 (Alaska) CCHRC found the most representative estimate to be 90,690 BTU/ft^2/yr, which closely agrees with the estimate for their own office building. This CBECS value of 90,690 was assumed to best represent average annual heating energy intensity of commercial structures in Fairbanks.

To use this annual intensity within the episodic inventory, the average of number of heating degree days (HDD) referenced to 65°F in Fairbanks was estimated to be 14,274 HDD based on data compiled for Fairbanks International Airport by Weather Underground[47]. Dividing this local HDD into the annual commercial building intensity for Fairbanks yields an estimate of 6.35 BTU/HDD/ft^2. This HDD-normalized building energy intensity was then used to calculate commercial heating energy demand within each grid cell. This was done by summing the total building space of all commercial structures within each grid cell developed from parcel-level Assessor data supplied by the Borough and then multiplying by the daily HDD for each day in the historical modeling episodes and the HDD-normalized intensity as follows:

$$Energy_{x,y} = 6.35\ BTU/HDD/ft^2 \times HDD_i \times Buildings \times Avg\ Size\ (ft^2)$$

Where: *Energy*$_{x,y}$ is the total commercial building heating energy estimated for grid cell (x,y) on episode day *i* (in BTU/day), HDD_i is the heating degree days for day *i* (referenced to 65F), *Buildings* represent the number of commercial structures in the grid cell and *Avg Size* is the average commercial building size (in ft^2).

These daily estimates for each grid cell were then apportioned to hourly values using an average hourly energy use profile for oil-heating devices within the energy model (assuming commercial building are similarly thermostatically controlled).

For non-solid fuel burning, commercial space heating energy use was assumed to be allocated to two fuel types: 1) heating oil; and 2) natural gas. Based on usage data compiled for Fairbanks under the aforementioned "Big 3" inventory study a split of 98% oil and 2% natural gas was assumed. The commercial device emission factors for oil and natural gas heating shown earlier in Table 7-6-44 were then used to compute commercial space heating emissions within each grid cell.

As noted earlier in the "Specialized Wood Burning Surveys" sub-section, a limited number of commercial businesses were found to burn wood and coal. Their emissions were calculated using the emission factors for residential wood and coal devices and allocated to appropriate grid cells where these businesses were located.

[47] www.degreedays.net (using temperature data from www.wunderground.com)

Calculation Workflow

Given the calculation complexity of the Space Heating emission spreadsheet, it was set up in a manner in which the following "inputs" were specified in two shaded cells within the *Emis* tab:

- *Scenario* – Either "FBASE" for final 2008 baseline or "PB" for projected baseline, which triggered different logic used to calculate baseline emissions or project emissions to future years that included adjustments for trends in moisture level from the 2008 baseline and in natural turnover of uncertified wood stoves and inserts.

- *Calendar Year* – The inventory calendar year (2008, 2015 or 2019).

A Visual Basic for Applications (VBA) program written within the spreadsheet was then used to cycle through and calculate emissions for each day of the two modeling episodes. When emissions for each day were calculated within the *Emis* tab, they were translated to data structures in two other sheets in formats required by the SMOKE inventory processing model and then exported by the VBA program to external fixed-length ASCII files for subsequent input to SMOKE. In addition, emission estimates were automatically copied by the VBA program to a series of tabulation sheets (e.g., *DevTabs*, *ZipTabs*, *GridTabs*, *DevSumOut*) as calculations were being performed for each episode day.

Use of Episodic Emissions in SMOKE Model

A re-written version of the SMOKE Version 2.7.1 was used to provide space heating emissions to the pre-processor model on an episodic day and hour basis. Although the SMOKE model as originally written allowed point source emissions to be input by individual day and hour, area source emission categories (such as space heating) had to be temporally allocated using a combination of monthly, weekday and hourly profiles that would have lost the individual day- and hour-specific resolution reflected in the calculation of space heating emissions.

In short, the source code was modified in several locations to allow SMOKE to utilize space heating emission inputs by day and hour identically to its handling of episodic point source emissions.

OTHER AREA SOURCES

Emission contributions from other area sources in Fairbanks during winter are relatively modest compared to those from space heating. As a result, the methods used to estimate emissions for all other sources within the area source sector (besides space heating) were less complex. However, they still relied on local data where it was available, rather than national defaults or a "top-down" approach. The data sources used to estimate "Other" area source emissions were as follows:

1. DEC's Minor Stationary Source emissions database (for calendar year 2014);
2. Locally-collected data for coffee roasting facilities within the nonattainment area; and
3. EPA's 2014 National Emission Inventory (NEI).

This section of the technical appendix describes the data sources and methods used to estimate emissions from other non-space heating sources within the area source sector, beginning with the DEC's Minor Stationary Source database.

DEC MINOR STATIONARY SOURCES

Emissions for sources within the Fairbanks North Star Borough were extracted from the 2014 Minor Source database for the following source types and SCCs:

- Batch Mix Asphalt Plant (SCC 30500247);
- Drum Hot Mix Asphalt Plants (SCC 30500258);
- Gold Mine (SCC 10200502);
- Hospital (SCC 20200402);
- Refinery (SCC 30600106);
- Rock Crusher (SCC 30504030); and
- Wood Production (SCC 10300208).

Emissions for these sources from the 2014 Minor Source file were actual emissions in tons per year and are summarized in Table 7-6-45. In the Arctic, asphalt plants are not operated during winter. For these source categories along with Rock Crushers, winter nonattainment season activity and emissions were assumed to be zero. For all other source categories listed above, emissions were assumed to be constant throughout the year.

Table 7-6-45
2014 DEC Minor Stationary Source Emissions within Fairbanks North Star Borough by SCC Code

Source Category	SCC Code	2014 Emissions (tons/year)				
		CO	NOx	SO_2	PM[a]	VOC
Batch Mix Asphalt Plants	30500247	0.18	0.39	0.05	0.04	0.03
Drum Hot Mix Asphalt Plants	30500258	0.99	11.41	1.23	2.23	2.11
Gold Mines	10200502	5.50	1.40	4.20	1.90	0.00
Hospitals	20200402	6.14	14.30	0.01	0.00	4.24
Refineries	30600106	13.77	23.80	0.50	3.00	9.50
Rock Crushers	30504030	76.31	61.79	5.86	49.08	17.87
Wood Production	10300208	0.00	5.38	0.00	5.94	7.32
Total Minor Sources		**102.90**	**118.47**	**11.85**	**62.19**	**41.08**

[a] DEC's database did not separately report $PM_{2.5}$ and PM_{10}. All PM emissions were assumed to be $PM_{2.5}$.

Coffee Roasters

A Fairbanks Business database (with confirmation from Borough staff) was used to identify a total of four facilities within the nonattainment area that use on-site coffee roasters. These businesses were contacted and two of the four provided data on annual roasting throughput (tons of beans roasted). Throughput was conservatively estimated for the two non-reporting facilities based on the maximum from those that reported their throughput. Emission factors for PM, VOC and NOx from EPA's WebFIRE AP-42 database for batch roasters were used to calculate emissions. (No emission factors were available for SO_2 or NH_3). Uncontrolled emission factors were applied to three of the four facilities. The other facility utilizes a thermal oxidizer; its emission factors were based on WebFIRE factors for a batch roaster with a thermal oxidizer. Coffee roasting emissions were assumed to be constant throughout the year.

Table 7-6-46 shows the resulting emissions tabulated for the coffee roasters within the nonattainment area. It was assumed that the 2017 activity data for coffee roasters was identical to that in 2013; the estimates in Table 7-6-46 were applied directly within the 2013 baseline inventory.

Table 7-6-46
Coffee Roasting Emissions within the Fairbanks Nonattainment Area

Source Category	SCC Code	2017 Emissions (tons/year)		
		PM[a]	VOC	NOx
Coffee Roasters	30200220	0.0101	0.0021	0.0003

[a] DEC's database did not separately report $PM_{2.5}$ and PM_{10}. All PM emissions were assumed to be $PM_{2.5}$.

Remaining Sources - 2014 NEI

The 2014 NEI was used to represent SCC-level annual emissions for all other remaining area source categories that included fugitive dust, commercial cooking, solvent use, forest and structural fires and petroleum project storage and transfer. A number of source categories within the Other Area Source sector from the NEI were estimated to have no emissions during episodic wintertime conditions. These “zeroed” wintertime source categories are listed below (with SCC codes in parentheses).

- Fugitive Dust, Paved Roads (2294000000)
- Fugitive Dust, Unpaved Roads (2296000000)
- Industrial Processes, Petroleum Refining, Asphalt Paving Materials (2306010000)
- Solvent Utilization, Surface Coating, Architectural Coatings (2401001000)
- Solvent Utilization, Miscellaneous Commercial, Asphalt Application (2461020000)
- Miscellaneous Area Sources, Other Combustion, Forest Wildfires (2810001000)
- Miscellaneous Area Sources, Other Combustion, Firefighting Training (2810035000)
- Waste Disposal, Open Burning (2610000100-500, 2610030000)

Some of these source categories, notably those for fugitive dust and forest wildfires, have significant summer season (and annual average) emissions; however, emissions from these categories do not occur during winter conditions in Fairbanks when road and land surfaces are covered by snow and ice.

For all other categories except Construction Dust (SCC 2311010000) emissions were assumed constant throughout the year. Based on discussions with Borough staff, constructions dust was split 37% in winter months (October-March) and 63% in summer months (April-September).

Table 7-6-47 provides a listing of annual emissions (tons/year) by SCC code for these remaining other area source categories for the Fairbanks North Star Borough that were extracted from the 2014 NEI. (Though not shown, similar data were extracted for the other three counties within the modeling domain, Denali, Southeast Fairbanks and Yukon-Koyukuk.)

2014 emissions from the Minor Stationary Source database and the NEI were backcasted to 2013 using historical year-to-year county-wide population estimates compiled by the Alaska Department of Labor and Workforce Development (ADLWD). The 2013-2014 population growth factor for Fairbanks from the historical ADLWD data was 1.013, reflecting a 1.3% increase from 2013 to 2014. Thus, emissions were backcasted to 2013 by dividing 2014 emissions by 1.013.

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Dust - Paved Road Dust - Mobile Sources - Paved Roads - All Paved Roads - Total: Fugitives	2294000000	0.0	0.0	0.0	0.0	114.3	114.3	0.0
Dust - Unpaved Road Dust - Mobile Sources - Unpaved Roads - All Unpaved Roads - Total: Fugitives	2296000000	0.0	0.0	0.0	0.0	1651.3	1651.3	0.0
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Charbroiling - Conveyorized Charbroiling	2302002100	0.6	0.0	0.0	0.0	2.5	0.0	2.5
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Charbroiling - Under-fired Charbroiling	2302002200	2.0	0.0	0.0	0.0	16.1	0.0	16.0
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Frying - Clamshell Griddle Frying	2302003200	0.2	0.0	0.0	0.0	0.2	0.2	0.0
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Frying - Deep Fat Fying	2302003000	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Frying - Flat Griddle Frying	2302003100	0.3	0.0	0.0	0.0	3.3	0.0	3.3
Industrial Processes - Petroleum Refineries - Industrial Processes - Petroleum Refining: SIC 29 - Asphalt Paving/Roofing Materials - Total	2306010000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Non-Industrial Surface Coating - Solvent Utilization - Surface Coating - Architectural Coatings - Total: All Solvent Types	2401001000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Commercial - Asphalt Application: All Processes - Total: All Solvent Types	2461020000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 2: Spillage	2501060103	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 2: Displacement Loss/Controlled	2501060102	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Storage and Transfer - Storage and Transport - Petroleum and Petroleum Product Storage - All Storage Types: Working Loss - Gasoline	2501995120	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Storage and Transfer - Storage and Transport - Petroleum and Petroleum Product Storage - All Storage Types: Breathing Loss - Gasoline	2501000120	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fires - Wildfires - Miscellaneous Area Sources - Other Combustion - Forest Wildfires - Wildfires	2810001000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Miscellaneous Area Sources - Other Combustion - Structure Fires - Unspecified	2810030000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Miscellaneous Area Sources - Other Combustion - Firefighting Training - Total	2810035000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Comb - Industrial Boilers, ICEs - Coal - Stationary Source Fuel Combustion - Industrial - Bituminous/Subbituminous Coal - Total: All Boiler Types	2102002000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Comb - Industrial Boilers, ICEs - Oil - Stationary Source Fuel Combustion - Industrial - Distillate Oil - Total: Boilers and IC Engines	2102004000	23.7	66.1	4.9	0.0	5.9	1.6	4.3
Fuel Comb - Industrial Boilers, ICEs - Oil - Stationary Source Fuel Combustion - Industrial - Residual Oil - Total: All Boiler Types	2102005000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Comb - Industrial Boilers, ICEs - Natural Gas - Stationary Source Fuel Combustion - Industrial - Natural Gas - Total: Boilers and IC Engines	2102006000	29.0	528.2	3.2	16.9	2.3	0.6	1.7
Fuel Comb - Industrial Boilers, ICEs - Oil - Stationary Source Fuel Combustion - Industrial - Kerosene - Total: All Boiler Types	2102011000	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Industrial Processes - Oil & Gas Production - Industrial Processes - Oil and Gas Exploration and Production - All Processes - Total: All Processes	2310000000	9.9	23.7	1.0	0.0	3.0	3.0	0.0
Industrial Processes - Oil & Gas Production - Industrial Processes - Oil and Gas Exploration and Production - All Processes : On-shore - Total: All Processes	2310001000	9.9	23.7	1.0	0.0	3.0	0.0	0.0
Dust - Construction Dust - Industrial Processes - Construction: SIC 15 - 17 - Residential - Total	2311010000	0.0	0.0	0.0	0.0	0.5	0.5	0.0
Dust - Construction Dust - Industrial Processes - Construction: SIC 15 - 17 - Industrial/Commercial/Institutional - Total	2311020000	0.0	0.0	0.0	0.0	55.4	55.4	0.0
Solvent - Industrial Surface Coating & Solvent Use - Solvent Utilization - Surface Coating - Traffic Markings - Total: All Solvent Types	2401008000	21.6	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Industrial Surface Coating & Solvent Use - Solvent Utilization - Surface Coating - Machinery and Equipment: SIC 35 - Total: All Solvent Types	2401055000	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Industrial Surface Coating & Solvent Use - Solvent Utilization - Surface Coating - Miscellaneous Manufacturing - Total: All Solvent Types	2401090000	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Degreasing - Solvent Utilization - Degreasing - All Processes/All Industries - Total: All Solvent Types	2415000000	49.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Dry Cleaning - Solvent Utilization - Dry Cleaning - All Processes - Total: All Solvent Types	2420000000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Graphic Arts - Solvent Utilization - Graphic Arts - All Processes - Total: All Solvent Types	2425000000	36.6	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Personal Care Products - Total: All Solvent Types	2460100000	99.5	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Household Products - Total: All Solvent Types	2460200000	109.5	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Automotive Aftermarket Products - Total: All Solvent Types	2460400000	67.7	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Coatings and Related Products - Total: All Solvent Types	2460500000	47.3	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Adhesives and Sealants - Total: All Solvent Types	2460600000	28.4	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All FIFRA Related Products - Total: All Solvent Types	2460800000	88.6	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - Miscellaneous Products (Not Otherwise Covered) - Total: All Solvent Types	2460900000	3.5	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Commercial - Emulsified Asphalt - Total: All Solvent Types	2461022000	9.6	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Permeation	2501011011	2.5	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Evaporation (includes Diurnal losses)	2501011012	2.8	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Spillage During Transport	2501011013	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Refilling at the Pump - Vapor Displacement	2501011014	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Refilling at the Pump - Spillage	2501011015	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Permeation	2501012011	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Evaporation (includes Diurnal losses)	2501012012	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Spillage During Transport	2501012013	3.0	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Refilling at the Pump - Vapor Displacement	2501012014	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Refilling at the Pump - Spillage	2501012015	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Bulk Gasoline Terminals - Storage and Transport - Petroleum and Petroleum Product Storage - Bulk Terminals: All Evaporative Losses - Gasoline	2501050120	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 1: Submerged Filling	2501060051	29.3	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 1: Splash Filling	2501060052	8.5	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 1: Balanced Submerged Filling	2501060053	12.7	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Underground Tank: Breathing and Emptying	2501060201	8.6	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Airports : Aviation Gasoline - Stage 1: Total	2501080050	38.2	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Airports : Aviation Gasoline - Stage 2: Total	2501080100	3.9	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Storage and Transfer - Storage and Transport - Petroleum and Petroleum Product Transport - Truck - Gasoline	2505030120	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Storage and Transfer - Storage and Transport - Petroleum and Petroleum Product Transport - Pipeline - Gasoline	2505040120	7.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Mining - Industrial Processes - Mining and Quarrying: SIC 14 - All Processes - Total	2325000000	3.0	17.8	1.0	0.0	3.9	3.9	0.0
Waste Disposal - Waste Disposal, Treatment, and Recovery - Open Burning - All Categories - Yard Waste - Leaf Species Unspecified	2610000100	1.9	0.4	0.1	0.0	1.2	1.2	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year) VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Waste Disposal - Waste Disposal, Treatment, and Recovery - Open Burning - All Categories - Yard Waste - Brush Species Unspecified	2610000400	1.3	0.3	0.1	0.0	1.0	1.0	0.0
Waste Disposal - Waste Disposal, Treatment, and Recovery - Open Burning - All Categories - Land Clearing Debris (use 28-10-005-000 for Logging Debris Burning)	2610000500	73.0	31.5	10.4	0.0	82.5	82.5	0.0
Waste Disposal - Waste Disposal, Treatment, and Recovery - Open Burning - Residential - Household Waste (use 26-10-000-xxx for Yard Wastes)	2610030000	12.7	8.9	1.5	0.0	51.4	51.4	0.0
Waste Disposal - Waste Disposal, Treatment, and Recovery - Landfills - Municipal - Total	2620030000	0.0	2.0	3.0	0.0	0.1	0.1	0.0
Miscellaneous Non-Industrial NEC - Miscellaneous Area Sources - Other Combustion - Charcoal Grilling - Residential (see 23-02-002-xxx for Commercial) - Total	2810025000	1.4	1.7	0.0	0.0	4.4	0.0	0.0
Totals, 2014 NEI Sources		**858**	**704**	**26.1**	**16.9**	**2002**	**1967**	**27.8**

On-Road Mobile Sources

This section of the Emissions Inventory Technical Appendix describes the data/sources, methods and tools/workflow used to estimate on-road vehicle emissions across the Fairbanks SIP modeling domain. EPA's MOVES2014b vehicle emissions model was used to generate detailed fleet emission rates and was combined with EPA's SMOKE-MOVES integration tool to pass the highly-resolved and emission process-specific emission rates into SMOKE-ready input structures for use in preparation of gridded, episodic on-road mobile source emissions.

The sequence of steps in generating gridded episodic on-road mobile emissions using the SMOKE-MOVES Tool[48] consists of: 1) MOVES model processing; 2) meteorological data pre-processing; and 3) SMOKE model processing. This process does not create emission estimates (e.g., in tons/day) as is the case with other sectors of the inventory, but instead emission lookup tables are produced which are used by SMOKE to create photochemical model-ready emission fields. Local inputs were used where available when configuring each of the tools used in the steps of this process. The MOVES input data, resulting look-up tables and final processed emissions fields were developed to reflect episode specific conditions in the Fairbanks region during the spans of the two modeling episodes examined in the SIP's attainment analysis:

- Episode 1 - January 23rd – February 12th, 2008; and
- Episode 2 - November 2nd – November 17th, 2008.

The first sub-section discusses MOVES model processing, documenting assembly of model input data. It also describes the meteorological data pre-processing and emission rate processing performed using SMOKE-MOVES sources. The next sub-section explains the importing and model execution workflows used to generate vehicle emission rates processed through SMOKE-MOVES, including generation of lookup tables and processing performed within SMOKE.

Development of MOVES Inputs

Following EPA guidance for use of MOVES in SIP inventory applications, local data were assembled and analyzed to supply regional vehicle fleet and travel activity inputs to the model. Prior to detailed explanations of how the data inputs were developed, the key sources of local data are summarized below.

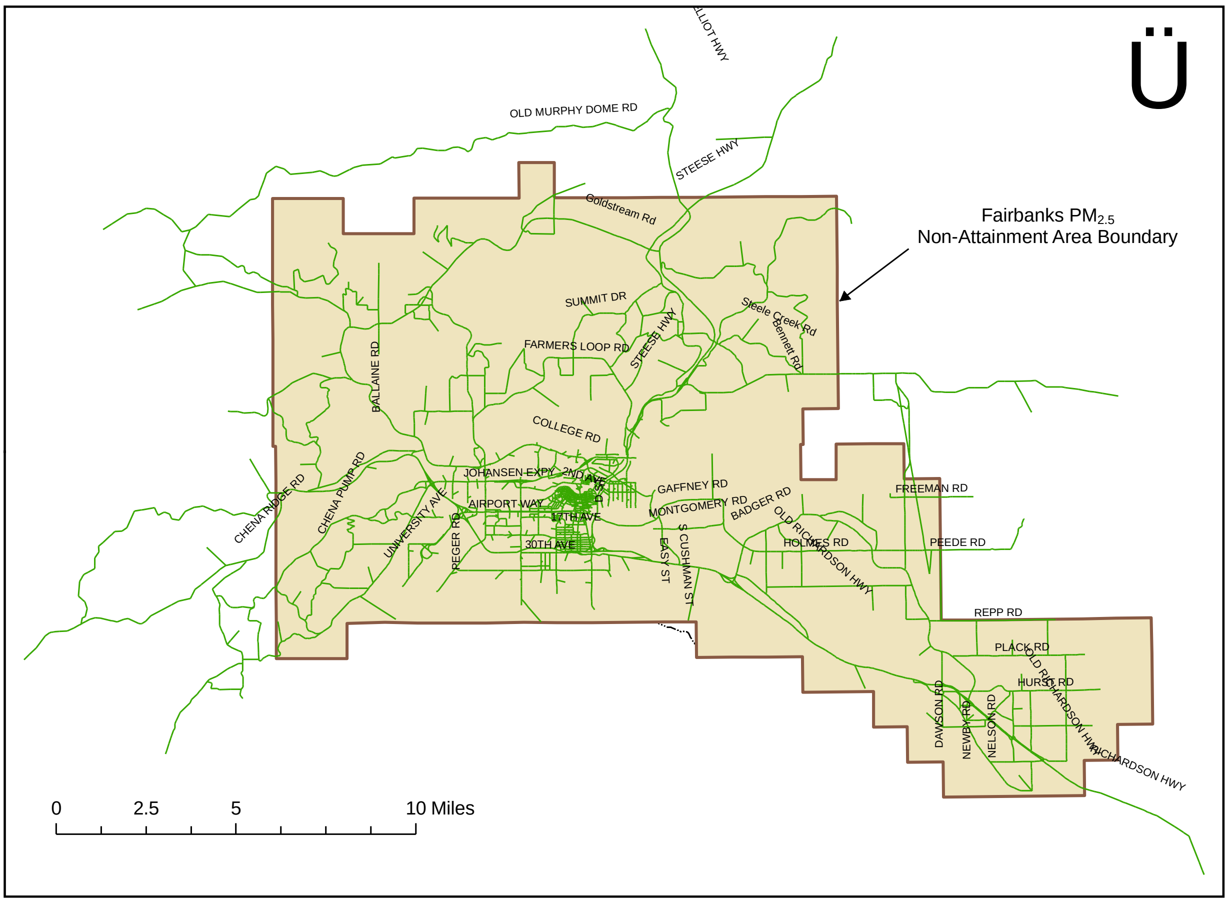
Key Data Sources - MOVES vehicle activity inputs were based primarily on data gathered as part of the conformity analysis for the Fairbanks Metropolitan Area Transportation System (FMATS) 2045 Metropolitan Transportation Plan (MTP)[49]. FMATS is the Metropolitan Planning Organization (MPO) for Fairbanks (In 2019, FMATS transitioned to the Fairbanks

[48] B. Baek, A. DenBleyker, "User's Guide for the SMOKE-MOVES Integration Tool", prepared for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, July 14, 2010. http://www.cmascenter.org/smoke/documentation/smoke_moves_tool/SMOKE-MOVES_Tool_Users_Guide.pdf
[49] M. Malchow, T. Carlson, "Conformity Analysis for the FMATS 2045 Metropolitan Transportation Plan (MTP), prepared for Fairbanks Metropolitan Area Transportation System, January 23, 2019.

Area Surface Transportation Planning organization – FAST Planning). The 2045 MTP was based on the same 2013 baseline travel modeling network as its predecessor, the 2040 MTP. Inputs from that conformity analysis were derived from local transportation modeling efforts, vehicle registration data, and other local data, each of which is discussed separately below.

Regional Travel Demand Modeling - Vehicle activity on the FMATS transportation network was based on the TransCAD travel demand modeling performed for 2045 MTP (identical to the 2040 MTP base network as noted above). The TransCAD modeling network covers the entire FNSB $PM_{2.5}$ Non-Attainment Area (NAA) and its major links extend beyond the nonattainment area boundary as illustrated below in Figure 7-6-34.

Figure 7-6-34
FMATS TransCAD Modeling Network



The TransCAD model was configured using 2010 U.S. Census-based socioeconomic data. TransCAD modeling was performed for a 2013 base year and a projected 2045 horizon year. Population and employment forecasts were based on an average of historical growth rates, combined with Alaska Department of Labor population forecasts and studies conducted by Woods & Poole Economics. These projections explicitly accounted for increased travel associated with the population and employment growth triggered by the F-35 deployment at

Eielson Air Force Base.

Attachment B provides further details on the travel demand model development.

Link-level TransCAD outputs were processed to develop several of the travel activity related inputs required by MOVES. Vehicle miles traveled (VMT) tabulated across the TransCAD network for each of the years for which Final 2045 MTP travel model outputs were available are presented below in Table 7-6-48**Error! Reference source not found.**.

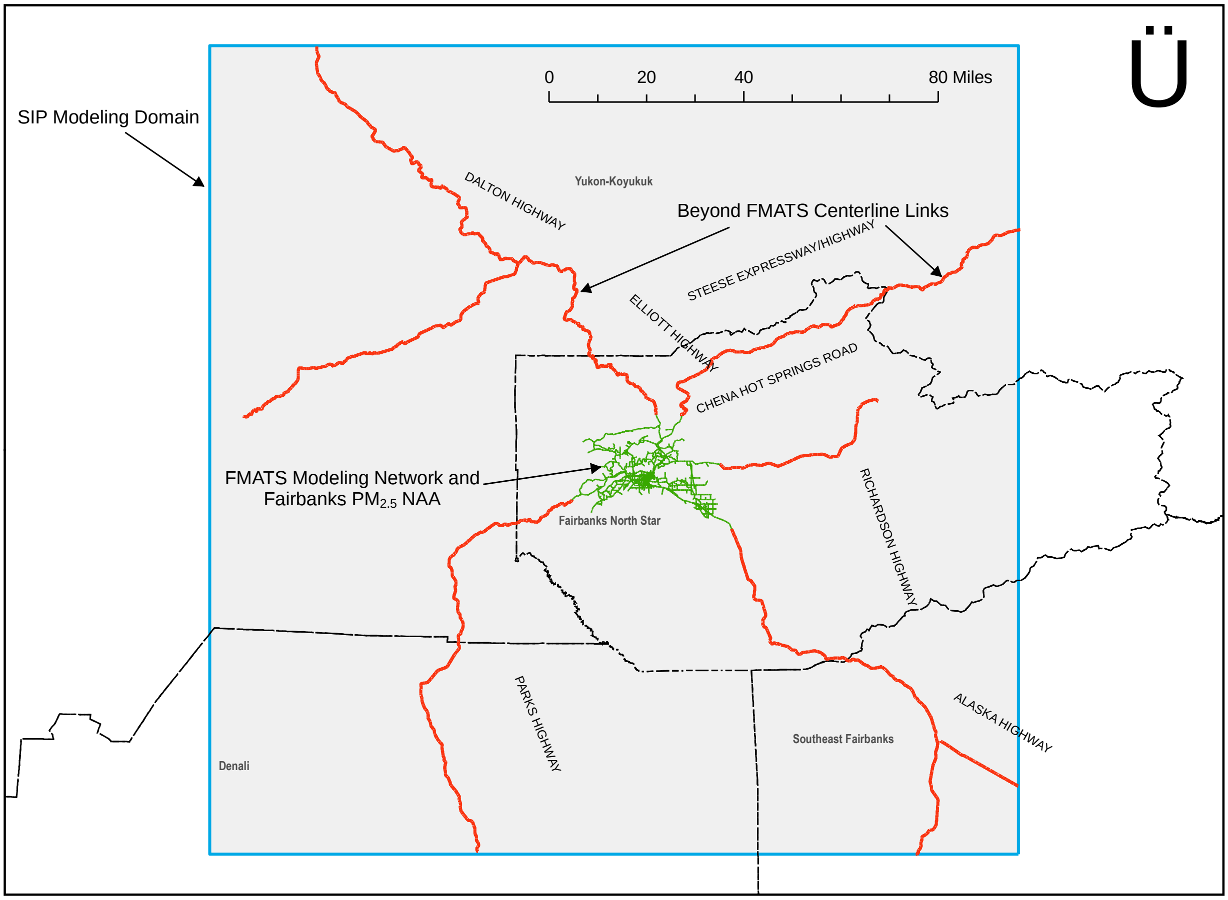
Table 7-6-48
TransCAD Average Daily VMT by Year and Daily Period,
Final 2045 MTP Forecast

Daily Period	2013	2019	2024	2025	2029	2035	2045
Entire TransCAD Modeling Network							
AM Peak	253,497	276,312	309,883	315,267	335,153	363,142	414,901
PM Peak	501,870	558,215	634,785	646,926	692,378	756,436	866,833
Off Peak	1,374,276	1,524,386	1,730,719	1,762,352	1,882,479	2,051,737	2,337,955
Daily Total	**2,129,642**	**2,358,912**	**2,675,387**	**2,724,546**	**2,910,010**	**3,171,315**	**3,619,689**
VMT Growth (2013=1.0)		1.108	1.256	1.279	1.366	1.489	1.700
PM Nonattainment Area							
AM Peak	205,465	220,221	244,801	248,669	262,920	282,982	320,515
PM Peak	400,283	439,227	495,365	504,213	536,915	582,865	662,054
Off Peak	1,092,896	1,195,145	1,345,403	1,368,250	1,453,659	1,573,484	1,774,618
Daily Total	**1,698,644**	**1,854,594**	**2,085,569**	**2,121,132**	**2,253,495**	**2,439,331**	**2,757,187**
VMT Growth (2013=1.0)		1.092	1.228	1.249	1.327	1.436	1.623

Vehicle Activity Beyond FMATS Network – The geographic extent of the FMATS network covers a small portion of the entire Grid 3 attainment modeling domain. Traffic density in the broader Alaskan interior is likely to be less than that concentrated in Fairbanks (and have less impact on ambient air quality in Fairbanks). Nevertheless, for completeness link-level travel estimates for major roadways beyond the FMATS network (and FNSB PM NAA) were developed using a spatial (ArcGIS-compatible) "Road Centerline" polyline coverage for the Interior Alaska region developed by the Alaska Department of Transportation and Public Facilities (ADOT&PF). This GIS layer identified locations of major highway/arterial routes within the Grid 3 domain broken down into individual milepost (MP) segments.

These road centerline segments are shown in red in Figure 7-6-35 along with the smaller FMATS link network (green lines) and the extent of the SIP Grid 3 modeling domain (blue rectangle). Annual average daily traffic volumes (AADT) and VMT (determined by multiplying volume by segment length) were assigned to each segment based on a spreadsheet database of calendar year 2013 traffic volume data compiled by ADOT&PF's Northern Region office. A Linear Reference System (LRS) approach was used to spatially assign volume and VMT data for each segment in the spreadsheet database to the links in the Road Centerline layer based on the route identifier number (CDS_NUM) and lineal milepost value.

Figure 7-6-35
Additional ADOT&PF Roadway Links beyond FMATS Network



DMV Registration Data – DEC obtained a dump or snapshot of statewide vehicle registrations from the Alaska Division of Motor Vehicle (DMV) as of June 2014. The Alaska DMV database includes vehicle make, model, model year, Vehicle Identification Number (VIN), vehicle class code, body style, registration status, expiration date and owner/operator address information. A subset of valid data for the FNSB NAA was created by extracting records from the statewide database based on current registration status and owner/operator ZIP codes located within the NAA.

As described in greater detail later under "MOVES Fleet Inputs", DEC also applied a licensed VIN decoder to the VINs for the FNSB NAA subset that provided additional vehicle attribute information that was used along with the DMV attributes to classify vehicles into the MOVES Source Use Type fleet classification scheme.

Seasonal Vehicle Activity Surveys – DEC has conducted a series of wintertime vehicle surveys in parking lots for commonly-frequented businesses (e.g., shopping centers) in Fairbanks in part as a cross-check to vehicle Inspection and Maintenance (I/M) program enforcement conducted by the Borough and to identify any seasonal variations in vehicle use. In conducting the surveys, personnel are stationed at various locations within the surveyed lots (over multiple days) and record license (and make/model) information for vehicles passing/parking within their viewing area. The results are then bounced against the DMV database to determine each vehicle's model year.

The most recent set of parking lot surveys was conducted in early 2009. As described in detail later, this and similar earlier surveys (with sample sizes of several thousand vehicles each) have found a clear, recurrent pattern that older vehicles tend to be driven less during winter because of drivability concerns under the harsh Arctic conditions.

MOVES Fleet Inputs - Outputs from several of the sources summarized earlier were used to develop the vehicle fleet-related inputs to the MOVES model runs. Each of these fleet-related MOVES inputs is described separately below. (The names of the individual inputs within MOVES are listed in parentheses.)

Vehicle Populations (Source Type Population & Age Distribution) - DMV registrations from the Alaska Division of Motor Vehicles (DMV) and 2009 Fairbanks Parking Lot Survey data provided the basis for the vehicle fleet populations and age distributions used to model the Fairbanks vehicle fleet with MOVES. As noted earlier, the DMV database includes vehicle make, model, model year, Vehicle Identification Number (VIN), vehicle class code, body style, registration status and expiration date.

Using a VIN decoding tool licensed by DEC, supplemental information such as vehicle class, gross vehicle weight, vehicle type, body type and fuel type (e.g., gasoline vs. diesel) were also determined in order to help classify each vehicle into one of the 13 MOVES Source Use Type categories. Vehicle attribute fields from the DMV database (Class Code, Body Style), and VIN decoder outputs (Vehicle Class, GVWR Class, Vehicle Type, Body Type) were used to categorize each vehicle record into one of the 13 usage-based "Source Type" categories as defined in MOVES to characterize the vehicle fleet.

Table 7-6-49 lists each of these "Source Type" categories and identifies the primary vehicle attribute fields in either the DMV database itself (DMV) or output from the VIN decoder (Decoder) that were used to determine the Source Type for each vehicle record.

For nearly all the records, the Source Type could be conclusively determined from specific combinations of these attributes. In some cases, such as Source Types 51 (Refuse Trucks) and 54 (Motorhomes), single values of the Body Style field in the DMV database were used to discern the appropriate Source Type. In other cases, Source Types were assigned based on categorical values in several attribute fields as noted in Table 7-6-49. In a few cases, vehicle make and model fields were also examined and then fed to a web-based search engine to identify whether the vehicle was a single or combination-unit truck.

Table 7-6-49
MOVES Vehicle Fleet Source Type Categories

Source Type ID	Source Type Description	Primary Attributes/Sources
11	Motorcycle	Class Code (DMV), Body Style (DMV) – Categories MB and MC, Vehicle Type (Decoder), Vehicle Class (Decoder)
21	Passenger Car	Class Code (DMV), Vehicle Type (Decoder) , Vehicle Class (Decoder)
31	Passenger Truck	Class Code (DMV), Vehicle Type (Decoder) , Vehicle Class (Decoder)
32	Light Commercial Truck	Class Code (DMV), Vehicle Class (Decoder), GVWR Class (Decoder) – up to Class 4 (14,001-16,000 lb)
41	Intercity Bus	Class Code (DMV), Body Style (DMV), Vehicle Type (Decoder), Vehicle Class (Decoder)
42	Transit Bus	Class Code (DMV), Body Style (DMV), Vehicle Type (Decoder), Vehicle Class (Decoder)
43	School Bus	Class Code (DMV), Body Style (DMV), Vehicle Type (Decoder), Vehicle Class (Decoder)
51	Refuse Truck	Body Style (DMV) – Category GG
52	Single Unit Short-haul Truck	Class Code (DMV), Body Style (DMV), Vehicle Class (Decoder), GVWR Class (Decoder) – Class 6 and above
53	Single Unit Long-haul Truck	Apportioned from MOVES default 52/53 splits
54	Motor Home	Body Style (DMV) – Category MH
61	Combination Short-haul Truck	Class Code (DMV), Body Style (DMV), Vehicle Class (Decoder) – Category “Truck Tractor”, GVWR Class (Decoder), Fuel Type (Decoder)
62	Combination Long-haul Truck	Apportioned from MOVES default 61/62 splits

As also noted in Table 7-6-49, the DMV and VIN decoder attribute data were not sufficient to distinguish between short-haul trucks (Source Types 52 and 61) and long-haul trucks (Source Types 53 and 62). All of the single and combination-unit truck records were assigned short-haul Source Type categories of either 52 or 61. The *SourceTypeYear* table in the MOVES database was then queried to extract nationwide vehicle populations for Source Type categories 52, 53, 61 and 62. Relative splits between short- and long-haul vehicle fractions in these categories were then calculated and used to estimate the populations of long-haul single-unit (53) and combination-unit (62) vehicles in the Fairbanks fleet.

Table 7-6-50 shows the resulting summation of vehicles by their sourceTypeID as determined from the VIN decoder and DMV data for the year 2014. The 2014 population data was scaled back to 2013 values by backcasting the vehicle population based on the VMT rates of growth from 2013 to 2019. The VMT growth rates are derived for each individual HPMS vehicle type

ID and then translated to MOVES source type ID. For the light duty vehicle fleet the annual rate of change in VMT was found to be 1.5%. The 2013 backcasted populations are shown in the rightmost column of Table 7-6-50.

Table 7-6-50
Fairbanks Baseline Vehicle Populations by MOVES Source Type

Source Type ID	Source Type Description	Vehicle Populations	
		2014 DMV	2013 Backcast
11	Motorcycle	4,803	4,731
21	Passenger Car	26,847	26,442
31	Passenger Truck	62,691	61,746
32	Light Commercial Truck	4,707	4,636
41	Intercity Bus	146	144
42	Transit Bus	128	126
43	School Bus	181	178
51	Refuse Truck	72	71
52	Single Unit Short-haul Truck	1,283	1,264
53	Single Unit Long-haul Truck	55	54
54	Motor Home	1,757	1,731
61	Combination Short-haul Truck	663	653
62	Combination Long-haul Truck	791	779
Total Vehicle Fleet		**104,124**	**102,555**

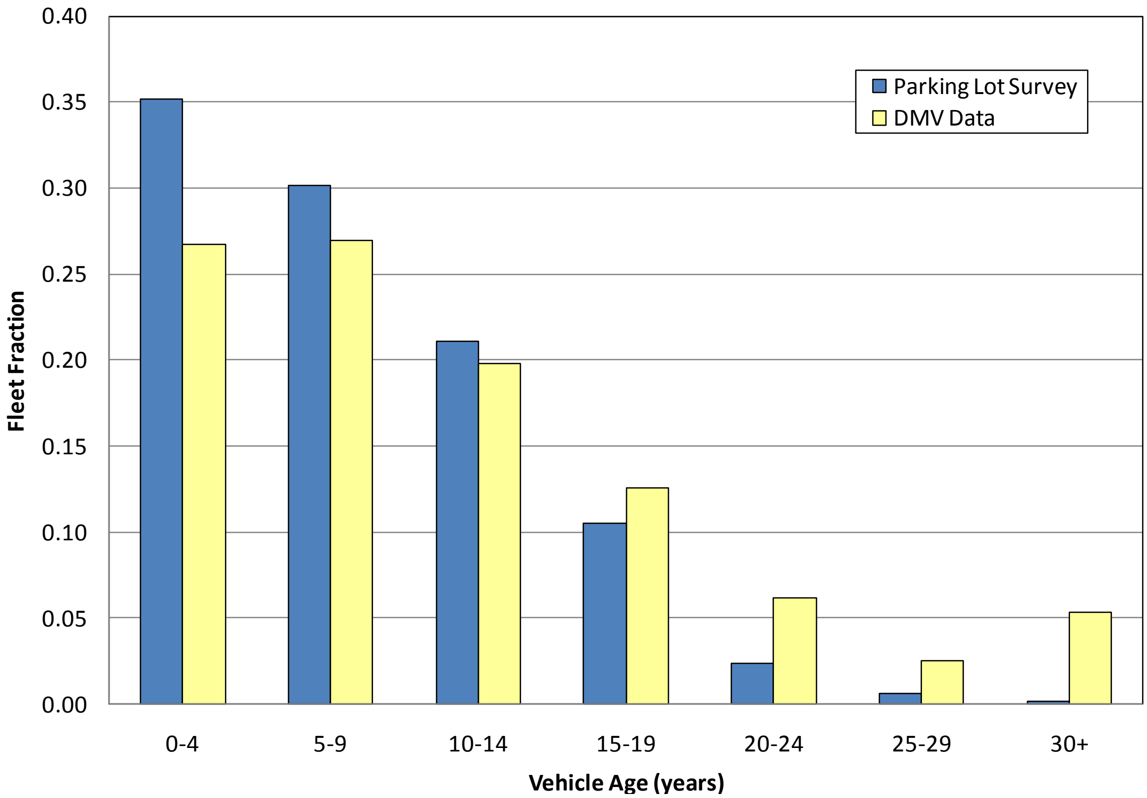
[a] As explained later, motorcycle activity in Fairbanks during the winter months was assumed to be zero.

The DMV registration data also identified the model year of the vehicle, which enabled distributions of populations by vehicle age[50] to be calculated for each Source Type and input to MOVES. For the three light-duty passenger vehicle types (11-motorcycles, 21-passenger cars, and 31-passenger trucks), vehicle age distributions from winter parking lot surveys[51] conducted by DEC in Fairbanks during January and February 2009 were used instead of those based on DMV registrations. This is because it was found in both these 2009 surveys as well as similar parking lot surveys conducted earlier by DEC in 2005 and 2000 that older passenger vehicles are driven less during harsh winter conditions in Fairbanks.

[50] Vehicle age in years was simply calculated by subtracting the model year from 2010, the calendar year in which the DMV database obtained.
[51] The purpose of the surveys was to collect data for assessing the performance of the I/M Program. A review of the location of the surveys found broad representation beyond the boundary of the CO nonattainment area in Fairbanks, North Pole, and Chena Ridge areas. While no data were collected in Goldstream Valley, the results sufficiently represent the $PM_{2.5}$ nonattainment area to be used in the analysis.

Figure 7-6-36 compares the vehicle age fractions (by age group) for light-duty passenger cars in Fairbanks developed from the DMV registrations and the Parking Lot Surveys. As Figure 7-6-36 clearly shows, vehicle fractions in the newer groups (< 15 years) from the Parking Lot Surveys are distinctly higher than from the DMV registrations. This pattern is reversed for the older vehicle groups (15 or more years old).

Figure 7-6-36
Comparison of DMV and Survey-Based Vehicle Age Distributions of Passenger Cars in Fairbanks



Another expected finding from the Fairbanks parking lot surveys is that motorcycles are simply not operated during cold wintertime conditions. Although motorcycles make up roughly 5% of the Fairbanks-registered vehicle fleet, as shown earlier in Table 7-6-50, only a single motorcycle was identified in the entire sample of over 8,500 vehicles from the 2009 Fairbanks surveys (which represents 0.01% of the survey sample).

Thus, for Source Type categories 11 (motorcycles), 21 (passenger cars) and 31 (passenger trucks), vehicle age distributions were based on the Parking Lot Survey data to reflect well-documented winter season shifts toward greater use of newer vehicles in the passenger car and passenger truck fleets as well as non-use of motorcycles during winter months. These survey-based winter seasonal adjustments for Fairbanks have been employed in wintertime emission inventories developed in previous CO SIPs and transportation conformity determinations that have been approved by EPA and FHWA.

For the remaining MOVES source type categories (32 and above), age distributions were based on the DMV registration data for Fairbanks These age distributions developed for the 2013 Baseline fleet were projected to future calendar year fleets using EPA's MOVES2014-based Age Distribution Projection Tool.[52]

Gasoline vs. Diesel-Fueled Vehicle Fractions (AVFT Strategies) – MOVES provides users the ability to override its default nationwide based travel splits between different fuels and technologies. These Alternative Vehicle Fuel and Technology (AVFT) inputs are supplied to MOVES through the Strategies panel in the user interface, not the County Data Manager.

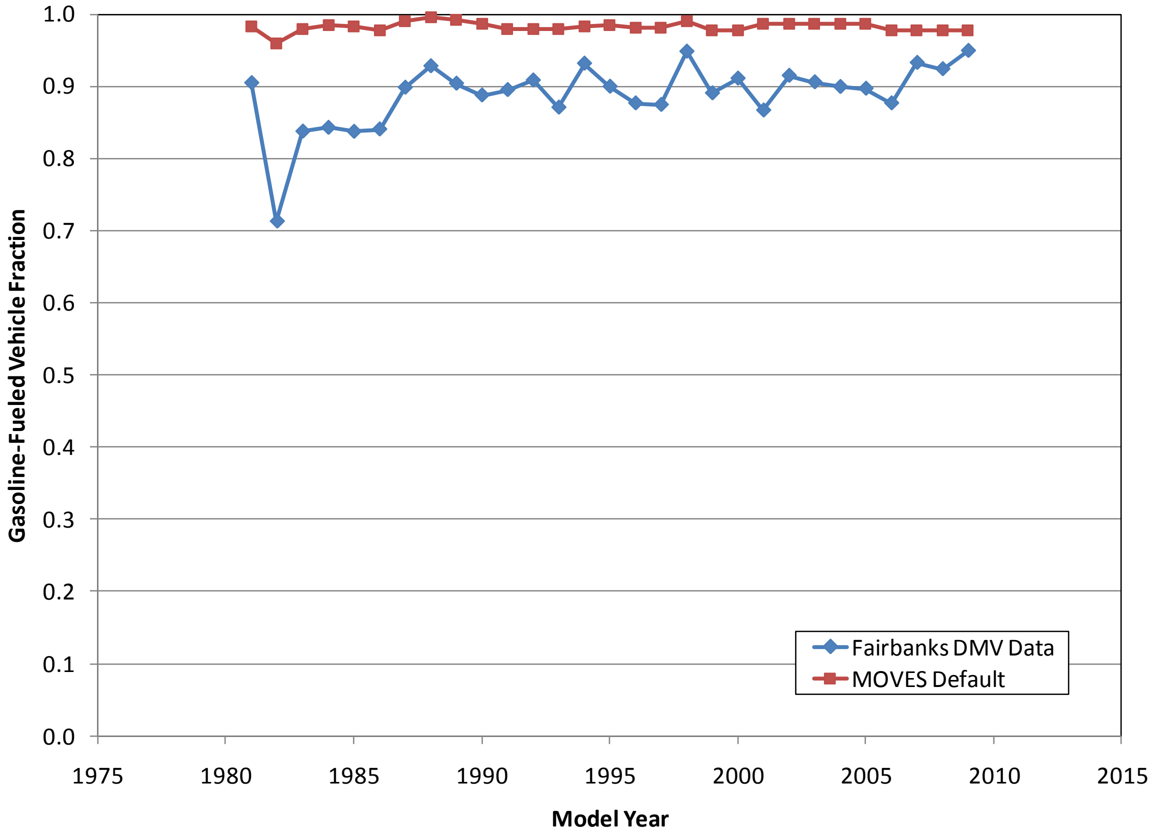
In order to account for differences in splits between gasoline- and diesel-fuel vehicles in the Fairbanks fleet compared to the U.S. as a whole, fuel fraction tables by source type and model year were also constructed using the DMV VIN decoded data described earlier. Not surprisingly, the MOVES default splits between gasoline and diesel vehicles was not representative of the Fairbanks fleet. Generally speaking, gasoline fractions were found to be lower in Fairbanks than the nationwide-based MOVES defaults (and diesel fractions were commensurately higher).

This is illustrated in Figure 7-6-37, which compares the gasoline vehicle fractions by model year for passenger trucks (MOVES Source Type 31) from the Fairbanks DMV data against the default fractions contained in MOVES. As seen in Figure 7-6-37, actual gasoline vehicle fractions for passenger trucks in Fairbanks are roughly 10% lower than the MOVES defaults (meaning diesel fractions are roughly 10% higher). Modest differences were also observed for some of the commercial vehicle categories as well.

As illustrated by the range of model years compared in Figure 7-6-37, DMV VIN decoder-based gasoline vs. diesel vehicle fractions were available only for model years 1981 through 2009 (the VIN decoder only operates on 1981 and later models). In setting up the AVFT fuel split input to MOVES, the fuel fractions must be specified by model year, not vehicle age. For earlier model years prior to 1981, the MOVES default fractions were used. For model years 2014 and later, the DMV-based fuel type fractions from model year 2014 were generally assumed to remain constant in future model years except in the passenger truck category where the MOVES defaults reflect a modest increase in diesel penetration in future model years. For passenger trucks in model years 2014 and later, the MOVES defaults were used.

[52] https://www.epa.gov/moves/tools-develop-or-convert-moves-inputs#fleet

Figure 7-6-37
Comparison of Passenger Truck Gasoline-Fuel Vehicle Fractions by Model Year
Fairbanks DMV Data vs. MOVES Defaults



Travel Activity (VMT) – Estimates of VMT over the FMATS modeling network (covering the entire $PM_{2.5}$ NAA) from the TransCAD travel model link output files were processed and input to MOVES through the "Vehicle Type VMT" input within the County Data Manager. The Vehicle Type VMT input must be in units of VMT per year, not VMT per day. The annual VMT must also be supplied by "HPMS Vehicle Type"[53] which is essentially an aggregated version of the 13-category MOVES Source Type scheme. Since states are required to provide periodic travel (i.e., VMT) estimates to FHWA via the Highway Performance Monitoring System (HPMS), EPA has designed MOVES to accept VMT input by these HPMS Vehicle Type categories.

Table 7-6-51 shows the mapping of Source Type to HPMS Vehicle Type categories. These mappings were based on FHWA's "VM-1" allocations as listed in EPA's latest MOVES2014 User's Guide.[54] It also shows how the Fairbanks baseline vehicle populations shown earlier in Table 7-6-50 were aggregated into the HPMS Vehicle Type categories.

[53] Although MOVES2014b allows VMT input by either the 13-category Vehicle Type scheme or the 5-category HPMS Type scheme, SMOKE-MOVES only supports the latter.
[54] "MOVES2014a User's Guide," U.S. Environmental Protection Agency, Report No. EPA-420-B-15-095, November 2015.

Table 7-6-51
MOVES Source Type to HPMS Vehicle Type Mapping

Source Type ID	Source Type Description	HPMS VehType ID	HPMS Vehicle Type Description	2014 Baseline Vehicle Popn.
11	Motorcycle	10	Motorcycles	4,803
21	Passenger Car	25	Light-duty vehicles	26,847
31	Passenger Truck			62,691
32	Light Comm. Truck			4,707
41	Intercity Bus	40	Buses	455
42	Transit Bus			
43	School Bus			
51	Refuse Truck	50	Single Unit Trucks	3,167
52	Single SH Truck			
53	Single LH Truck			
54	Motor Home			
61	Comb. SH Truck	60	Combination Trucks	1,454
62	Comb. LH Truck			
Total Vehicle Fleet				104,124

HPMS data for the Fairbanks urban planning area provided by ADOT&PF[55] were analyzed and used to determine the locally-based VMT split between light- and heavy-duty vehicles. This local VMT split was found to be 93% "Passenger/Light-Duty" and 7% "Commercial/Heavy-Duty". Since the ADOT&PF classifications separate passenger from commercial vehicles; their "Light-Duty Passenger" category includes only MOVES Source Types 11, 21 and 31 (but not 32) as shaded in green in Table 7-6-51. The remaining "Commercial/Heavy Duty" category includes MOVES Source Types 32 through 62 as highlighted in tan within Table 7-6-51. Thus prior to aggregating activity data into the five-category HPMS scheme, VMT allocations were performed at the more resolved Source Type level since it maps into the two groups of local VMT splits obtained from ADOT&PF.

The first step in generating these VMT allocations by Source Type consisted of running MOVES2014b in "default" mode to generate MOVES default-based annual mileage accumulation rates (miles/year/vehicle) by Source Type for calendar year 2014, the year for which DMV-based populations were obtained. Table 7-6-52 shows the calendar year 2014 default mileage rates and vehicle populations along with the ADOT&PF-based Passenger/Light-Duty vs. Commercial/Heavy-Duty VMT splits in the leftmost columns. The cell shading is used within Table 7-6-52 to show which Source Types these VMT splits apply to.

[55] Email from Jennifer Anderson, Alaska Department of Transportation, Fairbanks 2018 HPMS Sections (csv file), November 2, 2018.

Table 7-6-52
Allocation of Local VMT Splits by Source Type for DMV Year 2014

Source Type ID	ADOT&PF HPMS VMT Split	DMV Vehicle Popn.	MOVES Annual Default Mileage (miles/year-veh)	Default VMT (miles/day)	Aggregated VMT/Day			Allocated TransCAD VMT/Day
					Default	TransCAD	Ratio	
11	93.0%	4,803	2,191	28,827	2,890,219	1,603,911	1.802	15,997
21		26,847	10,743	790,206				438,520
31		62,691	12,059	2,071,186				1,149,394
32	7.0%	4,707	12,294	158,547	544,175	120,725	4.508	35,173
41		146	84,753	33,901				7,521
42		128	45,516	15,962				3,541
43		181	14,069	6,977				1,548
51		72	23,461	4,628				1,027
52		1,283	14,620	51,404				11,404
53		55	19,058	2,854				633
54		1,757	2,216	10,666				2,366
61		663	30,246	54,913				12,182
62		791	94,245	204,324				45,329
Totals	100%	104,124		3,434,394		**1,724,636**[a]		**1,724,636**

[a] 2014 VMT interpolated from 2013 and 2019 TransCAD travel model outputs.

As shown in Table 7-6-52, the next step consisted of calculating "Default" VMT by Source Type as the product of population and the MOVES-based annual mileage rates. For Source Type 21 for example:

$$Default\ VMT_{21} = Popn_{21} \times Mileage_{21} = 26{,}847 \times 10{,}743 / 365\ days/year = 790{,}206\ miles/day$$

The Default VMT was then aggregated into the Passenger vs. Commercial groups and compared to the VMT based on the local TransCAD travel model. As noted at the bottom of Table 7-6-52, 2014 travel model VMT was interpolated from TransCAD outputs for 2013 and 2019. This value, 1,724,636 miles/day for the nonattainment area, was then apportioned into the Passenger vs. Commercial groups using the 93% and 7% splits to yield the values of 1,603,911 and 120,725 VMT/day shown in the "Aggregated/TransCAD" column of Table 7-6-52. The ratio between the Default and TransCAD aggregated VMT in each group was then computed and used to allocate the total TransCAD-based VMT by individual Source Type shown in the rightmost column of Table 7-6-52. For Source Type 21 for example:

$$TransCAD\ VMT_{21} = Default\ VMT_{21} / Ratio_{Passenger} = 790{,}206 / 1.802 = 438{,}520\ miles/day$$

With this approach, the MOVES-based mileage rates are essentially used to scale VMT by Source Type within the larger Passenger and Commercial groups and yet preserve travel model-based total fleet VMT. VMT allocations by Source Type for other calendar years were similarly generated starting with TransCAD travel model VMT split into the Passenger and Commercial groups based on the 93%/7% splits from ADOT&PF.

Table 7-6-53 shows the resulting VMT allocations by Source Type for the key analysis years that preserve total fleet VMT produced by the TransCAD travel model outputs. The total daily fleet VMT at the bottom of Table 7-6-53 matches that for each calendar year presented earlier in Table 7-6-48.

Table 7-6-53
Fairbanks Nonattainment Area Allocated VMT by Calendar Year and Source Type

Source Type ID	Source Type Description	Nonattainment Area VMT (miles/day)		
		2013	2019	2024
11	Motorcycle	15,756	17,203	19,345
21	Passenger Car	431,912	471,565	530,294
31	Passenger Truck	1,132,071	1,236,005	1,389,940
32	Light Comm. Truck	34,643	37,824	42,535
41	Intercity Bus	7,408	8,088	9,095
42	Transit Bus	3,488	3,808	4,282
43	School Bus	1,524	1,664	1,872
51	Refuse Truck	1,011	1,104	1,242
52	Single SH Truck	11,232	12,263	13,790
53	Single LH Truck	624	681	766
54	Motor Home	2,331	2,545	2,862
61	Comb. SH Truck	11,999	13,100	14,732
62	Comb. LH Truck	44,646	48,745	54,815
Total Vehicle Fleet		**1,698,644**	**1,854,594**	**2,085,569**

As explained earlier, these VMT data were then mapped to the 5-category HPMS scheme for compatibility with SMOKE/MOVES VMT input requirements.

Scaling of Base Populations – Based on the allocated VMT for each calendar year, vehicle populations by Source Type were then scaled from the relationship between DMV populations and VMT in 2014 keeping annual mileage rates constant. (MOVES2014b default mileage rates from 2013-2032 were examined and found to exhibit very modest variation, so this approach was assumed to be reasonable.)

Beyond Network VMT - VMT on roadways outside the FMATS travel modeling network was calculated using the aforementioned spatial roadway VMT layer developed from merging the ADOT&PF Road Centerlines shapefile with 2013 AADT traffic volumes for those roads published by ADOT&PF's Northern Region office. Within ArcGIS, a masking operation was performed to discard the Road Centerlines layer segments corresponding to roadways already in and accounted from the FMATS travel model network. For 2013, total "outside FAST/FMATS network" VMT was 500,542 miles per annual average day, which was about 3.5 times lower than the total daily VMT within the FMATS network. VMT growth in future years and the distribution by HPMS vehicle type was assumed to be the same as for that within the FMATS network.

Other MOVES Inputs – The remaining MOVES modeling inputs representing the FNSB $PM_{2.5}$ nonattainment area included seasonal, daily and diurnal travel fractions; travel activity by speed range (or bin) and roadway type; freeway ramp fractions; ambient temperature profiles; I/M program inputs; and fuel specifications. Each of these inputs was supplied to MOVES to represent Fairbanks specific conditions through the model's County Data Manager Importer and are discussed separately below.

Monthly, Day-of-Week and Hourly VMT Fractions – In conjunction with VMT by HPMS Vehicle Type, MOVES also requires inputs of monthly, weekday/weekend, and hourly travel fractions. Based on data assembled by ADOT&PF from 2013 seasonal traffic counts, traffic within the FMATS modeling area exhibits a seasonal variation such that roughly 92% of annual average daily travel within the $PM_{2.5}$ nonattainment area occurs on average winter days (with 108% occurring on average summer days). These seasonal variations were incorporated into the MonthVMTFraction input table.

Day-of-week and hourly VMT fractions were similarly developed from the 2013 ADOT&PF data. The day-of-week fractions were then converted into Weekday vs. Weekend fractions as required for input to MOVES.

Travel by Speed Bin and Roadway Type (Average Speed & Road Type Distributions) – Link-level TransCAD model output files were processed to prepare these two sets of MOVES inputs for each analysis year.

The roadway type classification scheme employed in MOVES consists of the following five categories:

1. Off-Network;
2. Rural, Restricted Access;
3. Rural, Unrestricted Access;
4. Urban, Restricted Access; and
5. Urban, Unrestricted Access.

The "Off-Network" category is used by MOVES to represent engine-off evaporative or starting emissions that occur off of the travel network. For SIP and regional conformity analysis, EPA's MOVES guidance indicated that the user must supply Average Speed Distribution and Road Type Distribution inputs for the remaining on-network road types (2 through 5), but direct MOVES to calculate emissions over all five road types. In this manner, starting and evaporative emissions are properly calculated and output.

The first of the two sets of inputs, Average Speed Distributions, consists of time-based[56] (not distance-based) tabulations of the fractions of travel within each of MOVES' 16 speed bins (at 5 mph-wide intervals) by road type and hour of the day. These inputs were calculated from the TransCAD link outputs by time of day. The TransCAD outputs consisted of travel times, average speeds and vehicle volumes for each link in the expanded modeling network for each of three daily periods:

1) AM Peak (7-9 AM);
2) PM Peak (3-6 PM); and
3) Off-Peak (9 AM-3 PM, plus 6 PM-7 AM).

Spreadsheet calculations were performed on the TransCAD link outputs to calculate time-based travel (multiplying link travel time by vehicle volume to get vehicle hours traveled or VHT) across all links. The link VHT was then allocated by MOVES road type and average speed bin. (The link classification scheme employed in the TransCAD modeling could easily be translated to the MOVES Rural/Urban and Limited/Unlimited Access road types.) Normalized speed distributions (across all 16 bins) were then calculated for each road type and time of day period and formatted for input into MOVES.

Similar spreadsheet calculations were also performed to tabulate distance-based (i.e., VMT-based) Road Type Distribution inputs to MOVES.

Freeway Ramp Fractions (Ramp Fraction) – MOVES uses default values of 8% (or 0.08) to represent the fraction of time-based limited access roadway travel (Road Types 2 and 4) that occur on freeway ramps. Fairbanks-specific ramp fraction values were tabulated from the TransCAD link level outputs and were supplied to MOVES in the Ramp Fraction input section of the County Data Manager to override the nationwide-based defaults.

Ambient Temperature Profiles (Meteorology Data) – Episodic average temperature profiles were created per the guidance in the SMOKE-MOVES model documentation using the MET4MOVES. Some MET4MOVES code modifications were made to allow for sub-monthly temperature profiles to be generated. Code changes are detailed in the SMOKE modeling appendix. Different temperature profiles are required as inputs for a number of MOVES runs to create lookup tables for rate per distance, rate per vehicle and rate per profile activities. The modified MET4MOVES program was operated using a version of the run_met4moves.csh script included with the 2.7.1 version of SMOKE. The dates of the episode days, surrogates and ASSIGNS file were updated to reflect the SMOKE configuration for the baseline modeling episodes. Two script runs of the *run_met4moves.csh* file were performed to generate different average meteorology profiles for each episode. The MET4MOVES program requires the met field inputs already be processed through the Meteorology-Chemistry Input Processor (MCIP) software.

The domain-wide ground level average relative humidity (RH), minimum and maximum temperatures for each modeling episode are presented in Table 7-6-54. These outputs have been

[56] MOVES requires Average Speed Distribution inputs on a time-weighted basis and Road Type Distribution inputs on a distance-weighted basis.

rounded down to the nearest 5-degree increment in the case of the minimum temperature and up to the nearest 5-degree increment in the maximum temperature case.

Table 7-6-54
Fairbanks Model Domain Episodic Meteorology Conditions

Episode	Relative Humidity	Min. Temperature (F)	Max.Temperature (F)
Episode 1 (Jan - Feb)	72.3%	-50.0	30.0
Episode 2 (Nov)	82.3%	-20.0	35.0

Daily temperature profiles for each of the episodes are presented in Table 7-6-55. These profiles have been scaled to reflect the maximum and minimum temperatures for those respective episodes. These profiles form the basis of the RPV and RPP MOVES simulation meteorology inputs that are generated by the RunSpec generator script.

Table 7-6-55
Fairbanks Model Domain Episodic Average Temperature Profiles

Hour	Episode 1 Temperature (F)	Episode 2 Temperature (F)
1	-33.7	-17.8
2	-38.0	-20.0
3	-42.9	-18.5
4	-47.2	-13.1
5	-48.2	-16.2
6	-46.4	-17.1
7	-46.6	-15.6
8	-48.5	-19.8
9	-50.0	-18.8
10	-48.9	-18.2
11	-48.7	-9.0
12	-36.5	4.7
13	-10.6	14.7
14	15.7	26.6
15	30.0	35.0
16	29.1	32.3
17	12.3	19.7
18	-3.0	8.9
19	-11.6	0.8
20	-18.1	1.4
21	-22.1	-2.1
22	-26.2	-9.8
23	-31.4	-14.0
24	-29.2	-17.4

The RunSpec generator script has been rewritten to use the average RH, minimum temperature, maximum temperature and average profiles to create the RPD, RPV and RPP meteorology input fields.

I/M Program Data (I/M Programs) – Since the Fairbanks Inspection and Maintenance (I/M) program was terminated at the end of 2009, the "Use I/M Program" input element to MOVES was set from "Yes" to "No" to account for the elimination of the program.

Fuel Property Inputs – Fuel property inputs (e.g., fuel volatility, sulfur level, ethanol volume, aromatic, olefins and benzene content, etc.) were based on MOVES defaults for Fairbanks with one exception discussed below. In MOVES2014b, Fairbanks is grouped within Fuel Region 6, which includes Alaska and rural portions of California, Nevada, Arizona and Hawaii where Reformulated Gasoline (RFG) is not required. In consultation with EPA, the defaults were chosen over industry-based survey data[57] collected in Fairbanks which tend to be limited to a small number of fuel samples. The MOVES default fuel properties for this non-RFG region assume a 10% ethanol blend level in gasoline. Although this "E10" blend level is used for gasoline in the lower-48, there is no ethanol blending in Alaska. Thus, the MOVES2014b "Fuel Wizard" tool was used to zero the gasoline ethanol content and properly adjust the other fuel properties that would be affected by this change. The Fuel Wizard has been designed in MOVES2014b to be consistent with EPA refinery modeling based on the Tier 3 Motor Vehicle Emissions and Fuel Standards rulemaking.

Table 7-6-56 shows the MOVES2014b gasoline fuel properties used for Fairbanks for calendar year 2013 and years 2017 and later (2017+) before and after the Fuel Wizard-based ethanol adjustment to the defaults. (The "Null" values for T50 are as-extracted from the MOVES database, indicating this value is not defined in the default database.) Diesel fuel defaults for Fuel Region 6 were not changed.

Table 7-6-56
MOVES2014b Gasoline Fuel Properties Before and After Ethanol Adjustment

	MOVES2014b Defaults		Fuel-Wizard Adjusted	
Fuel Property	**2013**	**2017+**	**2013**	**2017+**
RVP (psi)	11.6	11.4	10.6	10.4
Sulfur Level (ppm)	30.0	10.0	30.0	10.0
Ethanol (% vol)	10	10	0	0
Aromatic Content (% vol)	22.1	21.4	25.7	25.0
Olefin Content (% vol)	7.1	6.7	9.1	8.7
Benzene Content (% vol)	0.7	0.7	0.7	0.7
e200 (% vol)	53.7	53.7	47.9	48.8
e300 (% vol)	87.4	87.4	86.7	86.8
T50 (deg F)	Null	Null	204.2	202.2
T90 (deg F)	194.2	192.2	312.7	312.0

Plug-In Adjustments to $PM_{2.5}$ Emissions – Finally, starting exhaust $PM_{2.5}$ emissions for light-duty gasoline vehicles were adjusted to account for the effects of wintertime vehicle plug-in block heater use in Fairbanks.

[57] Bi-annual fuel surveys across 30 U.S. cities conducted by the Alliance of Automobile Manufacturers 1999-2017.

Table 7-6-57 summarizes the reductions in starting exhaust $PM_{2.5}$ developed from measured data in the Fairbanks 2010-2011 Plug-In Testing program resulting from use of plug-ins while a vehicle is parked or "soaked." The column "Default Daily Soak Dist" lists the daily average soak time fractions extracted from MOVES2014b model for light-duty vehicles. The next column, "% $PM_{2.5}$ Redn" shows relative starting exhaust $PM_{2.5}$ emission reductions developed from the measurement data as a function of soak time. The plug-in reductions are expressed as percentages relative to the emissions of the vehicle if it had not been plugged in when parked. Only reductions for $PM_{2.5}$ are shown. (Although plug-in effects were also measured for gaseous pollutants, only directly emitted $PM_{2.5}$ reductions are being applied for the SIP inventory adjustments.)

Table 7-6-57
Local Measurement-Based Starting Exhaust $PM_{2.5}$ Emission Reductions from Plug-In Use

OpMode ID	Soak Time Intervals (min.)	Default Daily Soak Dist.	% $PM_{2.5}$ Redn	% Plug-In Use as a Function of Soak Time (minutes) and Daily Ambient Temperature (°F)					
				-50°F	-40°F	-30°F	-20°F	-10°F	0°F
101	Soak Time < 6	0.185	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
102	6 ≤ to < 30	0.205	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
103	30 ≤ to < 60	0.096	4.4%	25.9%	14.0%	2.4%	0.0%	0.0%	0.0%
104	60 ≤ to < 90	0.058	7.3%	44.4%	32.5%	20.8%	9.4%	0.0%	0.0%
105	90 ≤ to < 120	0.042	10.3%	56.6%	44.7%	33.1%	21.6%	10.4%	0.0%
106	120 ≤ to < 360	0.162	23.5%	86.8%	74.9%	63.2%	51.8%	40.6%	29.6%
107	360 ≤ to < 720	0.114	53.0%	100.0%	100.0%	93.1%	81.7%	70.5%	59.5%
108	720 ≤ Soak Time	0.139	70.8%	100.0%	100.0%	100.0%	100.0%	89.4%	78.4%
Daily Composite Plug-In Trip Fraction (%)				39.9%	35.9%	31.3%	27.4%	22.6%	18.5%
Daily Composite Plug-In $PM_{2.5}$ Reduction (%)				16.4%	15.9%	15.1%	14.1%	12.2%	10.4%

The six rightmost columns in Table 7-6-57 show plug-in usage fractions (percentage of trips) as a function of both soak time and ambient temperature (daily average temperature). The soak time intervals correspond to those defined in EPA's MOVES2014b model. The ambient temperature range is shown from -50°F to 0°F in 10-degree increments. At the bottom of Table 7-6-57, daily composite plug-in usage fractions and $PM_{2.5}$ starting exhaust reductions are shown.

The average ambient temperature over the modeling episode days was -11.8°F, which yields a plug-in $PM_{2.5}$ reduction (applied to starting exhaust light-duty gasoline vehicles) of 12.5% based on the analysis spreadsheet developed to compute plug-in benefits as a function of soak time and ambient temperature.

These adjustments were applied using an EPA- accepted approach that consisted of modifying the MOVES soak time distribution inputs for light-duty vehicles contained in *OpModeDistribution* table in the model's default database. Attachment D describes this process in further detail.

MOVES Data Importing and Execution and SMOKE Processing

Once all of the inputs were assembled, MOVES command input or "RunSpec" files and input importer scripts and processing workflows were set up to generate model runs and feed outputs to SMOKE as summarized below.

RunSpec and Importer Generation (SMOKE-MOVES) – Version 0.20 of the RunSpec generator script from the SMOKE-MOVES tool was used to create the MOVES RunSpec and import files for the RPD, RPV and RPP simulations in the baseline. Modifications to the script were made to allow for the use of Excel files and spreadsheet tabs in the importing process with the exception of the meteorology inputs. AVFT data was added through a separate text file via a change to the RunSpec configuration script. The RunSpec run control input for POLLUTANTS was set to both OZONE and PM in order to output pollutants for direct $PM_{2.5}$, precursor pollutants and CO.

The met profile inputs for the RPD, RPV and RPP rates are created in the RunSpec generator script based on the outputs from the modified MET4MOVES program. A new meteorology type was added to signal the creation of RPD and RPV temperature profiles from the temperature maximums, minimums and profiles extracted from the episode-processed meteorology files. Table 7-6-58 lays out the number of temperature profiles created for each of the model episodes and rates calculations.

Table 7-6-58
Fairbanks MOVES Rates Temperature Profile Count

Rates Scenario	Episode 1	Episode 2
RPD	1	1
RPV	8	11
RPP	66	36
Total Profiles	**75**	**48**

The RPD, RPV and RPP inventory importer scripts were run to import each of these different profiles with the 2008 baseline vehicle activity, population and fleet characteristics.

MOVES Simulations – Following the importing of the RPD, RPV and RPP input data the RunSpec scripts were configured to execute a series of 75 MOVES runs for episode 1 and 48 MOVES runs for Episode 2. These simulations were performed with MOVES version 20100826 installed on a custom-built Linux computer (Intel i7 950 4 core/8 thread, 8 GB system memory, 1 TB hard disk drive) running Ubuntu 10.04 OS.

NON-ROAD MOBILE SOURCES

Non-road sources encompass all mobile sources that are not on-road vehicles. They include recreational and commercial off-road vehicles and equipment as well as aircraft, locomotives, recreational pleasure craft (boats) and marine vessels.

This section of the appendix discusses the data and methodologies used to estimate emissions for the non-road source sector. (No information on either commercial marine or recreational vessel emissions is presented, as they do not operate in the arctic conditions experienced in the Fairbanks modeling domain during the winter.) The following sub-sections are organized based on the models or tools used to develop emission estimates for specific sources within the inventory sector.

NON-ROAD VEHICLES AND EQUIPMENT

EPA's MOVES2014b model includes the capability to model both on-road and non-road vehicle emissions. MOVES2014b was used to model non-road vehicle/equipment emissions for the following categories:

- Recreational vehicles (e.g., all-terrain vehicles, off-road motorcycles, snowmobiles);
- Logging equipment (e.g., chain saws);
- Agricultural equipment (e.g., tractors);
- Commercial equipment (e.g., welders and compressors);
- Construction and mining equipment (e.g., graders and backhoes);
- Industrial equipment (e.g., forklifts and sweepers);
- Residential and commercial lawn and garden equipment (e.g., leaf and snow blowers);
- Locomotive support/railway maintenance equipment (but not locomotives); and
- Aircraft ground support equipment[58] (but not aircraft).

It is important to note that none of these non-road vehicle and equipment types listed above were federally regulated until the mid-1990s. (As parenthetically noted for the last two types of equipment in the list above, MOVES/NONROAD was used to estimate emissions of support equipment for the rail and air sectors, but emissions from locomotives and aircraft were calculated separately using other models/methods as described in the sub-sections that follow.)

Default equipment populations and activity levels in the MOVES/NONROAD are based on national averages, then scaled down to represent smaller geographic areas on the basis of human population and proximity to recreational, industrial, and commercial facilities. EPA recognizes the limitations inherent in this "top-down" approach, and realizes that locally generated inputs to the model will increase the accuracy of the resulting output. Therefore, in some cases locally derived inputs which more accurately reflect the equipment population, growth rates, and wintertime activity levels in the Fairbanks area were substituted for EPA's default input values.

[58] Although NONROAD can be configured to also estimate emissions from airport ground support equipment (GSE), GSE emissions were estimated using the AEDT model as described under the "Aircraft" sub-section.

Calculation Methodology – MOVES/NONROAD model calculates emissions from each source category according to the following methodology:

$$\boldsymbol{Emissions = EF \times DF \times P \times LF \times Hours \times Units}$$

Where:

EF = emission factor in g/hp-hr;
DF = deterioration factor (dimensionless);
P = engine power in horsepower;
LF = load factor (dimensionless);
Hours = annual operating hours for each engine (unit); and
Units = total population of engines operating in a given year.

The above calculation yields emissions in grams per year, which MOVES/NONROAD then converts to tons per year. For seasonal or daily emissions estimates, the calculated annual emissions for each source are then distributed over a given number of calendar months. For example, NONROAD assumes by default that all snowmobile activity takes place during the winter months, which are defined by the model to be December, January, and February. For this analysis, several modifications were made to equipment population growth rates, seasonal activity distribution, and annual operating hours and equipment populations. Summarized below are the specific modifications made to EPA's default MOVES/NONROAD inputs.

Equipment Growth Rates – MOVES/NONROAD model predicts future equipment populations using national growth rates that have been determined using nationwide historical engine population estimates (i.e., for 1989 through 1996) from the Power Systems Research (PSR) PartsLink database. Given the relatively flat, and in some cases negative population growth predicted for Alaska's interior region, it is believed that the default NONROAD growth rates do not provide an accurate representation of equipment population growth trends in the 2013 through 2019 timeframe. For example, the default NONROAD growth factor results in a 2.8% annual increase in the snowmobile population in Fairbanks between 2010 and 2020—a figure that is twice as high as the annual human population growth rate predicted by the Alaska Department of Labor & Workforce Development for this area over the same period of time.

As shown in Table 7-6-59, a relatively flat annual growth rate of 1.4% for the total population of Alaska's interior region is predicted through 2020, which includes a negative growth rate in some of the smaller areas surrounding the Fairbanks nonattainment area. Therefore, to better reflect 2019 and later year equipment populations in the Fairbanks nonattainment area, the human population projections for the individual interior regions shown in Table 1 were used as surrogate equipment population growth rates for all non-road equipment modeling performed for this inventory.

Table 7-6-59 Alaska Interior Region Human Population by Area (2010 to 2020)				
Interior Region	July 1, 2010	July 1, 2015	July 1, 2020	Annual Growth Rate (2010-2020)
Denali Borough	1,826	1,796	1,752	-0.41%
Fairbanks North Star Borough	98,000	105,928	113,275	1.56%
Southeast Fairbanks Census Area	7,055	7,635	8,141	1.54%
Yukon-Koyukuk Census Area	5,615	5,288	5,001	-1.09%
Interior Region Total	112,496	120,647	128,169	1.39%

Modifications to Snowmobile Inputs – Because the overwhelming majority of the wintertime non-road emissions in the Fairbanks area are associated with snowmobile activity, it was important to utilize all available FNSB-specific input NONROAD modeling parameters for this equipment category. This analysis was performed using the following modifications to NONROAD's snowmobile inputs:

Snowmobile Populations – The current version of EPA's NONROAD model predicts a calendar year (CY) 2010 population of 12,193 snowmobiles in the Borough, which is very close to the 12,420 snowmobiles registered in FNSB for that same year.[59] However, snowmobile populations in the areas surrounding FNSB did not approximate DMV registration data as closely as in the Borough, as shown in Table 7-6-60 below. Consequently, the CY2014 DMV registration totals shown below were substituted for the default NONROAD snowmobile population.

Table 7-6-60 Alaska Interior Region Snowmobile Population by Area for CY 2014		
Interior Region	NONROAD Default Population	Alaska DMV Registrations
Denali Borough	168	410
Fairbanks North Star Borough	12,193	12,420
Southeast Fairbanks Census Area	518	1,115
Yukon-Koyukuk Census Area	567	808

[59] Data obtained from the Alaska Division of Motor Vehicles (DMV).

Snowmobile Activity – Snowmobile use inside the urban nonattainment area is largely banned because of public safety ordinances that prohibit their use on public trails and on public roadways. To address the fact that most snowmobile activity takes place outside the nonattainment area, the NONROAD default annual activity rate of 57 hours/year/unit was applied to only half of the FNSB snowmobile population. In addition, to account for loading, unloading, and maintenance activities that presumably take place inside the nonattainment area, an additional 1 hour/year/unit of snowmobile activity was assumed for the entire snowmobile population. All other snowmobile activity is assumed to occur in areas outside the Borough and/or the nonattainment area.

Snow Blowers – For purposes of this analysis, emissions from this equipment source were assumed to be zero. $PM_{2.5}$ violations (and consequently, $PM_{2.5}$ design days) always occur when there is a strong inversion layer over the region, rather than during periods of snow activity when snow blowers are typically used. Therefore, since snow blowers are not typically in use on the $PM_{2.5}$ design day, we have discounted their emissions from this analysis.

Nonexistent Wintertime Activity – Due to the severe outdoor weather conditions present in Fairbanks during the winter months, FNSB staff has determined that there is zero wintertime activity for a number of different equipment categories. Therefore, all activity and corresponding emissions for the following non-road equipment categories have been removed from this analysis:

- Lawn and Garden;
- Agricultural Equipment;
- Logging Equipment;
- Pleasure Craft (i.e., personal watercraft, inboard and sterndrive motor boats);
- Selected Recreational Equipment (i.e., golf carts, ATVs, off-road motorcycles); and
- Commercial Equipment (i.e., generator sets, pressure washers, welders, pumps, A/C refrigeration units).

Selected equipment from the following categories was retained, as follows:

- Construction and Mining – Graders, off-highway trucks, rubber tire dozers, and rubber tire loaders were retained to represent snow removal equipment activity.

- Industrial Equipment – Equipment that primarily operates indoors (such as forklifts, aerial lifts, and terminal tractors) was retained.

Equipment Not Included in NONROAD Model – Discussions with FNSB staff[60] indicate that indirect-fired temporary Diesel and propane heaters are commonly used in FNSB in connection with any indoor construction or repair work performed during the winter months. These heaters are in constant use (24 hours/day, 7 days/week) during the six-month FNSB winter period while

[60] Personal communication between Glenn Miller (FNSB) and Bob Dulla (Sierra Research), 3/4/2013.

regular indoor heating systems at construction sites are non-operational. Because these heaters are not included on the NONROAD model equipment list, we have calculated emissions from this source separately, as shown below in Table 7-6-61 and Table 7-6-62.

FNSB staff has estimated that a total of 30 heaters (10 small propane and 20 large Diesel units) operate continually at various construction sites during the winter months. Unit heating capacity was obtained from vendor specifications.[61]

Table 7-6-61
Emissions from Indirect-Fired Temporary Heaters - Diesel

# units	Unit Heating Capacity (Btu/hr)	Fuel Heat Value (Btu/gallon)	Emission Factors (lb/1000 gallons) (AP-42, Table 1.3-1)				
			NO_x	CO	PM	TOC	SO_x
20	2,000,000	138,500	10	5	2	0.556	0.61
Tons/Year from All Units:			6.3	3.2	1.3	0.35	0.39

Table 7-6-62
Emissions from Indirect-Fired Temporary Heaters - Propane

# units	Unit Heating Capacity (Btu/hr)	Fuel Heat Value (Btu/ft^3)	Emission Factors (lb/10^6 ft^3) (AP-42, Table 4-1)				
			NOx	CO	PM	TOC	SO_x
10	450,000	2,500	100	21	4.5	5.8	0.426
Tons/Year from All Units:			0.39	0.08	0.02	0.02	0.002

These indirect-fired temporary heater emissions were added to the inventory and assumed to occur only during winter months. The Source Classification Codes (SCCs) assigned to these heaters were as follows:

- SCC 2270002000 – Mobile Sources, Off-highway Vehicle Diesel, Construction and Mining Equipment, Total; and
- SCC 2267002000 – Mobile Sources, LPG, Construction and Mining Equipment, All.

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[61] http://www.etopp.com/indirect-fired-temporary-heaters.html.

Fuel and Temperature Inputs – NONROAD modeling runs were executed for the four counties within the $PM_{2.5}$ modeling domain:

1. Fairbanks North Star Borough (FNSB);
2. Denali Borough;
3. Southeast Fairbanks Census Area; and
4. Yukon-Koyukuk Census Area.

For each of these counties, calendar year 2013 and later wintertime fuel parameters for both gasoline and diesel fueled equipment were set to correspond to the levels EPA has assumed in the MOVES2014b model for FNSB. This reflects the fact that mobile source fuel in interior Alaska is refined locally. So the same gasoline and diesel refinery blends are used in both on-road and non-road sources in Fairbanks. Table 7-6-63 below shows both the NONROAD default values and the FNSB fuel parameters and temperature inputs used in this MOVES/NONROAD modeling effort.

Table 7-6-63
NONROAD Modeling Wintertime Fuel and Temperature Inputs

Fuel Parameter	MOVES/NONROAD Default	CY 2013 & Later
Gasoline RVP	8.0	14.7
Gas Oxygen Weight (%)	2.44	0.0
Gas Sulfur (%)	0.0339	0.0028
Diesel Sulfur (%)	0.0351	0.0011
Marine Diesel Sulfur (%)	0.0435	0.0011
CNG/LPG Sulfur (%)	0.003	0.003
Stage II Control (%)	0	0
EtOH Blend Market (%)	75.1	0
EtOH Volume (%)	9.3	0
Minimum Temperature (°F)	-	-15.7
Maximum Temperature (°F)	-	4.0
Average Temperature (°F)	-	-6.0

Annual and Seasonal Model Runs – As explained earlier, the NONROAD model was executed to generate average winter season emissions, overriding seasonal variation defaults in the model where local data were available. The winter season emissions were tabulated into winter daily averages over model runs for the six winter months (October through March). In addition, annual (12-month) model runs were also executed because of the way in which emissions must be formatted for input to the SMOKE emissions processing model to support the attainment modeling. For non-road sources, SMOKE requires annual average emission inputs (in tons/year) coupled with monthly temporal allocation factors. These temporal allocations were developed from the winter season average and annual emission estimates. Although non-road sources are not the dominant sector for direct $PM_{2.5}$ and precursor emissions in the modeling domain during the winter non-attainment season, several of the sources (e.g., snowmobiles) exhibit strong seasonal activity variations which needed to be accounted for in the inventory workflow feeding the attainment modeling.

Summary of Emissions – Calendar year 2013 non-road emissions tabulated by equipment category totaled across the four-county modeling domain are presented below in Table 7-6-64. (These tabulations also include emissions from temporary heaters which were added to the non-road model outputs as noted earlier.)

Table 7-6-64
Calendar Year 2013 MOVES/NONROAD Emissions by Equipment Category

Equipment Category	Grid 3 Domain MOVES/NONROAD Emissions (tons/year)						
	VOC	CO	NO_x	SO_x	PM10-PRI	PM25-PRI	NH3
Recreational Equipment	1,776.4	4,006.6	68.9	0.0	50.6	46.6	0.6
Construction & Mining Equipment	31.3	236.3	220.1	0.4	20.0	19.4	0.3
Industrial Equipment	2.4	47.0	19.1	0.0	1.2	1.1	0.0
Lawn & Garden Equipment (Res)	52.3	782.6	12.0	0.0	2.0	1.8	0.0
Lawn & Garden Equipment (Com)	4.8	66.2	1.4	0.0	0.4	0.4	0.0
Agricultural Equipment	2.2	18.0	21.0	0.0	1.7	1.7	0.0
Commercial Equipment	19.1	436.7	22.7	0.0	1.7	1.6	0.0
Logging Equipment	3.0	23.8	3.5	0.0	0.6	0.5	0.0
Pleasure Craft	195.5	733.3	69.5	0.0	3.7	3.4	0.1
Railroad Equipment	0.2	1.7	0.9	0.0	0.1	0.1	0.0
TOTALS	**2,087.2**	**6,352.2**	**439.0**	**0.4**	**81.9**	**76.5**	**1.1**

Spatial Allocation – In the absence of well-developed, source-specific surrogates for Alaska[62], MOVES/Non-road outputs were spatially allocated to individual grid cells in the modeling domain based on apportionment factors developed from block-level occupied household counts obtained from the 2010 U.S. Census. It was assumed that relative density of occupied households was a reasonable surrogate for allocating all SCC-specific categories from the MOVES/Non-road modeling runs with the exception of snowmobiles, which used a modified version of the Occupied Household surrogate based on allocations of snowmobile activity inside and outside the $PM_{2.5}$ non-attainment area that were discussed earlier in this sub-section.

[62] EPA has developed a detailed set of SMOKE-ready surrogate files for use in spatial allocation down to 4 km grid cell sizes as described here: http://www.epa.gov/ttn/chief/emch/spatial/index.html. However, although the domain over which these surrogates were developed convers much of North American, is does not extend to Alaska.

Locomotives

Emissions for two types of locomotive activity were included in the emissions inventory:

1) *Line-Haul* – locomotive emissions along rail lines within the modeling domain (from Healy to Fairbanks and Fairbanks to Eielson Air Force Base); and

2) *Yard Switching* – locomotive emissions from train switching activities within the Fairbanks and Eielson rail yards.

Information on wintertime train activity (circa 2013) was obtained from the Alaska Railroad Corporation[63] (ARRC), the sole rail utility operating within the modeling domain, providing both passenger and freight service. These activity data were combined with locomotive emission factors published by EPA[64] to estimate rail emissions within the emissions inventory.

Table 7-6-65 lists the train activity data by line segment and switching yard supplied by ARRC. Conversations with ARRC indicated that these November 2013 estimates were reasonably representative of the broader six-month winter season.

Table 7-6-65
Winter 2013 Train Activity by Line Segment and Yard

Line Segment or Switching Yard	November Avg. (# of trains/day) [1]	Hours of Operation	Miles (per train)	Locomotives (per train)[2]	Fuel Cons. (gal/train)[3]
Healy to Fairbanks	4.29	0001 - 1800	108	4	1210
Fairbanks to North Pole	1.7	2100 - 0800	17	2	95
North Pole to Eielson	1	0800 - 1600	12	1.5	50
Eielson to Ft. Greely	Zero	n/a	80	0	Zero
Fairbanks Yard	1	24 Hours	10	1.5	42
Eielson Yard[4]	1	8 Hours	5	1	14

Notes:
[1] The Healy to Fairbanks segment is based on average number of trains run in a week divided by seven days. The North Pole to Eielson value is an average number. ARRC does not go to Eielson from Fairbanks every day.
[2] Locomotive numbers from Fairbanks Operations Chief
[3] Fuel consumption from Mechanical Manager (~2.8 gallons/mi at average throttle speed)
[4] Eielson AFB has their own yard locomotives

Source: Alaska Railroad Corporation.

63 Email from Matthew Kelzenberg, Alaska Railroad Corporation to Alex Edwards, Alaska Department of Environmental Conservation, July 19, 2016.
64 "Emission Factors for Locomotives," U.S. Environmental Protection Agency, Office of Transportation and Air Quality, EPA-420-F-09-025, April 2009.

ARRC staff also indicated that train activity in this part of the state has been fairly flat from year to year. Thus, these 2013 estimates were assumed to be reasonably representative of future years. Given the modest rate of future economic growth forecasted for the Alaskan interior, the train activity shown in Table 7-6-65 was assumed constant in future year inventories through 2019.

These train activity data were combined with EPA-published locomotive emission factors which are presented in Table 7-6-66. In the absence of detailed locomotive age data from ARRC, the calendar year specific emission factors shown in Table 7-6-66 were based on Tables 5 through 7 of the cited EPA locomotives publication.

Table 7-6-66
EPA Emission Factors (g/gal) for Locomotives by Calendar Year and Activity Type

Calendar Year	Activity Type	HC	CO	NO_x	PM_{10}	$PM_{2.5}$	SO_2
2013	Large Line-Haul	6.5	26.6	139.0	3.8	3.7	0.09
2013	Large Switch	13.3	38.1	225.0	5.0	4.9	0.09
2019	Large Line-Haul	3.9	26.6	103.0	2.5	2.4	0.1
2019	Large Switch	11.4	38.1	200.0	4.4	4.3	0.1

Source: U.S. Environmental Protection Agency, EPA-420-F-09-025.

Emission factors for CO are constant across calendar year since the CO standard is the same across all locomotive Tier categories. Per EPA guidance, $PM_{2.5}$ emission factors were scaled from those for PM_{10} using a 97% scaling factor. SO_2 emission factors were also developed based on EPA guidance using estimates of diesel fuel density (3200 g/gal), sulfur to SO_2 conversion rate (97.5%) and fuel sulfur (15 ppm in 2012 and later from Alaska Ultra Low Sulfur Diesel[65] phase in).

Table 7-6-67 shows the 2013 locomotive emissions calculated by combining activity and emission factor data in the preceding two tables, multiplying fuel consumption by the gram per gallon emission factors.

[65] https://dec.alaska.gov/air/anpms/ulsd/ulsdhome.htm

Table 7-6-67
Calendar Year 2013 Locomotive Emissions by Line Segment and Yard

Line Segment or Switching Yard	HC	CO	NO_x	PM_{10}	$PM_{2.5}$	SO_2
Healy to Fairbanks (lb/day)	74.39	304.41	1590.72	43.49	42.18	1.03
Fairbanks to North Pole (lb/day)	2.31	9.47	49.49	1.35	1.31	0.03
North Pole to Eielson (lb/day)	0.72	2.93	15.32	0.42	0.41	0.01
Eielson to Ft. Greely (lb/day)	0	0	0	0	0	0
Fairbanks Yard (lb/day)	1.23	3.53	20.83	0.46	0.45	0.01
Eielson Yard (lb/day)	0.41	1.18	6.94	0.15	0.15	0.00
Total Locomotive Emissions (lb/day)	79.06	321.52	1683.31	45.88	44.50	1.08
Total Locomotive Emissions (tons/year)	**14**	**59**	**307**	**8**	**8**	**0**

Spatial Allocation – Line-haul locomotive emissions over each of the rail segments listed in the preceding tables were spatially allocated to individual grid cells in the modeling domain using GIS software and a statewide rail line shapefile developed by the U.S. Department of Transportation. The allocations assumed a constant line-haul speed and thus were proportional to the lineal track length within each grid cell.

Yard-switching emissions were allocated to specific grid cells that encompassed the Fairbanks and Eielson rail yards using estimated apportionment factors that corresponded to the amounts of switching track lines within each cell.

AIRCRAFT

Emissions were estimated from aircraft operations at three regional airfields within the modeling domain: 1) Fairbanks International Airport (FAI); 2) Fort Wainwright Army Post[66] (FBK); and 3) Eielson Air Force Base (EIL). The aircraft emissions were developed using the Federal Aviation Administration's (FAA) AEDT2c aircraft/airfield emissions model. AEDT considers the physical characteristics of each airport along with detailed meteorological and operations information in order to estimate the overall emissions of aircraft, ground support equipment (GSE) and auxiliary power units (APUs) at each airport. At the time the analysis was performed, AEDT2c was the latest available version.

AEDT Methodology Summary - The AEDT model requires as input detailed information on landings and take-offs (LTO) for each aircraft type in order to assign GSE and estimate the associated emissions. Each LTO is assumed to comprise six distinct aircraft related emissions modes: startup, taxi out, take off, climb out, approach, and taxi in. The AEDT modeled defaults for time in mode and angle of climb out and approach were used for purposes of this analysis. In order to properly allocate aircraft emissions to each vertical layer of analysis (elevation above ground level), aircraft emissions were estimated for each mode and ascribed to a specific vertical

[66] Formerly Ladd Air Force Base.

layer. The vertical grid structure established for the Fairbanks $PM_{2.5}$ attainment modeling consists of 38 vertical layers ranging between ground level and 100,000 feet as shown in Table 7-6-68. The current version of AEDT allows the user to vary the mixing height over a range from 1,000 feet to a maximum of 10,000 feet. Thus, the tan-shaded layers (1 through 21) in Table 7-6-68 represent those for which AEDT emissions were assigned or distributed as described below.

Table 7-6-68
Vertical Layer Boundaries Included in the Emissions Analysis

Layer	Meters	Feet	Layer	Meters	Feet
1	0	0	20	2,408.84	7,903.01
2	4.00	13.13	21	2,922.27	9,587.47
3	8.00	26.26	22	3,470.92	11,387.50
4	12.81	42.03	23	4,059.98	13,320.13
5	23.63	77.54	24	4,695.90	15,406.45
6	46.94	153.99	25	5,386.76	17,673.05
7	67.89	222.73	26	6,142.97	20,154.05
8	112.79	370.05	27	6,978.19	22,894.28
9	177.96	583.87	28	7,910.89	25,954.32
10	276.73	907.91	29	8,966.86	29,418.78
11	410.35	1,346.28	30	10,126.79	33,224.30
12	546.23	1,792.09	31	11,416.93	37,457.05
13	684.46	2,245.61	32	12,875.50	42,242.38
14	825.13	2,707.10	33	14,512.04	47,611.59
15	968.31	3,176.85	34	16,445.80	53,955.93
16	1,150.96	3,776.12	35	18,747.26	61,506.62
17	1,375.80	4,513.78	36	21,744.80	71,341.08
18	1,646.36	5,401.43	37	25,751.01	84,484.76
19	1,987.69	6,521.28	38	32,139.07	105,442.93

Emissions associated with aircraft start up, taxi in or out, and take off, were assigned to Layer 2 (approximately 13 feet above ground level) to reflect average engine heights above ground. GSE and APU emissions were assigned to Layer 1. Climb out and approach emissions were ascribed proportionately between layers 2 and 11 (from 13 to approximately 1,300 feet) based upon the relative size of the distance between layer boundaries. Separate AEDT runs were made for each of the remaining 10 layers (Layers 12-21) with boundaries between 1,000 and 10,000 feet.

All AEDT runs assumed the minimum temperature allowable in default mode of -9.08°C (15.7°F). The following sub-sections separately describe the data sources, assumptions and methods used to generate AEDT-based aircraft emission estimates for each airfield.

Fairbanks International Airport - Fairbanks International Airport is a state-owned public-use airport located three miles (5 km) southwest of the central business district of Fairbanks in the

Fairbanks North Star Borough of Alaska. Given the fact that FAI is positioned only 9.5 hours from 90% of the northern industrialized hemisphere and considering that the airport is open 24 hours a day (including holidays), FAI is convenient for servicing cargo airlines as a refueling stop for aircraft on trans-polar routes. FAI is also served by a number of passenger airlines.

Annual LTOs for FAI in 2013, 58,621, were obtained from the Alaska International Airport System (AIAS)[67]. However, these AIAS data did not include the distribution of LTOs by aircraft type. The LTO distribution by aircraft types was derived from the FAI Statistics System.[68] A report generated for January of 2013 included the activity of 45 air carriers utilizing 39 different types of aircraft. 92% of the reported LTOs were attributable to aircraft types that were included in the AEDT model. The remaining LTOs were either ascribed to similar aircraft with respect to manufacturer, size and purpose, or proportionately distributed among those aircraft types present in the model. Table 7-6-69 presents the distribution of 2013 LTOs by airframe for FAI used in the modeling.

Table 7-6-69
2013 LTOs by Aircraft Type for Fairbanks International Airport (FAI)

Airframe	LTOs
ATR 42-200, "-300", -400, and -500	15
ATR 72-"200", ATR 72-500	259
Airbus A319-100 Series	74
Raytheon Beech 1900-C, Raytheon Beech 1900-D	2297
Raytheon Super King Air 200	1
Raytheon Beech Bonanza 36	144
Raytheon Beech 18	287
Boeing 727-200 Series	1
Boeing 737-100 Series, Boeing 737-200 Series	3
Boeing 737-400 Series	3141
Boeing 737-700 Series	524
Boeing 737-800 Series	708
Boeing 737-900 Series	293
Boeing 747-400 Series	0
Boeing 757-200 Series	207
Boeing 767-300 Series, Boeing 767-300 ER	0
CASA 212-200 Series, "CASA 212-300 Series", CASA 212-400 Series	2
Cessna 208 Caravan	4806
Cessna 206, Cessna 210 Centurion	395
Boeing C-118	54
DeHavilland DHC-8-100	2152
Embraer EMB120 Brasilia	66
Helio U-10 Super Courier	115
Lockheed C-130 Hercules	61

[67] Alaska International Airport System – Statistics, Alaska Department of Transportation and Public Facilities, http://dot.alaska.gov/aias/stat2557scascca.shtml.
[68] http://dot.alaska.gov/faiiap/index.shtml.

Table 7-6-69 2013 LTOs by Aircraft Type for Fairbanks International Airport (FAI)	
Airframe	**LTOs**
Boeing DC-6	175
Boeing DC-9-30 Series	36
Boeing MD-11	2
Pilatus PC-12	186
Piper PA-31 Navajo	6266
Piper PA-32 Cherokee Six	282
HS125-8	1
Saab 340-B	1
Shorts 330	148
Boeing C-118	1404
Boeing DC-9-10 Series	117
Raytheon Beech 1900-C	273
Cessna 206	1170
Cessna 208 Caravan	546
Cessna 210 Centurion	117
Helio U-10 Super Courier	351
Piper PA-31 Navajo	936
Raytheon Beech 18	195
Piper PA-32 Cherokee Six	390
Raytheon Beech Bonanza 36	117
Cessna 150 Series	2612
Cessna 172 Skyhawk	8539
Cessna 182	6238
Cessna 310	117
Cessna 337 Skymaster	117
Piper PA-23 Apache/Aztec	10839
Piper PA-24 Comanche	39
Piper PA-28 Cherokee Series	312
Piper PA-30 Twin Comanche	195
Piper PA-34 Seneca	39
Piper PA46-TP Meridian	78
Raytheon Beech 60 Duke	39
Lockheed C-130 Hercules	934
Boeing C-17A	47
Boeing 707-300 Series	16
Lockheed Martin F-16 Fighting Falcon	24
Boeing F/A-18 Hornet	8
Boeing KC-135 Stratotanker	55
Lockheed P-3 Orion	47
Lockheed S-3 Viking	8
TOTAL	**58,621**

In default mode, AEDT automatically assigns GSE and auxiliary power units (APU) to each LTO based upon airframe type. GSE include air conditioning units, air starts, aircraft tractors, baggage tractors, belt loaders, bobtails, cabin service trucks, cargo loaders, carts, catering trucks, deicers, fork lifts, fuel trucks, generators, ground power units, hydrant carts, lavatory trucks, lifts, passenger stands, service trucks, sweepers, water service trucks, and any other vehicles or equipment that tend to the aircraft while at the gate. Although APUs are most often on-board generators that provide electrical power to the aircraft while its engines are shut down, many aircraft utilize external generators. For purposes of this analysis, the AEDT defaults for GSE and APU age distribution, motive power and operating time per LTO were used. All GSE and APUs emissions were assigned to ground level as noted earlier.

The AEDT estimated 2013 emission inventory for FAI is presented in Table 7-6-70 below.

Table 7-6-70
2013 FAI Emissions Inventory by Source Category (Metric Tons per Day)

Source	CO	THC	TOG	VOC	NOx	SOx	PM2.5	PM10
Aircraft	5.358	0.233	0.234	0.204	0.256	4.780	0.114	0.114
APU	0.009	0.001	0.001	0.001	0.004	0.001	0.001	0.001
GSE	0.127	0.000	0.005	0.005	0.020	0.000	0.001	0.001
Totals	**5.493**	**0.233**	**0.239**	**0.210**	**0.280**	**4.781**	**0.115**	**0.116**

Fort Wainwright/LADD Army Airfield **-** Fort Wainwright (FBK) is located adjacent to Fairbanks in the interior of Alaska in the Fairbanks North Star Borough about 365 miles north of Anchorage. Information regarding 2008 LTOs was obtained from FBK in the form of monthly average flights by group. (Annual LTOs were developed by multiplying the monthly averages by a factor of 12.)

Summaries of the type of aircraft in each of these groups are provided below:

- *Military/Local* - denotes activity by Army-owned aircraft stationed at Ladd Army Airfield which are all rotary-wing aircraft; CH-47 Chinook, UH-60 Blackhawks and OH-58 Kiowa Warriors. The monthly LTOs for this group were distributed according to the proportion of available aircraft.

- *Military/Transient* - reflects activity by military aircraft that utilize the airspace/airfield that are not stationed at Ladd Army Airfield. The aircraft inventory includes the A-10 Warthog, C-12 Huron, C-130 Hercules, C-17 Globe Master, F-16 Falcon and KC-135 Strato-Tanker. The monthly LTO for this group were assumed to be evenly distributed across the available airframes.

- *General Aviation/Local* - represents activity by Bureau of Land Management (BLM) owned aircraft stationed at Ladd Army Airfield. The aircraft mix in this group includes the Bell 212, Euro-Copter AS-350, Canadair CL-215 Scooper, CASA C-212 Avio-car, Cessna 206 Sky Wagon, Dornier 228 and Short Sherpa. The LTOs for this group were evenly distributed across all airframes.

- *General Aviation/Transient* - denotes activity by non-military aircraft not stationed at Ladd Army Airfield. The mix of aircraft in this group includes the Beech King Air 350, Boeing 737, Citation Cessna 552, Gulfstream Jet V, and Bell 206 Jet-Ranger.

As was the case with FAI, some of the aircraft in use at FBK were not found in the AEDT database. In these instances, alternative airframes were selected according to similarity, or the LTOs associated with those missing aircraft were proportionately distributed among the remainder of the fleet. The LTOs by aircraft used in the Fort Wainwright modeling are presented in Table 7-6-71.

Table 7-6-71
2013 LTOs by Aircraft Type for Fort Wainwright/LADD Army Airfield (FBK)

Airframe	LTOs
Boeing CH-46 Sea Knight	2286
Sikorsky UH-60 Black Hawk	4382
Bell 206 JetRanger	5715
Cessna 182	0
Boeing C-17A	670
Boeing KC-135 Stratotanker	670
F16	670
Lockheed C-130 Hercules	167
Beechcraft C-12 Huron	167
Raytheon Beech 1900-C, Raytheon Beech 1900-D	167
Bell 214B-1	57
Eurocopter AS 355NP	57
Bombardier CL-415	57
CASA 212-200 , -300 and -400 Series	57
Cessna 206 and 210 Centurion	57
Dornier 228-200 Series	57
Shorts 330	57
Raytheon Super King Air 300	962
Boeing 737-400 Series	962
Cessna 552 T-47A	962
Gulfstream V-SP	962
Bell 206 JetRanger	962
Total	**40,206**

GSE and APU assignment and emissions were modeled using the AEDT defaults. The resulting inventory for FBK is summarized in Table 7-6-72 as follows.

Table 7-6-72
2013 FBK Emissions Inventory by Source Category (Metric Tons per Day)

Source	CO	THC	TOG	VOC	NOx	SOx	PM2.5	PM10
Aircraft	0.112	0.035	0.040	0.040	0.416	4.094	0.078	0.078
APU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GSE	0.042	0.000	0.002	0.002	0.011	0.000	0.001	0.001
Totals	**0.154**	**0.035**	**0.042**	**0.042**	**0.428**	**4.094**	**0.078**	**0.078**

Eielson Air Force Base - Eielson Air Force Base (EIL) is located approximately 26 miles (42 km) southeast of Fairbanks, Alaska in central Alaska's Fairbanks North Star Borough. North Pole is the nearest community to the base, located nine miles away. Established in 1943 as Mile 26 Satellite Field, Eielson is home to the 354th Fighter Wing which is part of the Eleventh Air Force (11 AF) of Pacific Air Forces (PACAF).

Eielson played an important role because of its strategic location. Aircraft movement information including take off, landings, touch-and-go, low approach, or aircraft passing though EIL airspace were provided by AFB personnel for February of 2008. It was estimated that some 1,100 aircraft movements per month (13,200 annual LTOs) were attributable to AFB operations with an approximately 60% / 40% military / civilian distribution.

The airframes assigned to EIL include the A-10 Thunderbolt II, C-123, F-4 Phantom II, F-16 Fighting Falcon, KC-135 Strato-Tanker, and the OV-10 Bronco. Lacking aircraft specific LTO information, it was assumed that each aircraft was equally likely to have contributed to overall emissions for the purposes of this analysis. Civilian traffic was attributed to the Piper PA-31 as the most frequent flyer found in the analysis of FAI. The assumed LTOs by aircraft type for EIL are included in Table 7-6-73.

Table 7-6-73 2013 LTOs by Aircraft Type for Eielson Air Force Base (EIL)	
Airframe	LTOs
Rockwell Commander 500	1
Raytheon Super King Air 200	53
Raytheon King Air 90	1
Boeing DC-10-10 Series	5
Boeing DC-6	2
Boeing DC-9-30 Series	2
Boeing 707-300 Series	6
Boeing 737-700 Series	8
Boeing 737-800 Series	4
Boeing 747-400 Series	6
Boeing 757-200 Series	1
Boeing 767-200 Series	3
Boeing 767-300 Series, Boeing 767-300 ER	2
Boeing 777-200 Series	2
Boeing F-15 Eagle	220
Boeing C-17A	90
Boeing KC-135 Stratotanker	459
Bombardier Challenger 600	1
Cessna 208 Caravan	1
Cessna 560 Citation V	6
Cessna 172 Skyhawk	6
Convair CV-580	2
Fairchild A-10A Thunderbolt II	148
Fokker F27 Friendship	2
Rockwell Commander 690	1
Gulfstream G500	2
Gulfstream G100	1
Lockheed C-130 Hercules	116
Lockheed C-5 Galaxy	7
Lockheed Martin F-16 Fighting Falcon	1465
Lockheed P-3 Orion	10
Shorts 330-100 Series	6
Boeing F/A-18 Hornet	145
Pilatus Turbo Trainer PC-9	1
Gulfstream G300	7
F-16	0
F-16	0
Total	**5,580**

As for the other airfields, GSE and APU assignment and emissions were also modeled using the AEDT defaults. The resulting inventory for Eielson is presented in Table 7-6-74.

Table 7-6-74
2013 EIL Emissions Inventory by Source Category (Metric Tons per Day)

Source	CO	THC	TOG	VOC	NOx	SOx	PM2.5	PM10
Aircraft	0.171	0.114	0.132	0.131	0.137	1.876	0.048	0.048
APU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GSE	0.003	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Totals	**0.174**	**0.114**	**0.132**	**0.131**	**0.140**	**1.876**	**0.048**	**0.048**

Combined Airfield Emissions Inventory - Taken in the aggregate, the three airfields included in the current analysis contribute only modestly to the overall emissions of the region. The vast majority of emissions associated with aircraft take off, landing and related ground support equipment occur near ground level which may result in increased exposure. Table 7-6-75 presents the combined emissions of the three analyzed airfields stratified by vertical layer.

The emission units in Table 7-6-75 differ from those in the earlier airfield-specific tables. AEDT output units of metric tons were used in those tables. They have been converted to tons in Table 7-6-75 for comparison with other sectors of the emissions inventory. AEDT does not estimate ammonia (NH_3) emissions for aircraft; thus, they were assumed to be zero.

Table 7-6-75
2013 Combined Emissions Inventory of Aircraft Operations (Tons/Day)

Layer	VOC	CO	NO_x	SO_x	NH_3	PM_{10}	$PM_{2.5}$
1	0.0085	0.2000	0.0425	0.0013	0	0.0026	**0.0027**
2	0.1472	0.6319	0.0873	1.2878	0	0.0470	**0.0470**
3	0.0015	0.0241	0.0042	0.0665	0	0.0023	**0.0023**
4	0.0009	0.0145	0.0025	0.0399	0	0.0014	**0.0014**
5	0.0021	0.0325	0.0057	0.0900	0	0.0030	**0.0030**
6	0.0045	0.0701	0.0122	0.1937	0	0.0066	**0.0066**
7	0.0040	0.0630	0.0110	0.1741	0	0.0059	**0.0059**
8	0.0086	0.1350	0.0235	0.3732	0	0.0126	**0.0126**
9	0.0125	0.1959	0.0342	0.5417	0	0.0183	**0.0183**
10	0.0189	0.2970	0.0518	0.8209	0	0.0278	**0.0278**
11	0.0256	0.4017	0.0700	1.1105	0	0.0376	**0.0376**
12	0.0134	0.3179	0.0419	0.5978	0	0.0230	**0.0230**
13	0.0125	0.3170	0.0349	0.4942	0	0.0190	**0.0190**
14	0.0132	0.3174	0.0353	0.4954	0	0.0190	**0.0190**
15	0.0143	0.3231	0.0429	0.5640	0	0.0082	**0.0082**
16	0.0186	0.4086	0.0528	0.6647	0	0.0075	**0.0075**
17	0.0686	0.8585	0.0592	0.8806	0	0.0050	**0.0050**
18	0.0192	0.5035	0.0571	0.7014	0	0.0040	**0.0040**
19	0.0147	0.4810	0.0725	0.8012	0	0.0046	**0.0046**
20	0.0057	0.3754	0.0867	0.8687	0	0.0050	**0.0050**
21	0.0072	0.4494	0.1060	1.0832	0	0.0062	**0.0062**
Totals	**0.4217**	**6.4173**	**0.9341**	**11.8509**	**0**	**0.2666**	**0.2667**

Spatial Allocation – In addition to the vertical layer allocations represented in Table 7-6-75, simple horizontal allocations of aircraft emissions were developed within a GIS system based on a map overlay of each of the three airfields and the modeling domains grid cells. Ground-based and elevated (climb out and approach) emissions were distributed into the 3-5 specific grid cells that encompassed the runway and taxiway/terminal apron areas of each airfield. (Refined allocations of climb out and approach emissions by horizontal and vertical cell reflecting typical in-air flight trajectories at each airfield were not developed given the magnitude of airfield emissions relative to the entire emissions inventory and significance of ground-based sources under the limited vertical mixing characterizing winter $PM_{2.5}$ episodes in Fairbanks.)

Inventory Summary Tabulations

Based on the source-specific data, assumptions and methodologies described in detail in the preceding section, episodic "Modeling" inventories (across the entire Grid 3 modeling domain and "Planning" inventories (for the $PM_{2.5}$ nonattainment area) are summarized by source sector in this section.

Table 7-6-76 through Table 7-6-79 present these summaries for the 2013 Baseline, 2019 Project Baseline, 2019 Control and 2029 Control/Attainment inventories, respectively. For directly-emitted $PM_{2.5}$, condensable and filterable components are separately reported (along with the combined total). The splits between condensable and filterable $PM_{2.5}$ emissions were developed from SCC-level emission factor data in EPA's latest WebFIRE emission factor database[69] (dated September 2016). As shown in Table 7-6-76 through Table 7-6-79, condensable and filterable components were only available for all SCCs within the Point Source sector. For the remaining sectors, there were few SCC source categories for which condensable/filterable emissions were listed in WebFIRE (Area Sources), or for which emissions are developed directly from EPA models (MOVES for Mobile Sources) that do not report the separate PM components. Thus in Table 7-6-76 through Table 7-6-79, sector-summed condensable and filterable $PM_{2.5}$ emissions are only given for the Point Source sector.

In addition to these summary tables, a spreadsheet is included in the electronic Appendix III.D.7.06. This spreadsheet reports emissions for all sources at the SCC-level and shows which SCCs outside the Point Source sector for which separate condensable and filterable $PM_{2.5}$ emissions could be determined.

Table 7-6-76
2013 Baseline Episode Average Daily Emissions (tons/day) by Source Sector

	Modeling Inventory Grid 3 Domain Emissions (tons/day)							*Planning Inventory Nonattainment Area Emissions (tons/day)*						
Source Sector	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NOx**	**SO_2**	**VOC**	**NH_3**	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NO**	**SO_2**	**VOC**	**NH_3**
Point Sources	1.24	0.94	0.29	10.57	7.40	0.23	0.051	1.23	0.94	0.29	10.45	7.22	0.23	0.051
Area, Space Heat	2.91	n/a	n/a	2.51	3.91	10.57	0.149	2.59	n/a	n/a	2.34	3.62	9.50	0.136
Area, Other	0.22	n/a	n/a	1.75	0.04	2.36	0.046	0.22	n/a	n/a	1.72	0.03	2.27	0.045
On-Road Mobile	0.32	n/a	n/a	4.11	0.02	4.90	0.067	0.27	n/a	n/a	3.36	0.02	4.07	0.054
Non-Road Mobile	0.47	n/a	n/a	2.11	11.67	9.31	0.002	0.15	n/a	n/a	0.86	6.10	0.41	0.000
TOTALS	**5.16**	**n/a**	**n/a**	**21.05**	**23.04**	**27.37**	**0.316**	**4.46**	**n/a**	**n/a**	**18.73**	**17.00**	**16.48**	**0.286**

n/a – Not available

[69] https://cfpub.epa.gov/webfire/index.cfm?action=fire.downloadInBulk

Table 7-6-77
2019 Projected Baseline Episode Average Daily Emissions (tons/day) by Source Sector

	Modeling Inventory Grid 3 Domain Emissions (tons/day)							*Planning Inventory Nonattainment Area Emissions (tons/day)*						
Source Sector	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NOx**	**SO_2**	**VOC**	**NH_3**	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NO**	**SO_2**	**VOC**	**NH_3**
Point Sources	0.84	0.71	0.13	10.76	7.32	0.09	0.020	0.83	0.71	0.13	10.63	7.13	0.09	0.020
Area, Space Heat	2.55	n/a	n/a	2.62	4.16	9.58	0.145	2.24	n/a	n/a	2.44	3.85	8.62	0.132
Area, Other	0.21	n/a	n/a	0.25	0.02	2.44	0.050	0.20	n/a	n/a	0.25	0.02	2.35	0.049
On-Road Mobile	0.18	n/a	n/a	2.32	0.01	3.61	0.048	0.14	n/a	n/a	1.83	0.01	2.86	0.038
Non-Road Mobile	0.52	n/a	n/a	2.51	15.29	6.58	0.002	0.24	n/a	n/a	1.21	10.62	0.41	0.000
TOTALS	**4.30**	**n/a**	**n/a**	**18.46**	**26.79**	**22.30**	**0.265**	**3.67**	**n/a**	**n/a**	**16.36**	**21.62**	**14.33**	**0.238**

n/a – Not available

Table 7-6-78
2019 Control Episode Average Daily Emissions (tons/day) by Source Sector

	Modeling Inventory Grid 3 Domain Emissions (tons/day)							*Planning Inventory Nonattainment Area Emissions (tons/day)*						
Source Sector	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NOx**	**SO_2**	**VOC**	**NH_3**	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NO**	**SO_2**	**VOC**	**NH_3**
Point Sources	0.84	0.71	0.13	10.76	7.32	0.09	0.020	0.83	0.71	0.13	10.63	7.13	0.09	0.020
Area, Space Heat	2.41	n/a	n/a	2.62	4.17	9.58	0.145	2.11	n/a	n/a	2.44	3.87	8.62	0.132
Area, Other	0.21	n/a	n/a	0.25	0.02	2.44	0.050	0.20	n/a	n/a	0.25	0.02	2.35	0.049
On-Road Mobile	0.18	n/a	n/a	2.32	0.01	3.61	0.048	0.14	n/a	n/a	1.83	0.01	2.86	0.038
Non-Road Mobile	0.52	n/a	n/a	2.51	15.29	6.58	0.002	0.24	n/a	n/a	1.21	10.62	0.41	0.000
TOTALS	**4.16**	**n/a**	**n/a**	**18.46**	**26.81**	**22.30**	**0.265**	**3.53**	**n/a**	**n/a**	**16.36**	**21.64**	**14.33**	**0.238**

n/a – Not available

Table 7-6-79
2029 Control Episode Average Daily Emissions (tons/day) by Source Sector

	Modeling Inventory Grid 3 Domain Emissions (tons/day)							*Planning Inventory Nonattainment Area Emissions (tons/day)*						
Source Sector	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NOx**	**SO_2**	**VOC**	**NH_3**	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NO**	**SO_2**	**VOC**	**NH_3**
Point Sources	0.94	0.71	0.13	12.05	3.74	0.07	0.022	0.93	0.71	0.13	11.91	3.52	0.07	0.022
Area, Space Heat	0.93	n/a	n/a	3.01	2.25	11.73	0.169	0.56	n/a	n/a	2.81	1.91	10.57	0.154
Area, Other	0.27	n/a	n/a	0.44	0.03	2.57	0.057	0.24	n/a	n/a	0.38	0.03	2.21	0.057
On-Road Mobile	0.12	n/a	n/a	2.16	0.04	3.54	0.064	0.08	n/a	n/a	1.17	0.01	2.36	0.042
Non-Road Mobile	0.55	n/a	n/a	2.04	17.80	4.68	0.003	0.26	n/a	n/a	1.25	11.33	0.43	0.002
TOTALS	**2.82**	**n/a**	**n/a**	**19.70**	**23.86**	**22.59**	**0.315**	**2.07**	**n/a**	**n/a**	**17.52**	**16.80**	**15.64**	**0.277**

n/a – Not available

Attachment A

Fairbanks Home Heating & Wood Household Survey Scripts

Fairbanks 2011 Home Heating Survey

Final Script

Phone # _______________ Survey # __________
Interviewer Name __________________
Date _______________

(Location of Home)

Good evening, I am calling from Hays Research Group; we are conducting a brief survey on behalf of the Alaska Department of Environmental Conservation (DEC) and the Fairbanks North Star Borough (BURR-oh) regarding home space heating options. May I please speak to the person most knowledgeable about the heating devices in your home? (IF NOT AVAILABLE – When would be the best time to reach him/her? Set a callback and get a name.)

Q1-Q8) Please tell me which of the following devices provide space heat for your home?

Q1) A wood burning device?

1. Yes
2. No
3. DK/REF

Q2) A central Oil furnace?

1. Yes
2. No
3. DK/REF

Q3) Portable Fuel Oil/Kerosene heating device?

1. Yes
2. No
3. DK/REF

Q4) Toyo (TOY-oh), Monitor or other direct vent type heater?

1. Yes
2. No
3. DK/REF

Q5) Natural Gas Heat?

1. Yes
2. No
3. DK/REF

Q6) Coal Heat

1. Yes
2. No
3. DK/REF

Q7) Municipal Heat?
1. Yes
2. No
3. DK/REF

Q8) Other not listed? ___________________

QQ) And can you please tell me how many square feet are in your home, not including any garage space?

1. _______________sq. ft.
2. DK/REF

(At least one of the questions between Q1-Q7 must = 1 yes, otherwise terminate)

(Ask Q1a if Q1=1, otherwise skip to Q9)

Q1a) Is your wood burning device a fireplace, a fireplace with insert, a wood burning stove or outdoor wood boiler?

1-Fireplace
2-Fireplace with insert
3-Wood burning stove
4-Outdoor Wood Boiler (note could called hydronic heater by some)
5-DK/REF

Q9) (Q9 answers must total 100%) What percentage of your heating is done by each of the following devices during the winter months, from October to March?

a. Wood Burning Device	%
b. Central Oil furnace	%
c. Portable Fuel Oil/Kerosene	%
d. Direct Vent type	%
e. Natural Gas Heat	%
f. Coal Heat	%
g. Municipal Heat	%
h. Other	%

We'll now get into some usage details of each type of heating.

(Section 1: Wood burning stove/Fireplace insert)

(Ask Q10-Q12 if Q1a = 2) "Fireplace with insert" or 3) "Wood burning stove", otherwise skip to Q13)

Q10a) Was your wood burning stove or insert installed before or after 1988?

1) Before
2) After
3) DK/REF

Q11a) How old is your wood burning stove or insert? Allow multiple responses

1) Less than 1 year
2) 1-5
3) 5-10
4) 10-15
5) 15+ years
6) DK/REF

Q11b) Is your wood stove or insert catalytic or non –catalytic?

1) catalytic
2) non-catalytic
3) DK/REF

Q12) Does your stove or insert burn pellets or cord wood? Allow multiple responses

1)Pellets
2)Cord Wood
3) DK/REF

(Ask Q13-Q14 if Q12=2 “Cord wood”, otherwise skip to Q15)

Q13) What best describes your use of wood heat during the winter months, October to March?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don’t know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Q14) Where do you get the wood for your heating? Allow multiple responses
1. Buy wood
2. Cut your own
3. DK/REF

(Ask Q15-Q17a if Q14=2 “Cut your own”, otherwise skip to Q18)

Q15) When cutting wood do you get a permit?

1. Yes
2. No
3. DK/REF

Q16) How many months do you season your wood before burning it?

1.________Months
2. DK/REF=9999

Q17) Do you know what the moisture content of your wood is, and if so, what is it?

1.________Percent
2. DK/REF=9999

(Ask Q18-Q19 if Q12 =2 “Cord wood”, otherwise skip to Q20)

18) In cords, how much wood do you burn in your wood burning stove or insert annually?
(If the respondent asks, one cord of wood is four feet wide, four feet high, and eight feet long stacked)

1. Wood in cords _______
2. DK/REF=9999

Q19) In cords, how much do you burn from October to March?

1. Wood in cords _______
2. DK/REF=9999

(Ask Q20-Q21 if Q12=1 “pellets”, otherwise skip to Q22)

Q20) How many 40 lb bags of pellets do you burn in your wood burning stove or insert annually?

1. 40 lb bags of pellets ________
2. DK/refused=9999

Q21) How many bags do you burn from October to March?

1. 40 lb bags of pellets ________
2. DK/refused=9999

(Ask Q22 if q18 or q19= DK/REF, otherwise skip to Q23)

Q22) How much do you spend per year on wood?

1. $__________
2. DK/refused=9999

(Ask q23 if q20 or q21 = DK/REF, otherwise skip to Q24)

Q23) How much do you spend per year on pellets?

1. $__________
2. DK/refused=9999

Q23a) Is there a pellet source that you prefer?

1. Yes
2. No
3. DK/REF

(Ask Q23b if Q23a=”Yes”, otherwise skip to Q24)

Q23b) Why do you prefer that source?

Specify ___________

(Section 2: Wood burning Fireplace)

(Ask Q24-Q25 if Q1a = 1 “Fireplace”, otherwise skip to Q32)

Q24) From this list, what best describes your use of wood heat during the winter months, from October to March?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don't know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Q25) Where do you get the wood for your heating? (Allow multiple responses)

1. Buy wood
2. Cut your own
3. DK/REF

(Ask Q26-Q31 if Q25=2, otherwise skip to Q32)

Q26) When cutting wood do you get a permit?

1. Yes
2. No
3. DK/REF

Q27) How many months do you season your wood before burning it?

1. Months ______
2. DK/refused=9999

Q28) Do you know what the moisture content of your wood is, and if so, what is it?

1. Percent ______
2. DK/refused=9999

Q29) In cords, how much wood do you burn in your fireplace annually?

1. ________cords
2. DK/refused = 9999

Q30) How much do you burn from October to March?

1. ________cords
2. DK/REF=9999

Q31 How much do you spend per year on wood?

1. $__________
2. DK/REF=9999

(Section 3: Outdoor Wood Boiler)

(Ask Q32-Q33 if section if Q1a = 4 "outdoor wood boiler", otherwise skip to Q34)

Q32) What best describes your use of wood heat during the winter months, from October to March?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don't know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Q33) Where do you get the wood for your heating? (allow multiple responses)

1. Buy wood
2. Cut your own
3. Purchase Pellets
4. DK/REF

(Ask Q34-Q36 if Q33=2 "cut your own", otherwise skip to Q37)

Q34) When cutting wood do you get a permit?

1. Yes
2. No
3. DK/REF

Q35) How many months do you season your wood before burning it?

1. Months ______
2. DK/REF=9999

Q36) Do you know what the moisture content of your wood is, and if so, what is it?

1. Percent ______
2. DK/REF=9999

Q37) How much wood do you burn in your outdoor wood boiler annually?

1. ________cords
2. ________ pellets
3. DK/REF=9999

Q38) How much do you burn from October to March?

1. ________cords
2. ________ pellets

3. REF=9999

(ask Q39 if Q33= 1 “Buy wood”, otherwise skip to Q40)

(ask Q38a if Q33= 3 “Purchase Pellets”, otherwise skip to Q40)

Q38a) Is there a pellet source that you prefer?

1. Yes
2. No
3. DK/REF

(Ask Q38b if Q38a=”Yes”, otherwise skip to Q40)

Q38b) Why do you prefer that source?

Specify ____________

Q39) How much do you spend per year on wood?

1. $___________
2. DK/REF=9999

Q40) What is the brand name of your outdoor wood boiler? (open ended)

(Section 4: Central Oil)

(ask Q41-Q44 of Q2=1 “yes”, otherwise skip to Q45)

Q41) How large is your fuel oil tank, in gallons?

1. _______Gallons
2. DK/REF=9999

Q42) In gallons, how much oil do you use annually?

1. _______Gallons
2. DK/REF=9999

Q43) How many gallons do you use during the winter months (October – March)?

1. _______Gallons
2. DK/REF=9999

Q44) How much do you spend per year on fuel oil?

1. $__________
2. 9999=No/DK/REF

(Section 5: Portable Fuel Oil/Kerosene Heating Device)

(Ask Q45-Q46 if Q3=1 “YES”, otherwise skip to Q47)

Q45) You mentioned using a Portable Fuel Oil or Kerosene Heating Device, does the device use Fuel Oil?

1. Yes
2. No
3. DK/REF

Q46) Does the device use Kerosene?

1. Yes
2. No
3. DK/REF

(If Q45 OR Q46 = 1 “yes”, read Q47-Q48, otherwise skip to Q49)

Q47) In gallons, how much oil/kerosene do you use annually?

1. ________gallons
2. DK/REF=9999

Q48) How many gallons do you use during the winter months (October – March)?

1. ________gallons
2. DK/REF=9999

Q49) How much do you spend per year on oil/kerosene? No/DK/REF=9999

1. $________
2. DK/REF=9999

(Section 5.1
For homes using Central Oil, and/or Portable Fuel Oil/Kerosene Heating Devices, and/or Other devices)

(Ask Q50 if Q2=1 “yes” or Q3=1 “yes” or Q7=1 “yes”, otherwise skip to Q51

Q50) From this list please tell me what best describes your use of fuel oil and kerosene burning devices during the winter months, from October to March?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don't know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Section 6: Toyo, Monitor, or other Direct Vent Type of Heater if uses fuel oil and direct vent fuel consumption question

(Ask this section if Q4=1 "yes", otherwise skip to Q55)

If Q2=1 and Q4=1 skip Q 51 & Q52

Q51) In gallons, how much oil do you use annually?

1. _______Gallons
2. 9999=DK/refused

Q52) How many gallons do you use during the winter months (October – March)?

1. _______Gallons
2. 9999=DK/REF

Q53) How much do you spend per year on oil?

1. $________
2. 9999=DK/REF

Q54) What best describes your use of direct vent heating device during the winter months, from October to May?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don't know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Section 7: Natural Gas Heating Device

(if Q5=1 "yes", ask Q55-Q56, otherwise skip to Q57)

Q55) How much do you spend on natural gas annually?

1. $________
2. DK/REF=9999

Q56) How much do you spend during the winter months, from October to March?

1. $________

2. DK/REF=9999

Section X: Coal Heating Device

(if q6=1 “yes”, ask Q57-Q60, otherwise skip to Q61)

Q57) How much coal do you use annually?

1.__tons
2.__bags
3. DK/refused

Q58) How much did you pay for the coal?

1.___$/bag
2.___$/ton
3. DK/refused

Q59) How much coal do you use during the winter (October – March)?

1.__tons
2.__bags
3. DK/refused

Q60) Is your coal burned in an indoor stove or an outdoor boiler?

1. Indoor stove
2. Outdoor boiler
3. DK/refused

(Section F: Municipal Heat)

If Q7=1 “yes”, ask Q61-Q62, otherwise skip to Q63)

Q61) How much do you spend on municipal heat annually?

1. $________
DK/refused =9999

Q62) How much do you spend on municipal heat during the winter months, October to March?

1. $________
DK/REF=9999

Future Section (to be completed for every survey)

Q63) Do you anticipate acquiring a new or different type of heating device within the next 2 years?

1. Yes
2. No
3. DK/refused

(If Q63=1 “yes”, ask Q64, otherwise skip to

Q64) What type of device do you plan to acquire? READ LIST

a. Wood Stove	d. Fuel Oil		h. Don’t know (do not read)
b. Wood Pellet	e. Kerosene		i. Refused (do not read)
c. Outdoor Wood Boiler	f. Coal stove	g. Outdoor coal boiler	j Other (Specify)

(If Q64= a. ‘Wood stove”, ask Q64a, otherwise skip to Q65)

Q64a) Newer EPA certified stoves are more efficient and require less chimney cleaning than older stoves. These benefits ultimately offset the purchase price, particularly if you hire chimney sweepers. How quickly would a new stove need to pay for itself in order for you to buy one?

1. 1 year
2. 2 years
3. 3 years
4. 4 years
5. 5 years or more
6. None
7. Don’t Know/Refused (do not read)

Q64b) Would you invest in a new more efficient stove if you were to receive a price incentive paid by either state or local government of $250? (like a rebate)

1. Yes
2. No >> ask 64c

if answer to 64 b is no then proceed to 64c:
Q64c) What if the price incentive was $500?

1. Yes
2. No >> ask 64d

if answer to 64 c is no then proceed to 64 d:

Q64d) And if the price incentive were $750, would you invest in a new stove?

1. Yes
2. No >> ask 64e

if answer to 64 d is no then proceed to 64 e:
Q64e) What if the incentive were $1,000?

1. Yes
2. No >> ask 64f

if answer to 64e) is no then proceed to 64f)

Q64f How much of an incentive would it take for you to invest in a new stove?

1. $1000 – 1200
2. $1201 – 1500
3. $1501 – 1750
4. $1751 – 2000
5. $2001 or more
6. DK/refused

(If Q1a=1 or Q12=2 ask Q65-Q68, otherwise skip to Q69)

Q65) Did you burn more wood this winter to minimize the cost of heating oil?

1. Yes
2. No
3. DK/REF

Q66) What fuel oil price would cause you to shift away from using wood for heating?
(If respondent is unclear of question ask: If fuel oil prices decline, at what price will you shift to using more fuel oil to heat and decrease the use of wood?)

Specify:____________

Q67) Natural gas is currently priced at $2.34/hundred cubic feed which is equivalent to $3.04 of #2 Heating Oil. How much lower would natural gas need to be priced to cause you to shift away from fuel oil? (If respondent is unclear of the question, ask what the equivalent fuel oil price per gallon that would cause them to shift away from fuel oil?)

Specify:____________

(ASK Q68 ONLY IF ZIP=99709, otherwise skip to Q69)

Q68) Can you please tell me whether you live inside of Chena Ridge (to the east of the ridge) or outside of Chena Ridge (to the west of the ridge).

1. Inside Chena Ridge
2. Outside Chena Ridge
3. DK/REF

(ASK Q69 ONLY IF ZIP=99712, otherwise skip to Q70)

Q69) Can you please tell me if you live inside of Farmers Loop Road or outside of Farmers Loop Road?

1. Inside Farmers Loop Road
2. Outside Farmers Loop Road
3. DK/REF

(ASK ALL)

Q70) Are you being impacted by wood smoke from your neighbors?

1. Yes
2. No
3. DK/REF

Q71) Does the Borough have a winter time air quality problem?

1. Yes
2. No
3. DK/REF

Q72) How do you keep abreast of current issues is it (read list, allow more than one answer)

1. TV
2. Radio
3. Newspaper
4. Internet
5. Other
6. DK/refused

Thank you, that is all the questions I have this evening. If you have questions or comments about this survey, I can give you the contact information for Hays Research Group. Again, thank you for your time.

2013 Wood-Burning Household Tag Survey

Intro / Screener

Hello, this is ____________ calling from Hays Research Group, an Alaskan research firm. We are conducting a survey today on behalf of the State and The Fairbanks Northstar Borough to gather information about specific models of heating devices to help us better understand the air quality issues in the area. Your number was selected at random, and all information collected will be kept confidential, your name address and phone number will not be included in any of the information given to the State or Borough. Can I speak to the person in the household who would be most knowledgeable about heating methods in your home?

Q1) Do you use any wood-burning heating devices in your house during winter?

(this could include wood stoves, fireplaces, hydronic heaters, outdoor wood boilers and pellet stoves)

1. Yes (continue)
2. No or Don’t know / Refused (terminate “the survey today deals with wood heating devices, so you are ineligible to participate, thanks for your time”)

Q2) What type of wood device(s) do you use? Read list (multiple answers OK)

1. Wood Stove
2. Pellet Stove
3. Insert
4. Fireplace
5. Hydronic heater (sometimes referred to as an outdoor wood boiler)
6. Other (specify) – removed 20913
7. (Don’t know/Refused) - terminate

[IF Q2=1. WOOD, ASK Q3-Q9]

WOOD STOVE SECTION

Q3) I am going to ask you a few questions about your wood stove. Are you able to look at it to give me some specific information?

1. Yes
2. No (ask if there is a better time to call back)

Q4) What year was the wood stove installed in your home? (date range between 1950-2013)

1. (open ended)
2. Don’t know=9998, Refused=9999 (ask Q4 again after Q9 if DK/REF)

Q5A-B) Do you know the make and model of your wood stove?

Q5A) Make

1. (open-end)
3. Don’t know / Refused (ask Q5 again after Q9 if DK/REF)

Q5B) Model
1. (open-end)
2. Don’t know / Refused (ask Q5 again after Q9 if DK/REF)

Q6) If you have a wood stove and it is EPA certified, it should have an EPA-certification label on the back or side. Please take a look at it as the next questions I will ask you are specific to the information written on the label.

If the respondent refuses or is unable to see the label - ask if you can set up a call back time to speak with someone who can or a time that is more convenient – be sure to reread the list of information you will be calling back for.

If respondent refuses to set up a call back time - ask if you can send them a postcard to be returned by mail with the requested information. (GO TO Q22 IF Q2=1 or 3 only and Q6=3 (Refused-YES TO POSTCARD). IF Q2=1 AND Q6=3 (Refused-YES TO POSTCARD) GO TO Q22. IF Q2=1 & 5 AND Q6=3 (Refused-YES TO POSTCARD) GOT TO Q10)

1=Continue
2=Set callback
3= Refused (YES TO POSTCARD)
4=Refused (NOT TO POSTCARD) – terminate
5=Wood stove not EPA Certified (go to Q22 if Q2=1 only, If Q2=1, 3 & 5, go to Q3I, then DQ10)
6=Label no longer available/Unreadable ((go to Q22 if Q2=1 only, If Q2=1, 3 & 5, go to Q3I, then DQ10)

Is it Catalyst Equipped or Non Catalytic?

1. Yes
2. No
3. Don’t Know / Refused

Q7) What is the Smoke Rating (grams/hour)? – (range = 0.5 – 8 grams per hour)

______ (DK=98/REF=99)

Q8) What is the Efficiency (50% - 100%)?

1. Open ended (in percent)
2. Don’t know=998, Refused=999

Q9) What is the Heat Output range (Btu/Hr.)? (range = 1000-80,000 btu)

1. Open ended (defined as range in # Btu/Hr eg “7000-30000”)
2. Don’t know=99998, Refused=99999

[IF Q2=3. INSERT, ASK Q3I-Q9I]

INSERT SECTION

Q3I) I am going to ask you a few questions about your Insert heating device. Are you able to look at it to give me some specific information?

3. Yes
4. No (ask if there is a better time to call back)

Q4I) What year was the Insert heating device installed in your home? (date range between 1950-2013)

4. (open ended)
5. Don’t know=9998, Refused=9999 (ask Q4 again after Q9 if DK/REF)

Q5AI-Q5BI) Do you know the make and model of your Insert heating device?

Q5AI) Make

1. (open-end)
6. Don’t know / Refused (ask Q5AI again after Q9I if DK/REF)

Q5BI) Model
1. (open-end)
2. Don’t know / Refused (ask Q5BI again after Q9I if DK/REF)

Q6I) If you have an Insert heating device and it is EPA certified, it should have an EPA-certification label on the back or side. Please take a look at it as the next questions I will ask you are specific to the information written on the label.

<u>If the respondent refuses or is unable to see the label</u> - ask if you can set up a call back time to speak with someone who can or a time that is more convenient – be sure to reread the list of information you will be calling back for.

<u>If respondent refuses to set up a call back time</u> - ask if you can send them a postcard to be returned by mail with the requested information. (GO TO Q22 IF Q2=1 or 3 only and Q6=3 (Refused-YES TO POSTCARD). IF Q2=3 AND Q6I=3 (Refused-YES TO POSTCARD) GO TO Q22. IF Q2=3 & 5 AND Q6I=3 (Refused-YES TO POSTCARD) GOT TO Q10)
1=Continue
2=Set callback
3= Refused (YES TO POSTCARD)
4=Refused (NOT TO POSTCARD) – terminate
5= Insert stove not EPA Certified (go to Q22 if Q2=3 only. If Q2=3 & 5, go to DQ10 before Q22)
6=Label no longer available/Unreadable (go to Q22 if Q2=3 only. If Q2=3 & 5, go to DQ10 before Q22)

Is it Catalyst Equipped or Non Catalytic?

4. Yes
5. No
6. Don't Know / Refused

Q7I) What is the Smoke Rating (grams/hour)? – (range = 0.5 – 8 grams per hour)

______ (DK=98/REF=99)

Q8I) What is the Efficiency (50% - 100%)?

3. Open ended (in percent)
4. Don't know=998, Refused=999

Q9I) What is the Heat Output range (Btu/Hr.)? (range = 1000-80,000 btu)

3. Open ended (defined as range in # Btu/Hr eg "7000-30000")
4. Don't know=99998, Refused=99999

[IF Q2=5 Hydronic heater, ASK Q10-Q21]

HYDRONIC HEATER SECTION

Q10) If you have a hydronic heater and it is "Phase 1 or Phase 2 Qualified", it will have a white label. Please take a look at it as the next questions I will ask you are specific to the information written on the label.

If the respondent refuses or is unable to see the label - ask if you can set up a call back time to speak with someone who can or a time that is more convenient – be sure to reread the list of information you will be calling back for.

If respondent refuses to set up a call back time - ask if you can send them a postcard to be returned by mail with the requested information. (GO TO Q22 IF Refused=Yes to Postcard, terminate if Q2=5 only and Q10=4 Refused-No to Postcard)
1=Continue
2=Set callback
3= Refused (YES TO POSTCARD)
4=Refused (NOT TO POSTCARD) – terminate
5= Hydronic heater not Phase 1/Phase 2 (go to Q22)
6= Label no longer available/Unreadable (go to Q22)

What is the Smoke Emissions This Model number (0.xx lbs/million btu)?

(IF NEEDED, read: This will be shown as a triangle along the bottom of a line. The number we are looking for is the one that says "this model")
(range = 0 - 0.5 lbs / million btu)

1. Open ended (in lbs/million Btu)
2. Don't know=98 / Refused=99

Q11) If it is not too difficult, please provide information on the following items:

Manufacturer (of the hydronic heater)
1. Open ended
2. Don't know / Refused

Q12) Model Number (of the hydronic heater)

1. ENTER MODEL NUMBER
2. Don't know / Refused

Q13) 8-Hour Heat Output Rating (Btu/Hr)
- (range = 1,000-400,000 btu/hr, answer will be in a range such as "10,000-40,000"

1. Open ended (in Btu/Hr)
2. Don't know=999998, Refused=999999

Q14) 8-Hour Average Efficiency (in %)
- We will set this as a numeric open-end with 0-100% range then we can code DK as 101 and REF as 102 or both with 101
1. Open ended (in %)
2. Don't know=101, Refused=102

Q15) Is your hydronic heater tag orange or white ?
1. Orange with a white border
2. White with an orange border
3. Don't know / Refused (skip to Q19)

Q16) (ask Q16 only if Q15 = 1. Orange)

What is the Average emissions in Grams per Hour? This is denoted as blank grams per hour average
- (range = 5-30 grams /hr)

1. Open ended (in GRAMS/HR)
2. Don't know / Refused

Q17) (ask Q17 – Q18 only if Q15 = 2 White)

What are the average emissions in grams per hour?
(range = 0-15 grams / hr)

1. Open ended (in GRAMS/HR)
2. Don't know=98 / Refused=99

Q18) What is the maximum test run emissions? (IF NEEDED, read: This is denoted as blank grams per hour maximum test run).
- (range = 0-20 grams/hr)

1. Open ended (in GRAMS/HR)
2. Don't know=98 / Refused=99

Q19) The next number down should be blank lbs per million BTU heat input. Can you read me that number?
- (range = 0-1 lbs/million btu)

1. Open ended (in LBS/MILLION BTU)

2. Don't know=98 / Refused=99

Q20) The next number down should be blank lbs per million BTU heat output. Can you read me that number?

- (range = 0-3 lbs/million btu)

1. Open ended (in LBS/MILLION BTU)
2. Don't know=98 / Refused=99

Q21) The last number on the bottom should read blank grams per hour per ten thousand BTU output. Can you read me that number?

- range = 0-2 grams / hr)

1. Open ended (in GRAMS/HR/10000BTU OUTPUT)
2. Don't know=98 / Refused=99

ALL DEVICE SECTION

ASK ALL

Q22) What other heating devices do you use?

1. A central oil furnace
2. Portable fuel oil or kerosene heating device
3. Toyo (toy-oh), Monitor, or other direct vent type heater
4. Natural gas heat
5. Coal heat
6. Municipal heat
7. Other (specify)
8. Don't Know / Refused
9. No other heating device (go to Q27)

ASK ALL

Q23A-Q23B) Roughly how much of your winter heating is done with wood versus other heating methods? For instance would you say you heat with 20% wood and 80% heating oil? (Should equal to 100%)

1. % Fuel oil
2. % Wood
3. DK=998
4. Refused=999

Q24) (For multi-device HHs) Do you always burn wood at colder temps as a secondary source of heat?

1. Yes
2. No
3. Don't know / Refused

Q25) Ask only if Q24 = 1. Yes, otherwise skip to Q27)

Is that because

1. You need the extra heat to keep all areas of the house warm
2. To save money?
3. Both?
4. Other specify
5. (Don't know/Refused)

Q26) (ask only if Q25 = 1. Yes, otherwise skip to Q27)
At what temperature do you have to start burning wood to keep all of the areas of the house warm?

1. Open ended (in degrees Fahrenheit) = (range: -60 to 100 degress)
2. Don't Know=998 / Refused=999

Q27) Have you participated in any of the following programs? (allow multiple responses)

1. Borough's Wood Stove Change Out Program
2. AHFC Home Rebate
3. AHFC Weatherization
4. No
5. Don't Know / Refused

(AHFC = Alaska Housing Finance Corporation)

ALL DEVICES, NEVER PARTICIPATED IN OTHER PROGRAMS SECTION

Q28) (ask only if Q27 = 4. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

If you did not participate in these programs, would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 75% of the cost of installing a new replacement device?

1. Yes
2. No
3. Don't Know / Refused

Q29) (ask if Q28= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 80% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q30) (ask if Q29= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 85% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q31) (ask if Q30= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 90% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q32) (ask if Q31= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 95% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q33) (ask if Q32= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 100% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q34) Do you cut your own firewood or buy it from someone else?

1= Cut your own (go to Q37)
2= Buy it from someone else
3= Both
4= Don't Know / Refused

Q35A-Q35B) Ask if Q34 = 3. Both, otherwise skip to Q36)

How much of your wood do you buy versus cutting. For instance would you say you cut 75% and buy 25%?

1 = open ended (answer in terms of % cut / % bought)
2 = Don't know=998 / Refused=999

Q36) (ask only if Q34 = 2. Buy it from someone else, or 3. Both)

Where do you buy your firewood? Be as specific as possible as in the name of the person or company if possible.

1 = Open ended
2 = Don't Know / Refused

Q36A) What price, per cord, did you pay for wood this winter? (in $/cord of wood)

(Open ended) (99998=Don't know/99999=Refused)

Q36B) Does that price include the cost of delivery?

Yes
No
Don't know / Refused

[ASK Q37 ONLY IF Q2=1, 3-5]

ALL DEVICES, CORDWOOD SECTION

Q37) What types/species of wood do you burn? What's the share of each type? (read list) (IF 1 type of wood only/Other type of wood – do not ask follow up question but auto code it as 100%)
Birch (x%)
Spruce (y%)
Alder (z%)
Other type of wood (a%)

Q38A) (Ask Q38A only if Q2 = 1 "wood stove", 3. "insert" , 4 . "Fireplace" or 5. "Hydronic Heater/ Outdoor wood boiler", otherwise skip to Q38B)

In cords, how much wood do you burn from October to March?

1. ________cords
2. DK=9998/Refused = 9999

ALL DEVICES, PELLETS SECTION

Q38B) (Ask Q38B only if Q2 = 2 “pellet stove”, otherwise skip to Q38C)For Pellet Stoves:

Q38) How many 40 lb bags of pellets do you burn in your wood burning stove or insert from October to March?

1. 40 lb bags of pellets ________
2. DK=9998/refused=9999

Q38C) How long do you season your wood, if at all? (range: 0 to 120 months)

(open ended) (record answer in number of months) code Don’t know as 998 and Refused as 999

Q39) Knowing that dry wood provides 25 percent more heat than wet wood, would you pay $25 more per cord for dry wood?

1 = Yes
2 = No
3 = Don’t Know / Refused

Q40) (ask if Q39 = 1. Yes, otherwise skip to Q43)

Would you pay 50 dollars more per cord for dry wood?

1 = Yes
2 = No
3 = Don’t Know / Refused

Q41) (ask if Q40 = 1. Yes. Otherwise skip to Q43)

Would you pay 75 dollars more per cord for dry wood?

1 = Yes
2 = No
3 = Don’t Know / Refused

Q42) (ask if Q41 = 1. Yes. Otherwise skip to Q43)

Would you pay 100 dollars more per cord for dry wood?

1 = Yes
2 = No
3 = Don't Know / Refused

Q43) On a scale of zero to a hundred with zero being wide open and a hundred being completely shut, where do you typically set the air damper on your wood stove or insert? (0-100% for min/max)?

Open ended (%)
Don't know=101 / Refused=102

Q44) Is there a difference between your nighttime and daytime setting?

1 = Yes
2 = No
3 = Don't Know / Refused

Q45) (Ask if Q44 = 1. Yes, otherwise skip to Q 47)

On a scale of zero to a hundred with zero being wide open and a hundred being completely shut, where do you set your air damper at night?

1. Open ended (%)
2. Don't know / Refused

Q46) (Ask if Q44 = 1. Yes, otherwise skip to Q 47)

On a scale of zero to a hundred with zero being wide open and a hundred being completely shut, where do you set your air damper during the daytime?

3. Open ended (%)
4. Don't know / Refused

Q47) If natural gas becomes available in Fairbanks, What natural gas price would get you to stop burning wood? This is a little bit difficult, but if you could, please phrase it in terms of dollars per gallon of heating fuel. For example you could say I would stop burning wood if natural gas cost the equivalent of four dollars a gallon of heating oil, or three dollars a gallon, etc.

1. Open ended (in $/GALLON) (range: 0-20 dollars)
2. Don't know / Refused

Q48) If natural gas were available in Fairbanks, would you still need to burn wood at lower temperatures to keep your house warm regardless of how gas is priced?

1. Yes
2. No
3. Don't know / Refused

IF RESPONDENT AGREED TO BE SENT A POSTCARD IN Q6, Q6I OR Q10, ASK the following information before terminating the call:

Name to send the Postcard to (full name)
Full Address

(END)
Those are all the questions I have today. Thank you for your time and participation. Have a good day/evening.

2013 Fairbanks Wood Purchasing Survey Questionnaire

Hello, this is ____________ calling from Hays Research Group, an Alaskan research firm. We are conducting a survey today on behalf of the State and The Fairbanks Northstar Borough to gather information about house heating devices to help us better understand the air quality issues in the area. Your number was selected at random, and all information collected will be kept confidential, your name address and phone number will not be included in any of the information given to the State or Borough. Can I speak to the person in the household who would be most knowledgeable about heating methods in your home?

Q1) Do you use any wood-burning heating devices in your house during the winter?

1. Yes (continue)
2. No (end call)

Q2) What type of wood device(s) do you use? Read list (allow multiple responses)

1. Stove
2. Insert
3. Fireplace
4. Hydronic heater (also known as an outdoor wood boiler)
5. Other (specify)
6. Don't know / Refused

Q3) Do you cut your own firewood, or buy it?

1. Cut
2. Buy
3. Both
4. Don't Know / Refused

Q4) (ask only if Q3 = both) How much of your wood do you buy versus cutting. For instance would you say you cut 75% and buy 25%?

1. open ended (answer in terms of % cut / % bought)
2. Don't know / Refused

PURCHASED WOOD (WOOD BUYERS) SECTION

Q5) (ask only if Q3 = 2. Buy, or 3. Both, otherwise skip to Q14) Regarding the firewood you purchase, do you have the wood delivered or do you pick it up?

1. Delivered
2. Pick It Up
3. Both
4. Don’t know / Refused

Q6) Do you have a consistent firewood supplier?

1. Yes
2. No
3. Don’t know / refused

Q7) (ask Q7 only if Q6 = 1. Yes, otherwise skip to Q09) How many years have you bought wood from them?

1. 1 year
2. 2 years
3. 3 years
4. 4 years
5. 5 years
6. 6 years
7. 7 years
8. 8 years
9. 9 years
10. 10 or more years
11. Don’t know / Refused

Q8) What do you like most about the supplier? (multiple responses OK)

1. Price
2. Reliability
3. Honesty
4. Wood is split
5. Wood is dry
6. Delivery (when and where you want it dumped)
7. Other (please specify)
8. Don’t know / Refused

Q9) (ask Q9 only if Q6 = 2. No, or 3, Don’t know / Refused, otherwise skip to Q10) How do you choose a firewood supplier?

1. Advertisement (e.g., newspaper, Craigslist, etc.)
2. Word of mouth
3. Review old supplier info
4. Other (describe)
5. Don’t know / Refused

Q10) Is the wood you buy already split or in the round?

1. Split
2. In the round
3. Both
4. Don't know / Refused

Q11) (ask Q11 only if Q10 = 2. In the round, or 3. Both, otherwise skip to Q12)

If the wood is in the round, when do you split it? (READ OPTIONS)

1. As needed
2. Upon delivery
3. Don't know / Refused

Q12) Do you know where your suppliers are getting their wood from?

1. Yes
2. No
3. Don't know / Refused

Q13) Where do they get their wood from?

(OPEN ENDED)

Q14) Are you aware of firewood theft?

1. Yes (from newspaper and news articles)
2. Yes (from personal experience)
3. No
4. Don't know / Refused

Q15) Do you ask suppliers what the moisture content of the firewood is that they are selling?

1. Yes
2. No
3. Don't know / Refused

Q16) Do the suppliers tell you the moisture content of the firewood they are selling?

1. Yes
2. No
3. Don't know / Refused

Q17) (ask Q17, only if Q16 = yes, otherwise skip to Q18)

Are they truthful about the moisture content when they tell you? Is it as dry as they say it is?

1. Yes
2. No
3. Don't Know / Refused

Q18) (Ask Q18 only if Q5 = 1. Yes, or 3. Both, otherwise skip to Q19) What is the delivery fee you pay for your wood? This is not the price of the wood, but only the delivery charge.

1. $__
2. Don't Know / Refused

CUT WOOD (WOOD BUYERS) SECTION

Q19) (ask Q19 only if Q3 = 1. Cut, or 3. Both, otherwise skip to Q20) With regard to the wood that you cut, where do you cut it (read list) (accept multiple answers)

1. State Lands
2. Military Bases
3. Railroad Land
4. Personal Property
5. Other (Please specify)
6. Don't Know / Refused

Q20) How long do you season your wood, if at all?

(open ended) (record answer in number of months)

Q21) (ask Q21 only if Q3 = 2. Buy or 3. Both, otherwise survey is complete)

What price did you pay for your wood this winter per cord? ($/cord)?

Q22) Knowing that dry wood provides 25 percent more heat than wet wood, would you pay $25 more per cord for dry wood?

1. Yes
2. No
3. Don't Know / Refused

Q23) (Ask Q23 if Q22 = 1. Yes, otherwise survey is complete)

Would you pay 50 dollars more per cord for dry wood?

1. Yes
2. No
3. Don't Know / Refused

Q24) (Ask Q24 if Q23 = 1. Yes, otherwise survey is complete)

Would you pay 75 dollars more per cord for dry wood?

1. Yes
2. No
3. Don't Know / Refused

Q25) (Ask Q25 if Q24 = 1. Yes, otherwise survey is complete)

Would you pay 100 dollars more per cord for dry wood?

4. Yes
5. No
6. Don't Know / Refused

(END OF SURVEY)

Attachment B

FMATS Regional Travel Demand Modeling Documentation

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING / PLANNING
155 Grand Avenue, Suite 900, Oakland, CA 94612 P 510.839.1742 F 510.839.0871

MEMORANDUM

Fairbanks North Star Borough Updated Population and Employment Forecasts

Date:	November 22, 2017	Project #: 13520.10
To:	ADOT&PF	
From:	Mike Aronson and Anais Malinge	

SUMMARY

Kittelson and Associates, Inc. (KAI) recommends the use of population and employment forecasts for the Fairbanks North Star Borough (FNSB) based on an average of historical growth rates, the Alaska Department of Labor population forecasts and studies conducted by Woods & Poole Economics. Base population and employment totals were estimated for each five year increment between 2015 and 2050.

Forecasts may be affected by potential changes at Eielson Air Force Base (EAFB) or the Alaska Liquid Natural Gas (LNG) Project. The recommended forecasts include additional activity associated with the proposed F-35A deployment at EAFB, but do not include population or employment changes related to the LNG project.

The resulting average annual growth rates are 0.82% annual growth for population and 1.34% annual growth for total employment. Without the EAFB deployment, the resulting average annual growth rates would be 0.66% annual growth for population and 1.16% annual growth for total employment.

DIFFERENCES FROM PRIOR FORECASTS

Prior population and employment forecasts for the FNSB were documented in memoranda dated August 4, 2016 and March 1, 2017. The base population and employment forecasts (without F-35A deployment) are identical in all of the forecasts. The March 1, 2017 forecast added a small amount of supporting non-military employment based on the F-35A deployment, and also added additional temporary employment for the EAFB construction period. This November 2017 update incorporates newer EAFB projections, and includes the following changes from prior forecasts:

- Decrease in direct EAFB employment from 1,563 to 1,474
- Increase in dependents from 1,202 to 1,798

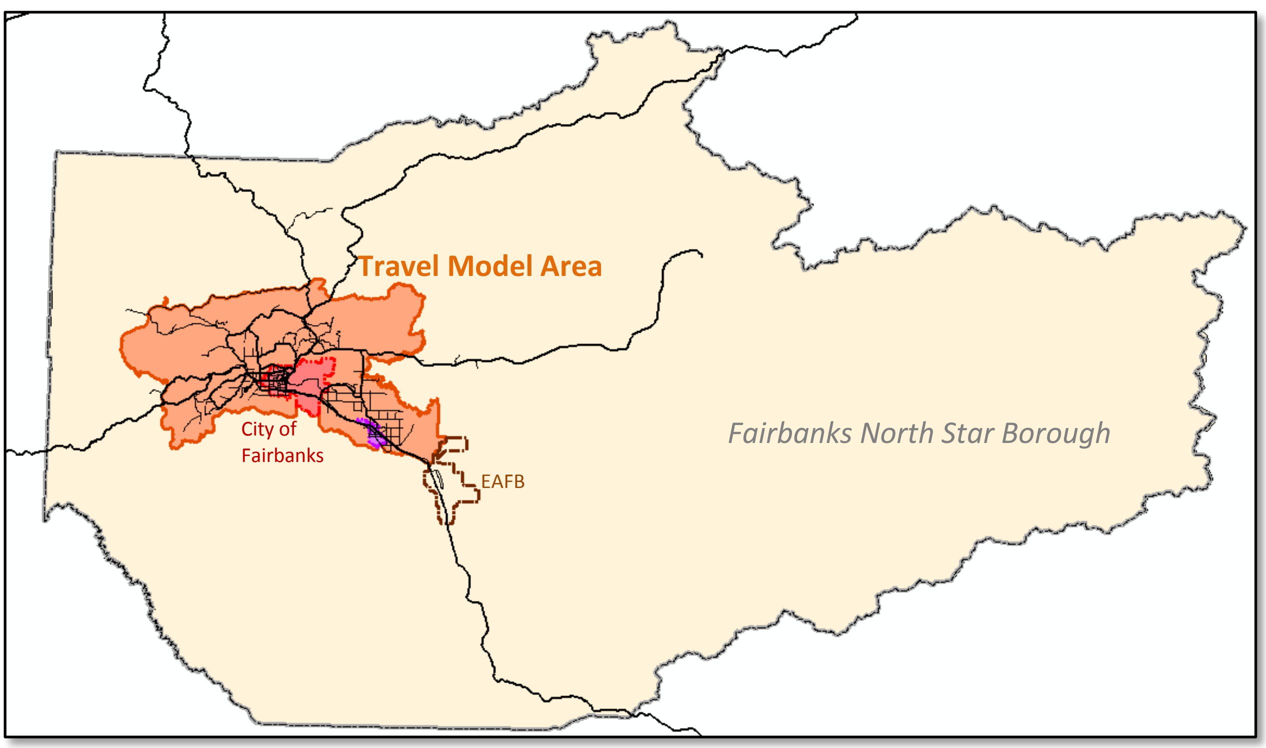
- Estimate of additional induced population growth due to births and supporting activity, with 2,152 additional population estimated by 2030
- Revised estimates of temporary construction activity, with a peak of 852 employees in 2020
- Increased estimates of induced employment growth related to serving the increased population, with 2,123 additional employees projected by 2045

Compared to the forecasts documented March 1, 2017, the 2045 FNSB population estimate would increase from 122,706 to 125,541 (+2.3%). The 2045 FNSB employment estimate would increase from 81,317 to 83,080 (+2.2%).

STUDY AREA

The Alaska Department of Labor and Woods & Poole Economics data reflect forecasts for the entire FNSB. However, the travel model area encompasses a smaller area within the larger FNSB, as shown in Figure 1. The travel model area contains approximately 35,000 out of the 39,000 total households in the FNSB (90 percent), and includes about 45,000 out of the 59,000 total FNSB employees (76 percent), with EAFB contributing most significantly to the differences. The forecasts documented in the subsequent sections represent the projected growth in population and employment for the larger FNSB area. The forecast growth rates for each land use type and time period will be applied to the smaller travel model area.

Figure 1: Fairbanks Model Area



DATA SOURCES

Alaska Department of Labor and Workforce Development

The Alaska Department of Labor and Workforce Development (Alaska DOL) produces population estimates and projections for the State of Alaska and its regions. Population estimates and projections are reported in the April 2016 *Alaska Population Projections* report from 2015 to 2045. The Alaska DOL population forecast uses the cohort component method, which accounts for in- and out-migration, births, and deaths as the primary factors for population fluctuations.

In addition, the Alaska DOL produces a ten-year industry forecast for the State of Alaska. The ten-year forecast for the State of Alaska is documented in the October 2014 *2012 to 2022 Alaska Economic Trends* article.

Woods & Poole

Woods & Poole Economics, Inc. is a private firm that specializes in long-term county economic and demographic projections. Woods & Poole industry and population projections for the FNSB were purchased in June 2016 and used as a basis for comparison with the DOL forecasts.

The Woods & Poole forecast methodology applies a regional projection technique which captures regional economic flows at the county, state and regional levels and constrains the results with an estimated United States total. The Woods & Poole employment forecast is founded on an export- based approach for Economic Areas (EA) as defined by the Bureau of Labor Statistics which is then used to estimate earnings. The employment and earnings projections become explanatory variables to estimate population and households, essentially assuming net migration rates projected from employment opportunities. The EA projections are then disaggregated to counties and used as control totals.

HISTORICAL TRENDS

The following shows historical trends from 1985 to 2015 for population and employment by industry growth, as summarized by Woods & Poole.

Population Trends

Table 1 and Figure 2 show the historical population trend for the FNSB. As calculated and shown in Table 1, population for the 30 year period between 1985 and 2015 experienced an average increase of 950 persons per year, corresponding to a 1.3% annual growth rate compared to the 1985 population or a 1.0% annual growth rate compared to the 2015 population. The population growth for the five year period prior to 1985 was faster, averaging nearly 3,400 persons per year.

Table 1: Historical FNSB Population Trends (1980-2015)

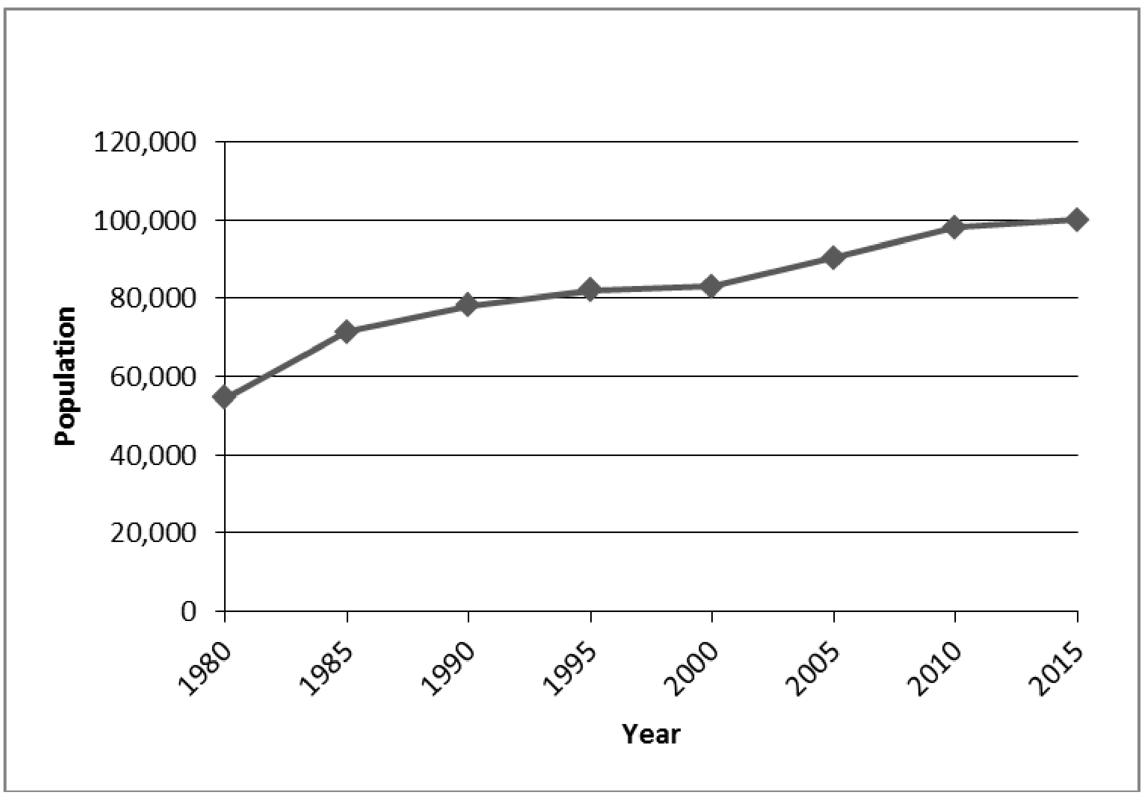
Year	1980	1985	1990	1995	2000	2005	2010	2015	Average Annual Growth Rate (%)
Population	54,503	71,435	78,067	81,941	83,005	90,431	98,279	100,000	0.96%
Households	18,445	22,725	26,862	28,927	29,831	35,224	36,704	39,060	1.37%

Note: Annual growth rate calculated relative to 2015 totals for the 30 year period, 1985-2015.

Source: Woods & Poole Economics, 2016.

Figure 2 indicates that there were several different growth rates during the past 30 years. Population grew at a rate of 1,325 persons per year between 1985 and 1990, then less than 800 per year between 1985 and 2000. Using the most recent 10 year period from 2005 to 2015, the growth rate has averaged 955 persons per year. This rate is similar to the 30-year average.

Figure 2: Historical FNSB Population Trends (1985-2015)



Employment Trends

Table 2 shows the historical employment trends for the period between 1980 and 2015 for industry sectors in the FNSB. The largest employment sectors in 2015 were Government, Military and Professional Services.

The FNSB region added an average of 530 jobs per year for the 30-year period between 1985 and 2015. The sectors with the highest increases were Health Services (115 jobs per year), Professional Services (95 jobs per year), and Leisure/Hospitality and Government (each 75 jobs per year).

In terms of growth rates compared to 2015 totals, the average annual growth rate was 0.8%, similar to the population growth rate during the same 30-year period. The industry sectors that experienced the greatest annual growth rates were the Health Services sector (1.9%) and the Leisure and Hospitality sector (1.4%).

Table 2: Historical Industry Trends in FNSB (1980-2010)

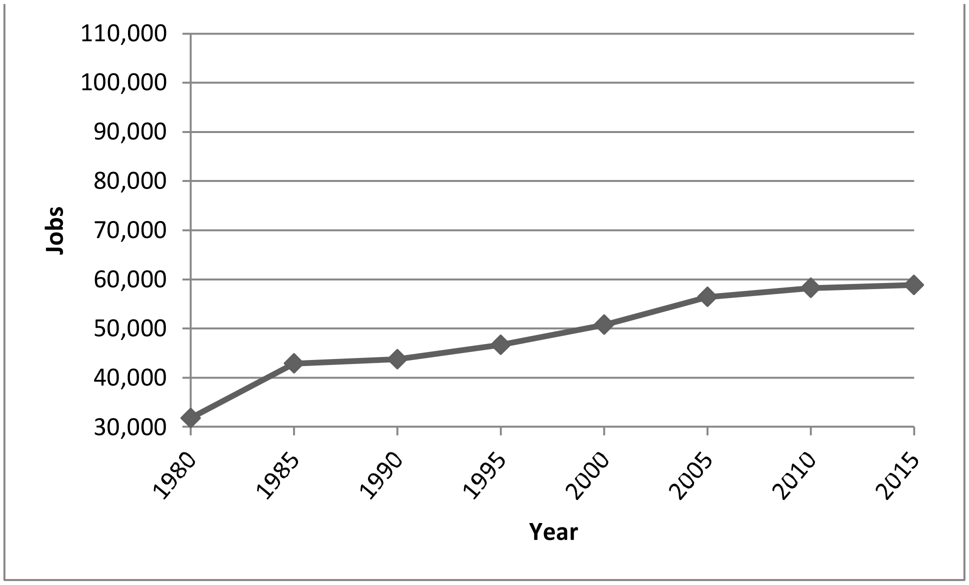
Industry Sector	1980	1985	1990	1995	2000	2005	2010	2015	Average Annual Growth Rate (%)
Agriculture	169	232	219	221	216	205	213	271	0.5%
Resources/Mining	896	1,436	1,370	1,679	1,835	1,733	1,924	3,081	1.8%
Construction	1,969	4,221	2,172	2,732	2,729	4,117	3,754	3,623	-0.6%
Manufacturing	826	757	853	946	902	930	905	938	0.6%
Wholesale	483	725	602	629	608	757	780	885	0.6%
Retail	2,728	4,310	4,612	5,326	5,242	6,222	5,751	5,956	0.9%
Trans/Ware/Utility	2,253	2,523	1,978	2,184	2,833	2,577	2,900	2,501	-0.03%
Prof Services	4,442	5,314	5,371	5,881	7,206	8,120	8,619	8,142	1.2%
Health Services	1,694	2,457	2,855	3,320	4,119	4,995	5,540	5,854	1.9%
Leisure/Hospitality	2,139	3,210	3,609	4,233	4,725	5,277	5,261	5,439	1.4%
Other Services	1,161	1,713	1,994	2,323	2,408	2,524	2,440	2,336	0.9%
Government	7,400	9,246	9,735	9,640	10,351	10,982	11,550	11,470	0.6%
Military	5,622	6,738	8,368	7,569	7,562	7,983	8,591	8,355	0.6%
Total Employment	**31,782**	**42,882**	**43,738**	**46,683**	**50,736**	**56,422**	**58,228**	**58,851**	**0.9%**

Note: Annual growth rate calculated relative to 2015 totals for the 30 year period, 1985-2015..

Source: Woods & Poole Economics, 2016.

Figure 3 shows the historical trend for total employment for the 30 year period. As shown, the largest growth in total employment occurred between 1980 and 1985, when the region added an average of 2,220 jobs per year. During the most recent 10-year period from 2005 to 2015, employment increased by an average of 240 jobs per year (0.4% compared to the 2015 total).

Figure 3: Historical Trend for FNSB Total Employment (1980-2015)



FORECAST COMPARISON

The following section provides updated population and employment forecasts as well as comparisons with the prior forecasts used for the 2040 Metropolitan Transportation Plan (MTP) and documented in the 2014 *Recommended Population and Employment Forecast* Memorandum ("2014 Memo"). The 2014 Memo was informed by 2013 Woods & Poole data and 2012 Alaska DOL data, while the updated forecasts are informed by updated 2016 Woods & Poole data and updated 2014 Alaska DOL data.

Population Forecast

Table 3 and Figure 4 provide the long-term population forecast comparison between Woods & Poole and Alaska DOL projections. The DOL and Woods & Poole start at similar 2010 population levels. As shown, the prior 2012 DOL population projections assumed a notably higher average annual growth rate (1.41%) than those assumed in the more current 2014 DOL population projections (0.34%). Woods & Poole estimates an average annual population growth rate of 0.60% to the year 2050, which is higher than the new DOL forecast but lower than the prior 2012 DOL forecast.

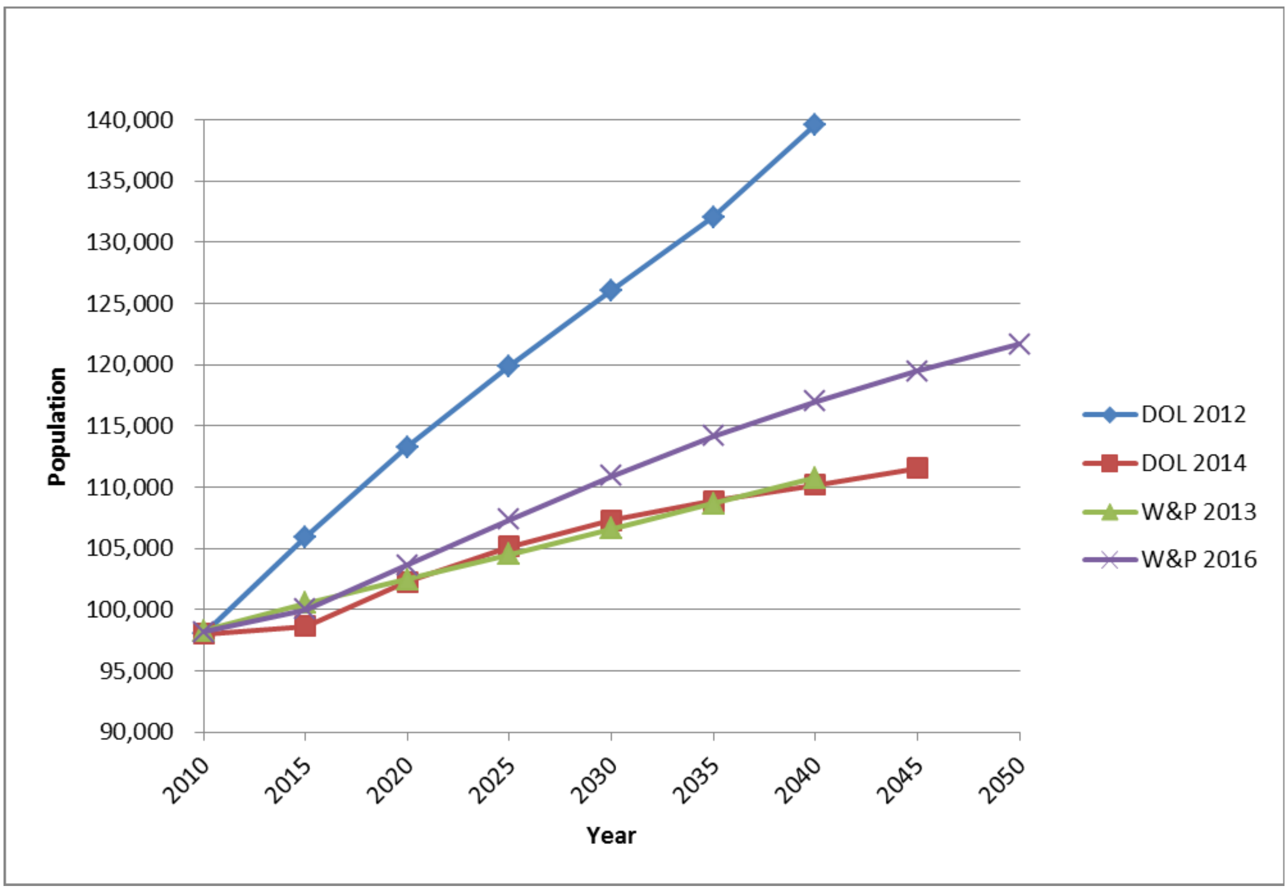
Table 3: Comparison of FNSB Population Forecasts (2010-2050)

Projection Series	2010	2015	2020	2025	2030	2035	2040	2045	2050	Average Annual Growth Rate[1]
2012 DOL[1]	98,000	105,928	113,275	119,910	126,067	132,076	139,620	n/a	n/a	1.41%
2014 DOL[1]	98,000	98,645	102,237	105,139	107,276	108,869	110,197	111,562	n/a	0.34%
2013 W&P[1]	98,279	100,539	102,471	104,528	106,596	108,656	110,764	n/a	n/a	0.42%
2016 W&P	98,174	100,000	103,643	107,326	110,933	114,192	117,009	119,460	121,664	0.60%
Compare 2016 W&P to 2014 DOL	-1.4%	-1.4%	-2.0%	-3.3%	-4.7%	-5.8%	-6.6%	-7.9%	n/a	

[1] Annual growth rates based on linear trend lines for population forecasts between 2010 and 2040.

Source: Alaska DOL, 2012; Alaska DOL, 2014; Woods & Poole, 2013; Woods & Poole, 2016.

Figure 4: Comparison of FNSB Population Forecasts (2010-2050)



Employment Forecast

Table 4 shows the current long-term forecast for industry sectors as projected by Woods & Poole. The forecast assumes a total employment change of 44% between 2015 and 2050, corresponding to a 0.87% annual growth rate. Table 4 also documents the annual growth rate for each industry sector. As shown, the Retail (114%), Wholesale (82%), Agriculture (58%), and Professional Services (58%) sectors are projected to experience the greatest growth rates. In particular, Woods & Poole projects virtually no growth in military employment in the Fairbanks area.

Table 4: Employment Projections, 2015-2050

Industry Sector	2015	2020	2025	2030	2035	2040	2045	2050	Growth (%)	Annual Growth Rate (%)
Agriculture	271	294	317	340	363	386	408	429	58.3%	1.06%
Resources/Mining	3,081	3,288	3,505	3,730	3,962	4,201	4,446	4,697	52.5%	0.98%
Construction	3,623	4,060	4,444	4,712	4,914	5,106	5,327	5,574	53.9%	0.95%
Manufacturing	938	1,009	1,062	1,107	1,148	1,187	1,225	1,262	34.5%	0.71%
Wholesale	885	993	1,093	1,197	1,302	1,406	1,507	1,609	81.8%	1.28%
Retail	5,956	6,783	7,567	8,426	9,369	10,401	11,531	12,766	114.3%	1.51%
Trans/Ware/Utility	2,501	2,554	2,652	2,750	2,835	2,901	2,948	2,980	19.2%	0.49%
Prof Services	8,142	8,828	9,535	10,247	10,945	11,618	12,258	12,875	58.1%	1.06%
Health Services	5,854	6,340	6,856	7,383	7,884	8,333	8,714	9,034	54.3%	1.03%
Leisure/Hospitality	5,439	5,785	6,135	6,441	6,669	6,897	7,152	7,406	36.2%	0.74%
Other Services	2,336	2,470	2,614	2,763	2,915	3,067	3,217	3,363	44.0%	0.88%
Government	11,470	12,125	12,694	13,171	13,554	13,855	14,098	14,298	24.7%	0.56%
Military	8,355	8,380	8,405	8,429	8,454	8,479	8,504	8,529	2.1%	0.06%
Total Employment	**58,851**	**62,909**	**66,879**	**70,696**	**74,314**	**77,837**	**81,335**	**84,822**	**44.1%**	**0.87%**

Source: Woods & Poole, 2016.

Table 5 and Figure 5 provide the long-term (2040) employment forecast comparison between the previous and current Woods & Poole projections. The comparison of growth rates only extends to 2040, as 2040 was the last forecast year for the 2013 Woods & Poole projections. The newer forecasts result in 4.2 percent more jobs by 2040 compared to the prior forecasts.

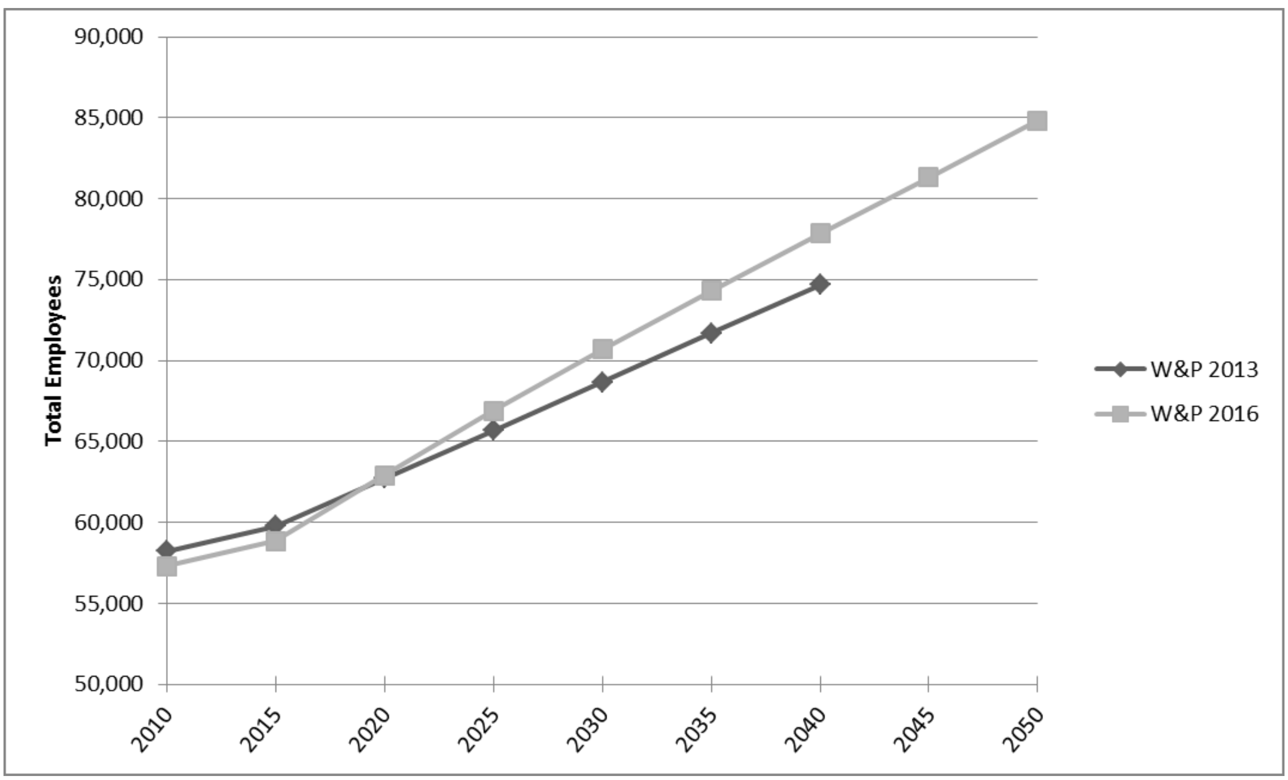
The most significant increases between the growth rates in the prior and current forecasts are in the Resource/Mining and Retail sectors. Large percentage changes are projected for the Agriculture and Manufacturing sectors, but the increases in numbers of employees are relatively small (change in 30-year employee growth from 37 to 120 for agriculture and from 53 to 336 for manufacturing). The newer forecasts result in slower growth in the Health Services sector.

Table 5: Comparison of FNSB Employment Growth by Sector

Industry Sector	2013 Woods & Poole			2016 Woods & Poole		
	2010	2040	Growth (%)	2010	2040	Growth (%)
Agriculture	213	250	17.4%	266	386	45.1%
Resources/Mining	1,924	2,552	32.6%	2,175	4,201	93.1%
Construction	3,754	5,223	39.1%	3,665	5,106	39.3%
Manufacturing	905	958	5.9%	851	1,187	39.5%
Wholesale	780	1,350	73.1%	758	1,406	85.5%
Retail	5,751	8,331	44.9%	5,616	10,401	85.2%
Trans/Ware/Utility	2,900	3,756	29.5%	2,414	2,901	20.2%
Prof Services	8,619	11,584	34.4%	8,500	11,618	36.7%
Health Services	5,540	9,632	73.9%	5,572	8,333	49.6%
Leisure/Hospitality	5,261	7,017	33.4%	5,192	6,897	32.8%
Other Services	2,440	3,153	29.2%	2,101	3,067	46.0%
Government	11,550	12,535	8.5%	11,561	13,855	19.8%
Military	8,591	8,344	-2.9%	8,621	8,479	-1.6%
Total Employment	**58,228**	**74,685**	**28.3%**	**57,292**	**77,837**	**35.9%**

Source: Woods & Poole, 2013; Woods & Poole, 2016.

Figure 5: Comparison FNSB Employment Forecasts



RECOMMENDED FORECASTS

Recommendations are provided for a "base forecast" and for additional potential activities which would increase the population and employment forecasts above the base. The "base forecast" refers to the population and employment forecasts based on documented sources, and without explicit consideration of changes due to EAFB or the LNG project. The potential changes due to EAFB and the LNG project are also described.

Recommended Base Forecasts without Additional Activity

The base total population and employment forecasts are summarized in Table 6, excluding the effects of potential changes at EAFB and the LNG Project. The average annual growth rates are not strictly the averages of the individual growth rates, but are instead summarized annual growth rates based on a statistical analysis of the recommended forecasts by 5-year increments described in the following sections.

Table 6: Comparison of FNSB Growth Rates without Additional Activity

Forecast	Population	Employment
Historic	0.96%	1.05%
Alaska Department of Labor	0.37%	n/a
Woods & Poole	0.51%	1.26%
Recommended	**0.66%**	**1.15%**

Source: Kittelson & Associates, 2016

Base Population Forecast

It is recommended that the base population forecast use an average of the three available sources: historical trends, Alaska DOL and Woods & Poole. The historical trends were extrapolated from the 2015 population using the average 0.96% annual growth rate from 1985-2015. The recommended base forecast for each five year increment is the average of the extrapolated historical growth, the Woods & Poole forecast and the DOL forecast (Table 7). A statistical analysis of the average population numbers results in a 0.66% annual population growth rate.

Table 7: Recommended Base Population Forecast

	2015	2020	2025	2030	2035	2040	2045	2050	Growth (%)
Historical	100,000	104,800	109,600	114,400	119,200	124,000	128,800	133,600	0.96%
W&P Forecast	100,000	103,643	107,326	110,933	114,192	117,009	119,460	121,664	
DOL Forecast	98,645	102,237	105,139	107,276	108,869	110,197	111,562	111,993	
Average	99,548	103,560	107,355	110,870	114,087	117,069	119,941	122,419	0.66%

Base Employment Forecast

Woods & Poole projects a higher employment growth rate than the historical employment growth rate. For employment forecasts, it is recommended that an average of the historical trends and Woods & Poole be used (Table 8). The historical trends were extrapolated from the 2015 employment using the average 1.05% annual growth rate from 1985-2015. A statistical analysis of the averages results in a 1.15% annual employment growth rate.

Table 8: Recommended Base Employment Forecast

	2015	2020	2025	2030	2035	2040	2045	2050	Growth (%)
Historical	58,851	61,945	65,039	68,132	71,226	74,320	77,414	80,508	1.05%
W&P Forecast	58,851	62,909	66,879	70,696	74,314	77,837	81,335	84,822	1.26%
Average	58,851	62,427	65,959	69,414	72,770	76,079	79,374	82,665	1.15%

Once the total employment forecasts are established, it is recommended that the percentages from the Woods & Poole forecasts be used to allocate employment type by sector for each five year time period.

ADDITIONAL POPULATION AND EMPLOYMENT GROWTH

Additional population and employment growth beyond the “base forecasts” may occur related to the basing and operation of two F-35A squadrons at EAFB and to the LNG Project.

Eielson Air Force Base

The expansion of the EAFB will involve phased workforce increases during construction and at full build-out. Construction activity is anticipated to start in 2017 and continue through 2022, while the EAFB workforce is anticipated to be phased across a five year period, between 2017 and 2022.

An initial estimate of population and employment growth associated with the F-35A deployment was documented in the United States Air Force, “F-35A Operational Beddown – Pacific Environmental Impact Statement,” February, 2016 (EIS) as summarized in FNSB, Baseline and Projected Populations for EAFB Memorandum, June 29, 2016. Since the publication of the EIS, the Air Force has conducted additional studies of potential effects in the Fairbanks area. The most recent available projections were prepared by Northern Economics on October 31, 2017. The newer projections use a more comprehensive forecast model by Regional Economics Models, Inc. (REMI) which consider a wide variety of induced population and employment effects.

Table 9 provides a summary of the anticipated growth in population and employment related to the EAFB expansion.

Table 9: EAFB Additional Population and Employment Growth

	2015	2020	2022	2025	2030	2035	2040	2045
Population								
EAFB Personnel	0	569	1,353	1,353	1,353	n/a	n/a	n/a
EAFB Contractors	0	n/a	121	121	121	n/a	n/a	n/a
EAFB Dependents	0	n/a	1,798	1,798	1,798	n/a	n/a	n/a
EAFB Induced	0	n/a	n/a	n/a	2,152	n/a	n/a	n/a
TOTAL	0	n/a	n/a	n/a	5,424	n/a	n/a	n/a
Total Employment	0	620	1,474	1,474	1,474	n/a	n/a	n/a

Source: Northern Economics, "F-35A Beddown and Military Construction," October 31, 2017.

A summary of the population and employment growth assumptions are provided below:

- Total population increase of 3,272 military personnel, civilian personnel, and their dependents phased in between 2017 and 2022);
- An additional induced population (births, etc… associated with increased population) of 2,152 by 2030

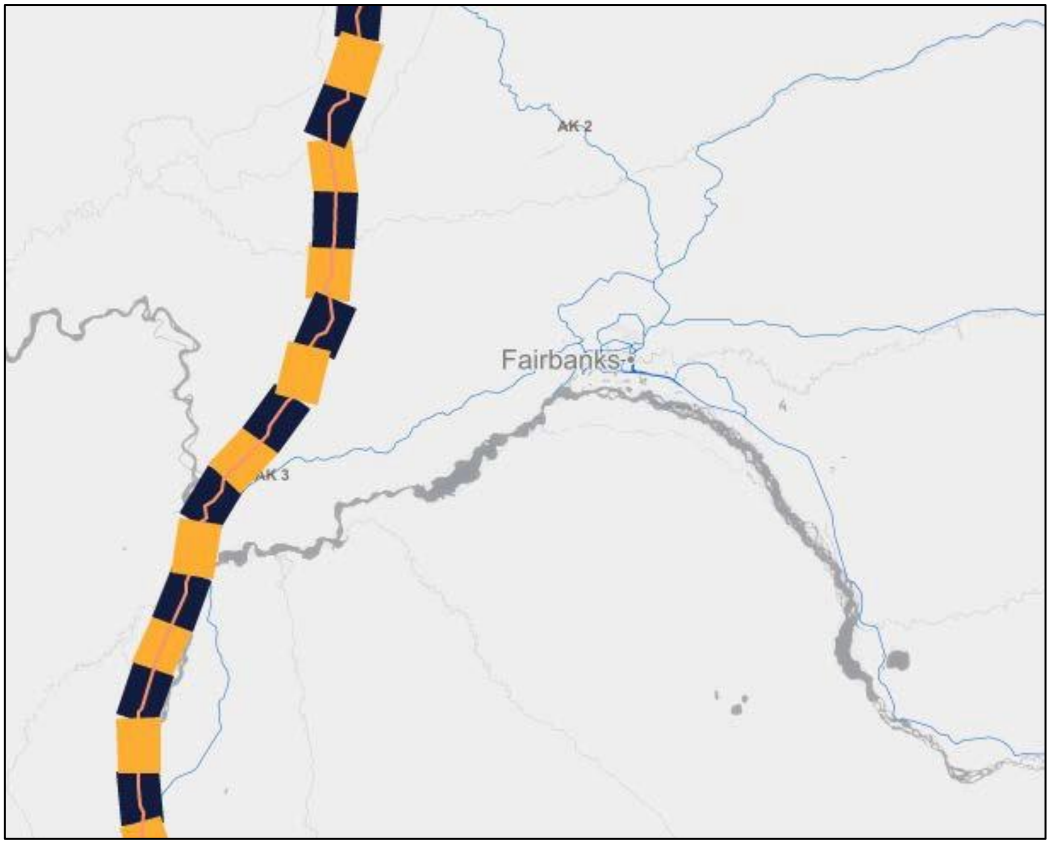
The Northern Economics summary did not include several components of growth. These have been estimated separately based on proportions from the information provided:

- EAFB personnel, contractors and dependents are assumed to remain at 2030 levels for years beyond 2030.
- The numbers of contractors for years prior to 2022 are estimated based on the 2022 proportions of contractors to Air Force personnel.
- The numbers of dependents for years prior to 2022 are estimated based on the 2022 proportions of dependents to Air Force personnel.
- The induced population growth for years prior to 2030 is estimated based on the proportions to Air Force personnel. The induced population after 2030 is assumed to grow at the same rate as the base (non-EAFB) population forecast.
- EAFB construction jobs were estimated based on an earlier Northern Economics projection dated September 22, 2017.
- Additional induced employment was estimated to serve the additional population, based on the proportion of base (non-EAFB) employment to base (non-EAFB) population.

Alaska Liquid Natural Gas Project

Potential construction of the proposed LNG Project could have temporary and permanent impacts on population and employment in the Fairbanks area. The proposed alignment of the LNG pipeline would be along the western edge of the Fairbanks North Star Borough (Figure 6).

Figure 6: Potential Alaska LNG Pipeline Alignment



Source: http://alaska-lng.com/project-overview/map/

The LNG project is still under study, and the schedule for its implementation is uncertain at this time. A feasibility study prepared by Wood Mackenzie in August 2016[1] stated that, "currently the competitiveness of the Alaska LNG project ranks poorly when compared to competing LNG projects…. This ranking also means that not only will the project not make sufficient returns for investors at current LNG market prices, but it may struggle to make acceptable returns even under a US $70/barrel price. There are certain levers that could be used to improve the competitiveness of the Alaska LNG project and potentially also improve the competitiveness compared with other

[1] Wood Mackenzie, Alaska LNG Competitiveness Study (presentation), August 2016.

jurisdictions." As of December, 2016, the Alaska Gasline Development Corp. (AGDC), a state entity, was taking over the technical and regulatory activities associated with the LNG project.[2]

A set of resource reports were prepared for the LNG in 2016, with one of them covering potential impacts on population and employment[3]. The report states that, "Project data are not yet available for modeling. These data would be incorporated when available. As a result, Draft 2 of Resource Report No. 5 provides a qualitative discussion of potential Project effects by affected resource."

Resource Report 5 provides the following information:

- The first phase of construction was projected for 2019 to 2025 and would include most of the pipelines, liquefaction facilities and marine facilities.
- Operations and the second phase of construction would start in 2025.
- The new local resident population increases caused by Project construction would likely be highest in the main economic activity centers of Fairbanks, Anchorage, or around other identified pick up locations, the Kenai Peninsula Borough (KPB), and the Matanuska-Susitna Borough (MSB).
- Fairbanks and Anchorage would be the primary locations in Alaska where goods and services for the Project would be purchased from local businesses during the construction phase. The additional temporary economic activity and jobs these purchases would generate are expected to result in an increase in the populations of the two cities. In addition, Fairbanks and Anchorage, together with the KPB and MSB, would be where many of the persons directly and indirectly working on the Project would spend a portion of their incomes on consumer goods and services. The additional jobs this spending would generate are expected to also result in temporary population increases in the affected areas.
- Project construction would create temporary and seasonal increases in jobs in Alaska. The employment effects of construction would be felt primarily from 2019 through 2027.
- The additional economic activity and jobs that would be generated by the Project in Fairbanks and Anchorage would temporarily result in a substantial increase in local demand for housing in absolute terms, but the increase in percentage terms would be minor due to the large existing supply of temporary accommodations in the municipalities.
- Most permanent employment after construction would be in the Anchorage area or near the liquefaction facility in the KPB. Of the approximately 700 operations personnel projected for the Project, approximately 400 are anticipated to be located in Anchorage.

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[2]Natural Gas Intelligence website, http://www.naturalgasintel.com/articles/108904-state-of-alaska-taking-over-pipeline-lng-project-from-producers, December 30, 2016.

[3] Alaska LNG Project, "Draft Resource Report No. 5, Socioeconomics," July, 2016

Potential Temporary LNG Effects

Temporary changes would occur during the pipeline construction period and would be expected to be greater than the permanent changes. These would include Fairbanks' role as a base for residences of construction workers, materials suppliers and their employees, and auxiliary businesses that support the construction activity. Changes in population and employment during construction may affect a focused five to ten year period but would not necessarily significantly revise the long-term population and employment forecasts to the year 2045.

Potential Long Term LNG Effects

Permanent changes in population and employment would depend on Fairbanks' role in the ongoing operation and maintenance of a LNG pipeline. Although most of the permanent employment would be in Anchorage or KPB, it would be reasonable to assume that there would be some ongoing presence of LNG and LNG-related employees in the Fairbanks area. That number would not be expected to significantly change the overall population and employment growth rates.

Recommendation

It is recommended that the current population and employment forecasts for FNSB not include any adjustments for the LNG project. This is due to the following considerations:

- The long-term effects of LNG operation in the Fairbanks area are expected to be minimal after the construction period.
- The financing and implementation of the project is uncertain at this time.
- Quantification of the population and employment changes associated with construction are not yet available.

RECOMMENDED FORECASTS WITH ADDED ACTIVITY

Table 10 and Table 11 show the recommended FNSB population and employment forecasts, respectively, for each five year increment, and for several interim years required for air quality analysis. The recommended forecasts assume a base population and employment forecast, and the added growth resulting from the EAFB expansion.

Indirect employment associated with EAFB would represent additional employment to serve the additional population. The indirect employment was estimated based on maintaining the ratio of total employment to total population, increasing the total employment associated with the additional population compared to the base population, then subtracting the additional employment that would be directly employed at EAFB. This maintains the overall proportions of total employment to total population.

Table 10: Recommended Population Forecast

		2015	2017	2019	2020	2021	2022	2023	2024	2025	2030	2035	2040	2045	2050	Growth (%)	Annual Growth Rate (%)
Base Population		99,548	101,153	102,758	103,560	104,319	105,078	105,837	106,596	107,355	110,870	114,087	117,069	119,941	122,419	22.97%	0.66%
Eielson AFB Personnel		0	18	104	569	1,186	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353		
Eielson AFB IContractors		0	2	9	51	106	121	121	121	121	121	121	121	121	121		
Eielson AFB Dependents		0	24	138	756	1,576	1,798	1,798	1,798	1,798	1,798	1,798	1,798	1,798	1,798		
Eielson AFB Induced		0	4	44	302	755	1,004	1,148	1,291	1,435	2,152	2,152	2,152	2,152	2,152		
Alaska LNG																	
Total Population		**99,548**	**101,200**	**103,053**	**105,238**	**107,942**	**109,354**	**110,257**	**111,159**	**112,062**	**116,294**	**119,573**	**122,613**	**125,541**	**128,067**	**28.65%**	**0.82%**
5-Year Growth					5,689					6,824	4,232	3,280	3,040	2,928	2,526		
5-Year Growth Rate (%)					5.72%					6.48%	3.78%	2.82%	2.54%	2.39%	2.01%		

Table 11: Recommended Employment Forecast

Industry Sector	Category	2015	2017	2019	2020	2021	2022	2023	2024	2025	2030	2035	2040	2045	2050	Growth (%)	Annual Growth Rate (%)
Agriculture	Industrial	271	279	288	292	296	300	304	308	313	334	355	377	398	418	54.28%	1.55%
Resources/Mining	Industrial	3,081	3,154	3,226	3,263	3,302	3,340	3,379	3,418	3,457	3,662	3,880	4,106	4,339	4,578	48.57%	1.39%
Construction	Industrial	3,623	3,785	3,948	4,029	4,100	4,170	4,241	4,312	4,383	4,627	4,812	4,991	5,199	5,432	49.94%	1.43%
Manufacturing	Industrial	938	963	989	1,001	1,010	1,020	1,029	1,038	1,047	1,087	1,124	1,160	1,195	1,230	31.12%	0.89%
Wholesale	Industrial	885	925	965	985	1,004	1,022	1,041	1,059	1,078	1,175	1,275	1,374	1,471	1,568	77.18%	2.21%
Retail	Retail	5,956	6,266	6,576	6,731	6,877	7,024	7,170	7,317	7,463	8,273	9,174	10,166	11,253	12,441	108.89%	3.11%
Trans/Ware/Utility	Industrial	2,501	2,514	2,528	2,534	2,551	2,567	2,583	2,599	2,616	2,700	2,776	2,835	2,877	2,904	16.12%	0.46%
Prof Services	Office	8,142	8,389	8,637	8,760	8,889	9,018	9,146	9,275	9,404	10,061	10,718	11,356	11,963	12,548	54.11%	1.55%
Health Services	Office	5,854	6,029	6,204	6,291	6,385	6,480	6,574	6,668	6,762	7,249	7,720	8,145	8,504	8,804	50.40%	1.44%
Leisure/Hospitality	Retail	5,439	5,560	5,680	5,741	5,803	5,865	5,927	5,989	6,051	6,324	6,530	6,741	6,980	7,218	32.70%	0.93%
Other Services	Industrial	2,336	2,382	2,428	2,451	2,476	2,502	2,527	2,553	2,578	2,713	2,854	2,998	3,139	3,277	40.30%	1.15%
Government	Office	11,470	11,695	11,920	12,032	12,130	12,227	12,324	12,422	12,519	12,932	13,272	13,542	13,758	13,934	21.49%	0.61%
Military	Military	8,355	8,339	8,324	8,316	8,310	8,305	8,300	8,295	8,289	8,276	8,278	8,287	8,299	8,312	-0.51%	-0.01%
Total Base		**58,851**	**60,281**	**61,712**	**62,427**	**63,133**	**63,840**	**64,546**	**65,252**	**65,959**	**69,414**	**72,770**	**76,079**	**79,374**	**82,665**	**40.46%**	**1.16%**

Eielson AFB Military	Not in Model	0	20	113	620	1,292	1,474	1,474	1,474	1,474	1,474	1,474	1,474	1,474	1,474		
Eielson AFB Construction	Not in Model	0	235	821	852	783	701	564	443	339	109	109	109	109	109		
Eielson AFB Indirect	Retail	0	0	0	0	27	98	153	205	253	433	467	504	545	590		
Eielson AFB Indirect	Industrial	0	0	0	0	32	114	177	235	289	483	507	532	556	582		
Eielson AFB Indirect	Office	0	0	0	0	59	211	328	436	537	897	942	985	1,022	1,059		
Alaska LNG	Industrial	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Total Employment		**58,851**	**60,536**	**62,646**	**63,899**	**65,326**	**66,438**	**67,241**	**68,046**	**68,851**	**72,810**	**76,270**	**79,682**	**83,080**	**86,479**	**46.95%**	**1.34%**
5-Year Growth					5,048					4,952	3,960	3,460	3,412	3,399	3,398		
5-Year Growth Rate (%)					8.58%					7.75%	5.75%	4.75%	4.47%	4.27%	4.09%		

Construction jobs estimated from Northern Economics, "Updated Population Forecasts," September 22, 2017 - difference between Approved + Pending with and without military construction projects.

Indirect employment estimated as ratio of base employment/base population * revised population.

Note: Forecasts directly from the Northern Economics forecasts from October 31, 2017 are shown in grey shading. Other EAFB forecasts are estimated based on these inputs.

Attachment C

MOVES Operating Mode Distribution Adjustments to Reflect Plug-In Benefits

Approach Used to Account for Plug-In Block Heater Emission Effects Using MOVES in Fairbanks $PM_{2.5}$ SIP Inventories

Overview

Engine block heaters or "plug-ins" are widely used in Fairbanks during winter to ensure engine startup and drivability during harsh ambient conditions. Based on chassis dynamometer emission testing conducted in Fairbanks during winter 2010-2011, they also provide a significant reduction in vehicle starting emissions by keeping the engine warmer than the ambient environment when parked with the engine off. Within the Fairbanks $PM_{2.5}$ SIP, the effects of these plug-in reductions are not being accounted for as a control measure but rather as an adjustment to baseline (and projected baseline) light-duty vehicle starting exhaust emissions.

EPA's MOVES2014b vehicle emissions model is being used to generate vehicle emissions for the on-road mobile source portion of the SIP inventory. Despite MOVES' far-reaching scalability and the complex set of conditions it is designed to address, the model's input structure does not explicitly incorporate support for cold temperature plug-in effects. However, an approach was conceptually designed and informally presented to EPA/OTAQ that accounts for measured plug-in effects by iteratively adjusting MOVES' default *OpModeDistribution* table in a manner that when executed, generates reductions in output start exhaust emissions that equal those from the local measurement study (as a function of ambient temperature).

The processes for assembling local fleet, activity, ambient and other SIP-level inputs to MOVES and running the model follow EPA guidance and are explained elsewhere in the Fairbanks SIP. This document focuses on describing how measured emission reductions from block heater plug-in use in Fairbanks during winter were accounted for via iterative adjustment to the starting operating mode distributions used within the model. The approach specifically adheres to OTAQ's requirement that it be applied within MOVES' inputs and design structure, rather than as an off-model adjustment. The following explanation provides a "proof of concept" of these procedures for the 2013 baseline calendar year fleet and a single winter daily average temperature of -20°F. Within the SIP inventories, similar procedures are being applied for a range of daily average ambient temperatures from -50°F to 0°F at 10°F increments to cover the entire range of ambient conditions across the SIP attainment modeling episodes.

Measurement-Based Plug-In Reductions

Table 1 summarizes the reductions in starting exhaust $PM_{2.5}$ developed from measured data in the Fairbanks 2010-2011 testing program resulting from use of plug-ins while a vehicle is parked or "soaked." The column "Default Daily Soak Dist" lists the daily average soak time fractions extracted from MOVES for light-duty vehicles. The next column, "% $PM_{2.5}$ Redn" shows relative starting exhaust $PM_{2.5}$ emission reductions developed from the measurement data as a function of soak time. The plug reductions are as expressed percentages relative to the emissions of the vehicle if it had not been plugged in when parked. Only reductions for $PM_{2.5}$ are shown. (Although plug-in effects were also measured for gaseous pollutants, only directly emitted $PM_{2.5}$ reductions are applied for the SIP inventory adjustments.) The rightmost columns show plug-in usage fractions (percentage of trips) as a function of both soak time and ambient temperature.

Table 1 **Local Measurement-Based Starting Exhaust $PM_{2.5}$ Emission Reductions from Plug-In Use**									
OpMode ID	Soak Time Intervals (min.)	Default Daily Soak Dist.	% $PM_{2.5}$ Redn	% Plug-In Use as a Function of Soak Time (minutes) and Daily Ambient Temperature (°F)					
				-50°F	-40°F	-30°F	-20°F	-10°F	0°F
101	Soak Time < 6	0.185	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
102	6 ≤ to < 30	0.205	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
103	30 ≤ to < 60	0.096	4.4%	25.9%	14.0%	2.4%	0.0%	0.0%	0.0%
104	60 ≤ to < 90	0.058	7.3%	44.4%	32.5%	20.8%	9.4%	0.0%	0.0%
105	90 ≤ to < 120	0.042	10.3%	56.6%	44.7%	33.1%	21.6%	10.4%	0.0%
106	120 ≤ to < 360	0.162	23.5%	86.8%	74.9%	63.2%	51.8%	40.6%	29.6%
107	360 ≤ to < 720	0.114	53.0%	100.0%	100.0%	93.1%	81.7%	70.5%	59.5%
108	720 ≤ Soak Time	0.139	70.8%	100.0%	100.0%	100.0%	100.0%	89.4%	78.4%
Daily Composite Plug-In Trip Fraction (%)				39.9%	35.9%	31.3%	27.4%	22.6%	18.5%
Daily Composite Plug-In $PM_{2.5}$ Reduction (%)				16.4%	15.9%	15.1%	**14.1%**	12.2%	10.4%

At the bottom of Table 1, daily composite plug-in usage fractions and $PM_{2.5}$ starting exhaust reductions are shown. Table 2 shows the adjusted OpMode Distribution that leads to a 14.1% reduction in direct $PM_{2.5}$ starting emissions for gasoline LDVs at -20°F in Fairbanks. The steps leading to the formulation of that adjusted MOVES *OpModeDistribution* table are explained in detail in the following section.

Table 2 **OpMode Distribution Adjustment to Achieve 14.1% Direct $PM_{2.5}$ Start Emission Reductions for Gasoline LDVs at -20°F**		
OpMode ID	Soak Time Intervals (minutes)	Adjusted OpMode Distribution
101	Soak Time < 6	0.225
102	6 ≤ Soak Time < 30	0.247
103	30 ≤ Soak Time < 60	0.116
104	60 ≤ Soak Time < 90	0.069
105	90 ≤ Soak Time < 120	0.050
106	120 ≤ Soak Time < 360	0.108
107	360 ≤ Soak Time < 720	0.082
108	720 ≤ Soak Time	0.103
Resulting Start Exh. Direct $PM_{2.5}$ Reduction		14.1%

MOVES Modeling Steps

1. *Enable Save Generators in Base RunSpec* - An existing Fairbanks MOVES RunSpec was loaded reflecting 2008 vehicle activity and population. This run was configured to span weekends and weekdays. The run configuration was modified to run in inventory mode and the input temperature was set to a fixed -20°F for all hours of the day. The "Start Operating Mode Distribution Generator" option within the Advanced Performance Features Panel was enabled (checking Save Data) to save the model's "default" OpModeDistribution values that are dynamically generated during execution for the baseline run. General output options were set to capture starts and population and units were configured for grams, joules and miles for the mass, energy and distance respectively. Output emissions details for time and location were set to "Hour" and "County". All other fields in the "Output Emission Detail" panel were left at defaults except the Fuel Type, Emission Process and Source Use Type options were all checked.

2. *Execute Baseline Run* - The MOVES model was then executed to generate and output emissions reflecting the baseline or unadjusted operating mode distributions. MOVES outputs were exported to a processing spreadsheet in which daily starting exhaust emissions were tabulated for gasoline passenger cars (SourceTypeID=21) and passenger trucks[70] (SourceTypeID=31) to determine baseline starting exhaust emissions prior to adjusting operating mode distributions.

3. *Export Baseline Operating Mode Distributions* - The data in the Start Operating Mode Distribution Generator were exported into a spreadsheet in order to adjust the *OpModeDistribution* table for light duty vehicle starts (source types 21 and 31) using fuel type 1 (gasoline) for the $PM_{2.5}$ pollutant processes (polprocid 11102 and 11202).

4. *Adjust Starting Operating Mode Distributions* - Adjustments to the baseline distributions were performed by reducing the frequencies in the longer soak categories and increasing fractions in the shorter soak categories to simulate the effects of reduced start exhaust emissions. The cutoff between long and short soak categories was arbitrarily set at OpModeID 106 (2 to 6-hour soaks). Frequencies for OpModeIDs 106,107,108 were decreased using a constant multiplier for each of these three soak categories. Once those soak categories were reduced all of the soak categories for source types 21 and 31 for the $PM_{2.5}$ pollutant processes were then renormalized to sum to 1. The initial adjustment multiplier was set to 80% (0.80). A new set of starting OpMode distributions were then calculated in this manner. These adjustment multipliers were applied universally over all hours of the day for the aforementioned source types, but using the hour-specific soak fractions reflected in the baseline *OpModeDistribution* table.

[70] The analysis and adjustments were restricted to gasoline-fueled cars and passenger trucks because the plug-in measurement study was limited to these vehicle types. Although plug-in reductions may occur for other vehicle types, those reductions were not measured. Therefore, adjustments made within MOVES were restricted to those vehicle and fuel types for which test measurements were collected.

5. *Load Adjusted Operation Model Distributions* - The adjusted OpMode distributions were exported from Excel and then imported into a new separate MySQL database and *OpModeDistribution* table matching the structure required by MOVES.

6. *Create RunSpec for Adjusted Distributions and Re-Run MOVES* - The MOVES model was then configured with the existing default inputs with the adjusted *OpModeDistribution* table imported through the Manage Inputs Data Sets panel of the MOVES GUI. No other configuration changes from the baseline RunSpec were made except to change the output database name. The model was then executed again to generate start emission outputs using the new *OpModeDistribution* table.

7. *Tabulate and Compare Starting Exhaust Emission Outputs* - The MOVES outputs were exported for this revised simulation and compared against the original emissions outputs from the baseline run.

Steps 4 through 7 were repeated a number of times until the start emission outputs from Source Types 21 and 31 using Fuel Type 1 showed an emission reduction of 14.1% from the baseline MOVES run based on the default OpMode distributions. (As shown earlier in Table 1, 14.1% is the daily composite $PM_{2.5}$ reduction from plug-in use for the proof-of-concept test case at -20°F.)

Table 3 shows the results of these iterations for the multipliers, daily OpMode distribution composites and emissions reductions. After five iterations, the adjusted OpMode distributions using a 51.4% multiplier yielded a targeted 14.1% reduction in starting exhaust $PM_{2.5}$.

Table 3
Iterative Approach to OpMode Distribution Adjustments and Start Emission Reductions for Gasoline LDVs at -20°F[71]

OpMode ID	Soak Time Intervals (minutes)	Default Distribution	Iterations				
			1	2	3	4	5
101	Soak Time < 6	0.185	0.199	0.239	0.227	0.226	0.225
102	6 ≤ Soak Time < 30	0.205	0.220	0.260	0.248	0.247	0.247
103	30 ≤ Soak Time < 60	0.096	0.103	0.123	0.117	0.117	0.116
104	60 ≤ Soak Time < 90	0.058	0.062	0.072	0.069	0.069	0.069
105	90 ≤ Soak Time < 120	0.042	0.045	0.052	0.050	0.050	0.050
106	120 ≤ Soak Time < 360	0.162	0.143	0.092	0.106	0.108	0.108
107	360 ≤ Soak Time < 720	0.114	0.103	0.072	0.081	0.082	0.082
108	720 ≤ Soak Time	0.139	0.126	0.090	0.101	0.102	0.103
OpMode Distribution Adjustment Multiplier			80%	40%	50%	51%	51.4%
Resulting Start Exh. Direct $PM_{2.5}$ Reduction			5.1%	18.5%	14.6%	14.3%	**14.1%**

[71] See Table 1 for the measurement-based daily-composite $PM_{2.5}$ reduction target for -20°F along with the range of $PM_{2.5}$ reduction targets spanning temperatures -50°F to 0°F.

Adjustments to the OpMode distributions were restricted to directly emitted $PM_{2.5}$ for light-duty passenger vehicle source types 21 and 31. As explained earlier, no plug-in adjustments were developed for gaseous pollutants. Therefore a separate set of MOVES runs based on the default soak distributions were used to estimate emission rates for gaseous pollutants within the SIP on-road inventory workflow. This separate MOVES run was also require to calculate the $PM_{2.5}$ emissions from the source types other than 21 and 31 as well as the emissions from vehicles in source types 21 and 31 using fuels other than gasoline.

The steps laid out above are being repeated over the range of temperatures modeled during the 2008 baseline episodes. The OpMode distribution adjustments are being calculated at 10°F intervals from -50°F to 0°F to cover the full range of possible conditions and provide reasonable plugin benefits over the two SIP attainment modeling episodes.

Based on the information in Table 1 and using the steps laid out above OpMode distribution adjustments were iteratively calculated for -50°F and 0°F, the two endpoints of the temperature range used in the SIP modeling. The target reduction in starting exhaust directly emitted $PM_{2.5}$ would be 16.4% at -50°F. Two deviations were made from the methodology used for the -20°F. First the baseline starting emissions were calculated using a uniform daily temperature input of -50°F. And second the starting OpMode distribution adjustment multiplier was set based on the final step in the -20°F scenario. Table 4 summarizes the three iterative adjustments made to capture the final targeted direct $PM_{2.5}$ starting exhaust reduction of 16.4%.

Table 4
Iterative Approach to OpMode Distribution Adjustments and Start Emission Reductions for Gasoline LDVs at -50°F[72]

OpMode ID	Soak Time Intervals (minutes)	Default Distribution	Iterations 1	Iterations 2	Iterations 3
101	Soak Time < 6	0.185	0.225	0.214	0.234
102	6 ≤ Soak Time < 30	0.205	0.247	0.236	0.256
103	30 ≤ Soak Time < 60	0.096	0.116	0.111	0.121
104	60 ≤ Soak Time < 90	0.058	0.069	0.066	0.071
105	90 ≤ Soak Time < 120	0.042	0.050	0.048	0.051
106	120 ≤ Soak Time < 360	0.162	0.108	0.122	0.097
107	360 ≤ Soak Time < 720	0.114	0.082	0.091	0.075
108	720 ≤ Soak Time	0.139	0.103	0.113	0.094
OpMode Distribution Adjustment Multiplier			51.4%	43.5%	45.3%
Resulting Start Exh. Direct $PM_{2.5}$ Reduction			14.1%	17.1%	**16.4%**

[72] See Table 1 for the measurement-based daily-composite $PM_{2.5}$ reduction target for -50°F along with the range of $PM_{2.5}$ reduction targets spanning temperatures -50°F to 0°F.

The 0°F scenario again followed the approach from the -20°F with the exceptions of the meteorology profile inputs reflecting 0°F hourly temperatures and the first iteration adjustment. The first iteration adjustment at 0°F was determined based on interpolating the -20°F results between the 80% adjustment and 5.1% direct $PM_{2.5}$ reduction and 51.4% adjustment with 14.1% direct $PM_{2.5}$ reduction. Interpolation yields an estimated adjustment of 63.2% for the first iteration step. Table 5 summaries the OpMode Distribution adjustments and resulting direct $PM_{2.5}$ starting exhaust reductions for each of the three iterations.

Table 5
Iterative Approach to OpMode Distribution Adjustments and Start Emission Reductions for Gasoline LDVs at 0°F[73]

OpMode ID	Soak Time Intervals (minutes)	Default Distribution	Iterations		
			1	2	3
101	Soak Time < 6	0.185	0.213	0.215	0.214
102	6 ≤ Soak Time < 30	0.205	0.235	0.236	0.236
103	30 ≤ Soak Time < 60	0.096	0.110	0.111	0.111
104	60 ≤ Soak Time < 90	0.058	0.066	0.066	0.066
105	90 ≤ Soak Time < 120	0.042	0.047	0.048	0.048
106	120 ≤ Soak Time < 360	0.162	0.124	0.122	0.122
107	360 ≤ Soak Time < 720	0.114	0.092	0.091	0.091
108	720 ≤ Soak Time	0.139	0.113	0.112	0.113
OpMode Distribution Adjustment Multiplier			63.2%	62.1%	62.3%
Resulting Start Exh. Direct $PM_{2.5}$ Reduction			10.1%	10.5%	**10.4%**

73 See Table 1 for the measurement-based daily-composite $PM_{2.5}$ reduction target for -50°F along with the range of $PM_{2.5}$ reduction targets spanning temperatures -50°F to 0°F.

Estimating FNSB Home Heating Elasticities of demand using the Proportionally-Calibrated Almost Idea Demand System (PCAIDS) Model: Postcard Data Analysis

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Contents

Summary of Results

Findings indicate that overall household heating energy use decreased by 15% in 2016 relative to the same household level use in 2014/2015. Wood use (in cords) use decreased by approximately 32% in 2016 relative to 2014, and oil use (in gallons) decreased by approximately 9.64%. Change in overall household heating efficiency,[1] as well as differences in the severity of winter temperatures accounts for a portion of the decrease in household energy usage.[2] Results indicate that median estimates for own-price elasticities for oil are -0.274 and -0.353 respectively. Based on the predicted median values a 1% increase in the price of heating oil (mmBTU) is estimated to result in a reduction of 0.274% to 0.353% in the quantity (mmBTU) of residential heating oil consumed by the average household. As an increase in heating oil price is predicted to increase the use of firewood these predicted cross-price elasticities indicate heating oil and firewood are treated as substitutes. Based on robust regression the median cross-price elasticity of firewood with respect to a change in the price of heating oil is wood is 0.224.[3] Based on median predictions, a 1% increase in the price of heating oil (mmBTU) is estimated to increase the consumption of wood (mmBTU) approximately 0.224%.

Additionally, given a 10% increase in the price of oil and average firewood use in FNSB households of 1.68 cords (51.29 mmBTU) annually and an estimated cross-price of 0.224, a 10% increase in the price of oil translates into an additional 0.03 cords or (1.14 mmBTU) burned per household. The resulting confidence intervals for the means of the own- and cross-price

[1] On average, wood-burning devices have lower heating efficiency than oil heating devices. Thus, a relative shift from wood to oil will result in a decrease in fuel energy needed. Changes in overall household heating efficiency due to the shift in wood vs. oil use[1] account for 0.7% of the decrease in energy usage (Sierra Research Inc).
[2] Differences in the severity of winter temperatures in 2016 versus 2014 and 2015 account for 3.8% of this 15% decrease (Sierra Research Inc).
[3] Both estimates are found using a robust regression which uses a weighted estimation scheme to control for leverage exerted by potential outliers.

elasticities, at 95% confidence level, validate that the resulting coefficients for elasticity of demand and the elasticity measurements are statistically significant.

Introduction

In December of 2009, the EPA designated Fairbanks as a Serious Nonattainment Area for Particulate Matter (PM)2.5 emissions for the 2006 24-hour air quality standards. The Fairbanks North Star Borough (FNSB) has recorded some of the highest levels of PM2.5 in the United States. The largest contributors to PM2.5 in the FNSB are wood stoves and hydronic heaters.[4] Currently, two of the measures implemented to mitigate PM2.5 emissions are requiring a removal of inefficient wood heating devices when a property is sold or leased[5] and requiring commercial wood sellers to register with the state and report the moisture content of wood they are selling to residential wood-burners.[6]

According to the American Lung Association - based on PM2.5 emissions data Fairbanks ranked No. 5 in its 2016, 2017 and No. 4 in its 2018 State of the Air Report for People at Risk during Short-Term 24-hour PM2.5 episodes (State of the Air, 2016, 2017, 2018). Only four areas – all located in California ranked worse than Fairbanks during this period.

Analysis in this paper is focused on using community level household energy consumption data and prices to determine the own-price elasticities of oil and cross-price elasticities of firewood with respect to changes in the price of home heating oil from 2016-2018. Price elasticities of energy demand have become increasingly relevant in determining the economic and environmental effects of energy policies on countries and communities alike. Elasticity values can be used to help

[4] (U.S. Environmental Protection Agency, n.d.)
[5] Alaska State regulation. 18 AAC 50.077 and 18 AAC 50.079
[6] Alaska State regulation. 18 AAC 50.076(d)

identify how residents of the FNSB will alter home heating preferences in response to a change in the price of heating oil. Of particular interest, given the need to improve local air quality, is how firewood usage might change if the price of home heating oil increases if the use of lower sulfur fuels (i.e., #1 heating oil and ultra-low sulfur diesel) is mandated. The analysis draws on the "proportionally calibrated almost ideal demand system" (PCAIDS) developed by Epstein and Rubinfeld (2002) and also presented by Coloma (2006) to estimate the own- and cross-price elasticities of demand for home heating oil and firewood.

Own-price and cross-price elasticities were estimated through an application of data from the 2016 Fairbanks Home Heating Household Survey, a postcard-type instrument that provided a streamlined approach to collecting information on residential home heating practices. The survey collected more specific data on wood and heating oil usage from the same set of households in the Fairbanks North Star Borough (FNSB) during the period 2014-2016. The panel dataset provides two observations for each household surveyed making it possible to control for heterogeneity across responding units. The postcard panel data is used to estimate own-price elasticities of oil and cross-price elasticities of firewood with respect to changes in the price of home heating oil from 2014 to 2016.

Own- and Cross- Price Elasticity of Demand

Own-price elasticity of demand measures how sensitive the quantity demanded of a good or service is to a change in price. The sensitivity of the quantity of heating oil consumed by a household relative to changes in fuel price depends on several factors, including: temperature preferences, heating appliance(s) type and efficiency, the presence of alternate heating appliances in the home, home age, and overall energy efficiency of the home. Demand is said to be "inelastic" when the percentage change in quantity demanded is less than the percentage change in price. Demand is said to be "elastic" when the percentage change in quantity demanded is greater than the percentage change in price.

Cross-price elasticity of demand estimates the responsiveness in the quantity demanded of one good given the change in price of another good. In this case, we are looking at the quantity demanded of firewood given a change in the price of heating oil. When the cross-price of elasticity of demand is positive, the goods are substitutes. In the case of substitutes, as the price of one good increases, consumers can substitute with the relatively less expensive good. Meaning that, all else equal, as the price of the good increases demand for the corresponding substitute good increases. Alternatively, when the cross-price elasticity of demand is negative, the goods are complements. As the price of one good increases, the demand for both goods will decrease or vice versa.

Estimates of the own-price elasticity of demand for heating oil will be influenced by the presence of an alternate heating source, in this instance a wood stove or wood stove insert. Based on standard economic theory homes without an alternate source of heat will have a more inelastic demand for home heating oil. Conversely, homes with an additional source of heat, such as a wood stove or insert would be expected to be less sensitive to heating oil price changes since they will be able to shift a portion of home heating needs to the other appliance. The estimated cross-price elasticity of firewood demand in response to a change in heating oil price measures the corresponding increase in firewood consumption.

For example, if the cross-price elasticity of wood is 0.5, a 1% decrease in the price of oil will decrease firewood consumption by 0.5% as households substitute use towards oil given the lower relative price. It is assumed that wood and oil are substitute goods – or as the price of oil decreases, households tend to increase oil consumption and decrease wood consumption.

Increases in oil prices would increase firewood consumption and subsequently increase PM2.5 emissions in the non-attainment zone.

PCAIDS Model

Own and cross-price elasticities for residential heating oil demand and firewood consumption were estimated using the proportionally calibrated almost ideal demand system (PCAIDS). In many instances data limitations make it difficult to estimate the full almost- ideal demand system (AIDS) model developed by Deaton and Muelbauer (1980). An alternative to the AIDS model is the "proportionally calibrated almost idea demand system" (PCAIDS) model developed by Epstein and Rubinfeld (2002).

The PCAIDS model has fewer data requirements than the typical AIDS model, providing an alternative strategy for estimating demand systems in the presence of imperfect information. The PCAIDS model avoids many of the challenges of the traditional AIDS framework, notably the estimation of a large set of parameters and the potential for low statistical significance, implausible magnitudes, or wrong signs inconsistent with economic theory. The PCAIDS model applies the same logic as the AIDS model, but incorporates restrictions to make all elasticity values depend on a single parameter and market shares of the respective goods. The restrictions imposed ensure the correct signs and magnitudes of required parameters and elasticities (Epstein & Rubinfeld, 2002). The modeling approach used here follows Coloma (2006) who presents a two stage process of deriving own- and cross-price elasticities of demand using the PCAIDS framework.

Household expenditure shares for residential heating oil (S_0) and firewood (S_w) measure the proportional share of the home heating budget spent on each heating fuel type. Total household expenditures on wood and oil in mmBTU are calculated as:

$$E_T = (E_O + E_W) \quad (1);$$

Where E_O is the household expenditure on heating oil, E_W is household expenditures on wood, and E_T total household expenditures on oil and wood. The expenditure shares of oil and wood can then be calculated directly:

$$S_o = \frac{E_O}{E_T} \quad (2);$$

$$S_w = \frac{E_W}{E_T} \quad (3);$$

$$S_T = S_o + S_w \quad (4);$$

Where S_1 is the share of household expenditures on oil, S_2 the share of household expenditures on wood.

It is important to note that approximately 31% of households surveyed indicate collecting firewood for use. For present purposes, it is assumed that the time and input costs associated with the collection of firewood are commensurate with the market price used in the analysis. The dependent shares are modeled as a function of the relative fuel price ratio and other factors (Y) which include the square footage of the home, age of the home in years, the elevation at the housing location, and zip code level median household income. A year level fixed effect controls for annual variations due to changes in heating degree days. Following Coloma (2006) three separate equations are estimated in order to calculate the appropriate elasticities.

In order to estimate the own-price elasticity of demand for oil and cross-price elasticity of demand for wood, two required parameters must be recovered from the models*:* a_{11} is represented as the adding-up property of the PCAIDS model which is equal to the summation of the cross price parameter (Coloma 2006), and *n* the aggregate demand elasticity of oil. Using available price data for wood and oil, and expenditure shares of wood and oil, the dependent shares model can be applied to gain a direct estimate for a_{11}. Following Coloma (2006) the demand system models are derived:

$$\frac{S_O \cdot (1-S_O)}{S_w} = -a_i \cdot b_{10} + a_{11} \cdot \ln\left(\frac{P_O}{P_W}\right) - a_{11} \cdot b_{1Y} \cdot Y \quad (5);$$

Where $ln\left(\frac{P_O}{P_W}\right)$ is the natural log of the relative price ratio of oil and wood per million of BTU (mmBTU). By estimating a_{11} through equation (1) as the coefficient of $ln\left(\frac{P_O}{P_W}\right)$, the required a_{11} parameter assumed by the PCAIDS model can be recovered. The parameter a_{11} is of interest as it helps describe the relative spending behavior of price-taking buyers and is a required input to calculate both own- and cross-price elasticities. Similarly, the own-price elasticity of demand for wood a_{22} and a_{12} can be calculated by estimating the dependent shares model for wood:

$$\frac{S_W \cdot (1-S_W)}{S_0} = -a_i \cdot b_{10} + a_{22} \cdot \ln\left(\frac{P_W}{P_O}\right) - a_{22} \cdot b_{1Y} \cdot Y \quad (6);$$

Where $ln\left(\frac{P_W}{P_O}\right)$ is the natural log of the relative price ratio of wood and oil respectively in mmBTUs. Parameter a_{22}, the own-price elasticity of wood can be recovered as the coefficient of $ln\left(\frac{P_W}{P_O}\right)$ which can then be used to estimate the cross-price effect of wood with respect to a change in price of heating oil.

In the second stage of the model, the household heating demand equation is estimated to determine aggregate demand elasticity (n):

$$ln(Q) = C_0 + n \cdot \ln(P_A) + C_Y \cdot Y \qquad (7);$$

Where Q is the level of mmBTU consumption for the household, $ln(P_A)$ is a natural log of weighted average price per mmBTU for wood and oil, and C represents the estimated coefficients. The required parameter n is recovered as the coefficient of $ln(P_A)$. Parameter $ln(P_A)$ is expected to have a negative coefficient to satisfy the law of demand in the aggregate demand equation.

The aggregate mmBTU consumption *(Q)* of home heating fuel is calculated as follows:

$$Q_G = \frac{G}{P_1} \qquad (8);$$

$$Q_W = \frac{W}{P_2} \qquad (9);$$

$$Q = Q_G + Q_W \qquad (10);$$

Where G represents the quantity of oil in mmBTUs consumed, W represents the quantity of wood consumed in mmBTUs by household, and P_O and P_W are the price per mmBTU of oil and wood respectively; Q_G is the aggregate mmBTU consumption of gallons of heating oil, Q_W is the aggregate mmBTU consumption of wood, and Q represents the aggregate product quantity in mmBTUs consumed by household.

The weighted average price per mmBTU of wood and oil is calculated by adjusting the wood and heating oil prices by the respective household spending shares; the adjusted values are then summed:

$$P_{AO} = AP_1 \cdot S_1 \qquad (11);$$

$$P_{AW} = AP_2 \cdot S_2 \qquad (12);$$

$$P_A = P_{AO} + P_{AW} \qquad (13);$$

Where P_{AO} is the weighted average price per BTU of oil, P_{AW} is the weighted average price per BTU of wood, AP_1 is the average price per BTU of oil, AP_2 is the average price per BTU of wood, and P_A, is the weighted average price per mmBTU consumed by the household.

Using the weighted average prices per mmBTU, the aggregate demand equation can be estimated to recover the required parameter n, which the coefficient of $ln(P_A)$. The recovered parameters of n and a_{11} can be used to calculate a_{22}, a_{12} and the own-price (n_{own}) and cross-price (n_{cross}), elasticities of demand for oil and wood respectively.

Using the n and a_{11} parameters, the own- and cross-price elasticity be calculated directly as follows:

$$n_{own} = -1 + \frac{a_{11}}{S_O} + S_O \cdot (n+1) \qquad (14);$$

$$n_{cross} = \frac{a_{12}}{S_O} + S_W \cdot (n+1) \qquad (15);$$

Where n is the aggregate demand elasticity of the product recovered from equation (2), n_{own} is the own-price elasticity of oil and n_{cross} is the cross-price elasticity of demand for wood. The cross-price elasticity of demand, a_{12} and a_{22} , is calculated with respect to the expenditure shares, and the a_{11} parameter estimated in equation (1). Estimating the a_{12} cross-price parameters has the following relationship with the own-price parameters of the second product (wood) a_{22} from equation (2):

$$a_{22} = \frac{S_W \cdot (1 - S_W)}{S_2 \cdot (1 - S_O)} \cdot a_{11} \qquad (16);$$

$$a_{12} = \frac{-s_O}{(1-s_W)} \cdot a_{22} \qquad (17);$$

a_{12} is then used to estimate n_{cross}, the cross-price elasticity of demand for wood with respect to a change in oil price.

Data and Analysis

The 2016 home heating postcard survey was conducted by Sierra Research and consisted of questions which asked respondents about their household's annual use of home heating oil and firewood (Sierra, 2016). A total of 1,401 postcards was mailed, encompassing all the respondents in the 2014 and 2015 home heating telephone surveys and providing pre-printed 2014 or 2015 device/usage data for each individual respondent. A total of 271 postcards was ultimately returned over the ensuing three months, reflecting a return rate of just under 20%.

The set of 271 responding households provided heating fuel use information in either 2014 or 2015 by telephone survey. Data from the 2014/2015 telephone survey and 2016 postcard survey were paired by household. Sierra Research performed a series of calculations to validate the data for each household. Sierra calculated fuel use data by device from each survey "point" (2014/2015 vs. 2016 postcard) which were then translated into estimates of winter heating energy use, measured in BTUs.

To ensure the validity of the household responses, Sierra Research looked at total household energy use in BTUs and compared the results based on the 2014/2015 data point and that from the 2016 postcard survey. If the energy use from one survey was dramatically different from the other, both data points for the household were deemed invalid. Sierra Research utilized a validation threshold of a ±75% change in energy use to validate or reject the data for each household.[7] Through the validation process, 38 out of the 271 respondents were deemed "invalid." All models are estimated using the 233 responses determined to be valid by Sierra Research.

Information on the square footage and age of respondent homes were collected by Sierra Research. Data on the median household income by zip code was collected from the American Community Survey (ACS). Home size as well as home age have been shown to be important explanatory factors in home heating demand. Likewise, household income is a standard variable included in home heating demand models (Rehdanz & Meier, 2008), (Sardianou, 2007) and (Song, Aguilar, Shifley, & Goerndt, 2012).

Rehdanz & Meier (2008) examine determinants of heating expenditures which include socio-economic and building characteristics and analyze households' heating behavior from 1991 to 2005. The regression controls for annual household income, household size, average age of householder, and employment of householder. Sardianou (2007) investigates the determinants of household energy conservation patterns in Greece employing a cross-sectional data using monthly income, number of rooms in the dwelling, and dwelling size. Song et al. (2012) examines the factors affecting individual U.S. household wood energy consumption. The regression controls for number of household members, household consumption of wood, location, household income, household size in square meters, annual heating degree days, and price of wood.

Song et al. (2012) estimates that for every 1% increase in non-wood energy prices is predicted to induce a 1.55% increase in firewood energy consumption.

[7] Sierra Research indicated that the validation level was selected to account for the combination of variations due to reporting precision of wood use, year-to-year differences in winter severity, and effects of differences in net heating efficiencies across the key devices.

Average household heating oil and firewood use in gallons, cords, and mmBTU from 2014/2015 to 2016 are presented in *Table 1*.

Table 1: Average Household Use by Fuel Type

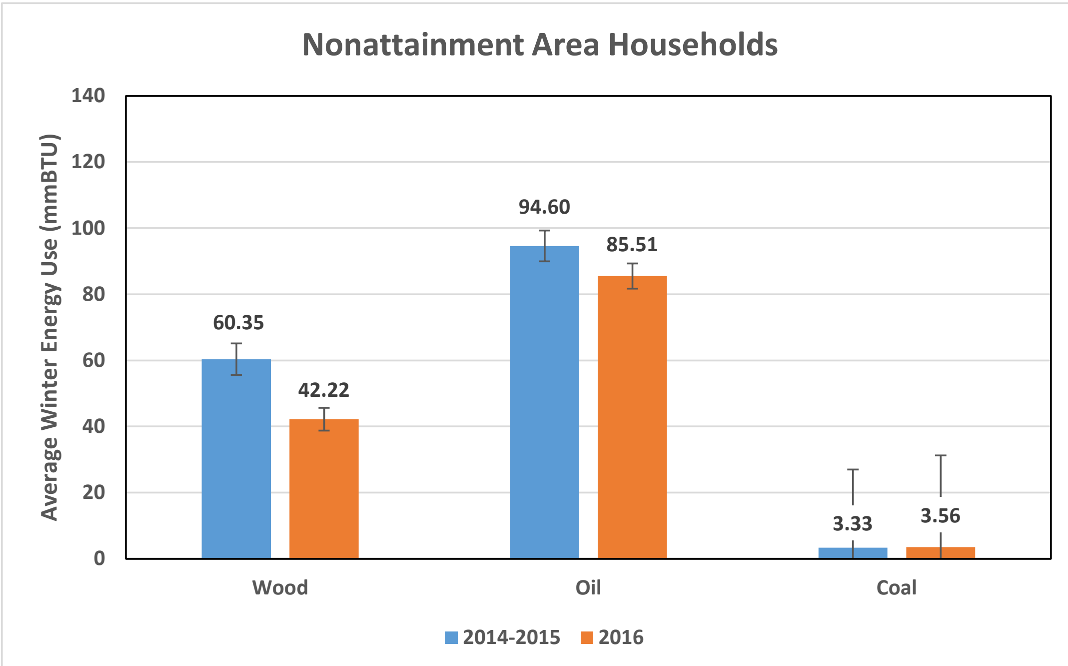
Year	Central Oil (gallons)	Wood (cords)	Central Oil (mmBTU)	Wood (mmBTU)
2014/2015	658.62 (535.65)	2 (2.71)	94.60 (72.31)	60.35 (56.41)
2016	595.07 (451.36)	1.36 (1.85)	85.51 (60.93)	42.22 (40.93)
Total	626.84 (495.65)	1.68 (2.34)	90.05 (66.91)	51.29 (49.66)

Note: Standard errors in parentheses.

There was a notable decrease in average reported household heating oil and firewood usage between 2014/2015 and 2016 (*Table 1*). The change in heating oil use of 658.62 gallons in 2014/2015 to 595.07 gallons in 2016 or in terms of mmBTU, 94.60 to 85.51 mmBTU, is approximately 9.6% The change from the household average use of 2 cords to 1.36 cords annually represents a 32% decrease in wood use from 2014/2015 to 2016. The associated reduction in terms of mmBTU's, is 60.35 mmBTU to 42.22 mmBTU.

Figure 1 provides a comparison of average winter season household energy use by fuel type between the 2014/2015 and 2016 surveys. This is visually represented in *Table 1*.

Figure 1:
Change in Average Winter Household Energy Use (mmBTU) by Fuel Type, Entire Nonattainment Area



Source: Sierra Research Inc, Postcard Data White Paper, 2016

Table 2: Total Household Energy Consumption in (millions) of BTUs and Heating Degree Days

Year	Energy consumption (mmBTU)	Heating Degree Days
2014/2015	134.42 (111.91)	10,199
2016	119.14 (78.75)	9,735
Total	12.78 (96.97)	9,967

Note: Standard deviations in parentheses

These reductions are driven by decreases in the number of heating degree days between 2014/2015 and 2016. *Table 2* displays household change in total energy use in mmBTU, and Heating Degree Days from 2014/2015 to 2016. The change from 138.81 mmBTU to 118.1

mmBTU annually represents a 15% decrease in energy usage from 2014/2015 to 2016. The change from 10,119 to 9,735 heating degree days represents a 3.75% decrease in annual heating degree days in the FNSB.

Table 3: Market Prices (Wood and Oil in Dollars)

Year	Oil Price	Wood Price	Oil Price (mmBTU)	Wood Price (mmBTU)	HH Expenditures	Oil Shares	Wood Shares
2014/2015	3.38	275.51	24.87	13.53	$2,900 ($2,985)	0.71 (0.36)	0.29 (0.36)
2016	2.39	266.99	17.70	13.11	$2,600 ($1,778)	0.76 (0.30)	0.24 (0.30)
Net Change	0.99	8.52	7.17	0.42	$300 ($1,207)	-0.05 (0.06)	0.05 (0.06)
Average	2.87	271.25	21.04	13.32	$2,750 ($2,459)	0.74 (0.33)	0.26 (0.33)

Note: Standard deviations in parentheses

Table 3 presents the change in market prices for wood and oil from 2014/2015 to 2016 in gallons and cords of wood, as well as in price per mmBTU by fuel type.[8] The change from $275.51 to $266.99 represents a 3.10% decrease in the market price for a cord of wood. The change from $3.38 to $2.39 represents a 28.66% decrease in the market price for heating oil. Overall expenditures for households decreased from $2,900 to $2,600 annually, representing a 10% decrease in annual household heating expenditures. Oil shares increase from 71% to 76% of household heating expenditures between the two time periods, this represents a 7% increase in expenditures on heating oil. Wood shares decreased from 29% to 24% of household heating expenditures, this represents a 17% decrease in household expenditures on firewood between the two time periods.

[8] Firewood and Oil prices found from the Alaska Energy Data Gateway.

Table 4: Sociodemographic and Household Characteristics

	Median HH Income	Home size (Sqft)	Home age (years)	Elevation (feet)
Mean	$73,984 ($10,070)	1,960 (803)	34 (14)	620.84 (238.25)

Note: Standard deviation in parentheses

Table 4 represents median household income, average home size, average home age, and elevation in meters above sea-level in the data over all time periods.

Estimated Models and Results

The household share of expenditures devoted to firewood and heating oil, as well the total share of expenditures is estimated for the average household. Models in this analysis were specified emulating the empirical model employed by (Song, Aguilar, Shifley, & Goerndt, 2012) looking at household heating preferences and (Coloma, 2004).

Table 5: Mean Proportion of Appliance Type

	Central Oil	Direct Vent Oil	Wood Stove	Wood-Oil	Wood Collect
Mean	0.83 (0.37)	0.17 (0.38)	0.56 (0.49)	0.42 (0.49)	0.32 (0.47)

Note: Standard errors in parentheses

Table 5 presents a summary of reported appliance use in FNSB homes. 83% of households report using a central oil heating appliance, 17% of households report using a direct vent appliance, 56% of households report using cord-wood (primarily for wood stoves), and 42% of households report using a combination of both wood and oil appliances. The *woodcollect* variable indicates whether a household reports collecting or purchasing firewood – approximately 32% of households report collecting their own firewood in the dataset.

Table 6: Summary Statistics of Regression Variables

Year	Dependent Shares	Dependent Shares Wood	Aggregate Demand	$Ln(P_a)$
2014/2015	0.52 (0.32)	0.18 (0.24)	4.78 (0.51)	3.07 (0.28)
2016	0.59 (0.30)	0.20 (0.26)	4.61 (0.50)	2.81 (0.89)
Average	0.57 (0.31)	0.19 (0.25)	4.70 (0.51)	2.94 (0.25)

Note: Standard deviations in parentheses

Table 6 presents the summary statistics of regression variables used in the models below. *Dependent Shares* increased from 0.52 to 0.59 between the two time periods, as oil shares tended to increase between the two time periods, the dependent shares are expected to increase. *Ln(BTU_Ratio)* decreased given the ratio of the price per mmBTU decreased between the two time periods. Aggregate demand decreased between both time periods which could be contributed to a decrease in the overall heating degree days in the FNSB. Weighted price variable $ln(P_a)$ also decreased given the weighted price per mmBTU dropped for both oil and firewood between the two periods.

Two estimation strategies were used, standard linear regression and robust regression. Robust regression is an alternative to least squares regression which uses a weighted estimation scheme to control for heteroscedasticity and leverage exerted by potential outliers in the data.[9] Robust regression first runs the OLS regression and calculates Cook's distance for each

[9] An observation with an extreme value on a predictor variable is a point with high leverage. Leverage is a measure of how far an independent variable deviates from its mean. High leverage points can have a great amount of effect on the estimate of regression coefficients (UCLA: Statistical Consulting Group, 2016).

observation and drops any observation with a Cook's distance greater than 1.[10] [11] [12] In short, the most influential points are dropped, then those observations with large absolute residuals are weighed downward. Using the expenditure shares, the equation (5) is estimated as follows:

$$Depshares = \beta_0 + \beta_1 ln\left(\frac{P_O}{P_W}\right) + \beta_2 year + \beta_3 DV + \beta_4 CentralOil + \beta_5 Woodcollect +$$
$$\beta_6 \ln(size) + \beta_7 \ln(MHH) + \beta_8 elevation + \beta_9 homeage + u \quad (18);$$

Where $ln\left(\frac{P_O}{P_W}\right)$ is the natural log of relative price ratio of both wood and oil in mmBTU, *DV* is a dummy variable indicating if a household has a direct vent appliance, *CentralOil* is a dummy variable indicating if a household has a central oil appliance, *Woodcollect* is a dummy variable indicating if the household bought or collected wood, *size* is the size of the home in square feet, *year* is a dummy variable indicating the survey year where the use was reported,[13] *MHH* is the median household income by zip code,[14] *elevation* is the meters the home is located above sea-level, and *homeage* is the age of the home in years. Regression results are displayed below.

[10] Cook's distance measures the influence of the observation on the fitted values. It assigns leverage to variables based on their distance from the fitted values. See (Kutner, Nachtsheim, Neter, & William, 2005) for further information.
[11] For more information on robust regression techniques please see: Verardi, V., & Croux, C. (2009). Robust Regression in Stata. Stata Journal, 439-453.
[12] Using Stata defaults, robust regression is approximately 95% as efficient as OLS (Hamilton, 1991).
[13] Dummy variable *year* also represents the heating degree days in the FNSB for that particular year. Heating degree days and year effect variables are not included, as they are perfectly correlated.
[14] Median household income was collected from the American Community Survey from 2011-2015.

Table 7: Dependent Shares Model Results (Heating Oil)

VARIABLES	**Linear Regression** Depshares	**Robust Regression** Depshares
ln(BTU_Price_ratio)	0.0290	-0.0128
	(0.140)	(0.142)
2015	-0.0604	-0.0883
	(0.0665)	(0.0672)
2016	0.00922	-0.0351
	(0.0773)	(0.0781)
Direct Vent	0.161***	0.172***
	(0.0582)	(0.0588)
CentralOil	0.477***	0.538***
	(0.0559)	(0.0565)
Woodcollect	-0.0449	-0.0474
	(0.0362)	(0.0366)
ln(size)	-0.0958*	-0.0980*
	(0.0508)	(0.0514)
ln(MHH)	0.220	0.141
	(0.161)	(0.163)
Elevation	-0.000102	-0.000114
	(7.51e-05)	(7.59e-05)
Homeage	-0.000720	-0.000822
	(0.00141)	(0.00143)
Constant	-1.458	-0.526
	(1.832)	(1.852)
Observations	244	244
R-squared	0.285	0.333

Note: Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Dummy variables *DirectVent* and *CentralOil* are statistically significant at the 1% level, *size* is statistically significant at the 10% level in both the linear and robust regression models. *Size* is statistically significant at the 10% level in both models. 244 observations are analyzed in the heating oil dependent shares model, this is due to the way the dependent shares heating oil model is calculated. If a household does not have an expenditure share on wood, there would be no dependent shares calculated for that household given the denominator (wood share) would be zero, which would generate a missing dependent shares observation for that household.

To estimate the cross-price effect of wood with respect to a change in oil, equation (2) is estimated using:

$$DepSharesWood = \beta_0 + \beta_1 ln\left(\frac{P_W}{P_O}\right) + \beta_2 year + \beta_3 DV + \beta_4 CentralOil + \beta_5 Woodcollect + \beta_6 ln(size) + \beta_7 ln(MHH) + \beta_8 elevation + \beta_9 homeage + u \quad (19);$$

Table 8: Dependent Shares Wood Regression Results

VARIABLES	**Linear Regression** Dependent Share Wood	**Robust Regression** Dependent Share Wood
ln(BTU_Ratio_Wood)	-0.00764	-0.0281
	(0.0354)	(0.0190)
2015	0.0331	-0.00891
	(0.0433)	(0.0233)
2016	0.0373	-0.00646
	(0.0302)	(0.0162)
Direct Vent	-0.00407	-0.0690**
	(0.0504)	(0.0271)
CentralOil	-0.253***	-0.126***
	(0.0539)	(0.0290)
Woodcollect	0.207***	0.198***
	(0.0242)	(0.0130)
ln(size)	0.0139	-0.00558
	(0.0272)	(0.0146)
ln(MHH)	0.0608	0.0146
	(0.0863)	(0.0464)
Elevation	4.83e-05	1.83e-05
	(5.38e-05)	(2.89e-05)
Homeage	-0.000833	-0.00117**
	(0.000866)	(0.000466)
Constant	-0.484	0.0368
	(0.976)	(0.525)
Observations	407	407
R-squared	0.288	0.422

Note: Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Dummy variables *Central Oil* and *Woodcollect* are statistically significant at the 1% level a lower in both the robust and linear regressions. *Direct Vent* and *Homage* were statistically significant at the 1% and 5% levels respectively in the robust regression. 407 observations are analyzed in the wood dependent shares model, again the discrepancy between the number of valid households and the number of analyzed households is due to the way the wood dependent shares model is calculated. If a household does not have an expenditure share on oil, there would be no dependent shares calculated for that household given the denominator (oil share) would be zero, which would generate a missing wood dependent shares observation for that household.[15]

The aggregate market demand model is estimated using equation (3):

$$\ln(Q) = \beta_0 + \beta_1 ln(P_A) + \beta_2 year + \beta_3 DirectVent + \beta_4 CentralOil + \beta_5 Woodcollect + \beta_6 \ln(size) + \beta_7 \ln(MHH) + \beta_8 elevation + \beta_9 homeage + u \quad (20);$$

Where Q is the aggregate household heating consumption in mmBTU and $ln(P_A)$ is the natural log of the weighted average mmBTU prices of firewood and heating oil. Parameter $ln(P_A)$ is expected to have a negative coefficient representing the inverse relationship between price and quantity demanded. All other variables in the model are the same as described in the dependent shares model. Regression results are displayed below.

[15] The odd number of households analyzed in the dependent shares wood model is due to some households reporting oil use in one time period and reporting no oil use in the other time period. Therefore, the household would have a value for wood dependent shares in one time period, but not in the other.

Table 9: Aggregate Demand Model Results

VARIABLES	**Linear Regression** ln(Aggregate Demand)	**Robust Regression** ln(Aggregate Demand)
Ln(P_a)	-0.266**	-0.301***
	(0.109)	(0.111)
2015	-0.0329	-0.0489
	(0.0596)	(0.0608)
2016	-0.256***	-0.268***
	(0.0618)	(0.0630)
Direct Vent	0.127*	0.119
	(0.0769)	(0.0784)
Central Oil	0.515***	0.513***
	(0.0766)	(0.0781)
Wood Collect	0.114**	0.109**
	(0.0446)	(0.0455)
ln(size)	0.443***	0.438***
	(0.0499)	(0.0509)
ln(MHH)	0.175	0.169
	(0.154)	(0.158)
Elevation	-0.000179*	-0.000185*
	(9.29e-05)	(9.47e-05)
Homeage	0.000830	0.000678
	(0.00157)	(0.00160)
Constant	-0.0412	0.176
	(1.781)	(1.818)
Observations	434	434
R-squared	0.383	0.371

Note: Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Variables *ln(P_a), 2016, CentralOil* and *ln(size)* were statistically significant at the 1% level for both linear and robust regressions. *Elevation* and *Woodcollect* are statistically significant at the 1% and 5% level respectively, for both linear and robust regressions. *DirectVent* is statistically significant at the 10% level for the linear regression only.

It is important to see a negative coefficient on *ln(P_a)* to represent the inverse relationship between price and quantity demanded. The positive coefficient on the *ln(size)* indicates that as size of the home increases, there will be an increase in the aggregate demand for home heating, which is expected. In this case, a 1% increase in *size* results in a 0.443% increase in demand.

Estimated mean and median own- and cross-price elasticities for the sample are presented in Table 6 below.

Table 10: PCAIDS Estimates of Own- and Cross-Price Elasticity Estimates for Residential Heating Oil and Firewood

	Linear Regression	Robust Regression
Own-Price Oil (Mean)	-0.351 [-0.365, -0.342]	-0.455 [-0.475, -0.437]
Own-Price Oil (Median)	-0.274	-0.353
Cross-Price Wood (Mean)	0.259 [0.238, 0.288]	0.260 [0.242, 0.287]
Cross-Price Wood (Median)	0.219	0.224

Note: Confidence intervals are in brackets

Table 10 represents the own- and cross-price elasticity estimates for residential heating oil and firewood using the PCAIDS model. Estimated own-price elasticities indicate that residential heating oil demand is relatively insensitive to price changes over the observation period (2014-2016). Based on the predicted median values a 1% increase in the price of heating oil (mmBTU) is estimated to result in a reduction of 0.274% to 0.353% in the quantity (mmBTU) of residential heating oil consumed by the average household. Likewise, an increase in heating oil price is predicted to increase the use of firewood since the predicted cross-price elasticities indicate heating oil and firewood are treated as substitutes. Based on the median value, a 1% increase in the price of heating oil (mmBTU) is estimated to increase the consumption of wood (mmBTU) from 0.219% to 0.224%.

Using the average firewood use in the FNSB of 1.68 cords (51.29 mmBTU) from 2014-2016, and the estimated median cross-price elasticity of wood of 0.224, given a hypothetical 10% increase in oil price is estimated to increase the consumption of wood by 2.24%. This translates into an estimated additional use of 0.03 cords or 1.14 (mmBTU) given a 10% increase in the price of oil. Confidence intervals were constructed for the means of the own- and cross-price elasticities at 95% confidence level, it can be inferred from a statistically significant aggregate demand elasticity coefficient. The confidence intervals do not contain zero in either the own- or cross-price elasticity of demand, indicating that both elasticity measurements can be assumed to be statistically significant.

Table 11: Oil Price Elasticity Estimates in Literature

Author(s)	Own-price elasticity of Oil
Alberini, Gans, & Velez-Lopez, (2011)	-0.556 to -0.65
Galvin & Blank-Sunikka (2012)	-0.39 to -0.47
Madlener, Bernstein & Gonzalez (2011)	-0.15 to -0.34

Table 11 represents the results of other empirical results on own-price elasticity of demand for residential heating oil. Alberini, Gans, and Velez-Lopez (2011) estimate the own-price elasticity to be between -0.556 to -0.65. Galvin and Blank Sunikka (2012) estimate the own-price of heating oil to be between -0.39 to -0.47. Madlener, Bernstein & Gonzalez (2011) estimate the own-price elasticity to be between -0.15 to -0.34. The wide range of own-price elasticity measurements is due to difference in specification of the models, location, household preferences in that location, time-period of the dataset, etc. Estimates from this analysis fall within the range of other peer-reviewed journal articles. Due to the lack of peer-reviewed journal articles, Song et al., (2012) estimates the only cross-price elasticity of wood with respect to other non-wood energy prices, obtaining a cross-price elasticity of demand of 1.55.

Limitations

A few considerations should be mentioned. First, because the share equations were estimated separately homogeneity and symmetry restrictions were not imposed on the demand system. Second, given that the estimated elasticities are not normally distributed the median values presented in *Table* 6 provide a better measure of central tendency in the data. Third, while estimates across both robust and linear models are similar, those produced using the robust model address the leverage exerted by outliers. This consideration is important when noting potential issues associated with recall and accuracy in the post card survey data. Finally, many households in Fairbanks report collecting their own wood instead purchasing. However, data on the time-value of money, or the length of time spent collecting wood is not available for this dataset. This forces our analysis to assume that the time-value of their money is equal to the market price of wood, which may not always be the case.

Bibliography

Alaska Energy Data Gateway. (n.d.). *Community Data Summary*. Retrieved from Fuel Prices: https://akenergygateway.alaska.edu/community-data-summary/1401958/

Alberini, A., Gans, W., & Velez-Lopez, D. (2011). Residential consumption of gas and electricity in the U.S.: The role of prices and income. *Energy Economics*.

American Lung Association. (2016). *State of the Air*. Retrieved from American Lung Association: https://www.lung.org/our-initiatives/healthy-air/sota/

American Lung Association. (2017). *State of the Air*. Retrieved from American Lung Association: https://www.lung.org/our-initiatives/healthy-air/sota/

American Lung Association. (2018). *State of the Air*. Retrieved from American Lung Assocation: https://www.lung.org/our-initiatives/healthy-air/sota/

Coloma, G. (2004). Econometric estimation of PCAIDS Model. *University of CEMA, Buenos Aires*.

Epstein, R., & Rubinfeld, D. (2002). Merger Simulation: A Simplified Approach with New Applications. *Antitrust Law Journal*, 883-919.

Galvin, R., & Blank-Sunikka, M. (2012). Including fuel price elasticity of demand in net present value and payback time calculations of thermal retrofits: Case study of German dwellings. *Energy and Buildings*.

Hamilton, L. (1991). How robust is robust regression. *Stata Technical Bulletin*.

Hirst, E., Goeltz, R., & Carney, J. (1982). Residential Energy Use: Analysis of Dissagregate Data. *Energy Economics* .

Kutner, M., Nachtsheim, C., Neter, J., & William, L. (2005). Applied Linear Statistical Models.

Madlener, R., Berstein, R., & Gonzalez, M. (n.d.). Econometric Estimation of Energy Demand Elasticities. *Energy Research Center Series*.

Rehdanz, K. (2007). Determinants of Residential Space Heating Expenditures in Germany. *Working Paper*.

Rehdanz, K., & Meier, H. (2008). Determinants of residential space heating expenditures in Great Britian. *Kiel Working Paper*.

Sardianou, E. (2007). Estimating space heating determinants: An analysis of Greek households. *Energy and buildings*.

Sierra Research Inc. (n.d.). Fairbanks Home Heating Telephone Survey Data 2011-2015 - Unified Format.

Song, N., Aguilar, F., Shifley, S., & Goerndt, M. (2012). Factors affecting wood energy consumption by U.S. Households. *Energy Economics*.

Swinand, G., & Hennessy, H. (2014). *Estimating postal demand elasticities using the PCAIDS method,*. Edward Elgar Publishing.

U.S. Environmental Protection Agency. (n.d.). Retrieved from Fairbanks Air Quality Plan: https://www.epa.gov/ak/fairbanks-air-quality-plan

U.S. Environmental Protection Agency. (2017). Retrieved from Summary of Fairbanks Particulate (PM2.5) Moderate Area Attainment Plan: https://www.epa.gov/sips-wa/summary-fairbanks-particulate-matter-pm-25-moderate-area-attainment-plan

UCLA: Statistical Consulting Group. (2016). *Insitute for Digital Research and Education.* Retrieved from Robust Regression in Stata: https://stats.idre.ucla.edu/stata/dae/robust-regression/

Verardi, V., & Croux, C. (2009). Robust Regression in Stata. *Stata Journal*, 439-453.

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January 24, 2017

Memo to: Cindy Heil, ADEC

From: Tom Carlson and Michael Lombardo, Sierra Research
Robert Crawford, Rincon Ranch Consulting

Subject: Analysis of Fairbanks 2016 Home Heating Postcard Survey

Summary

Key Finding – Analysis of data from the 2016 Fairbanks Home Heating (HH) survey found that wood use in residential space heating has dropped notably, by 30.0%, compared to similar data collected one to two years earlier for the same set of households. Even after accounting for differences in winter severity (and resulting heating demand) and changes in overall heating efficiency from different fuel splits in each survey, the adjusted reduction in average wood use is at least 16.4%, and possibly higher. As heating oil prices have dropped substantially since early 2014, this finding is very consistent with estimates of the sensitivity of wood use to changes in oil prices developed by the University of Alaska, Fairbanks from local usage data.

Synopsis of Survey – The 2016 HH survey utilized a postcard-type survey instrument that provided a more streamlined and cost-effective approach to collecting data on residential home heating practices than earlier telephone-based surveys. Unlike the earlier surveys under which a random sample was drawn from all residents in the nonattainment area, the 2016 survey targeted household respondents who had participated in the 2014 and 2015 telephone surveys.

The approach used in the 2016 postcard survey was to collect more focused wood and heating oil usage data for winter 2015-2016 space heating that could be directly compared to similar data for the same set of households as sampled in the earlier 2014 and 2015 surveys. This approach was chosen to answer one fundamental question: Did Fairbanks residents use less wood and more oil for space heating as heating oil prices dropped from roughly $4 per gallon in early 2014 to less than $2 per gallon in 2016?

After processing and validating the response data, it was found that winter season residential wood use dropped 30.0% on average in the 2016 survey for the same set of households sampled in the 2014 and 2015 surveys. Heating oil use dropped more modestly, by 9.6%.

Overall heating energy use decreased by 17.1% in 2016 relative to usage levels from the same households in the 2014 and 2015 surveys. Differences in the severity of winter temperatures in 2016 versus 2014 and 2015 account for 3.8% of this 17.1% decrease. Changes in overall

household heating efficiency due to the shift in wood vs. oil use[1] account for 0.7% of the 17.1% decrease. Another factor that may contribute to this higher than expected overall energy use drop (after adjusting for year-to-year differences in ambient temperature and heating device efficiency effects) is that wood heat generally emanates from a single heating device within a residence while oil heat is more evenly distributed throughout the dwelling space. With a higher share of wood use (i.e., in 2014/2015), some additional amount of wood heat may be needed to keep the entire dwelling heated.

Thus, the remaining 13.6% drop in energy use (17.1% - 3.8% - 0.7%) results from the sampling precision/accuracy of the survey or other factors. For example, cordwood wood use responses were typically in the 2-5 cord range, rounded to the nearest cord; this yields an effective precision due to round off of 10% or more. Another possible factor is that the adjustment of -3.8% based on heating degree day (HDD)[2] data may understate the difference in winter severity between the survey periods. To test this, an examination of households that burned only oil in both surveys was performed because thermostatically controlled oil usage (in oil-only households) might be a better indicator of differences in winter severity. Oil-only households exhibited an average drop in heating energy use of 11%, which is significantly larger than the HDD-based adjustment.

Even if the 30.0% drop in wood use is normalized to account for the unexplained 13.6% decrease in overall energy use, the "effective" 16.4% decrease (30.0% - 13.6%) is still large and roughly consistent with oil vs. wood price sensitivity found in recent work[3] by the University of Alaska, Fairbanks (UAF). The UAF study, which examined data from DEC's entire historical Fairbanks HH survey database (2006 through 2015), estimated the cross price elasticity between oil and wood in home heating at 0.41 (meaning a 1% change in heating oil price would trigger a 0.41% change in wood use). The 50% drop in heating oil prices since early 2014 translates to a 20.5% reduction in wood use based on this elasticity, which is very consistent with the 16.4% effective decrease found from the postcard survey.

The results summarized above are based on the entire nonattainment area sample (233 valid postcards out of 271 returned). A separate analysis of responses within the North Pole area (39 valid responses) found that the reduction in wood use was also notable, at 20.5%, but not as large as the 30.0% average over the entire nonattainment area.

A statistical analysis was also performed to evaluate the significance of the reported wood decrease in the 2016 survey for the entire nonattainment area. It was found that the differences in average wood usage between the 2014/2015 and 2016 surveys were statistically significant with over 99.9% probability.

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[1] On average, wood-burning devices have lower heating efficiency than oil heating devices. Thus, a relative shift from wood to oil will result in a decrease in fuel energy needed (all other factors being equal).
[2] Heating degree day (HDD) is a measurement designed to measure the demand for energy needed to heat a building to a reference temperature, typically set at 65°F. HDD is derived from measurements of outside air temperature. The heating requirements for a given building at a specific location are considered to be directly proportional to the number of HDDs at that location.
[3] Email from Camilla Kennedy, Agency Economist, Alaska Department of Environmental Conservation, September 9, 2016.

The remainder of the memorandum discusses the postcard survey collection and analysis methodology and presents detailed survey findings.

Survey and Data Analysis Methodology

Postcard Survey Sampling – The 2016 survey consisted of a few simple questions expressed in tabular form on a small printed postcard. These questions provided respondents with their wood, oil, and coal device usage data when collected in either the 2014 or 2015 HH surveys and asked them to identify if those devices and/or usage levels had changed in 2016. Attachment A shows the organization and content of the postcard layout, which featured a pre-printed return address to Hays Research (who performed the survey) and postage for convenience.

A total of 1,401 postcards were mailed in mid-March 2016, encompassing all of the respondents in the 2014 and 2015 HH surveys and providing pre-printed 2014 or 2015 device/usage data for each individual respondent. A total of 271 postcards were ultimately returned over the ensuing three months, reflecting a return rate of just under 20%.

Survey Data Processing and Validation – Hays processed the returned postcards and provided the responses to Sierra in a spreadsheet, showing the 2014/2015 and 2016 postcard survey device data for each returned postcard along with the ZIP code, address, and contact information.[4] The spreadsheet also included a column for notes written by some respondents on their returned postcard that were used to clarify the provided fuel usage data. Roughly 40 postcards included notes, most frequently to correct fuel usage data that was misreported in the earlier 2014/2015 surveys. These notes were reviewed and corrections were applied to the data as applicable.

Sierra then performed a series of calculations to validate the data for each household.
First, fuel use data by device from each survey "point" (2014/2015 vs. 2016 postcard) were translated into estimates of winter season household space heating energy use (in BTUs) based on the energy contents of each key fuel listed in Table 1.

To ensure entries were reasonable, total household energy use (in BTUs) was compared based on the 2014/2015 data point and that from the 2016 postcard survey. If the energy use from one survey was dramatically different from the other, both data points for the household were deemed invalid. Based on technical judgment, a validation threshold of a ±75% change in energy use was used to validate or reject the data for each household. (Although this may seem high, it was set at this level to account for the combination of variations due to reporting precision of wood use, year-to-year differences in winter severity, and effects of differences in net heating efficiencies across the key devices.) Applying this energy use change threshold reduced the sample size of 271 by 38 households. This left a total of 233 valid households (271-38), 39 of which were in the North Pole area (ZIP code 99705).

An analysis of space heating energy use from the valid 233 paired households in the 2014/2015 telephone surveys and the 2016 postcard survey was conducted. Although the 2014/2015

[4] The address and contact information are confidential data not being transmitted to ADEC. They were collected only for the purpose of as-needed confirmatory analysis.

Table 1 Assumed Heating Fuel Energy Contents			
Fuel	**Energy Content (per fuel unit)**	**Units**	**Data Source/Notes**
Wood, cordwood	20.37	mmBTU/cord	"Purchasing Firewood in Alaska", Alaska Department of Natural Resources, composite of birch, spruce, aspen energy content, adjusted to current baseline 36.5% estimated wood moisture
Wood, pellets	16.0	mmBTU/ton	Fairbanks Community Research Quarterly
Fuel Oil	135,000	BTU/gal	Fairbanks Community Research Quarterly, local #2 and #1 heating oil blend
Coal	15.2	mmBTU/ton	Fairbanks Community Research Quarterly

BTU = British thermal unit
mmBTU = million BTU

surveys included data from other devices and fuel types such as natural gas, electric heat, and municipal/district steam heat, these heating sources are minor. Thus, the wood, heating oil, and coal usage data were compared between the telephone and postcard surveys. The postcard survey (like the telephone survey) collected wood use data for both cordwood and pellet devices and oil use data from both central oil furnaces and direct vent heaters. Since pellet use was much smaller than cordwood use, it was combined with the cordwood data (but using separate energy content as listed in Table 1) to generate "lumped" wood-based energy use for each household. The direct vent oil data were similarly combined with central oil usage for each household to estimate lumped oil-based energy use.

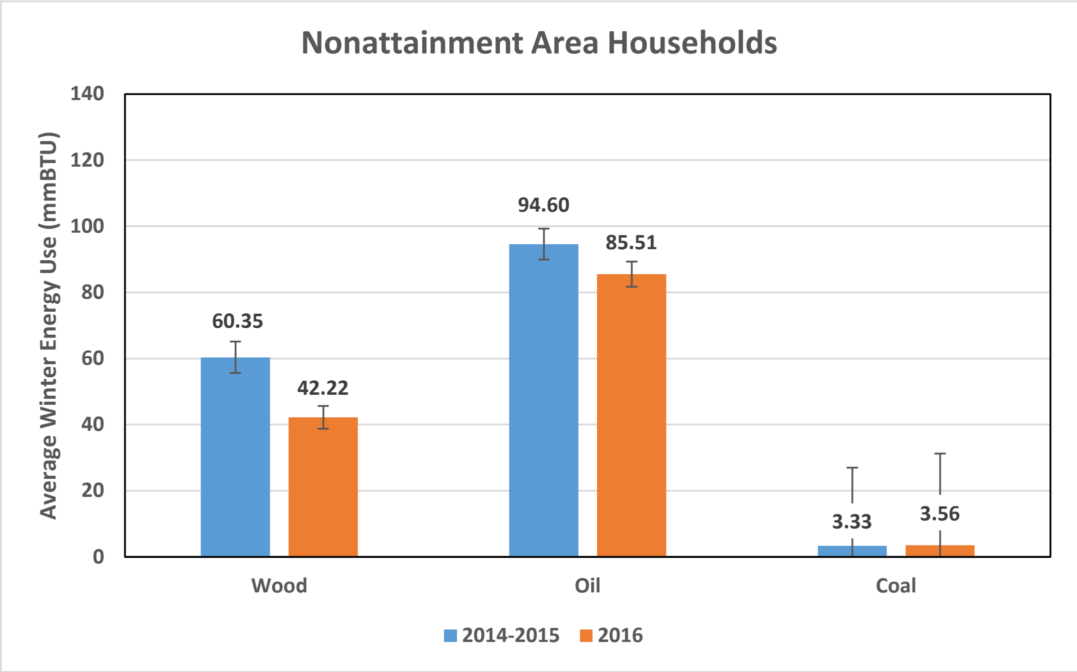
Key Results

Figure 1 compares average winter season household energy use by fuel type for the paired households in the 2014/2015 and 2016 surveys encompassing the entire nonattainment area. As shown, average household wood energy use dropped from 60.35 mmBTU to 42.22 mmBTU, a decrease of 30.0%. Oil use dropped more modestly, from 94.60 mmBTU to 85.51 mmBTU, a 9.6% reduction. Coal use increased by 6.9%, but there were few households using coal and the differences shown for coal in Figure 1 are not statistically significant. The error bars shown in Figure 1 represent the standard error[5] of the usage data by fuel type from each survey.

Figure 2 provides a similar comparison of household energy use changes for those residences in North Pole (based on ZIP code 99705). As seen in Figure 2, similar downward trends were observed in wood and oil usage in the North Pole households, but they are not as pronounced on a percentage basis as the entire nonattainment area, although absolute energy use is higher in the North Pole subsample. (No coal households were found in the North Pole sample.)

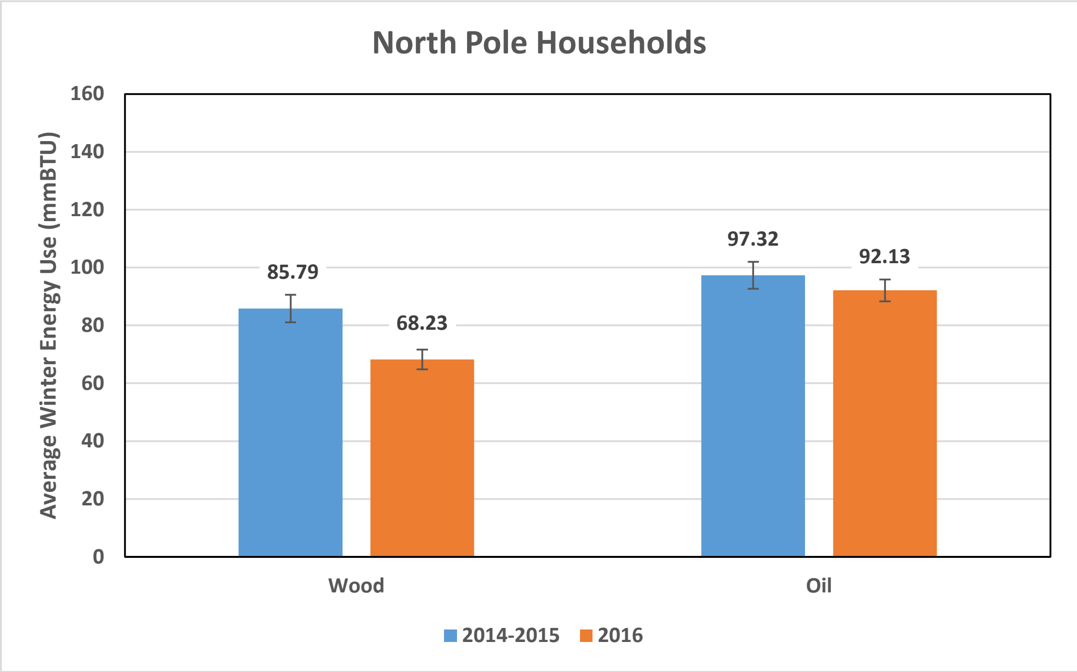
[5] Standard error or standard error of the mean is the standard deviation of the sample's estimate of the population's mean value. It is the error in the sample mean with respect to the true mean and is calculated as the sample standard deviation divided by the square root of the sample size.

Figure 1
Change in Average Winter Household Energy Use (mmBTU) by Fuel Type, Entire Nonattainment Area



Note: Error bars show range of standard error.

Figure 2
Change in Average Winter Household Energy Use (mmBTU) by Fuel Type, North Pole Area



Note: Error bars show range of standard error.

To provide more detailed examinations of the data points underlying these average changes, Figures 3 and 4 present scatter plot comparisons of wood and oil energy use for the 233 valid households in the 2014/2015 and 2016 surveys. Figure 3 presents wood energy usage; Figure 4 shows a similar plot for heating oil. In each figure, the horizontal axis shows fuel energy usage per the 2014/2015 survey and the vertical axis shows usage for the same fuel from the 2016 postcard survey. North Pole households are shown in red while those for the remainder of the nonattainment area are blue. The thick black line shows the "1:1" slope. Data points below this line represent reductions in fuel usage from the 2014/2015 survey; points above the line reflect fuel use increases. The dashed line shows the least-squares linear fit of the paired 2014/2015 and 2016 data.

As seen in Figure 3, most of the individual household data points fall below the 1:1 line, indicative of lower wood use in 2016 relative to 2014/2015. This is seen for both the entire nonattainment sample as well as the North Pole subsample.

Figure 3
Comparison of Winter Season Wood Energy Usage by Household in 2014/2015 vs. 2016 Surveys

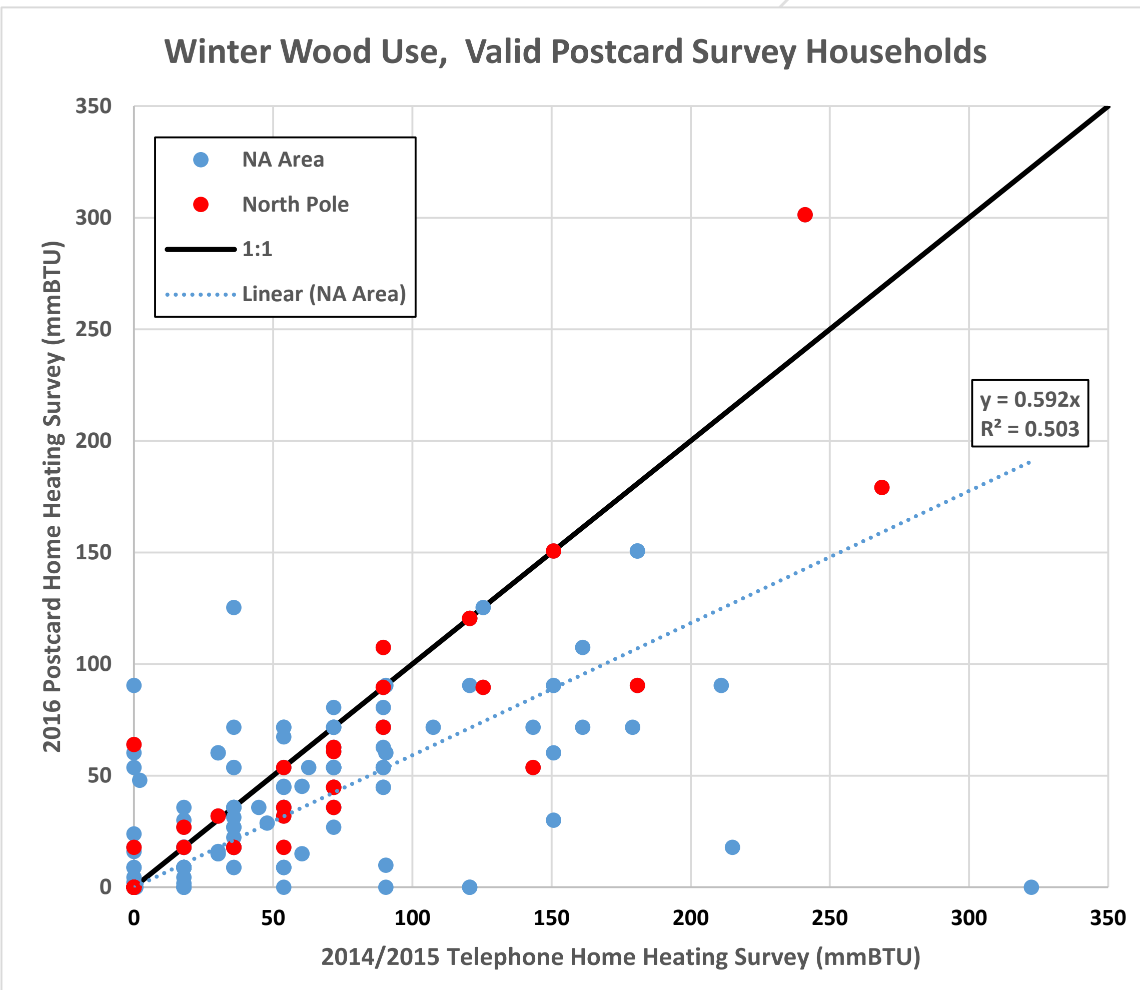
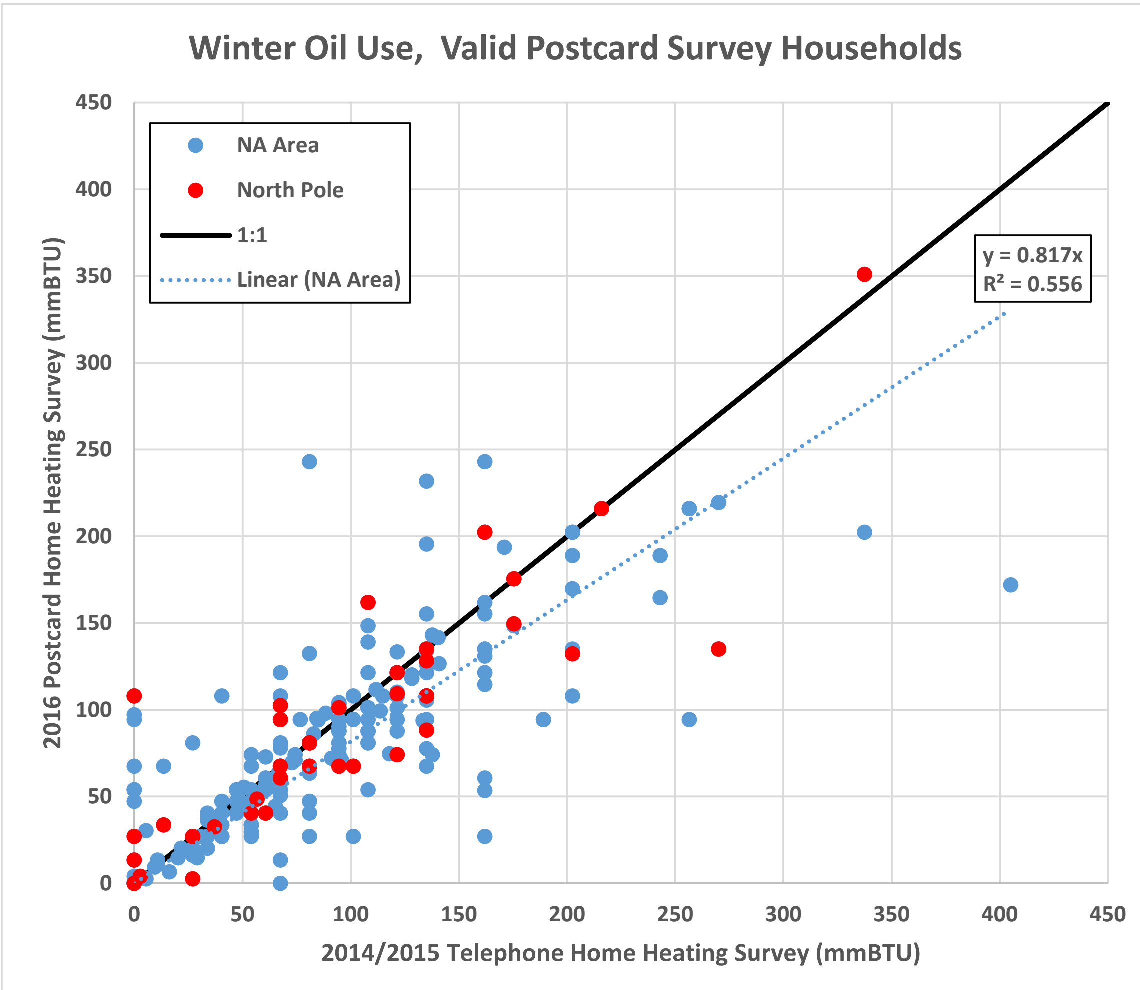


Figure 4
Comparison of Winter Season Heating Oil Energy Usage by Household in 2014/2015 vs. 2016 Surveys



As seen along the horizontal axis in Figure 3, there was no wood use in 2016 for several households that used wood in 2014/2015. Points clustered on the vertical axis represent households that used wood in 2016, but not 2014/2015.

In Figure 4, household oil usage between the two survey sets generally falls closer to the 1:1 line, reflecting similar oil usage levels in both sets. However, the least-squares linear regression line is still below the 1:1 slope, indicating an overall, but more modest, decrease in household oil usage between the 2014/2015 and 2016 surveys. (Note that the data points for oil use in Figure 4 on the vertical and horizontal axes still fall within the ±75% validation threshold that applies to all fuels in each household.)

Statistical Confidence – To evaluate the statistical significance of reported changes in household average fuel usage between the 2014/2015 and 2016 surveys, an analysis of the confidence bounds for the means of paired data was performed. For this, the difference between 2016 and

2014/2015 energy use by fuel type was computed for each household. The mean and standard deviation were computed for the paired differences and then expressed as confidence bounds on the mean difference for each fuel type. The confidence bounds for the difference in paired data are given by the following formula:

$$\overline{D} \pm t_{\alpha/2}\, S_d/\sqrt{n}$$

where $\overline{D}$ is the mean of differences between data points in each sample, S_d is the standard deviation of sample differences, $t_{\alpha/2}$ is a the point on the T_{n-1} distribution corresponding to an α confidence level, and *n* is the sample size. The analysis tested the null hypothesis that the means of wood use and oil use in each survey were equal. (Rejection of this null hypothesis means that the difference in average fuel use between each survey is statistically significant.)

For the differences in mean wood usage between the surveys across the nonattainment area, the probability that these differences are statistically significant is well above 99.9%; for the reported difference in average oil usage, the probability is 85.5%. We can be highly confident that wood use is truly down; our confidence that oil use is down does not reach the usual 90% or 95% confidence level, but it comes close.

Normalization for Differences in Winter Severity and Heating Efficiency – Finally, an analysis was performed to normalize or adjust the reported reduction in average wood usage between the 2014/2015 and 2016 surveys to account for differences in year-to-year winter severity and the effects of net heating efficiency when the split between wood and oil usage within a household changed. (Generally speaking, oil devices are more efficient than wood-burning devices.) Each adjustment is described below.

Winter Severity – HDD data were compiled from that reported[6] for the Fairbanks International Airport for the winters (October-March) of 2013-2014, 2014-2015, and 2015-2016. Data from the 2013-2014 and 2014-2015 winters were averaged to represent the heating load for the 2014/2015 telephone surveys. HDDs from 2015-2016 were compiled to represent the 2016 postcard survey. Table 2 presents the results. As shown at the bottom of Table 2, winter 2015-2016 (which represents the postcard survey) had just under 4% fewer HDDs than the average of the previous winters (which represent the telephone surveys).

Table 2
Comparison of Winter Heating Degree Days by Survey Period

Winter Period (Oct-Mar)	Survey	HDDs at Fairbanks Airport
2013-2014	-	10,086
2014-2015	-	10,151
Avg. Above	2014/2015 Telephone	**10,119**
2015-2016	2016 Postcard	**9,735**
Net Difference (%)		**-3.8%**

Source: *www.degreedays.net*

[6] *www.degreedays.net*

An alternative examination of winter severity was performed by comparing energy use in households that burned only oil during each survey. This could be a better metric for representing differences in heating demand from year-to-year weather variations since heating oil use is generally thermostatically controlled (assuming thermostats were set at the same point in each survey). The 81 oil-only households exhibited an average drop in energy use of 11.0% between the 2014/2015 and 2016 surveys. This suggests that HDDs based on ambient temperature data from a single location, Fairbanks International Airport, are not representative of heading energy demand across the entire nonattainment area.

Device Heating Efficiency Differences – Data from the 2014/2015 telephone surveys were examined to determine the specific types of wood, oil, and coal heating devices present in each valid household. Once these device types were determined (and assuming the same types of devices were present in the household during the 2016 postcard survey), the net heating efficiencies for all wood, oil, and coal devices in each household were calculated based on the reported fuel usage (translated to each appropriate device type) and heating device efficiencies shown below in Table 3. (These efficiencies are the same as those documented in the Moderate Area SIP inventory.)

Table 3
Wood, Oil, and Coal Device Heating Efficiencies

Code	Device-Technology	Heating Efficiency (%)
1	Fireplace (no insert)	7%
2	Insert-Conv	40%
3	Insert-NonCat	66%
4	Insert-Cat	70%
5	Wood Stove-Conv	54%
6	Wood Stove-NonCat	68%
7	Wood Stove-Cat	72%
8	Pellet Stove-Exempt	56%
9	Pellet Stove-EPACert	78%
10	Outdoor Wood Boiler	43%
11	Central Oil/Direct Vent Heaters	81%
12	Coal Heaters	43%

As seen in Table 3, heating efficiencies vary significantly for wood-burning devices and are lower than those assumed for oil-burning devices. Once net heating efficiencies were calculated from device/fuel usage data for each paired household, the effect of relative changes in wood vs. oil vs. coal usage across all household between the 2014/2015 and 2016 surveys was calculated. Even though wood and oil usage dropped, the relative shift was higher for wood than oil, reflecting a difference in the relative shares of each within each survey. Based on these calculations, the usage-weighted average heating efficiency across wood, oil, and coal devices in each household rose from 75.7% to 76.2%, an increase of 0.7%.

As discussed earlier, the HDD-based winter severity and device efficiency adjustments were applied to the reported overall energy usage differences to account for their effects, reducing the reported reduction of 17.1% to 13.6% (17.1 – 3.8 – 0.7).

ATTACHMENT A

2016 Home Heating Postcard Survey Form

	Wood Heating Devices)				Central Oil (boiler or furnace)	Direct Vent (Toyo or Monitor)	Coal Heater
	Fireplace (No insert)	Cordwood Stove or Insert	Pellet Stove or Insert	Outdoor Wood Boiler			
2015 Survey Winter Fuel Use (October thru March)	<filled>	<filled>	<filled>	<filled>	<filled>	<filled>	<filled>
	cords	cords	40 lb. bags	cords	gallons	gallons	tons
This Winter's Fuel Use (October thru March)							

After completing this survey, please detach along this perforation, and return the above postcard in the mail as soon as possible.

Instructions:

- Please review your reported fuel usage by device from the 2014/2015 survey listed on the shaded row at the top.
- Please enter your estimated fuel usage by device for this winter in the bottom row, using the fuel units shown for each.
- If did not use a device this winter, leave the box blank. If you used a device this winter, that was not present or not used in 2014/2015, please provide your estimated fuel usage in the appropriate box.

Hays Research Group
601 W. 5TH Ave., Ste. 205
Anchorage, AK 99501-6301

To better understand trends in air pollution, the State & Borough have been conducting annual telephone surveys to determine the mix of fuels used to heat homes in Fairbanks. You participated in the 2014 or 2015 surveys and provided the information inside this mailer on the fuels used to heat your home. This winter we are conducting a mailer-based survey to gauge trends in home heating fuel use. We are particularly interested in understanding if you took advantage of the drop in fuel oil prices and used more fuel oil to heat your home than in past winters. Similarly, we are interested to know if the amount of wood you burn also changed. There is a very brief survey on the top back fold of this letter. For the devices listed, please review the amounts of fuel you reported burning last winter and fill in the amounts that you burned this winter (October through March).

Once have you filled in the form, please detach the survey postcard and drop it in the mail. We have provided return postage for your convenience. If you have any concerns about this questionnaire, please contact Cindy Heil at the Alaska Department of Environmental Conservation (907) 269-7579 or Ron Lovell at FNSB (907) 459-1001.

Hays Research Group
601 W. 5TH Ave., Ste. 205
Anchorage, AK 99501-6301

Recipient Name
Street Address
Address 2
City, ST ZIP Code

ATTACHMENT B

Paired Survey Statistical Tabulations

Entire Nonattainment Area												
	Avg. HH Energy Use (mmBTU, winter)				**Households Using Each Fuel**				**Std Dev HH Energy Use (mmBTU, winter)**			
Survey Period	Wood	Oil	Coal	Total	Wood	Oil	Coal	Total	Wood	Oil	Coal	Total
2014-2015	60.35	94.60	3.33	158.28	133	214	3	233	55.02	68.43	41.02	79.45
2016	42.22	85.51	3.56	131.29	136	224	3	233	39.92	56.56	47.99	71.95
Net Changes	-18.13	-9.09	0.23	-26.99	3	10	0	-				
Std Error, 2014-2015	4.77	4.68	23.68	5.20								
Std Error, 2016	3.42	3.78	27.71	4.71								
Mean Diff (mmBTU)	-11.85	-9.09	0.23	-20.71								
Std Dev Diff (mmBTU)	37.86	42.38	10.76	47.36								
Std Error Diff (mmBTU)	2.48	2.78	0.70	3.10								
Confidence Bounds for Paired Means												
Test Statistic:	-4.78	-3.27	0.32	-6.67								
Probability (p value):	0.0%	0.1%	74.6%	0.0%								

North Pole ZIP Code (99705)												
	Avg. HH Energy Use (mmBTU, winter)				**Households Using Each Fuel**				**Std Dev HH Energy Use (mmBTU, winter)**			
Survey Period	Wood	Oil	Coal	Total	Wood	Oil	Coal	Total	Wood	Oil	Coal	Total
2014-2015	85.79	97.32	19.49	202.60	25	35	2	39	68.29	76.02	99.73	105.79
2016	68.23	92.13	20.07	180.43	27	38	2	39	61.95	68.77	116.92	123.21
Net Changes	-17.56	-5.19	0.58	-22.17	2	3	0	-				
Std Error, 2014-2015	13.66	12.85	-	16.94								
Std Error, 2016	11.92	11.16	-	19.73								
Mean Diff (mmBTU)	-9.57	-5.19	0.58	-14.17								
Std Dev Diff (mmBTU)	30.93	36.96	25.41	46.59								
Std Error Diff (mmBTU)	4.95	5.92	4.07	7.46								
Confidence Bounds for Paired Means												
Test Statistic:	-1.93	-0.88	-	-1.90								
Probability (p value):	6.1%	38.6%		6.5%								

Alaska Department of Environmental Conservation

Amendments to:

State Air Quality Control Plan

Vol. III: Appendix III.D.7.6

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 7. Fairbanks North Star Borough PM2.5 Control Plan, Serious Requirements}

Adopted

November 18, 2020

Michael J. Dunleavy, Governor

Jason W. Brune, Commissioner

Note: This appendix document provides the adopted language of the 2020 Amendment to Serious SIP for inclusion in this section of the State Air Quality Control Plan addressing the Fairbanks North Star Borough PM2.5 Serious nonattainment area.

(This page serves as a placeholder for two-sided copy)

Appendix III.D.7.06

Contents

The following document is included as part of the Appendix, however due to its electronic nature, it may be found posted separately at: http://dec.alaska.gov/air/anpms/communities/fbks-pm2-5-serious-sip/

Fairbanks PM2.5 Serious SIP Emissions by Source Sector and SCC Code; Emission Inventories Final Excel Spreadsheet.

2020 SIP Amendment

Content

Appendix III.D.7.6
2020 Amendment to the Serious State Implementation Plan
Emission Inventory Technical Appendix

INTRODUCTION

This technical appendix provides detailed documentation of the data sources, issues considered and methodologies and workflow applied in developing the baseline emission inventories developed to support the episodic attainment modeling in the Fairbanks North Star Borough (FNSB or Fairbanks) 2020 Amendment to the Serious Area SIP (2020 Amendment). The intent of this documentation is to explicitly describe the approaches used in calculating episodic emissions. Thus, the documentation is organized by source sector as follows:

- Episodic Point Sources;
- Home Heating Area Sources;
- Other Area Sources;
- On-Road Mobile Sources; and
- Non-Road Mobile Sources.

(Biogenic emissions do not occur in Fairbanks during the snow and ice-bound winter $PM_{2.5}$ season.)

Following the sector specific documentation, an inventory summary section is included that contains sector-specific tabulations of the 2019 Baseline, 2024 Projected Baseline and 2024 Control inventories. These tabulations include reporting of separate filterable and condensable components for $PM_{2.5}$ for those source sectors for which these components are available as explained therein.

For all inventory sectors, episodic modeling emissions were generally calculated using a “bottom-up” approach that relied heavily on an exhaustive set of locally measured data used to support the emission estimates.

Within the Home Heating sector, separate sections are provided that detail key underlying data sources and components of the approach used to estimate episodic home heating emissions, given their importance within the entire inventory as follows:

- Development of Energy Model – describes local instrumented data collection and analysis used to develop a home heating energy demand model calibrated to episodic wintertime conditions in Fairbanks;

- Residential Surveys – documents the structure, content and approach used to collect key activity, source mix and behavior pattern data in a series of home heating surveys of locally sampled residential households;

- Fairbanks Wood Energy and Moisture Content – explains the data sources used to identify the local mix and energy content of wood species used in home heating and the methods used to account for the effect of wood moisture content on emissions;

- OMNI and AP-42 Emission Factors – discusses the emission factors used to estimate home heating emissions in Fairbanks by device type and includes factors developed from laboratory testing local heating devices and AP-42-based rates; and

- Emission Calculation Details – explains how each of the data sources and upstream methods were combined to estimate gridded hourly estimates of home heating emissions.

EPISODIC POINT SOURCE DATA

Given the potential for strong seasonal variations in facility activity and demand, point source emissions to support the episodic modeling were developed on a day- and hour-specific basis for each of the key point source facilities within the modeling domain. This section of the technical appendix describes how episodic activity data were collected by DEC and emission estimates calculated for these point sources. It also explains how these data were reviewed for quality assurance before being loaded into the SIP modeling inventory.

BASE YEAR EPISODIC POINT SOURCE DATA

For the 2019 Baseline inventory under the 2020 Amendment, DEC queried facilities from its permits database to identify major and minor point source facilities within the modeling domain. DEC uses the definition of a major source under Title V of the Clean Air Act (as specified in 40 CFR 51.20) to define the "major source" thresholds for reporting annual emissions. These thresholds are the potential to emit (PTE) annual emissions of 100 tons for all relevant criteria air pollutants. Natural minor and synthetic minor facilities (between 5 and 99 TPY) reporting emissions under either New Source Review (NSR) or Prevention of Significant Deterioration (PSD) requirements were also in the query identify facilities down to the 70 TPY threshold required to classify stationary point sources under Serious Area inventory requirements.

A total of 14 facilities were identified. Of these, DEC noted that three of the facilities, the Golden Valley Electric Association (GVEA) Healy Power Plant and the heating/power plants at Fort Greely (near Delta Junction) and Clear Air Force Base (near Anderson) were excluded from development of episodic emissions. These facilities were excluded because of their remoteness relative to Fairbanks (all are between 55 and 78 miles away)[1] or the fact that they were located generally downwind of the non-attainment area under episodic air flow patterns (Healy Power Plant and Clear AFB). Three others were identified as minor/synthetic minor sources: 1) Fort Knox Mine (26 miles northeast of Fairbanks), 2) Usibelli Coal Preparation Plant (in Healy), and 3) CMI Asphalt Plant (in Fairbanks) and were excluded from treatment as individual episodic point sources because they were either located outside the non-attainment area (Fort Knox and Usibelli) or exhibited insignificant wintertime activity (CMI Asphalt Plant).

(These excluded facilities were treated as stationary non-point or area sources within the inventory.)

The names and primary equipment and fuels of the eight remaining facilities for which episodic data were collected and developed are summarized in Table 7-6-1. One facility, Eielson Air Force Base is located just outside the non-attainment area boundary on the southeast edge. All other facilities listed in Table 7-6-1 are located within the non-attainment area.

[1] Individual point source plume modeling conducted by DEC in support of the SIP using the CALPUFF model found that under the episodic meteorological conditions, emissions from facilities located outside the Fairbanks PM2.5 non-attainment area exhibited negligible contributions to ambient $PM_{2.5}$ concentrations in the area.

Table 7-6-1 Summary of SIP Modeling Inventory Point Source Facilities		
Facility ID	Facility Name	Primary Equipment/Fuels
71	Flint Hills North Pole Refinery	11 crude & process heaters burning process gas/LPG (9 operated during episodes), plus 2 natural gas-fired steam generators, gas flare
109	GVEA Zehnder (Illinois St) Power Plant	Two gas turbines burning HAGO[a], two diesel generators burning Jet A
110	GVEA North Pole Power Plant	Three gas turbines, two burning HAGO, one burning naphtha (plus an emergency generator and building heaters not used during episodes)
236	Fort Wainwright	Backup diesel boilers & generators (3 each) - none operated during episodes
264	Eielson Air Force Base	Over 70 combustion units - six coal-fired main boilers only operated during episodes
315	Aurora Energy Chena Power Plant	Four coal-fired boilers (1 large, 3 small), all exhausted through common stack
316	UAF Campus Power Plant	Two coal-fired, two oil-fired boilers (plus backup generators & incinerator not operated during episodes)
1121	Doyon Utilities (private Fort Wainwright units)	Six coal-fired boilers

[a] Heavy Atmospheric Gas Oil. HAGO is a crude distillate at the heavy end of typical refinery "cuts" with typical boiling points ranging from 610-800°F. Due to geographic proximity, GVEA seasonally used HAGO during winter, a by-product from Flint Hills Refinery until Flint Hills shutdown refinery operations after 2014. (Existing HAGO supply at the GVEA facilities was exhausted by 2016.)

As noted in Table 7-6-1, some of the equipment is not normally operated during wintertime modeling episodes. This infrequently operated equipment includes backup boilers and emergency generators.

In December 2010, DEC sent letters of request and spreadsheet templates to each of the eight point source facilities listed in Table 7-6-1, requesting additional actual day- and hour-specific activity and emissions data from each facility (as available) covering the two 2008 historical modeling episodes:

- Episode 1 (E1) – January 23 through February 10, 2008; and
- Episode 2 (E2) – November 2 through November 17, 2008.

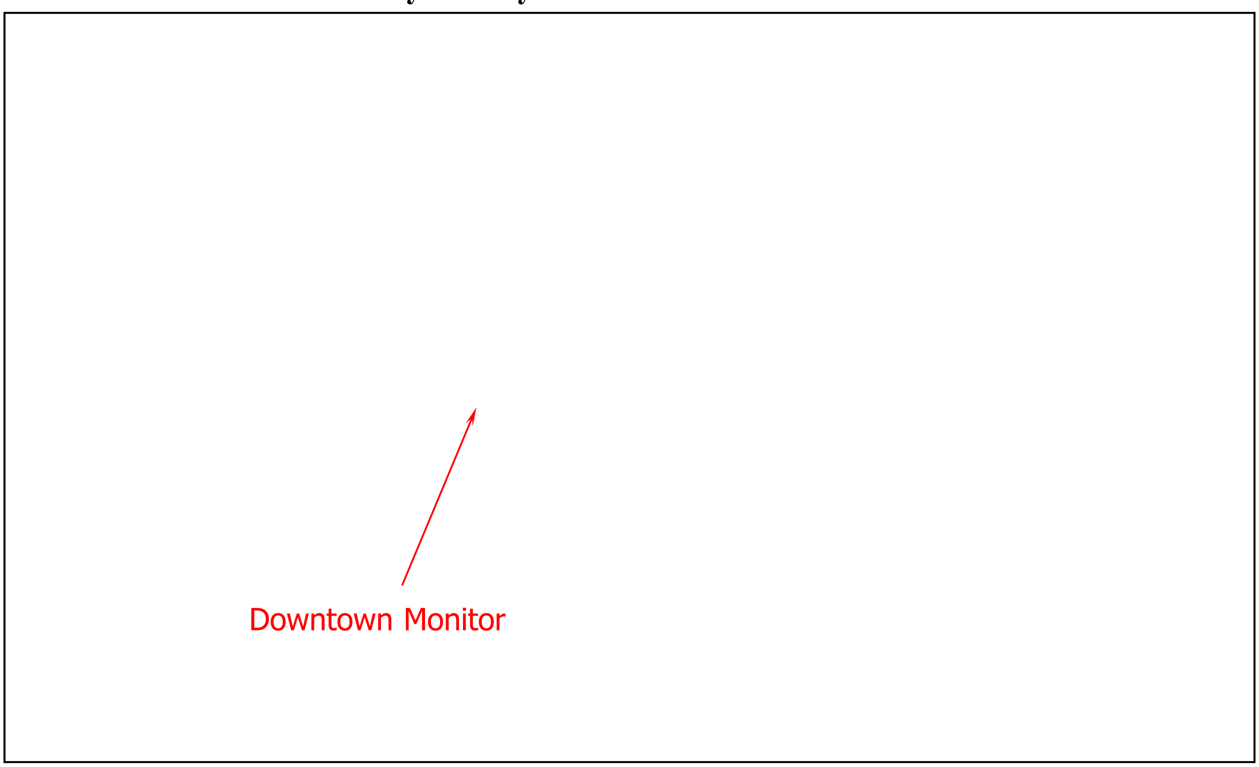
The spreadsheet template contained individual sheets organized in a structure similar to that use to collect and submit stationary point source data to EPA under National Emission Inventory (NEI) reporting requirements. Information was requested for both combustion and fugitive sources. Requested data elements included emission units, stack parameters (height, diameter, exit temperature and velocity/flow rate), release points (location coordinates), control devices (as applicable), seasonal and diurnal fuel properties and throughput.

If available (e.g. through continuous emissions monitoring systems) facilities were also directed to submit additional spreadsheets with day and hour-specific data for the two historical modeling episodes.

Episodic 2008 actual data were provided by seven of the eight facilities listed earlier in Table 7-6-1. (Episodic data were not provided for Fort Wainwright (Facility ID=236) since as its backup diesel generators and boilers were not in operation during the two 2008 modeling episodes as noted in Table 7-6-1.) The facilities provided fuel use, sulfur content, emission factor, and/or emissions data. The pollutants of interest included $PM_{2.5}$, sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOC).

Figure 7-6-1 shows the locations of each of the point sources contained within the $PM_{2.5}$ nonattainment area (the tan shaded area), by facility ID and stack ID. The green dots represent locations of combustion point sources while the orange dots signify fugitive VOC sources. The location of the downtown ambient $PM_{2.5}$ monitor is also shown in Figure 7-6-1.

Figure 7-6-1
Location of Point Sources by Facility ID Within Fairbanks $PM_{2.5}$ Non-Attainment Area



QUALITY ASSURANCE REVIEW

DEC's contractor, Sierra Research, Inc. (Sierra), then assembled and reviewed the submitted data for completeness, consistency and validity prior to integrating the episodic data into the SIP inventories. Given the differences in structure and content of the submitted episodic data, the data were individually reviewed for each facility before being assembled into a consistent inventory structure.

Generally, most facilities provided hourly $PM_{2.5}$ and SO_2 emission rates by individual emission unit. As explained in greater detail below, Sierra then developed estimates of NO_x and VOC emission rates from AP-42[2] based emission factors (where fuel use data were explicitly provided) or from fuel-specific emission factor ratios.

The actual episodic data obtained from each facility are summarized below. Any corrections made to the data during the review are specifically noted.

Flint Hills Refinery (#71) - The Flint Hills Refinery (FHR) provided DEC with hourly emissions data for $PM_{2.5}$/ SO_2/NO_x/ VOC for five release points encompassing 12 emission sources. Flint Hills Refinery did not differentiate the hourly emissions among the underlying emission sources. Flint Hills Refinery did not provide the underlying fuel usage rates, process throughput rates, or the emission factors associated with these emissions. Flint Hills Refinery did not provide the basis for the emissions data; it only provided the hourly emissions. Emissions from one of the four release points – the flare – are insignificant compared to the emissions from the four release points. Flint Hills Refinery did not provide stack temperature, stack flow rate, or stack velocity data for the flare. As noted earlier, with the closure of Flint Hills refinery operations in 2014 episodic emissions from this facility were zeroed in 2019.

GVEA Zehnder Power Plant (#109) - GVEA provided DEC with hourly fuel consumption and PM/SO_2 emissions data for two liquid-fired gas turbines and two liquid fired generators. The gas turbines (Units 1/2) burn HAGO/Jet A. GVEA calculated hourly PM/SO_2 emissions from the hourly fuel usage and emission factors. Sierra similarly calculated hourly NO_x/VOC emissions from the hourly fuel usage and emission factors.

For Units 1/2, GVEA used a source test-derived filterable PM emission factor; Sierra assumed that PM comprised 100% $PM_{2.5}$ since AP-42 does not distinguish PM emissions by particle size. Sierra further assumed that the condensable PM fraction was negligible compared to the filterable PM fraction. GVEA derived the HAGO/Jet A SO_2 emission factors from the averaged measured HAGO/Jet A sulfur contents and HAGO/Jet A higher heating values (HHV). Sierra obtained the NO_x/VOC emission factors for an uncontrolled gas turbine from Tables 3.1-1 and 3.1-2a, respectively, of AP-42 (April 2000).

For the generators (Units 3/4), GVEA obtained the $PM_{2.5}$ emission factor from Table 3.4-2 of AP-42 (October 1996). GVEA derived the diesel SO_2 emission factor from the averaged measured Jet A sulfur content and Jet A HHV. Sierra obtained the NO_x/VOC emission factors

[2] "AP-42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources," Environmental Protection Agency, January 1995.

for an uncontrolled engine from Table 3.4-1 of AP-42 (October 1996). Sierra corrected some errors it discovered while reviewing GVEA's calculations. Units 3/4 SO_2 emissions were overstated by a factor of 100 because the fuel sulfur content was not divided by 100 in the calculation. Unit 4 SO_2 emissions during November were further overstated. The combined emissions from Units 3/4 were calculated rather than apportioning the fraction attributable to Unit 4. Emissions from the two generators are insignificant compared to the emissions from the two gas turbines. GVEA did not provide stack temperature, stack flow rate, or stack velocity data for the generators.

<u>GVEA North Pole Power Plant (#110)</u> **-** GVEA provided DEC with hourly fuel consumption and PM/SO_2 emissions data for three liquid-fired gas turbines comprising five release points (two turbines each discharge to two separate stacks). Units 1/2 burn HAGO while Unit 5 burns a combination of naphtha and Jet A. GVEA calculated hourly PM/SO_2 emissions from the hourly fuel usage and emission factors. Sierra similarly calculated hourly NO_x/VOC emissions from the hourly fuel usage and emission factors.

For Units 1/2, GVEA used a source test-derived PM_{10} emission factor; Sierra assumed that PM_{10} comprised 100% $PM_{2.5}$ since AP-42 does not distinguish PM emissions by particle size. GVEA derived the SO_2 from the averaged measured HAGO sulfur content and HAGO HHV. Sierra obtained the NO_x/VOC emission factors for an uncontrolled gas turbine from Tables 3.1-1 and 3.1-2a, respectively, of AP-42 (April 2000). Sierra corrected an error it discovered while reviewing GVEA's calculations. Units 1/2 emissions were inadvertently calculated using the Jet A HHV rather than the HAGO HHV.

For Unit 5, GVEA obtained the PM emission factors (filterable and condensable) from Table 3.1-2a of AP-42 (April 2000); Sierra assumed that PM comprised 100% $PM_{2.5}$ since AP-42 does not distinguish PM emissions by particle size. The AP-42 PM emission factor used for Unit 5 is over an order of magnitude lower than the source test-derived PM_{10} emission factor used for Units 1/2. GVEA derived the naphtha/Jet A SO_2 emission factors from the averaged measured naphtha/Jet A sulfur contents and naphtha/Jet A HHVs. The naphtha/Jet A SO_2 emission factors used for Unit 5 are nearly an order of magnitude lower than the HAGO SO_2 emission factor used for Unit 5 because the sulfur content of HAGO is much higher than that of naphtha/Jet A. Sierra obtained the NO_x/VOC emission factors for a water injected gas turbine from Tables 3.1-1 and 3.1-2a, respectively, of AP-42 (April 2000).

<u>Eielson Air Force Base (#109)</u> **-** Eielson Air Force Base provided DEC with combined hourly $PM_{2.5}$ and SO_2 emissions data for six release points, each comprising one coal-fired spreader stoker boiler. Eielson did not differentiate the hourly emissions among the underlying boilers but did provide the underlying hourly steam production rates associated with each boiler. Eielson did not provide the basis for the hourly $PM_{2.5}$ and SO_2 emissions data; it only provided the combined hourly emissions. Sierra allocated hourly $PM_{2.5}$ and SO_2 emissions among the six boilers proportional to hourly steam production relative to the total steam production.

Sierra calculated hourly NO_x and VOC emissions from the hourly $PM_{2.5}$ emissions using the ratio of NO_x/VOC emission factors to an assumed $PM_{2.5}$ emission factor. Sierra obtained the assumed total $PM_{2.5}$ emission factor, representing the sum of filterable and condensable emission factors, for a spreader stoker boiler equipped with a baghouse and firing sub-bituminous coal (or bituminous coal when sub-bituminous coal emissions data were not available) from Tables 1.1-5 and 1.1-9 of AP-42 (September 1998). Sierra obtained the NO_x/VOC emission factors for a water injected gas turbine from Tables 1.1-3 and 1.1-19, respectively, of AP-42 (September 1998).

Emission factors for spreader stoker boilers firing sub-bituminous coal (or bituminous coal when sub-bituminous coal emissions data were not available). Sierra similarly allocated hourly emissions among the six boilers proportional to hourly steam production relative to the total steam production.

Aurora Energy, LLC (#315) **-** Aurora Energy, LLC provided DEC with hourly average $PM_{2.5}$/SO_2 emissions data, which Aurora derived from daily emissions, for one release point encompassing 4 emission sources (i.e., coal boilers). Aurora did not differentiate the daily emissions among the underlying emission sources. Aurora did not provide the basis for the $PM_{2.5}$/SO_2 emission calculations. Aurora did not provide any hourly fuel usage or steam production data to enable Sierra to allocate daily emissions on an hour basis proportional to hourly plant production.

Aurora also provided Sierra directly with daily coal usage data from which Sierra used emission factors (in lb/mmBTU) to calculate daily NO_x/VOC emissions. Aurora provided Sierra permitted NO_x emission rates and maximum heat input rates for each boiler, from which Sierra derived NO_x emission factors (in lb/mmBTU). Sierra obtained the VOC emission factor for a coal-fired spreader stoker boiler from Table 1.1-19 of AP-42 (September 1998). Since Aurora did not provide any hourly fuel usage or steam production data to enable Sierra to allocate daily emissions on an hour basis proportional to hourly plant production, Sierra calculated the average hourly NO_x /VOC emissions from the daily NO_x /VOC emissions.

University Of Alaska, Fairbanks (#316) **-** The University of Alaska, Fairbanks (UAF) provided DEC with hourly fuel use data for four boilers – two coal-fired and two oil-fired – comprising four separate release points. UAF subsequently confirmed with Sierra that the fuel oil usage units of measure are actually gallons per minute, though initially reported as gallons per hour. UAF did not provide hourly emissions data. Sierra calculated hourly $PM_{2.5}$/SO_2/ NO_x /VOC emissions using emission factors and fuel usage. UAF provided fuel sulfur content data and a source test-derived coal $PM_{2.5}$ emission factor. Sierra obtained SO_2/ NO_x /VOC emission factors for overfeed stoker boilers burning sub-bituminous coal from Tables 1.1-3 and 1.1-19 of AP-42 (September 1998). Sierra obtained $PM_{2.5}$/SO_2/ NO_x /VOC emission factors for industrial boilers burning #2 fuel oil from Tables 1.3-1, 1.3-2, and 1.3-3 of AP-32 (May 2010).

Doyon Utilities (#1121) **-** Doyon Utilities provided DEC with daily emissions data for $PM_{2.5}$ and SO_2 for six release points, each comprising one coal-fired spreader stoker boiler. Doyon did not provide the hourly emissions for each boiler but did provide the underlying hourly steam production rates associated with each boiler. Doyon calculated daily $PM_{2.5}$/SO_2 emissions from the daily coal usage, daily coal sulfur content, and emission factors. Doyon obtained the $PM_{2.5}$/SO_2 emission factors for spreader stoker boilers equipped with a baghouse and firing sub-bituminous coal (or bituminous coal when sub-bituminous coal emissions data were not available) from Tables 1.1-3, 1.1-5, and 1.1-9 of AP-42 (September 1998). Sierra similarly calculated daily NO_x / VOC emissions from the daily coal usage and emission factors. Sierra obtained the NO_x /VOC emission factors for spreader stoker boilers firing sub-bituminous coal from Tables 1.1-3 and 1.1-19 of AP-42 (September 1998). Sierra allocated hourly emissions among the six boilers proportional to hourly steam production relative to the daily steam production.

Doyon was unable to provide hourly steam production data for January 24th. Sierra allocated daily emissions by assuming that the hourly emissions were proportional to the average of the hourly emissions from the preceding and following day (i.e., January 23rd and 25th). Hourly steam production was also missing for Hours 14 through 16 on November 15th. Sierra assumed that hourly steam production for these missing hours equaled the average of the preceding and following hours (Hour 13 and 17).

Cross-Facility Fuel Properties Review – As an additional data validation check, a comparison of key fuel properties across all of the point source facility data was performed. Although fuel property data submitted by facilities were based on actual fuel measurements, the intent was to ensure there were no inadvertent transcription errors in the submitted data by confirming that these data fell within accepted ranges. Table 7-6-2 summarizes the results of sulfur and ash content comparisons by fuel type across all facilities using each fuel.

Table 7-6-2
Comparison of Key Point Source Fuel Properties

Fuel	Sulfur Content (%)	Ash Content (%)
LPG/Natural gas	~0.001	0
Naphtha	0.018 - 0.024	0
Jet A	0.083 - 0.093	0
Coal	0.12 – 0.34	7-15
Distillate Oil	0.39 – 0.44	0
HAGO	0.69 – 0.71	0

Source Coordinates Review – Coordinates for stack/vent release point locations obtained from each facility were also reviewed by Sierra. The transmittal spreadsheets requested latitude and longitude coordinates and the geodetic datum on which they were based for the source release points of each facility.

To validate the source coordinate data submitted by each facility, the latitude/longitude data and datum (when provided) were loaded into GIS software (ArcGIS). As-received coordinates were given based on a combination of WGS84, NAD1983 and NAD1927 datums. Thus the first step in validating the coordinate data consisted of converting them all to a single standardized datum

(WGS84) within ArcGIS. WGS84 was chosen since it is the datum upon with the Google Earth mapping utility is based. The unified datum coordinate data were then exported to a “KMZ” spatial data file for plotting and viewing within Google Earth.

Several coordinate inconsistencies were found for one or two of the facilities and were straightforward to visually identify using Google Earth. They generally appeared to be the result of either transcription errors in the latitude/longitude data provided or related to uncertainty about the datum upon which they were based. A list of facility-specific coordinate inconsistencies was prepared for DEC which was used to follow-up with and obtain corrected data from affected facilities. In one instance, revised location coordinates still did not accurately match comparisons of zoomed in Google Earth views and source locations on a building sketch map. For this instance, it was assumed that the datum with which the coordinates were associated was incorrect and the latitude/longitude coordinates were identified directly from the zoomed in Google Earth view.

Scaling of Episodic Emissions from 2008 to 2019 – Annual actual emissions by emission unit for each facility in calendar years 2008 and 2019 were obtained by DEC. The 2008 annual emission were extracted from DEC’s historical permit database (including facility operating reports and permit fee assessments). Annual 2019 data were collected by DEC in between January and March 2020 by email outreach to each applicable facility to obtain annual and quarterly fuel usage data (and updated emission factors where appliable) by emission unit for each facility. Actual annual emissions by facility and pollutant for each year were tabulated and then used to scale the day/hour specific 2008 episodic data provided by each facility from 2008 to 2019. This approach essentially simulates the levels of facility specific- emissions from the 2008 modeling episodes relative to annual emissions, carried forward to 2019.[3]

Table 7-6-3 compares annual fuel use by facility between 2008, 2013 (the baseline year for the earlier Serious SIP) and 2019 (the 2020 Amendments baseline year), including splits of HAGO vs. lighter distillates (distillate #2/#1, Jet A, Naphtha) at the GVEA facilities. As seen, there were generally modest changes (roughly within 10%) in annual throughput/fuel use between 2008, 2013 and 2019 for most facilities. The GVEA facilities were the biggest exception, using much less HAGO fuel in 2013 than in 2008 (although HAGO use increased at the Zehnder facility), but then increasing lighter distillate usage with the elimination of HAGO supply. This is important since HAGO has significantly higher $PM_{2.5}$ and SO_2 emissions per unit of fuel energy than the lighter distillate/Jet A/Naphtha fuels it also uses. Coal use at Doyon was 17% higher in 2013 than 2008, but then dropped in 2019 to 20% below the 2008 level.

Generally, each facility provided hourly $PM_{2.5}$ and SO_2 emission rates by individual emission unit. Estimates of NO_x, VOC and NH_3 emission rates were developed from AP-42 based emission factors[4] (where fuel use data were explicitly provided) or from fuel-specific emission factor ratios.

[3] Since day-specific 2019 modeling episodes for the SIP baseline year were not developed, there was no reason to obtain day- and hour-specific emissions or fuel use from facility operations in 2019.

[4] AP-42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources,” Environmental Protection Agency, January 1995.

Table 7-6-3
Comparison of 2019, 2013 and 2008 Annual Fuel Use by Facility and Fuel Type

Facility ID	Facility Name	Calendar Year	HAGO (1000 gal/year)	Light Distillate (1000 gal/year)	Coal (tons/year)
109	GVEA Zehnder	2008	827	8	n/a
		2013	1,200	1	n/a
		2019	0	1,255	n/a
		% Change, 2008-2013	+45%	-87%	n/a
		% Change, 2008-2019	-100%	+14922%	n/a
110	GVEA North Pole	2008	5,634	23,054	n/a
		2013	2,764	23,345	n/a
		2019	0	37,459	n/a
		% Change, 2008-2013	-51%	+1%	n/a
		% Change, 2008-2019	-100%	+62%	n/a
315	Aurora Energy	2008	n/a	n/a	222,592
		2013	n/a	n/a	214,961
		2019	n/a		221,799
		% Change, 2008-2013	n/a	n/a	-3%
		% Change, 2008-2019	n/a	n/a	-0%
316	UA Fairbanks	2008	n/a	935	73,900
		2013	n/a	852	68,599
		2019	n/a	1,587	51,697
		% Change, 2008-2013	n/a	-9%	-7%
		% Change, 2008-2019	n/a	+70%	-30%
1121	Doyon (Fort Wainwright)	2008	n/a	n/a	246,250
		2013	n/a	n/a	288,702
		2019	n/a	n/a	196,378
		% Change, 2008-2013	n/a	n/a	+17%
		% Change, 2008-2019	n/a	n/a	-20%

Note: Flint Hills Refinery closed in 2014 and was thus omitted from this comparison and fuel data in each year for Eielson AFB were not available, only annual emissions. Eielson, located just outside the nonattainment areas was also not included in this comparison.

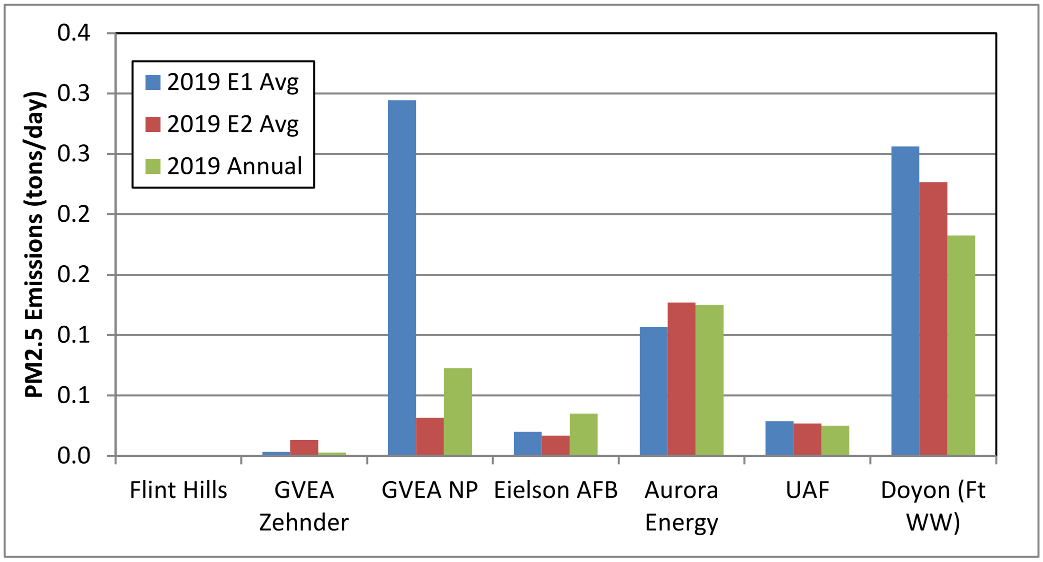
Emission Comparisons

Episodic vs. Annual Actual Emission Levels - Once the facility data were corrected and validated, a series of emission summaries for each facility were developed comparing emissions across each of the two modeling episodes (from the episodic data) to actual emissions for all of calendar 2019. Emission levels were converted to an average daily basis, to standardize the comparisons of episodic and annual emissions.

Figure 7-6-2 through Figure 7-6-6 provide comparisons of $PM_{2.5}$, SO_2, NO_x, VOC and NH_3 emissions (for facilities reporting NH_3 emissions), respectively, for each source facility for which episodic data were collected. Within each figure, three sets of daily average emissions (in tons/day) are plotted for each facility, as described below.

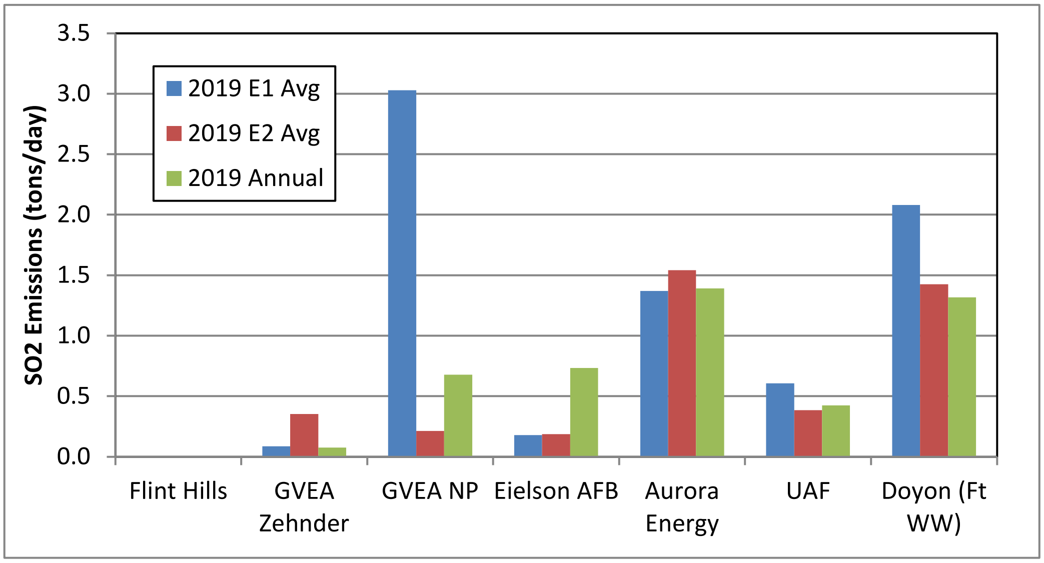
1. *2019 E1 Avg* – Episode 1 average daily emissions, scaled forward to 2013
2. *2019 E2 Avg* – Episode 2 average daily emissions, scaled forward to 2013
3. *2019 Annual* – 2019 annual average daily actual emissions (from DEC database)

Figure 7-6-2. 2019 $PM_{2.5}$ Episodic vs. Annual Average Point Source Emissions (tons/day)



All five pollutant plots show two elements very clearly. First, the strong seasonal nature of emissions at many of the facilities is evidenced where episodic daily emissions are higher than annual average daily emissions. For example, as shown in Figure 7-6-2 direct $PM_{2.5}$ emissions during the wintertime modeling episodes are much higher than the daily average over the entire year at both GVEA power plants and the Doyon facilities on the Fort Wainwright Army Base. This relates to the fact that more energy is needed for electric heat and power from these facilities during winter when temperatures are colder and nights are longer. Second, each plot shows which facilities are the major point source contributors for each pollutant.

Figure 7-6-3. 2019 SO_2 Episodic vs. Annual Average Point Source Emissions (tons/day)



Though not shown in Figure 7-6-2 through Figure 7-6-6, a cross-check of the 2008 to 2019 facility emissions scaling updates was performed to verify that scaled 2019 emissions did not exceed annual PTE limits for each facility.

In the modeling inventory, the episodic actual emissions for each point are represented on a day- and hour-specific basis. The E1 and E2 emission levels shown in the plots are averages compiled from the day- and hour-specific emissions across each modeling episode.

Figure 7-6-4. 2019 NO_x Episodic vs. Annual Average Point Source Emissions (tons/day)

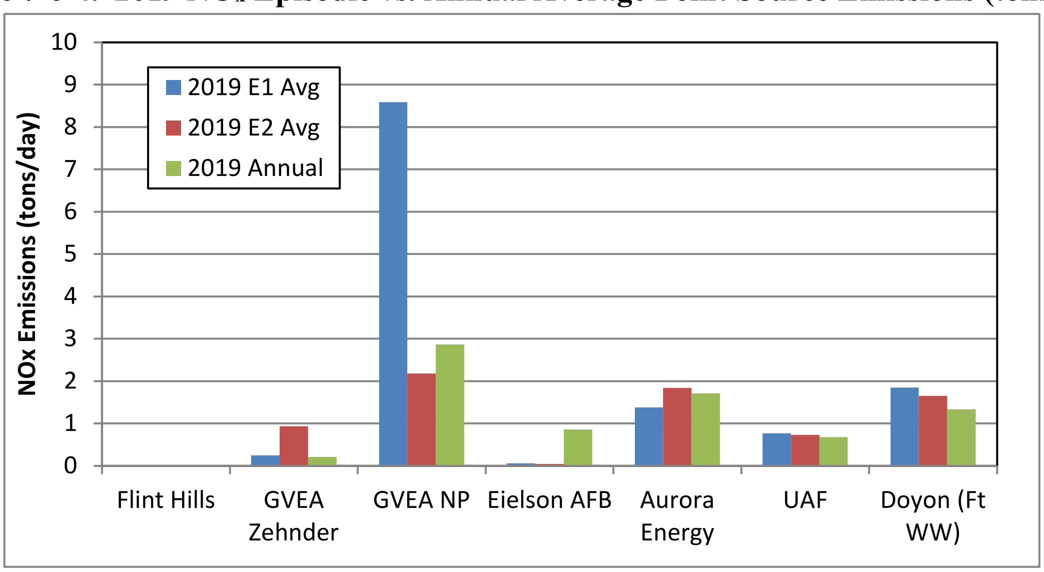


Figure 7-6-5. 2013 VOC Episodic vs. Annual Average Point Source Emissions (tons/day)

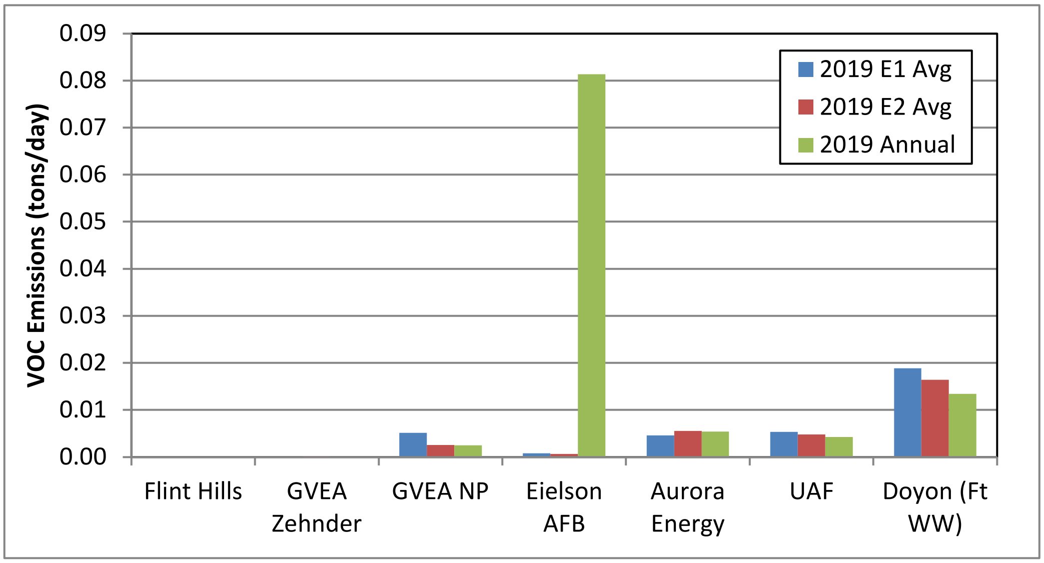
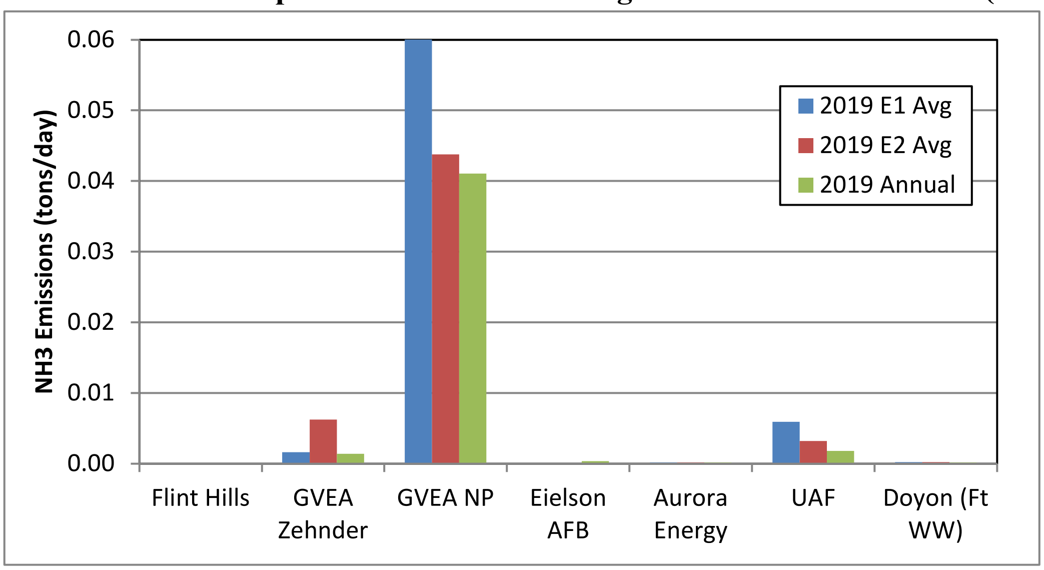


Figure 7-6-6. 2019 NH_3 Episodic vs. Annual Average Point Source Emissions (tons/day)



Note: NH_3 emissions were not reported from Flint Hills and Eielson AFB. Those for Aurora Energy and Doyon are too small to see on the scale of the plot.

Hourly Emissions – In addition to examining episodic and annual emissions, comparisons of hourly emissions averaged across all days in each episode were also developed for each facility.

Figure 7-6-7 and Figure 7-6-8 compare average hourly $PM_{2.5}$ emissions for each facility in Episode 1 and Episode 2, respectively. As seen in these two figures, the hourly $PM_{2.5}$ emission profiles vary both by facility within an episode, as well as across each episode for some facilities.

Figure 7-6-7
Episode 1 Average Hourly $PM_{2.5}$ Emissions (lb) by Facility

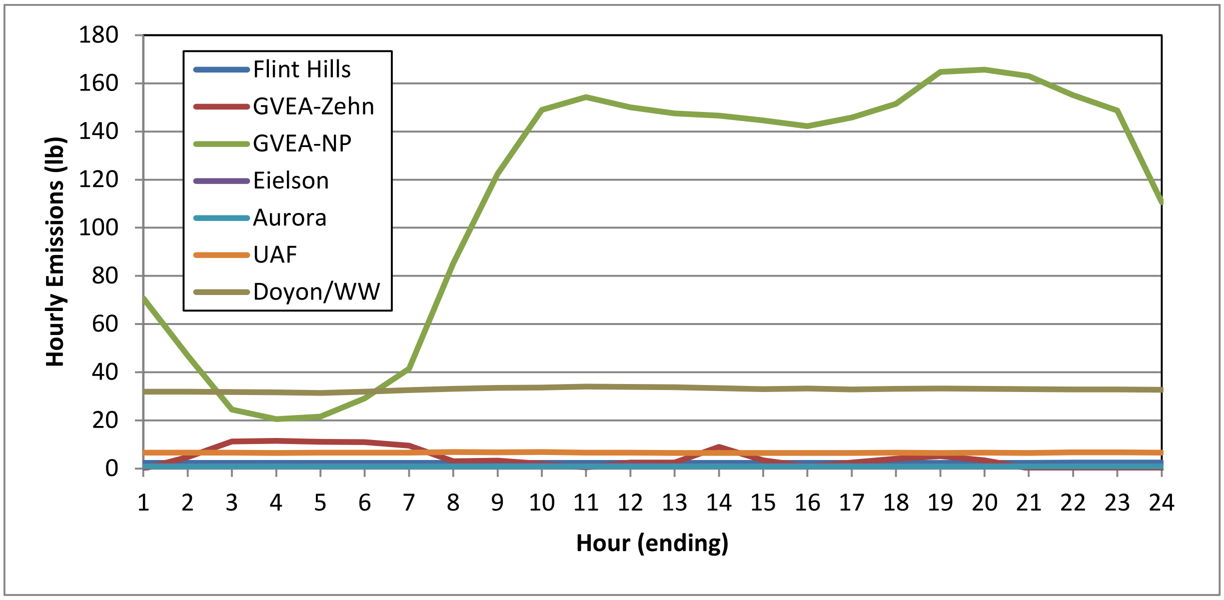
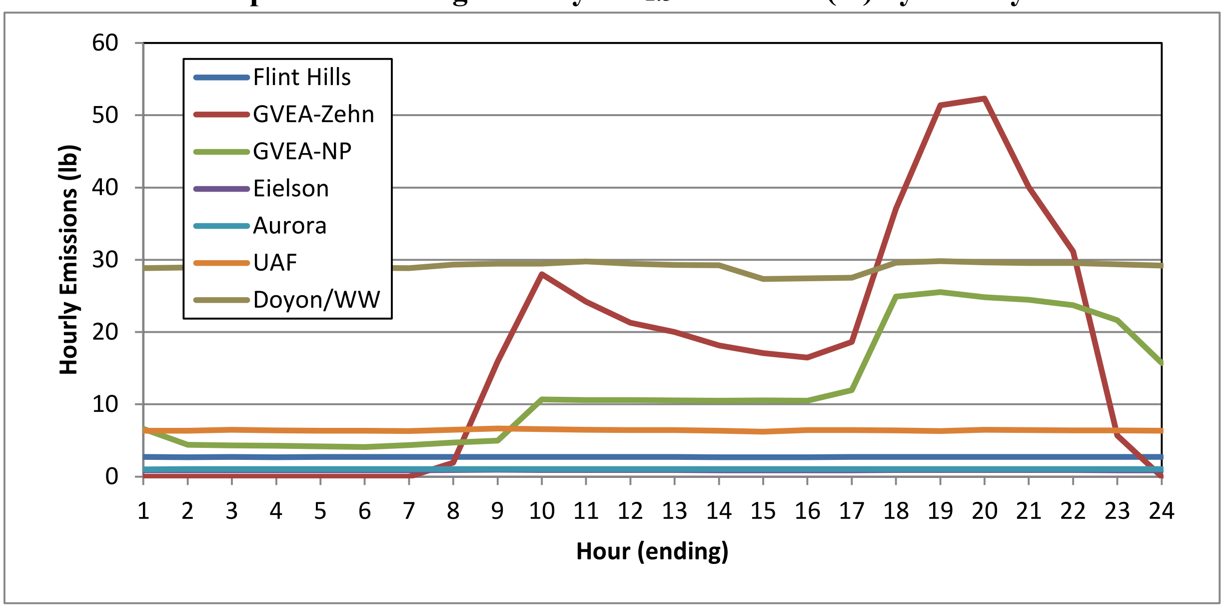


Figure 7-6-8
Episode 2 Average Hourly $PM_{2.5}$ Emissions (lb) by Facility



The two GVEA facilities show significant variation in hourly average emissions. As seen in Figure 7-6-7 hourly $PM_{2.5}$ emissions at GVEA North Pole (GVEA-NP) vary by nearly a factor of ten, with emissions highest from 10 am through around 10 pm before dropping significantly. The GVEA-Zehnder emissions also vary but appear more muted when plotted on the same scale because emissions for that facility during Episode 1 are much lower than at GVEA-NP. In contrast, Figure 7-6-8 shows that GVEA-Zehnder $PM_{2.5}$ hourly emissions vary even more dramatically that GVA-NP during Episode 2. Hourly $PM_{2.5}$ emissions for the other five facilities are much more constant throughout the day.

Figure 7-6-9 and Figure 7-6-10 present similar comparisons across Episodes 1 and 2 for hourly SO_2 emissions. Again, the two GVEA facilities exhibit significant variation in diurnal SO_2 emissions, while emissions for the other facilities are generally flat across each hour of the day.

Figure 7-6-9
Episode 1 Average Hourly SO_2 Emissions (lb) by Facility

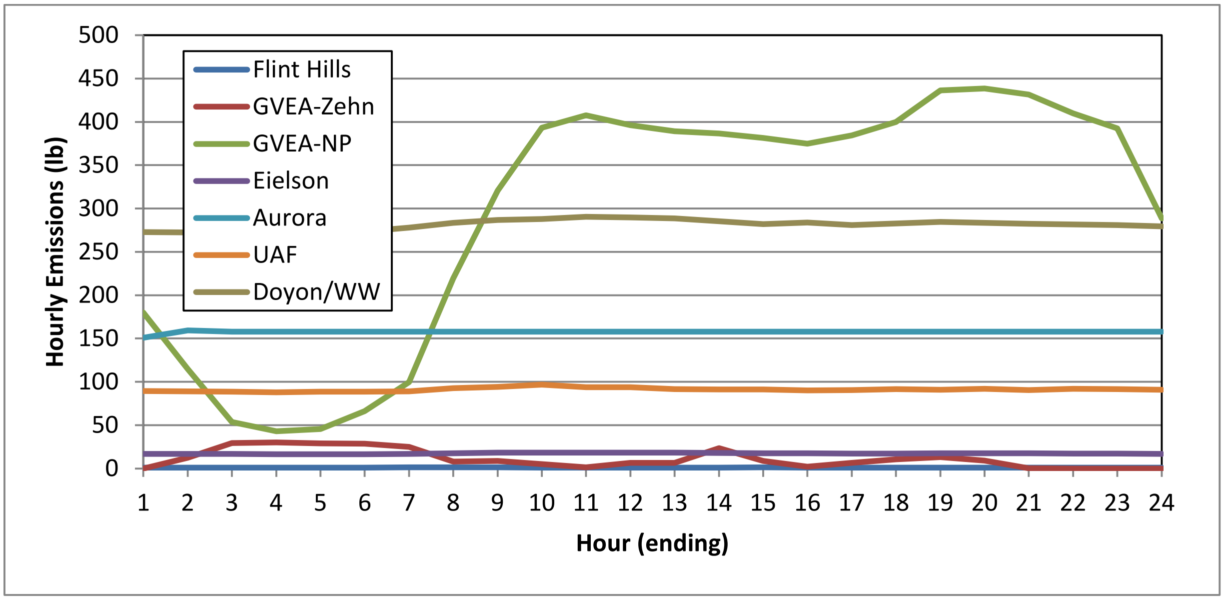
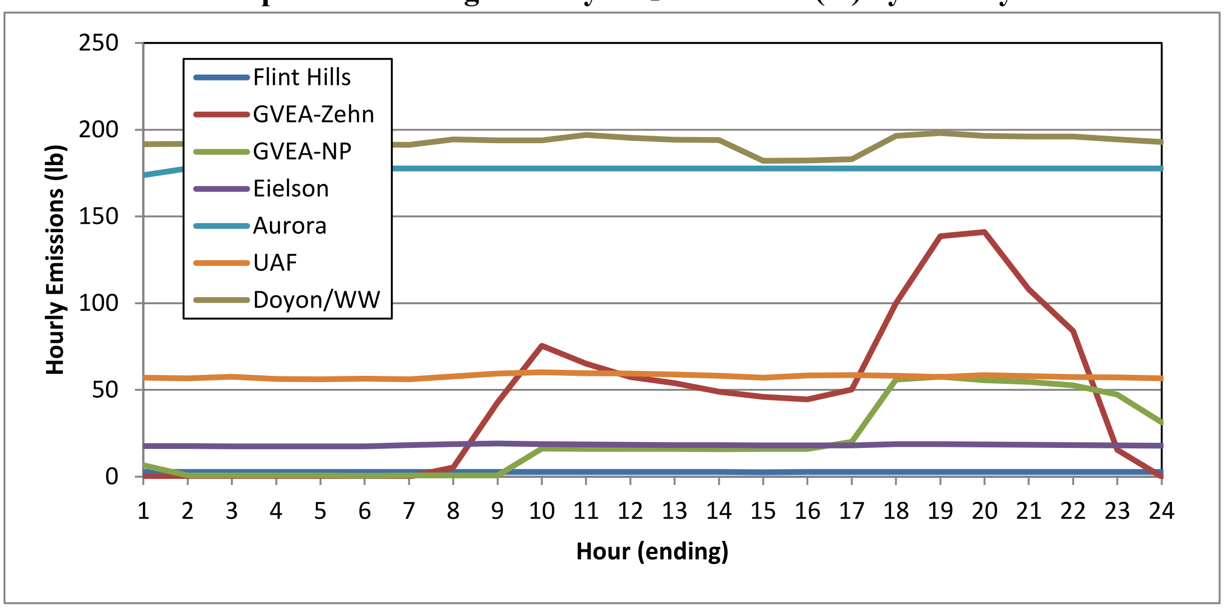


Figure 7-6-10
Episode 2 Average Hourly SO_2 Emissions (lb) by Facility



PROJECTED BASELINES

Often, projected baseline emissions for stationary point source facilities are developed based on actual emissions in the baseline year (2019 in this 2020 Amendment) with activity growth projected using population or employment forecasts or other reasonable growth surrogates, coupled with control factors that reflect effects of emission reductions from phase in or addition of industrial source controls triggered by technology-based regulatory standards (e.g., RACT/BACT[5]) for areas with an existing SIP.

Population-Based Activity Growth Factors – As explained earlier, annual emissions data from each point source facility in calendar years 2008 and 2019 were used to scale/update episodic emissions to 2019. Point source activity in future years beyond 2019 was projected using population growth rates from ADOT/Kittelson socio-economic forecasts for the FMATS (now Fast Planning) 2045 Metropolitan Transportation Plan and covered an area that extended beyond the nonattainment area. Table 7-6-4 presents the population-based activity growth factors by calendar year tabulated from these socio-economic forecasts (which include Eielson F-35 triggered growth). Growth factors are shown relative to calendar year 2019.

Table 7-6-4
Populated-Based Activity Growth Factors
by Calendar Year

Calendar Year	Relative Growth Factor (2019=1.00)
2019	1.0000
2020	1.0251
2021	1.0551
2022	1.0682
2023	1.0754
2024	1.0829
2025	1.0906
2026	1.0979
2027	1.1053
2028	1.1126
2029	1.1200
2030	1.1274
2031	1.1330
2032	1.1387

[5] RACT – Reasonably Available Control Technologies, BACT – Best Available Control Technologies.

Home Heating – Development of Energy Model

Overview

A spreadsheet-based household space heating "energy model" was developed to support the SIP inventory. This energy model was based on local developed home heating energy usage data collected from a stratified sample of residential homes in the Fairbanks area during cold wintertime conditions. The data were collected under a 2011 study[6] conducted by the Cold Climate Research Housing Center (CCHRC).

The primary objective of the study was to collect detailed heating appliance usage pattern data for homes using various combinations of oil and wood heating devices. The approach consisted of instrumentation and collection of fuel usage and device temperature data for a stratified random sample of 30 homes in Fairbanks that used various combinations of oil and wood home heating devices based on pre-study screening surveys. The target sampling matrix consisted of selection of 10 households in each of the following three groups (as identified based on the screening surveys):

1. *Group "O" (Oil Only)* – households heated solely with oil devices that included central oil boilers, oil-fired furnaces or direct-vent (DV) room heating oil devices;

2. *Group "M" (Mixed Oil and Wood)* – households heated with a mixture of oil devices (as listed above) and wood devices that included wood stoves, outdoor wood boilers (OWBs) and fireplaces with wood as the secondary heating source; and

3. *Group "W" (Wood Only/Primary)* – households heated exclusively or primarily with wood-burning devices.

Table 7-6-5 provides a summary of the homes sampled and heating devices within each group. Of the ten "oil" homes, seven used Central Oil boilers, two used direct vent oil heaters, and the tenth used an oil-fired furnace. Ten additional homes using a mix of fuel oil and wood were studied. The final ten homes were identified as primarily wood heating. The wood heating systems included seven wood stoves, one fireplace and two outdoor wood boilers. The rated output (in BTU/hour) of each household's oil device is also listed in Table 7-6-5. (For direct vent oil heaters which have 3-4 fuel rate settings, the maximum output is shown.)

The intent of this stratified sample of households was not to necessarily be a representative self-weighing sample of wintertime residential space heating in Fairbanks, but rather to ensure a sufficient range of the most commonly used residential heating devices were sampled and that the range of usage patterns for households with single and multiple heating devices (and their interactions) were adequately measured.

[6] "Heating Appliance Operation Survey, Phase II Fairbanks, Alaska," Cold Climate Research Housing Center, June 30, 2011.

Table 7-6-5 Home Heating Instrumentation Sample Summary				
Residence ID	Heated Area (ft^2)	Oil Appliance	Rated BTU/hour	Wood Appliance
O-01	2,448	Central Boiler	100,000	n/a
O-02	1,500	Central Boiler	147,000	n/a
O-03	2,775	Central Boiler	189,000	n/a
O-04	2,912	Borg Warner Furnace	156,800	n/a
O-05	1,400	Toyo Direct Vent	39,875	n/a
O-06	1,200	Toyo Direct Vent	39,875	n/a
O-07	1,200	Central Boiler	140,000	n/a
O-08	2,200	Central Boiler	189,000	n/a
O-09	2,100	Central Boiler	147,000	n/a
O-10	2,200	Central Boiler	95,200	n/a
M-01	2,464	Central Boiler	147,000	Wood Stove
M-02	2,900	Central Boiler	106,250	Wood Stove
M-03	2,500	Central Boiler	133,000	Wood Stove
M-04	1,770	Central Boiler	95,200	Wood Stove
M-05	1,900	Central Boiler	140,000	Fireplace
M-06	3,000	Central Boiler	252,000	Wood Stove
M-07	1,400	Central Boiler	105,000	Wood Stove
M-08	1,760	Central Boiler	147,000	Wood Stove
M-09	2,600	Central Boiler	118,750	Wood Stove
M-10	2,000	Central Boiler	231,000	Wood Stove
W-01	1,250	Central Boiler	119,000	Wood Stove
W-02	980	Toyo Direct Vent	43,750	Wood Stove
W-03	2,488	OWB preheat	137,500	Outdoor Wood Boiler
W-04	2,100	Central Boiler	140,000	Wood Stove
W-05	5,000	OWB (multi-fuel)	154,000	Central Boiler-oil/wood
W-06	915	Toyo Direct Vent	20,625	Wood Stove
W-07	4,580	Central Boiler	224,000	Outdoor Wood Boiler
W-08	1,400	Toyo Direct Vent	20,625	Wood Stove
W-09	884	Wood Stove only	n/a	Wood Stove
W-10	575	Toyo Direct Vent	20,625	Wood Stove

n/a = Not applicable

The final analysis revealed that during the sampling period, which was characterized by very cold ambient temperatures, three of the homes initially identified as primarily wood burning by the owners actually used oil for more than one-third of the heating energy consumed during the sampling, and could have been characterized as mixed.

Data loggers recording the fraction of time a motor was on were used to monitor central oil boiler and furnace heating appliances (which have a single fuel rate setting). Thermocouples mounted on the surface of the exhaust flue were used to monitor temperatures from wood burning devices and direct vent oil furnaces (which can run at several fuel rate settings). The sampling period extended from early December of 2010 through late February of 2011. Generally speaking, each home was instrumented, and fuel usage measurements were collected over a period spanning 6-10 weeks. Written diaries or "logs" of actual fuel use were also kept during the first couple of weeks of sampling in each household. As explained later, these fuel use logs were used to calibrate and validate raw data logger and thermocouple measurements.

Ambient temperature measurements were also collected by CCHRC from a handful of meteorological stations in the Fairbanks area during the winter 2010-2011 sampling period. CCHRC reviewed data from both National Weather Service and Citizen Weather Observer Program sites (CWOP), and selected sites to represent ambient temperatures at each sampled household based on completeness of record and proximity/representativeness of the weather station to each home. CCHRC then temporally merged historical ambient temperature data (recorded every 30 or 60 minutes) from each selected weather station into the appropriate household data file, providing a raw database of hourly oil device operating patterns and wood (and direct vent oil) thermocouple measurements and ambient temperatures.

Sierra then performed a series of data validation and completeness checks on measurements and fuel usage diaries from each sampled household. As discussed later, 4 of the 30 sampled homes were dropped from the analysis because of problems with the measuring equipment as installed in those homes, rendering most if not all of the data for those households invalid.

After reviewing/validating the data, they were analyzed to generate a dataset of household hourly heating energy use (in BTU/hour) by device type and ambient temperature. This winter 2010-2011 energy use dataset was then used to develop a multivariate model of residential household space heating energy use as a function of heated dwelling size, device mix, hour of the day and ambient temperature that could be readily applied within the SIP inventory workflow to generate episodic day-specific and hourly heating energy use and emission estimates. The details of these data analysis and energy model development elements are discussed in the next sub-sections.

Data Processing

Because of the device-specific nature by which usage patterns and fuel measurements were collected, different processing methods were utilized for each type of device. These device-specific methods are described separately below.

Central Oil Boilers/Furnaces – For central oil devices, the process of determining hourly energy usage was straightforward. Data loggers were used to continuously monitor and record the fraction of each hour in the sampling period that the boiler/furnace was operating. Hourly fuel usage rates were determined from the label on the unit (preferred) or from the instruction manual for the particular boiler/furnace model. The energy content (EC) of given volume of fuel was dependent on fuel oil type: 125,000 BTU/gal was used for Fuel Oil #1, while 140,000 BTU/gal was assumed for Fuel Oil #2.

The BTU output for each hour of operation was then simply calculated as:

BTUs/hr = % of Hour Operated × Fuel Usage Rate (gal/hr) × Fuel EC (BTU/gal)

For example, if an oil device burning #2 oil with a fuel usage rate of 0.8 gal/hr was measured to operate for 32.1% of the time during a given hour, the calculated oil energy use for that hour is:

32.1% percent on time × 0.8 gal/hour × 140,000 BTU/gal = 35,952 BTU/hour

Data logger results also included a date and time stamp of the reading. BTU calculations were performed in this manner for all central oil devices and merged into a common database across all households. Results were summarized by residence both as hourly and daily BTUs and inspected for reasonableness.

A log of oil usage was maintained by the homeowners for the duration of the sampling period. At the start and end of sampling and each time a delivery of heating oil was made to their tank, the homeowner used a calibrated dipstick to record the fill level in their oil tank. Tank volume calculations were performed by CCHRC to translate the fill level measurements to volumes and estimates of incremental fuel use between deliveries, although a source of uncertainty for these fill level-based fuel volume estimates occurred for homeowners with underground tanks with unknown capacity and geometry. Notwithstanding this uncertainty for underground tanks, total volume of fuel determined from summing the hourly usage rates was compared to total fuel estimates from storage tank volume logs for consistency/validation.

<u>Wood Burning Devices</u> - Determination of the hourly heat energy obtained from burning wood was less direct. Homeowners recorded the time and weight of all fuel added during an initial “calibration” sampling period. The duration of this period varied from a few days to, in one case, the entire sampling period, but typically averaged 1-2 weeks. The total sampling period within each household was generally two months.

All wood additions were assumed to be White Birch, the predominant wood type in Fairbanks. Using US Forest Products Laboratory tables, at 20% moisture content White Birch is reported to have a weight of 3,179 pounds/cord and an energy content of 20.3 mmBTU/cord, yielding an average energy content of 6,386 BTU/lb.

For the purpose of initially analyzing the wood usage data, the average moisture content of wood from sampled households with wood devices was assumed to be 26.6% based on moisture measurements of wood sampled from those households conducted by CCHRC. After adjusting for this sampled moisture content, the average energy content used to estimate hourly wood-based energy use was 6,053 BTU/lb. (As explained later, a second wood energy content adjustment was performed when using the energy model developed from these data to calculate

SIP inventory emissions based on specific wood species mix and moisture content data collected to support the inventory estimates.)

This energy content was multiplied by the pounds of fuel added from the homeowner wood diaries to arrive at BTUs added from each wood loading. These fuel-loading BTUs were then totaled across the initial instrumentation period during which wood loading diaries were kept.

A thermocouple was used to measure the flue temperature or surface temperature of the wood stoves from a single fixed location throughout the instrumentation period for each device. The thermocouple logger recorded temperature at 5-minute intervals, producing a value that is a relative indicator of the rate of heat release. Under a simplistic ideal case for distributing energy use across the fuel loading period, the flue temperature would be allowed to rise from ambient during combustion until all of the fuel had been consumed, when the temperature would return to ambient. The temperature rise above ambient in each five minute period during the combustion period would then be summed to provide a surrogate for total energy emitted from that fuel load. The ratio of flue temperatures and wood BTUs would then be used to estimate a rate of energy consumption per cumulative degrees per five-minute period using the data logger results.

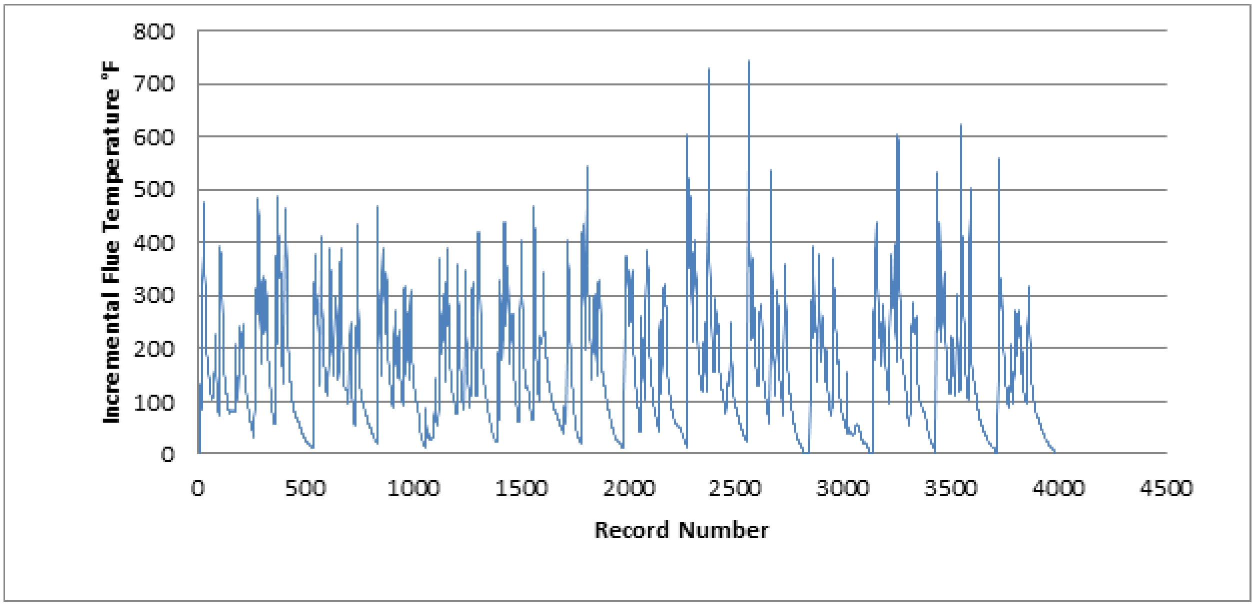
The challenge for wood-burning households was turning the record of wood BTUs added over time into a time series of heat energy (in BTUs) released by the unit. The approach taken was to use the temperature rise recorded by the datalogger to proportion the estimated amount of wood BTUs added to the unit. The temperature rise is the number of degrees Fahrenheit that the recorded temperature is above its baseline. The baseline was determined by locating the lowest temperature level recorded by the datalogger. For indoor devices (stoves, fireplaces) the baseline temperature was based on the indoor room temperature. Outdoor air temperatures were used as baselines for outdoor wood boilers (OWBs).

Some households burned wood sporadically. For these, data points could be determined for each burn event, consisting of the wood BTUs added and the total temperature rise over the time period of the burn. Temperatures were recorded every 5 minutes, so the total temperature rise has units of °F × 5-minute interval. For these households, the calibration determined an average factor (°F per BTU) that can be divided into the observed temperature rise in any 5-minute period to determine the BTUs released. The term "BTUs released" refers to the total BTUs estimated to be released by the fire in the time period, consisting of both BTUs that heat the home and BTUs that are lost to the environment.

Other households burned wood nearly continuously and offered no discrete events that could be used to develop an average calibration factor. The same general approach, however, was applied. The cumulative pounds of fuel added (as BTUs of fuel) were plotted against cumulative rise in flue temperature. A linear slope/intercept equation was fit to the data. This resulting equation was then used to estimate the BTUs produced through the entire sample period from the cumulative degree-minutes recorded by the data logger.

Figure 7-6-11 displays the flue temperature observed during the fuel weighing period for one home from the instrumented sample, mixed oil-wood household M-02, which used wood for about 30% of its heating energy. The 4,000 temperature readings made at 5-minute intervals

Figure 7-6-11
Example Wood Stove Fuel Temperature Trace, Household M-02



represent 14 days during which the owner weighed the fuel and recorded the results in a log. Individual temperature readings were adjusted by subtracting the lowest temperature observed in the study period. Thus, as labeled on the vertical axis of Figure 7-6-11, the plotted flue temperatures are incremental values over this baseline minimum temperature.

Figure 7-6-12 displays the cumulative BTU wood additions and cumulative flue degrees for the M-02 woodstove. During this sampling period, a total of 18 wood loadings were made. (Some contained smaller amounts of wood and cannot be discerned from the plotted scales in Figure 7-6-12.) A total of 630 lb of wood were burned across all 18 loadings, equivalent to 3,813,390 BTUs of fuel energy.

The red line in Figure 7-6-12 displays the fitted relationship used to estimate BTUs from flue temperatures recorded during the more extended data collection period for this specific woodstove. Based on the output for this particular stove and the location of the thermocouple during its instrumentation, the relationship between fuel loading data and flue temperatures (i.e. the fitted slope) was found to be 0.190 DegF-Hrs/BTU.

These same analyses of cumulative flue degree-hours vs. wood BTUs were developed for each of the households with valid wood device measurements. Separate fitted "temperature slopes" were developed for the wood devices in each household and were necessitated by the variation in flue temperature response to BTUs calculated from wood loading. This device-to-device variation was the result of difference in where the thermocouple was placed on or near each device, the size/output of the firebox and the general usage pattern of each device (frequent vs. occasional).

Figure 7-6-12
Cumulative Wood Stove BTUs and Flue Degrees, Household M-02

Table 7-6-6 lists the resulting fitted temperature slopes developed for each of the 16 Mixed and Primary wood device households with valid data. As shown in the highlighted column, the fitted slope (representing the relationship between measured flue temperature and fuel energy) differed across the devices by roughly an order of magnitude due to the aforementioned factors. Also listed for each household are the specific wood devices and sensor locations where the thermocouples were mounted on each device.

(As noted below Table 7-6-6, separate fitted slopes were developed for two distinct portions of sampling in household W-01, that corresponded to validated sampling periods before and after the thermocouple fell off the wood stove and was re-attached in a slightly different location.)

Using the individually fitted relationships for the wood-burning devices in each of these households developed based on that initial portion of the instrumentation period where wood loadings were measured (1-2 weeks), wood BTU usage estimates could be reasonably predicted based solely on the thermocouple-based flue temperature measurements over the entire (6-10 week) sampling period for each household.

As discussed later under "Quality Assurance and Data Validation," installation/removal diaries, homeowner observations and temperature traces over the entire sampling period for each wood device were carefully examined to ensure validity of the thermocouple data.

Table 7-6-6
Fitted Temperature/Fuel Energy Slopes for Sampled Wood Devices

Res. ID	Heated Area (ft^2)	Device No.	Wood Device	Temp. Slope (°F-hrs/BTU)	Temperature Sensor Location
M-02	2900	1	Wood Stove	0.190	Back of single wall stove pipe
M-03	2500	1	Wood Stove	0.078	Uninsulated flue pipe
M-04	1770	1	Wood Stove	0.072	Under the door
M-05	1900	1	Fireplace	0.142	Left firewall
		2	Wood Stove	0.175	Not recorded
M-06	3000	1	Wood Stove	0.046	Under the door area
M-08	1760	1	Wood Stove	0.120	Below door area
M-09	2600	1	Wood Stove	0.200	On side of firebox under heat shield
W-01	1250	1	Wood Stove	0.039, 0.043[a]	Uninsulated stove pipe
W-03	2488	1	OWB	0.031	Firebox door edge
W-04	2100	1	Wood Stove	0.046	Uninsulated exhaust stove pipe
W-05	5000	1	OWB (multi-fuel)	0.027	Exhaust flue
W-06	915	1	Wood Stove	0.042	On side of firebox under heat shield
W-07	4580	1	OWB	0.013	Fan motor
W-08	1400	1	Wood Stove	0.125	Side of stove
W-09	884	1	Wood Stove	0.130	Back of stove pipe
W-10	575	1	Wood Stove	0.115	Uninsulated stove pipe

[a] Two separately-fitted slopes were developed for this wood stove because the thermocouple fell off during the instrumentation period and as re-attached at a slightly different location for the remainder of the sampling.

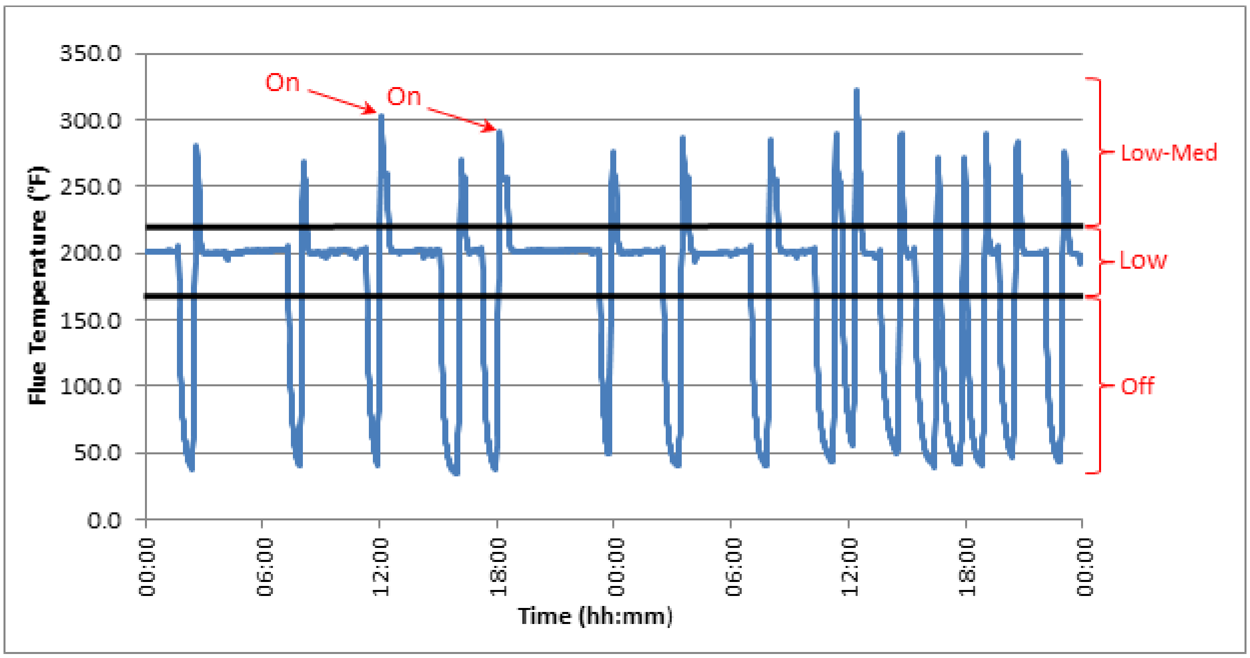
Direct Vent Fuel Oil - Direct Vent fuel oil combustion technology is used for both central home heating and room space heating. Both the large and small units use three or four fuel flow rates which are staged in response to ambient temperature and thermostat setting. This variable fuel flow precludes the use of the simple hourly fraction-on data loggers used with traditional constant-flow on/off centralized oil boilers. Instead, data loggers set to record flue temperatures at one-minute intervals were used. At the same time, fuel oil usage was recorded in a diary or logbook, providing a cross check of final fuel oil usage estimates.

The control operation and the flue temperature recording position varied between households. The flue temperature patterns similarly varied. Some common patterns, however, emerged. The most common pattern involved a sudden rise from ambient to an elevated level, which would be held from one to several minutes, followed by a reduction to a lower level which could be maintained from a few minutes to an hour or more, followed by a drop back to the initial ambient level. The length of the “hold” period was related to the outdoor ambient temperature, with lower temperatures resulting in longer run times.

Trial and error assignments of fuel usage rates to the different intervals were used to calculate total fuel usage during a period when the total amount of fuel used was known (from the diary logs). In general, the best agreement between recorded and estimated fuel usage was found when the second to lowest fuel usage rate was assigned to the initial startup period, followed by the lowest fuel usage rate for the extended stabilized period.

Figure 7-6-13 presents a representative example of measured flue temperatures from a direct vent heater (in household O-06) that clarifies this approach. Note the flue temperature in this example returns to just below 50°F when the device is off. When the heater starts, the flue temperature rises above 250°F, and holds from one to several minutes. In Figure 7-6-13, these events are marked with red arrows at times around 12:00 and 18:00 on the first day. The temperature then drops to about 200°F and holds from several minutes to several hours. It then shuts off and the temperature returns to below 50°F. The thick horizontal lines demonstrate “cut points” of 170°F and 220°F that were used to identify the fuel flow modes for this specific direct vent heater, a Monitor 2400.

Figure 7-6-13
Sample Direct Vent Oil Heater Fuel Temperature Trace



The Monitor 2400 has the following four fuel rates[7]:

1. High - 0.319 gal/hour;
2. High-Medium - 0.240 gal/hour;
3. Low-Medium - 0.180 gal/hour; and
4. Low - 0.120 gal/hour.

[7] Fuel rate data for each direct vent heater in the sample were looked up from published specifications based on the specific heater models identified in each household and recorded by CCHRC.

Discussions with CCHRC confirmed these direct vent heaters generally operate (under thermostatic control) at their lower fuel rates because they are often used as individual room heaters and are quite efficient. Thus as shown at the right of Figure 7-6-13, temperatures above the 220°F cutpoint established for this specific heater were assumed to reflect operation of the device at its Low-Medium setting. Flue temperatures between 170°F and 220°F were assumed to reflect operation at the Low setting. And temperatures below 170°F were assumed to reflect periods where the thermostatically controlled heater was shut off. For each region, fuel rates were translated into device energy use (in BTUs). Direct vent heaters generally operate on Fuel Oil #1 (125,000 BTU/gal).

The first day of operation in the example corresponds to a day with a low outdoor ambient temperature that results in a high demand and nearly continuous furnace operation. The second day demonstrates the reduced demand on warmer days, with furnace operation in the daytime hours cycling on for a short time and then remaining off for longer periods. This pattern of increasing furnace cycling frequency with higher ambient temperatures was typical.

Two higher capacity direct vent oil units and two supplemental direct vent room heating units were included in the study sample.

Quality Assurance and Data Validation

A number of problems were encountered in analyzing and processing the raw data from the instrumentation study. The raw data from CCHRC were provided in individual spreadsheets for each household. In addition to the raw measurements, each household spreadsheet included detailed descriptions of the heating devices and locations within each house, the heated building space, wood/oil usage diaries/logs and most importantly, installer/remover or homeowner observations regarding any operational issues noted during the sampling (e.g., a thermocouple stopped working or fell off). All results were carefully reviewed for completeness and reasonableness in assessing whether all or a portion of the data measured in each sampled household were deemed valid.

The temperature measurement sensors presented the greatest difficulty. The thermocouples were intended to be mounted in contact with the flue surface. It was sometimes noted that the thermocouples detached from the surface, and the recorded results reflected the significant drop in temperatures recorded at those times. In other cases, it appeared as if the thermocouple electrical connection to the data logger was intermittent or failed, as reflected by large negative readings (-328°F was typical). The results, therefore, were carefully reviewed to remove these data from the final results. It was also important that the temperature recorded during the calibration period when the fuel was being weighed be consistent with the temperatures recorded before and after this period. Three wood burning homes were removed from the sample because flue temperature recording problems invalidated the results.

The base time unit of all resulting data streams was adjusted to one-hour intervals. The standard centralized oil-based loggers began with a one-hour time base. The wood burning flue temperature loggers recorded data every five minutes. The direct vent temperature loggers recorded data every minute. In all cases, calculated BTUs for each device were tabulated on an hourly basis (i.e., five-minute and one-minute flue temperature-based BTUs were summed over each hour). Device and ambient temperatures reported for the hour were averaged.

Results from homes with more than one heating source were aligned to start and end at the same time. For example, the data logger used to measure fuel oil usage might have been activated three hours before the logger used to monitor wood stove flue temperature was installed and operating. In this instance, the oil data for those initial three hours were discarded. In other cases, at the end of a sampling period a logger might have been removed and allowed to continue running for several hours. If one logger failed during the trial, the results from loggers for any other heating devices in the household were also discarded to ensure the remaining sample was not biased in accounting for interactions/usage patterns between the two heating sources.

Table 7-6-7 summarizes the household-by-household data validation results from the original 30 household sample. Four of the 30 households (shaded rows in Table 7-6-7) had instrumentation failure or other issues. All the data from these households (M-01, M-07, M-10 and W-02) were invalidated and discarded from further analysis. As summarized in Table 7-6-7, data for portions of the instrumentation duration in some households that were suspect were also discarded. In general, the homes with oil heating ran much more consistently, with no corrections or deletions required for any sampling period. As noted earlier, the wood heating homes required more effort to validate and assemble consistent data sets. All told, roughly 85% of the originally measured data were validated/corrected and utilized as the basis for the Fairbanks home heating energy model.

Separate spreadsheets containing data for each household as received from CCHRC were combined into a single database during the data validation and quality-assurance processing. The final validated database consisted of time-aligned records of hourly energy usage and outdoor ambient temperature by residence.

Each hourly record in the final database contained the household ID, heated space, ambient temperature and the measured/calculated energy use (in BTUs) for each of five device types found in the sample:

1. Woodstoves/Inserts (WS);
2. Fireplaces (FP);
3. Outdoor Wood Boilers (OWB);
4. Central Oil Boilers/Furnaces (COil); and
5. Direct Vent Oil Heaters (DV).

The final database contained over 25,200 valid hourly energy use records. This represented an average sampling duration of 970 hours or 40 days per household for the 26 valid households.

Table 7-6-7 Home Heating Instrumentation Data Validation Summary	
Res. ID	Data Validation Results by Household
O-01	This is a 2,448 ft^2 home with central oil heating. The monitor was installed on 12/15/10 and removed 1/26/11. A total of 1,011 hours or 42 days of data were collected from this residence.
O-02	This is a 1,500 ft^2 home with central oil heating. The monitor was installed on 12/23/10 and removed on 2/16/11. A total of 1316 hours or 54 days of data were collected from this residence.
O-03	This is a 3,000 ft^2 home with central oil heating. The monitor was installed on 12/16/10 and removed on 1/27/11. A total of 1,015 hours or 42 days of data were collected from this residence.
O-04	This is a 2,912 ft^2 home with central oil heating. The monitor was installed on 12/16/10 and removed on 1/27/11. A total of 1,014 hours or 42 days of data were collected from this residence.
O-05	This is a 1,400 ft^2 home heated with a main direct vent (DV) oil furnace (40,000 BTU/hr) and a smaller DV bedroom unit (20,000 BTU/hr). The monitors were installed on 12/16/10 and removed on 1/27/11. A total of 1,007 hours or 42 days of data were collected from this residence.
O-06	This is a 1,200 ft^2 home heated with a single DV oil furnace. The monitor was installed on 12/16/10 and removed on 1/27/11. A total of 994 hours or 41 days of data were collected from this residence.
O-07	This is a 1,200 ft^2 home with central oil heating. The monitor was installed on 12/21/10 and removed on 2/04/11. A total of 1085 hours or 45 days of data were collected from this residence.
O-08	This is a 2,200 ft^2 home with central oil heating. The monitor was installed on 12/17/10 and removed on 2/04/11. A total of hours 1,255 or 52 days of data were collected from this residence.
O-09	This is a 2,100 ft^2 home with central oil heating. The monitor was installed on 12/23/10 and removed on 2/02/11. A total of 993 hours or 41 days of data were collected from this residence.
O-10	This is a 2,200 ft^2 home with central oil heating. The monitor was installed on 12/22/10 and removed on 2/09/11. A total of 1,152 hours or 48 days of data were collected from this residence.
M-01	This 2464 ft^2 home is heated by a wood stove and a central oil fired boiler. The results from the home were discarded when it was determined that logging of wood added was performed while there was a poor thermocouple connection, invalidating the temperature vs. BTU calibration.
M-02	This 2900 ft^2 home is heated by a wood stove and a central oil boiler. Recordings were made from 12/14/2010 through 1/27/2011. The wood stove was not used from 12/28/2010 through 1/21/2011. The temperatures recorded after 1/21 were inconsistent with the earlier recordings and were thus discarded. The oil usage logger performed well through the entire period but results after 12/28 were discarded to maintain a representative sample for a home with two heat sources. The final data set for both appliances was from 12/14/10 through 12/28/2011, a total of 337 hours or 14 days.
M-03	This 2500 ft^2 is heated by a wood stove and a central-oil fired boiler. Valid recordings were made from 12/15/2010 through 1/18/11 and from 2/3/11 through 2/4/11. The occupants were on vacation in late January so the period was removed from the data set to maintain a representative sample for a home with two heat sources. The final data set included 835 hours or 34 days of valid results.
M-04	This is a 1770 ft^2 residence with a wood stove and oil fired boiler with holding tank. Valid recordings were made from 12/22/10 through 2/4/11, a total of 45 days or 1,080 hours. An interesting inverse relationship between ambient temperature and wood usage was observed during the test period. Wood usage dropped off when the ambient temperature was above 0°F.

Table 7-6-7
Home Heating Instrumentation Data Validation Summary

Res. ID	Data Validation Results by Household
M-05	This is a 1900 ft^2 residence with a central oil fired boiler supplemented with heat from a fireplace and a wood stove. About 22% of the total BTU energy observed in the home was produced by the wood appliances. Data was collected from 12/21/10 through 02/15/11, a total of 55 days or 1,320 hours. The inverse wood fuel usage with ambient temperature seen with M-04 continued with this household.
M-06	Residence M-06 also uses an oil fired central boiler with holding tank and a wood stove. The 2700 ft^2 home includes an additional 300 ft^2 allowance for a basement that is generally maintained about 50°F. Data was collected here from 12/21/10 through 2/03/11, a total of 45 days or 1,080 hours.
M-07	Residence M-07 used an oil fired central boiler as its primary heating source, with a wood stove as a secondary source. The data logger used to monitor oil usage was not initialized during installation. No data was recorded during the study. Multiple problems were noted with the thermocouple used to monitor the wood stove. This residence was not used in analysis. It is a 1400 ft^2 residence. Monitors were installed on 12/23/10 and removed 02/03/11. No usable data was collected.
M-08	Residence M-08 uses an oil fired central boiler as its primary heating appliance (91%) and a secondary wood stove (9%). Wood usage was sporadic. The home has an area of 1,760 ft^2. The monitors were installed on 12/20/10 and removed on 02/04/11. A total of 43 days, or 1,035 hours of data were collected.
M-09	This residence used an oil-fired central boiler as its primary heating appliance (79%) and a wood stove for the remainder. Wood usage was not particularly related to outdoor ambient temperature. The home has an area of 2600 ft^2. The monitors were installed on 12/16/10 and removed 1/28/11. A total of 1033 hours, or 43 days, of data were collected.
M-10	This residence used an oil-fired central boiler and two wood stoves. Thermocouple problems with the wood stoves made the data from this home unusable. It is a 3,000 ft^2 home. Approximately 1,000 ft^2 was shut off during daytime hours. The monitors were installed on 12/17/10 and removed 02/03/11. No usable data was collected from this home.
W-01	This residence is primarily heated with a wood stove (83%), with central oil heating as a secondary source (17%). The home has 1,300 ft^2 of area, with a 50 ft^2 unheated artic entry, leaving 1,250 ft^2. The data collection monitors were installed on 12/24/10 and removed 2/9/11. The wood stove thermocouple fell off on 12/26/11 and was restored on 1/3/11. Both the wood and oil data collected in this period was removed from the data. A net total of 946 hours or 39 days of valid data were collected and used in the analysis.
W-02	This residence has a wood stove and direct vent oil heater. The thermocouple on the DV oil heater fell off after installation. A total of 120 gallons of fuel oil were reported as used but could not be allocated. The wood data collected during the same time period was, therefore, invalidated. The home has 980 ft^2 of heated area. The monitors were installed on 12/17/10 and removed 2/24/11. No data from this home was used in the final analysis.
W-03	This is a 2,488 ft^2 home. Primary heating is from an Outdoor Wood Boiler (OWB). Oil is used to ignite the OWB. A thermocouple monitor was installed on the firebox door on 12/17/10. A separate monitor was installed on the oil burner on 12/28/10. Data collection ended on both systems on 1/31/11. Only results collected when both monitoring systems were functioning were used in the final analysis. A total of 815 hours of data, or 34 days, were collected.

Table 7-6-7 Home Heating Instrumentation Data Validation Summary	
Res. ID	Data Validation Results by Household
W-04	This is a 2,100 ft^2 home that uses a central oil boiler and a wood stove. While initially classified as a primarily wood burning home, it was found that 72% of the heating energy during the sample period came from oil, with the remainder from wood. It was treated as a MIXED home in the analysis. Both the oil and wood sensors fell off during the data collection period. All data after the wood sensor came off on 12/31/10 was discarded. The sensors were installed on 12/15/10 and were removed on 2/9/11. Only 15 days of data were used in the final analysis.
W-05	This is a 5,000 ft^2 residence heated with an OWB and an indoor boiler. The OWB provided 96% of the total BTUs consumed during the sample period. The monitor equipment was installed on 12/16/10 and removed on 1/28/11. A total of 1260 hours or 53 days of data were collected.
W-06	This is a 916 ft^2 home heated primarily with a wood stove (99%) and a supplemental direct vent oil heater. The monitoring equipment was installed 12/16/10 and removed 1/28/11. An absence between 1/13/11 and 1/25/11 was noted when the data was examined. Wood usage stopped and oil heat was used to maintain the home during this period. The results for both oil usage and wood usage during the interval were removed from the final data. A total of 9041 hours or 31 days of data were retained.
W-07	This is a 4,580 ft^2 home heated with an OWB and two indoor oil-fired boilers. Oil and Wood were nearly equal in the production of BTU's during the sampled period (50% each). The monitors were installed 12/26/10 and removed on 2/9/11. Valid data was retained for a total of 810 hours or 33 days.
W-08	This is a 1,400 ft^2 home using primarily a wood stove (67%) for heating, with a direct vent oil heater as a secondary source (33%). Sensors were installed 12/30/10 and removed 2/19/11. A total of 1022 hours or 43 days of data were collected from this home.
W-09	This is an approximately 884 ft^2 home. It is heated exclusively with a wood stove. The data logger was installed on 12/21/10 and removed on 2/1/11. A total of 1006 hours or 41 days of data were collected.
W-10	This is a 575 ft^2 residence heated with a wood stove and DV oil heater. A problem was found with the DV temperature sensor, but the oil usage log revealed only 10.5 gallons of fuel oil were consumed during the sampling period. This is equivalent to about 10% of the total BTUs produced by the wood consumed during the same period. The sensors were installed on 12/28/10 and removed on 2/16/11. A total of 31 days of data were used.

Summary of Validated Results

Table 7-6-8 displays the average daily energy consumption (in BTUs) by heating device type for each of the remaining homes with validated data during the sampling period. The valid households are sorted by sampling group (O-Oil Only, M-Mixed/Primary Oil, W-Mixed/Primary Wood). Cells with "n/a" under the daily energy use columns reflect devices that do not exist in that household (e.g., wood devices in the first three columns are not applicable for the group of Oil Only households). Total average daily energy (across all devices in each household) are listed in bold. As shown in the "Total" column of Table 7-6-8, average household energy use ranges from 235,075 BTU/day (O-06) to 1,938,204 BTU/day (W-03), an eight-fold range, with a sample average of 839,622 BTU/day.

Table 7-6-8 Validated Home Heating Instrumentation Sample Summary									
	Heated	Avg. Household Daily Energy Use by Device (BTU/day)						Wood	BTU/Day
Res. ID	Area (ft^2)	Woodstove	Fireplace	OWB	CentOil	DirectVent	**Total**	Use Pct.	per ft^2
O-01	2,448	n/a	n/a	n/a	792,168	n/a	**792,168**	0%	324
O-02	1,500	n/a	n/a	n/a	972,312	n/a	**972,312**	0%	648
O-03	2,775	n/a	n/a	n/a	1,086,937	n/a	**1,086,937**	0%	392
O-04	2,912	n/a	n/a	n/a	918,548	n/a	**918,548**	0%	315
O-05	1,400	n/a	n/a	n/a	n/a	374,537	**374,537**	0%	268
O-06	1,000	n/a	n/a	n/a	n/a	235,075	**235,075**	0%	235
O-07	1,200	n/a	n/a	n/a	654,180	n/a	**654,180**	0%	545
O-08	2,200	n/a	n/a	n/a	1,021,203	n/a	**1,021,203**	0%	464
O-09	2,100	n/a	n/a	n/a	950,833	n/a	**950,833**	0%	453
O-10	2,200	n/a	n/a	n/a	454,368	n/a	**454,368**	0%	207
M-02	2,900	265,559	n/a	n/a	720,968	n/a	**986,528**	27%	340
M-03	2,500	249,740	n/a	n/a	830,137	n/a	**1,079,876**	23%	432
M-04	1,770	205,229	n/a	n/a	394,971	n/a	**600,200**	34%	339
M-05	1,900	See Note a	295,208[a]	n/a	973,542	n/a	**1,268,751**	23%	668
M-06	3,000	449,953	n/a	n/a	773,096	n/a	**1,223,049**	37%	408
M-08	1,760	73,282	n/a	n/a	744,147	n/a	**817,429**	9%	464
M-09	2,600	164,336	n/a	n/a	583,305	n/a	**747,640**	22%	288
W-01	1,250	903,366	n/a	n/a	174,558	n/a	**1,077,924**	84%	862
W-03	2,488	n/a	n/a	1,820,881	117,323	n/a	**1,938,204**	94%	779
W-04	2,100	395,049	n/a	n/a	978,646	n/a	**1,373,696**	29%	654
W-05	5,000	1,172,540	n/a	n/a	41,932	n/a	**1,214,472**	97%	243
W-06	915	284,096	n/a	n/a	n/a	n/a	**284,096**	100%	310
W-07	4,580	n/a	n/a	459,869	427,135	n/a	**887,004**	52%	194
W-08	1,400	201,224	n/a	n/a	n/a	94,377	**295,601**	68%	211
W-09	884	278,445	n/a	n/a	n/a	n/a	**278,445**	100%	315
W-10	575	297,106	n/a	n/a	n/a	n/a	**297,106**	100%	517
Averages	**2,129**	**379,994**	**295,208**	**1,140,375**	**680,515**	**234,663**	**839,622**	**35%**	**418**
Pct. of Energy Use		**23%**	**1%**	**10%**	**62%**	**3%**	**100%**	-	-

n/a = Not applicable.
[a] Energy use for both wood devices (fireplace and woodstove) were combined to better represent fireplace as secondary device.

The rightmost two columns in Table 7-6-8 list the average wood energy percentage and daily energy use per unit area (BTU/Day per ft^2). As shown and discussed earlier, the sample of households exhibit varying amounts of wood vs. oil use for each of the wood and oil devices measured. (All heating devices in each household were instrumented. The selected sample included only those five device types listed earlier and displayed in the table.)

As summarized in a footnote, wood-burning energy use for household M-05 was assigned entirely to its fireplace, even though the home also had a wood stove (and a central oil boiler). Although energy use was measured separately for both the fireplace and the wood stove, it was all assigned to the fireplace. The reason for this adjustment is the belief that few homes have multiple wood-burning devices, based on repeated home heating surveys of several hundred residences each. Since this was the only household with a fireplace in the instrumented study sample, the adjustment provided a "cleaner" approach for development of the fireplace-specific components of the resulting energy model.

In assessing this "all-as-fireplace" adjustment of wood energy use in household M-05, diurnal patterns of wood use in both devices was examined and within this household, found to be generally similar. Both wood devices were used on most days and typically fueled in the early morning and evening hours. By assigning all of the wood energy to the fireplace, this household was recast in a manner that matched the overwhelming majority of homes where fireplaces are used as a secondary heating source.

Daily energy use by device averaged across the household sample is shown in the "Sample Averages" row at the bottom of Table 7-6-8. These values are averaged over only those households with the given device (e.g., the OWB average is based on OWB household averages for W-03 and W-07).

The last row of Table 7-6-8 shows energy use percentage splits by device and is based on averages across all households, irrespective of whether they have each device. As shown, oil vs. wood energy use was split at 65% oil (62% CentOil + 3% DV) and 35% wood (10% stoves, 1% fireplaces, 24% OWBs). This is consistent with the oil/wood splits seen in local heating surveys, but not identical since these instrumented households were a targeted, not random sample.

Comparison of Measured Energy Use to Independent Source

Although the instrumented households represented a stratified (oil/mixed/wood), targeted sample, the results were compared to an independent estimate of winter residential space heating energy use in Fairbanks. In a November 2013 report[8] prepared for the Interior Gas Utility (IGU), Northern Economics assembled results from local residential survey data and found average household space heating in Fairbanks to be 154 mmBTU/year. (In the report, it is shown on a natural gas energy basis of 151 Mcf[9], with gas energy content of 1.023 mmBTU/Mcf.)

To account for the strong seasonal variation in energy use and enable a direct comparison to the instrumented data collected between December 2010 and February 2011, a monthly space heating demand profile published in a June 2013 natural gas engineering study[10] by Northern Economics was used to allocate the annual usage from the IGU-sponsored survey to a daily average over a December-February period. From Figure 5 of that study, 43.7% of annual space

[8] Northern Economics, "Natural Gas in the Fairbanks North Star Borough: Results from a Residential Household Survey, prepared for the Interior Gas Utility, November 2013.
[9] Mcf = Thousand cubic feet.
[10] L. Cuyno and P. Burden, Estimated Natural Gas Demand for NS LNG Project memorandum, June 21, 2013.

heating demand occurs during those three winter months (Dec-Feb). An independent estimate of daily average energy use during this period was then calculated as:

154 mmBTU/year × 43.7% ÷ 90 days/year = 0.750 mmBTU per average Dec-Feb day.

When accounting for the fact that Dec 2010-Feb 2011 period was cooler than the long-term average for the same three months as measured at Fairbanks International Airport (-10°F vs. -4°F long-term), the 840,000 BTU/day sample average from Table 7-6-8 compares reasonably well to the independent estimate of about 750,000 BTU/day. Although a targeted sample, the instrumented database appears to reasonably approximate average Fairbanks household space heating energy use during winter.

Home-Heating Energy Model

After the data were validated and assembled into a unified database of hourly energy use by household and device, a least-squares regression analysis was performed to develop a predictive model of household space heating energy use, calibrated to Fairbanks practices and wintertime ambient conditions.

Several different forms of regression models and independent variables were evaluated. This evaluation included the following elements:

1. Assessment of the data to examine patterns/dependencies in home heating energy use;
2. Identification of terms or variables with statistically-significant explanatory power; and
3. Examination of equations/model forms that could be readily applied in conjunction with other data in an episodic emissions inventory workflow.

Patterns Revealed from Instrumented Sampling

In support of the first element, scatter plots of the validated data were prepared and examined to evaluate temporal energy usage patterns and both external (ambient) and internal (device usage practices in multi-device households) factors. Figure 7-6-14 through Figure 7-6-16 present time series plots of hourly space heating energy use by household for Oil Only, Mixed (Oil & Wood) and Primary Wood households, respectively. In each plot, hourly energy use for each household is plotted using distinct symbols/colors on the left axis. Ambient temperatures recorded for each hour are plotted in blue against the right axis. (The right axis is appropriately scaled to locate the ambient temperature series at the upper portion of the panel so it can be more clearly compared to the energy use data located largely toward the bottom.)

Figure 7-6-14
Hourly Instrumented Energy Usage (BTU/hour), Oil Only Households

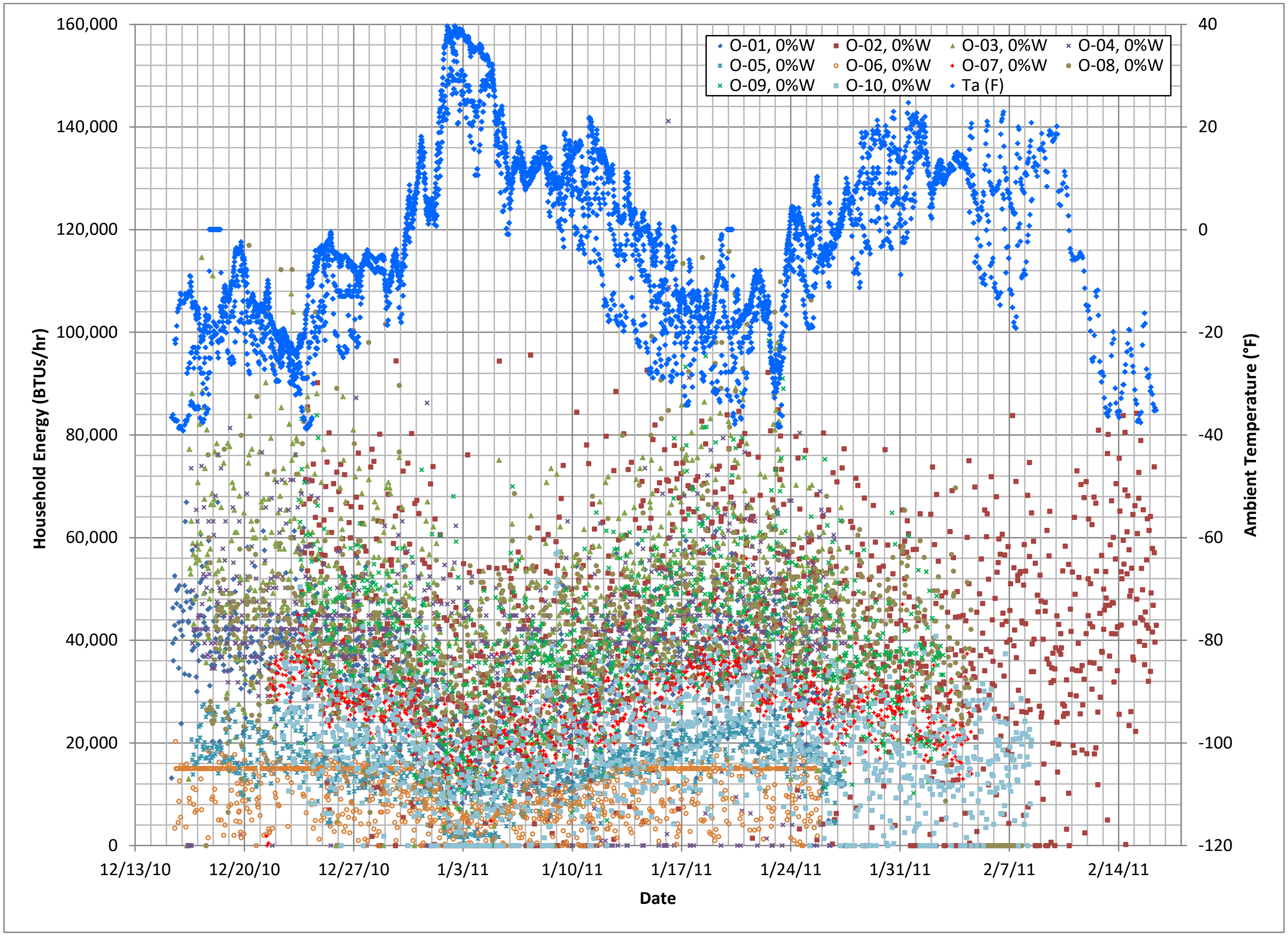


Figure 7-6-15
Hourly Instrumented Energy Usage (BTU/hour), Primary Wood Households

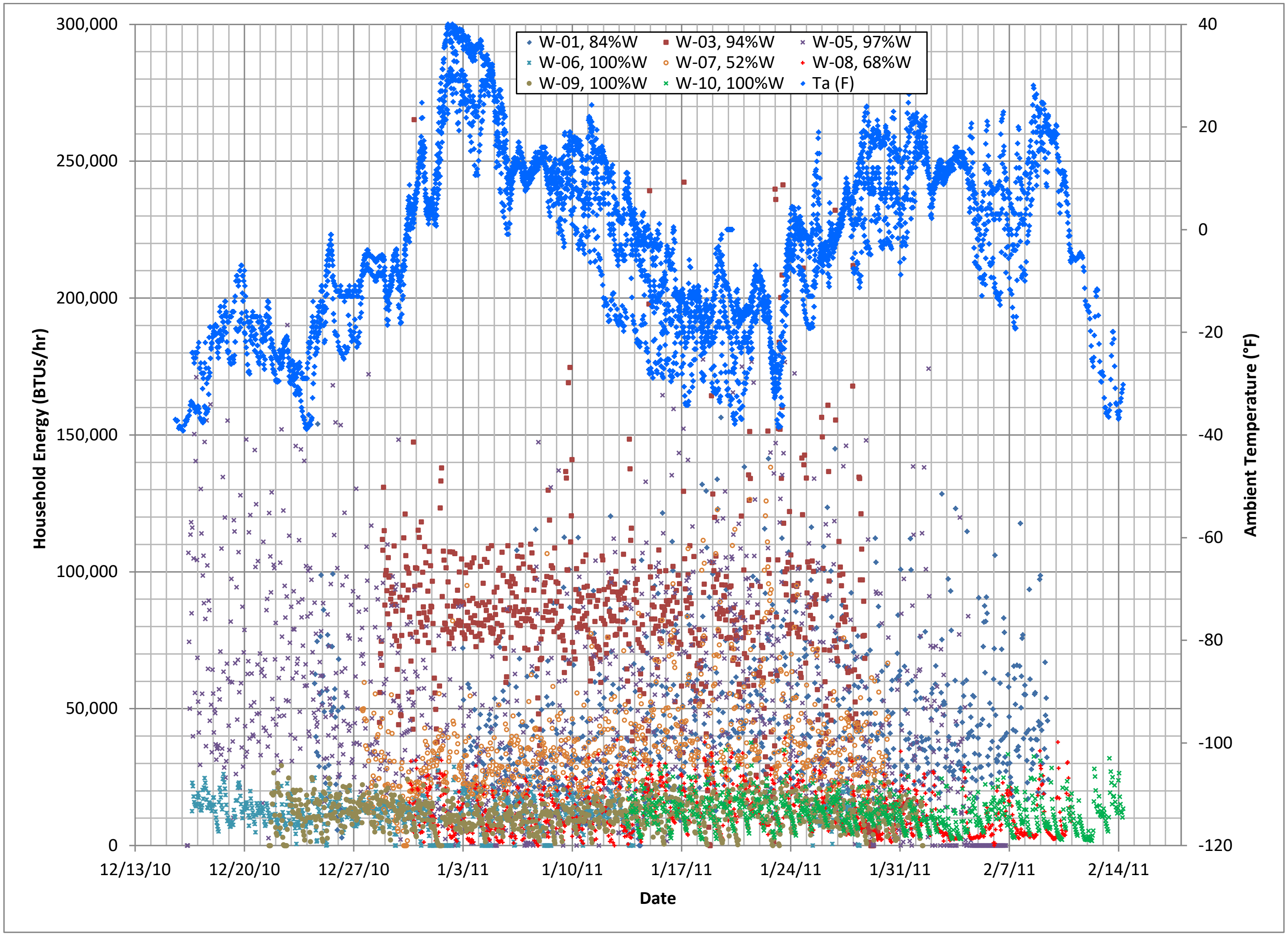
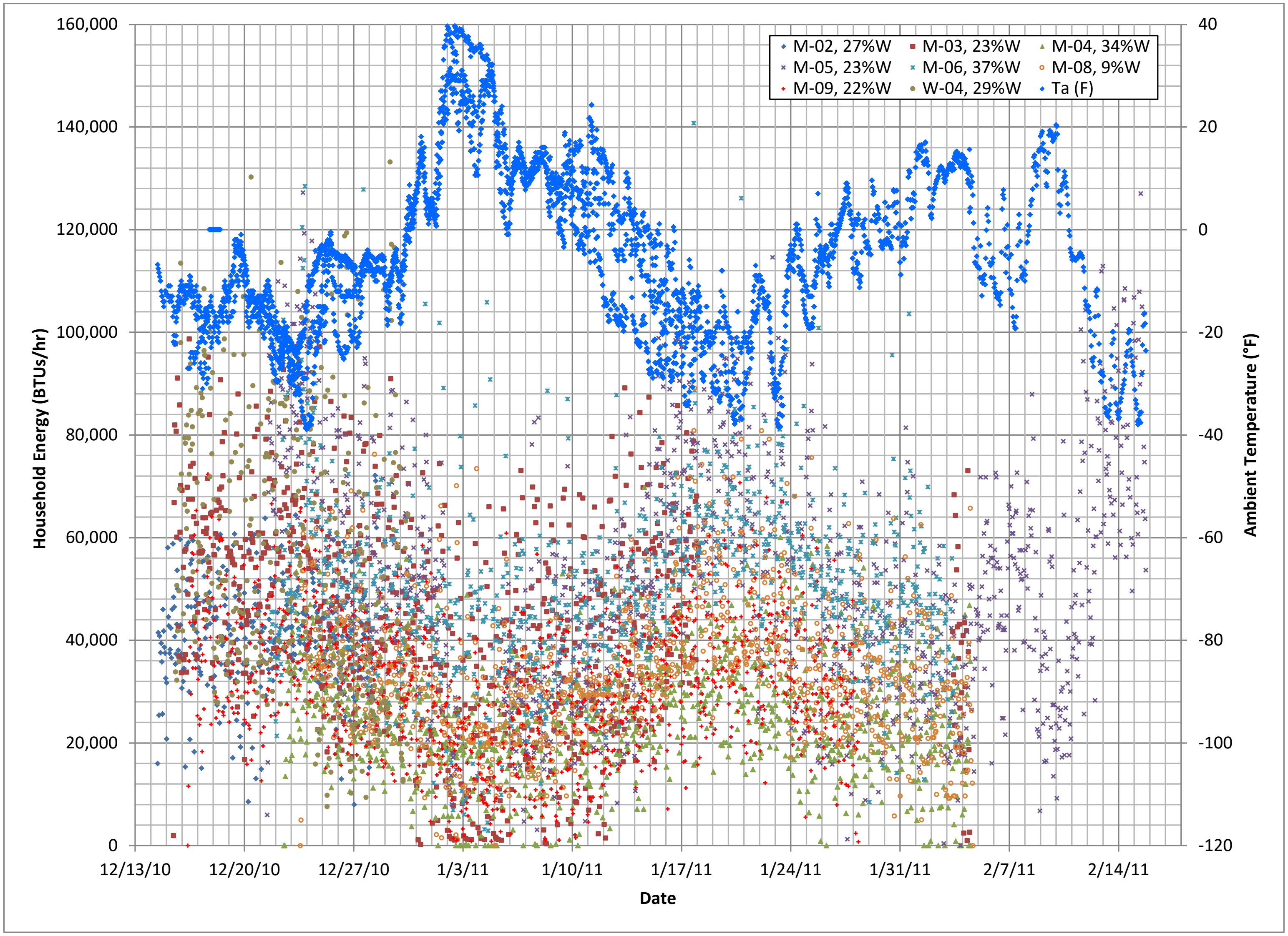


Figure 7-6-16
Hourly Instrumented Energy Usage (BTU/hour), Mixed Households



In Figure 7-6-14, ambient temperatures are shown to hover near the -20°F range at the start of the instrumentation period (mid-December) before rapidly warming to over +40°F in early January. Temperatures then head back near -20°F (and drop as low as -40°F) by mid-January, then rise to around +10°F at the end of the month before dropping toward -20°F again at the end of the instrumentation period in mid-February. Not surprisingly, plots for each Oil household's energy use tend to track variations in ambient temperature, but in the opposite direction.

Some other interesting patterns can also be seen. Comparing household sizes (shown earlier in Table 7-6-8) there is loose correlation between heated area and average energy use (R^2=0.41), although some homes exhibit disproportionally higher or lower energy use than reflected by their size (e.g. O-02 is higher, O-10 is lower). These size vs. energy use variations are also likely due to differences in construction/insulation and thermostat settings between households. As shown in Figure 7-6-4, the oil households exhibit differences in the magnitude of temporal variations over their sampling periods and generally show high degrees of scatter when plotted on an hourly basis, with one exception. Household O-06 (plotted with tan markers) is a small home (1,000 ft^2) heated entirely with a single direct vent heater. Based on its thermostat settings and heat output of the unit, the heater often operates at a steady rate of about 15,000 BTU/hour (which shows up as a horizontal line near the bottom of the plot). (The other direct vent oil home, O-05, has two direct vent units which operated together and are less steady in their output.)

Despite the high degree of visible scatter for the Oil households shown in Figure 7-6-14, temporal variation or scatter in hourly energy use was much higher in the Primary Wood households. As shown in Figure 7-6-15 (note the larger scale for energy use on the left axis), there tends to be much more scatter in hourly energy use, both within and across households that primarily burn wood. And at least on an hourly basis, energy use in Primary Wood households (R^2=0.05) is less correlated with ambient temperature than in Oil Only (R^2=0.19) homes. This lower correlation (on an hourly basis) is likely due to the fact that wood devices are not thermostatically controlled like oil devices. In addition, the Primary Wood group includes some households using oil as a secondary heating source, which affects total household energy use and hourly patterns.

Figure 7-6-16, the final plot in this series, shows hourly energy use for the Mixed households (those primarily heated using oil with wood as a secondary heating source). As shown earlier in Table 7-6-4, Wood household W-04 exhibited only 29% wood use, even though it was pre-screened as a primary wood home. Thus, it was plotted with the Mixed Households group in Figure 7-6-16.

Comparing Figure 7-6-16 (Mixed) to Figure 7-6-14 (Oil), the variation in energy use with ambient temperature appears more pronounced for Mixed households than Oil homes. A likely explanation for this is that in Mixed households, wood is used as supplemental or secondary heat, with oil providing a "base load" of heat energy. Given the relative heating efficiency of wood devices (40%-70%) compared to oil devices (over 80%), use of wood devices with lower efficiency, especially on colder days would result in more household energy use on those days compared to a case when the home is entirely oil-heated.

Since a portion of the scatter in this set of plots results from variation in hourly use, a second set of daily energy use plots were also developed and examined. Figure 7-6-17 shows total daily household energy use for each home in the Mixed group. Solid lines (with different colors and markers are used to show total daily energy use for each household. Similar to the earlier plots, daily average ambient temperature is plotted in Figure 7-6-17 using blue “diamond” markers against the right axis.

Comparing daily energy use across the Mixed households, day-to-day variations in energy use for all homes tend to work in reverse to ambient temperature variations. Homes M-05, M-06, M-03 and W-04 tend to exhibit higher energy use than others in the group (although the valid sample duration for W-04 was shorter than the rest). These four homes tended to be larger in size (M-06, M-03), use lower efficiency wood devices (M-05 used fireplace) or use a higher wood-based heating fraction (M-06=37%) than the rest of the group.

To better understand interactions in energy use for these multi-device households, Figure 7-6-18 presents daily energy use by device (oil, wood and total) for a selected set of Mixed households, M-04 and M-06. It illustrates two common patterns exhibited in multi-device homes even though their wood heating fractions are similar (~35%). For each household, total energy is plotted using a solid line and marker points; oil and wood energy are plotted using dashed and dotted lines, respectively. (Again, daily ambient temperature is also plotted against the right axis).

Shown in green lines in Figure 7-6-18, daily energy use in household M-04 exhibits a typical pattern, especially in smaller or more efficient/insulated homes. On colder days, both oil and wood are used (e.g. during the first week of sampling, from 12/22/10 through 12/30/12 and again from 1/10/11 and 1/24/11.) On warmer days (e.g. from 1/1/11 through 1/9/11 and again on 1/26/11) wood use actual dropped to zero and all heat was supplied by the oil device.

On the other hand, household M-06 displayed a different pattern in day-to-day interaction between oil and wood heating as shown in the three blue lines in Figure 7-6-18. Both devices were used to supply heat on every day of the sampling period, and with one exception around 12/29/10, the ratio in supplied heat between the oil and wood devices was fairly steady (roughly 2:1 oil-to-wood).

Figure 7-6-17
Daily Instrumented Energy Usage (BTU/day), Mixed Households

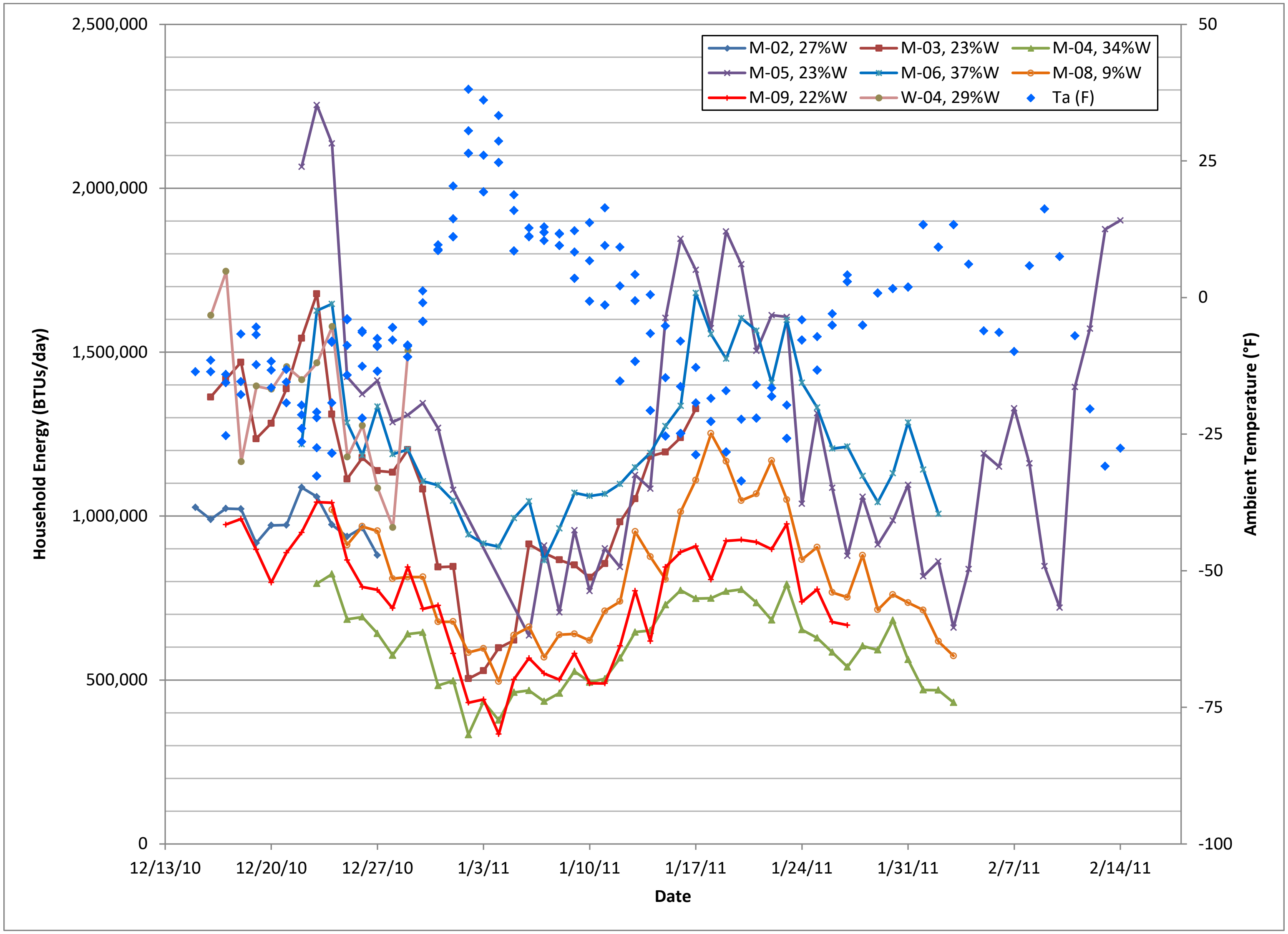
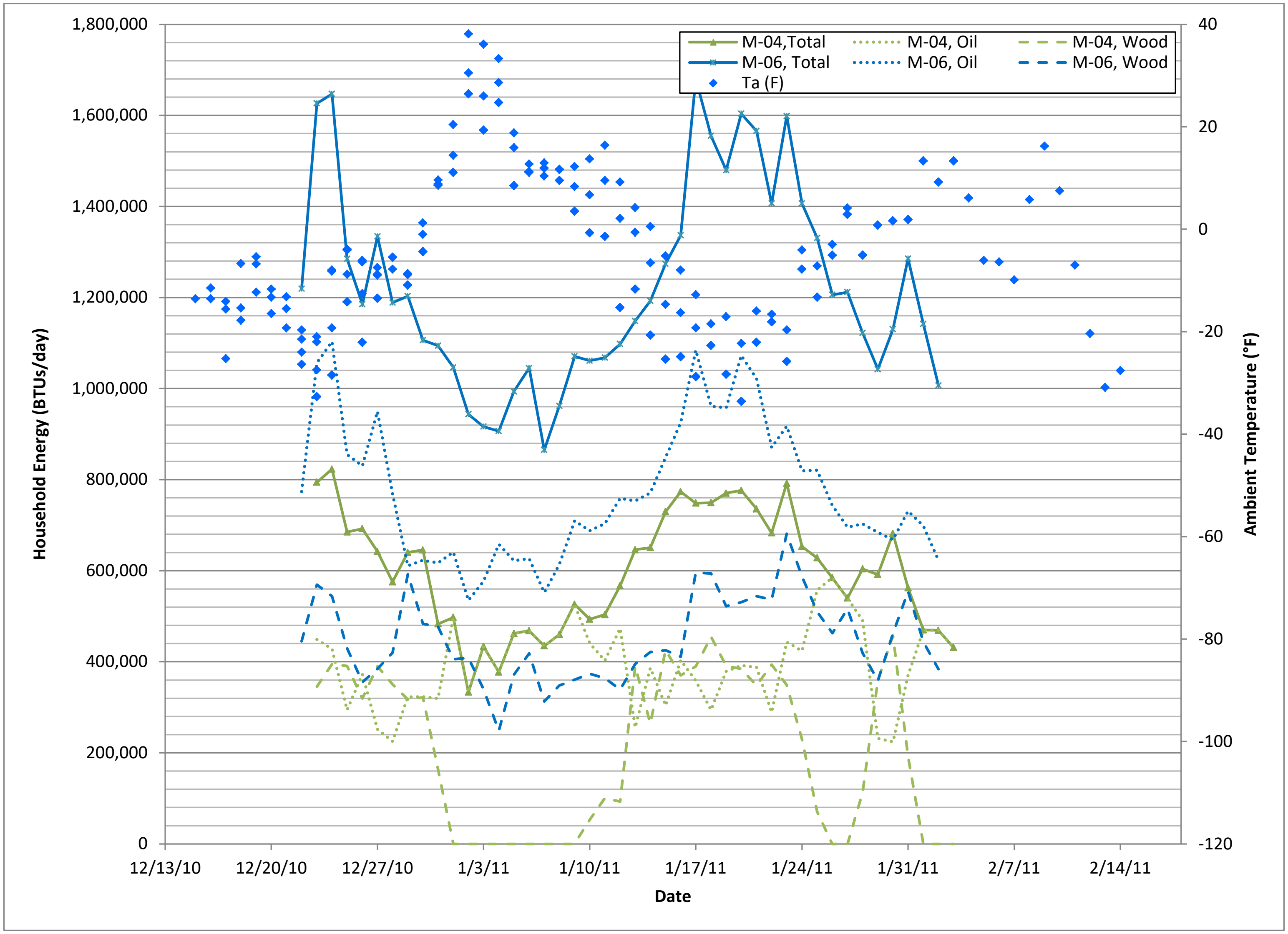


Figure 7-6-18
Daily Instrumented Energy Usage (BTU/day) by Fuel Type, Mixed Households M-04 and M-06



Identification and Selection of Explanatory Variables

Based on the review of space heating energy use patterns and examination of plotted results, several factors or variables were considered in building the regressions supporting the energy home heating model. These factors included:

- *Ambient Temperature* - Ambient temperature, as the primary measure of heat loss from the structure. An effort was made to determine if the energy use coefficient for temperature varied in different parts of the day, but there is insufficient data to make the determination.

- *Building Size* – Heated dwelling space was used as a marker of heat demand for each structure; the more heated area, the higher the heating demand.

- *Hour of Day* - Denoted by the beginning of the hour (the 00 hour is midnight-1 am). Dummy variables indicating the 24 individual hours of the day provide a diurnal profile of energy use (with other factors held constant) that reflects a combination of human behavior, particularly the times of day when the dwelling is occupied, and environmental contributions, such as the influence of daylight and dark on heat loss from the structure.

- *Device(s) Used* – The mix of devices used in each household was also considered. Examination of the patterns of variance in instrumented data suggested that both the type (in single-device homes) and the interaction (in multi-device homes) was a factor in explaining both total household energy use and diurnal usage patterns. Since wood devices are generally less efficient than oil devices, it is expected that all other factors being equal, homes primarily burning wood would exhibit higher energy use. In addition, the ability to thermostatically control the usage rate of oil-fired devices results in a different diurnal profile than for wood-burning devices, which are generally not thermostatically controlled (except hydronic heaters) and require manual fuel loading.

- *Day Type* - Weekday versus weekend days were distinguished, represented as a dummy variable for weekends, to capture overall differences in energy use that correspond to different occupancy and behavioral patterns between weekdays and weekends. An effort was made to determine if weekend-related differences could be related to time of the day, but there was insufficient data to make the determination. Thus, the weekend factor represents the average amount by which energy use is different on a weekend day versus a day during the work week.

The analysis was guided by the statistical significance of the estimated terms (at 95 percent confidence), but it did not require statistical significance in all cases because of the relatively small sample size available for study, especially for fireplace and direct vent oil devices. Terms have been retained where they appeared to be both important to capture and plausible, even if the desired level of statistical significance was not universally reached.

Inventory-Driven Regression Models – Given the review of the energy use patterns and selection of a set of factors believed to account for observed variations in the measured data, a series of multivariate regression models were considered and tested. In addition to statistical significance, a key element that guided the selection of appropriate model forms/equations was the applicability of the model for use in representing residential energy use (and device specific emissions) to support wintertime episodic modeling of space heating emissions in the SIP inventories. After trying a number of different models/forms, the final Fairbanks residential space heating energy use model consisted of two separate but serially-applied regression models that are listed below:

1. Daily Model – a single model predicting daily household space heating energy use (in BTUs) as a function of the average mix of the device usage in the home and its heated area; and

2. Hourly Device Models – a suite of device-specific models predicting diurnal usage patterns and unique responses of each device to daily ambient temperature variations and day of week effects.

Daily Model – The Daily model was a least-squares regression fitted model predicting daily household space heating energy as a function of heated living area and the fraction of each heating device type for each of the five device types represented in the instrumented sample:

1. Wood Stove (WS);
2. Fireplace (FP);
3. Outdoor Wood Boiler (OWB);
4. Central Oil (CO); and
5. Direct Vent Oil (DV).

These five device types account for over 95% of wintertime residential space heating energy use according to multiple residential home heating surveys performed in Fairbanks.
For each sampled day the total BTUs for each device type within a household were summed to find the total BTUs. The fraction of the total for each heating device type was then calculated by dividing the BTUs for the type by the total household BTUs for that day. A conventional multiple factor linear regression was performed on the resulting dataset. A total of 1,018 heating days were included in the regression.

The Daily model accounts for energy use effects of home size and heating device efficiency devices used within the home and their interactions on a given day. The Daily model predicts household energy per day (BTUs/day) using the following multivariate equation:

$$\boldsymbol{HH\ DayBTU = C_0 + C_1A + C_2\%WS + C_3\%FP + C_4\%OWB + C_5\%CO + C_6\%DV} \quad \textbf{(1)}$$

Where:

HH DayBTU = predicted daily household space heating energy use (BTU/day);
A = heated dwelling area (ft^2);
%WS = percentage of average winter household energy use by wood stoves;
%FP = percentage of average winter household energy use by fireplaces (no inserts);
%OWB = percentage of average winter household energy use by outdoor wood boilers;
%CO = percentage of average winter household energy use by central oil devices;
%DV = percentage of average winter household energy use by direct vent heaters; and
C_0 - C_6 = least squares-fitted coefficients (C_0 is the intercept).

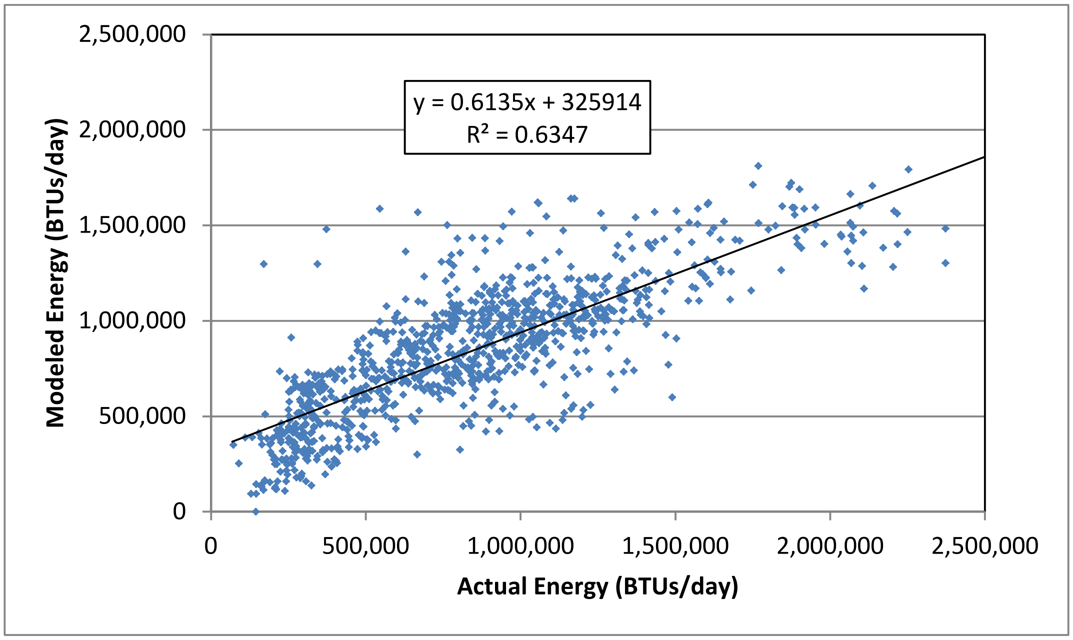
As discussed later in the "Emission Calculation Details" section of this appendix, heated dwelling area and fractions of device energy use over an entire winter season are elements that can be obtained from sources such as FNSB Assessor parcel database (building size) and home heating survey results (energy use splits over an entire winter season). Thus, for use in subsequent inventory calculations, these are known independent variables. Table 7-6-9 lists the resulting least squares-fitted coefficients used for the Daily model.

Table 7-6-9
Daily Model (Device Distribution and Area Model) Coefficients

Coefficient - Term	Value
C_0 - Intercept	-392560
C_1 – Heated Area	133.07
C_2 - % Wood Stove	799199
C_3 - % Fireplace	2462593
C_4 - % Outdoor Wood Boiler	1576799
C_5 - % Central Oil	987823
C_6 - % Direct Vent Oil	504552

Figure 7-6-19 presents a scatter plot of predicted daily household energy using the Daily regression model against actual measurements from the instrumented study database. Predicted estimates were generated by inputting the size and average device energy use splits of each household in the study. The plotted trend line and its equation box show that total daily BTUs in each household (predicted as a function of its size and device mix) are fairly well correlated with measured values (R^2=0.63), although the positive intercept for the trend line and the slope below unity indicate a bias toward over-prediction at the low end of measured daily energy and under-prediction at the high end. Given that ambient temperature dependence has yet to be factored in, this Daily model performs reasonably.

Figure 7-6-19
Modeled vs. Actual Household Energy by Day - Total Daily BTUs



To see how well the Daily model represents day-to-day energy use for each specific heating device, a set of similar scatter plot comparisons were developed showing predicted vs. measured energy use for each device in the household.

In Figure 7-6-20, predicted daily energy use from household wood stove use is also reasonably well correlated with measurements (R^2=0.66). Since the predictions here are being driven by the average energy split for wood stoves across all sampling days (for households equipped with wood stoves, the Daily model generally performed well in representing day-to-day and household-to-household wood stove energy use.

Figure 7-6-21 presents predicted vs. measured household energy use for fireplaces. As it shows, predicted energy use for fireplaces is not as well correlated as for wood stoves and tends to over-represent measured values. These relatively poor predictions are largely due to the fact that the instrumented study sample consisted of only a single household that used a fireplace and it was used intermittently as a secondary heating source. Evidence of this can be seen in Figure 7-6-21; there are several data points on the y-axis, meaning the model is predicting some fireplace energy use (based on average splits) on given days when the fireplace was not operated. The regression model would certainly benefit from additional sampling of fireplaces.

Figure 7-6-20
Modeled vs. Actual Household Energy by Day - Daily Wood Stove BTUs

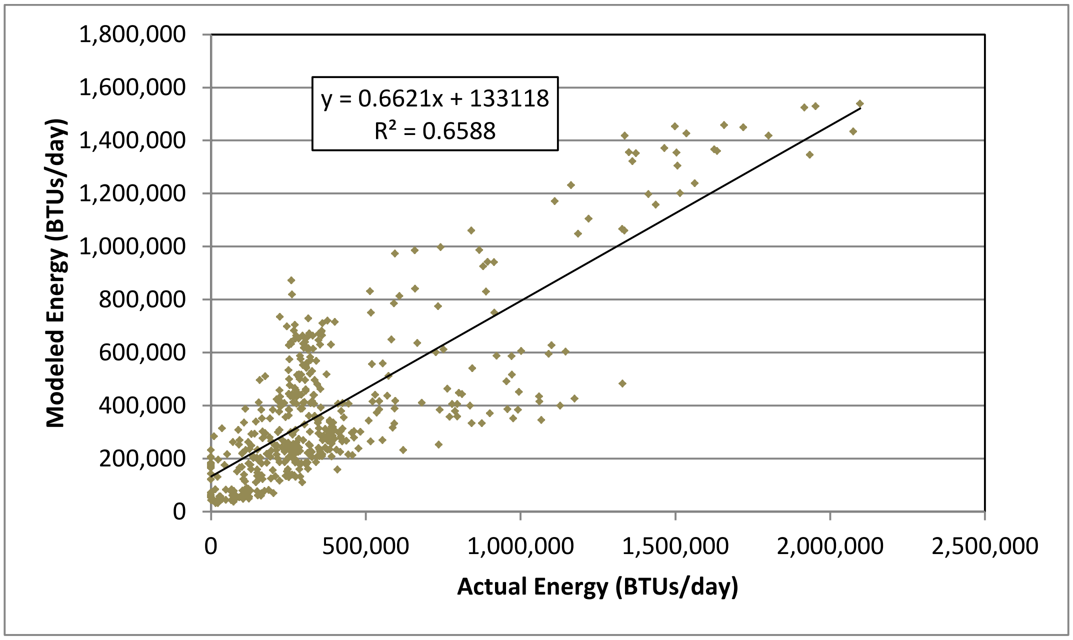
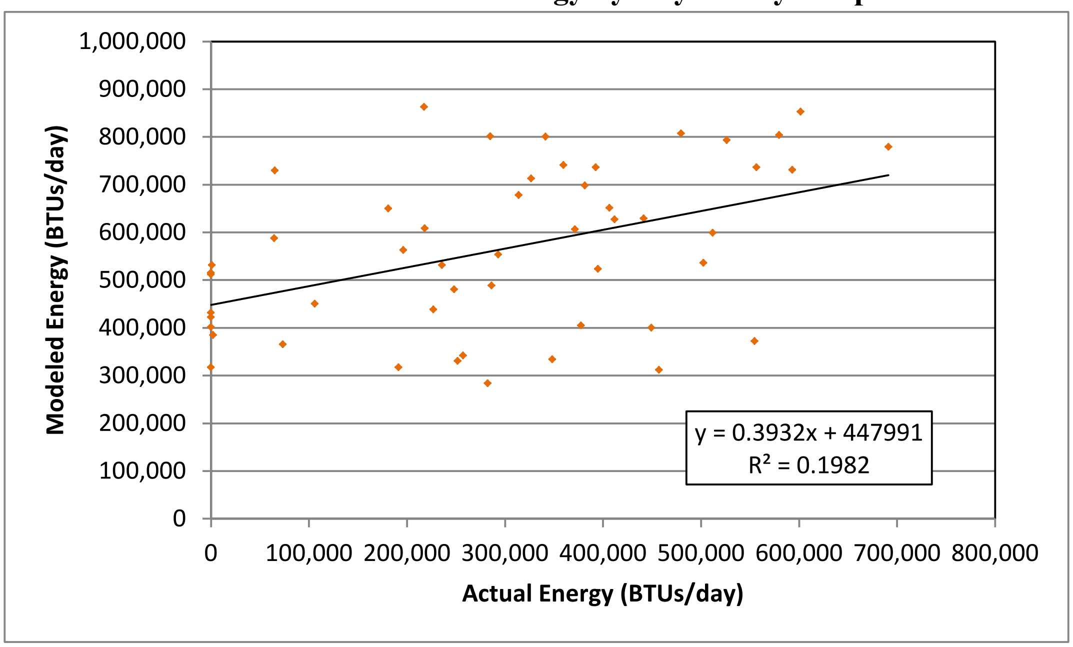
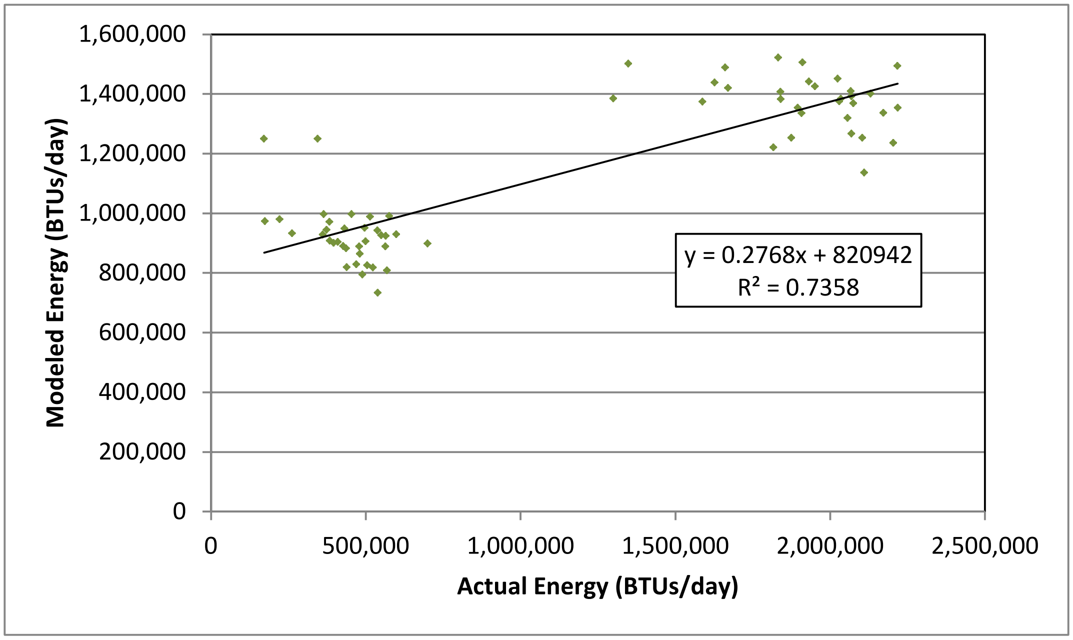


Figure 7-6-21
Modeled vs. Actual Household Energy by Day - Daily Fireplace BTUs



Predicted vs. measured daily household energy use for outdoor wood boilers (OWBs) is presented in Figure 7-6-22. Although it shows predicted results are better correlated with actual measurements (R^2=0.74), its two "clusters" of data represent the only two households with OWBs in the study sample. And the usage patterns exhibited by these two OWBs appear to span a wide range of actual practice. In the first OWB household (W-03), the OWB supplied 94% of the household heat energy over its measurement period, while in the second (W-07) there was a more even balance between OWB and central oil heating (52% vs. 48%).

Figure 7-6-22
Modeled vs. Actual Household Energy by Day - Daily Outdoor Wood Boiler BTUs



As shown in the preceding three plots, it is mildly problematic to accurately predict daily energy use for wood-burning devices on an individual device and household basis, because of their somewhat intermittent use. In contrast, predicted oil device household energy use better matched measured values.

Figure 7-6-23 and Figure 7-6-24 show predicted vs. measured household energy use for central oil devices and direct vent heaters, respectively. Predicted estimates for both oil device type are very well correlated with daily measurements ($R^2 \geq 0.8$), partially reflecting the fact that oil devices generally provide "base load" heat from day to day.

Figure 7-6-23
Modeled vs. Actual Household Energy by Day - Daily Central Oil Device BTUs

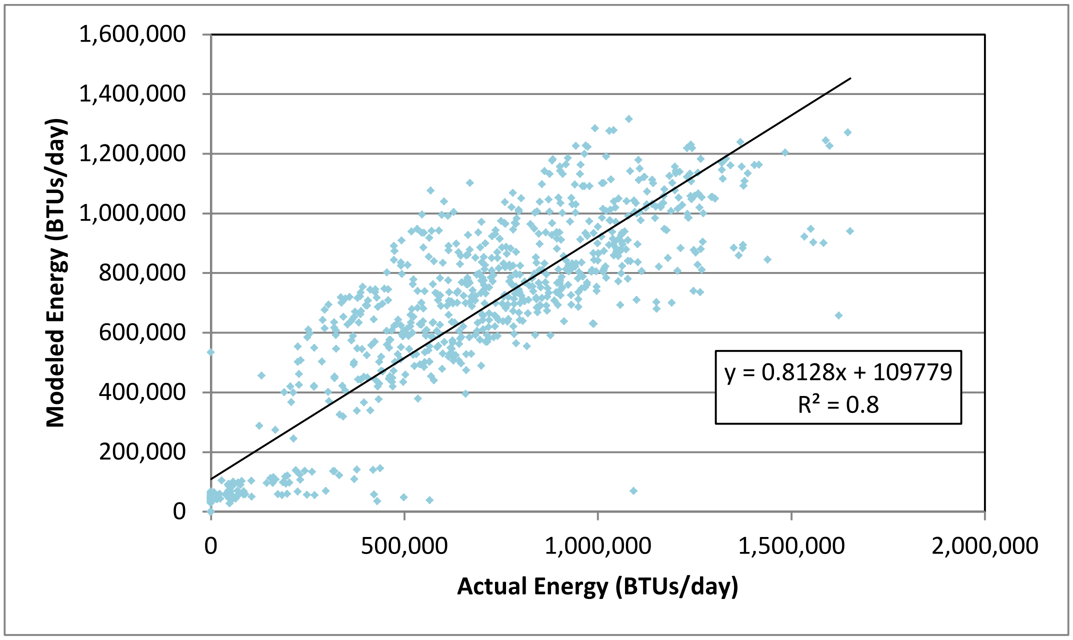
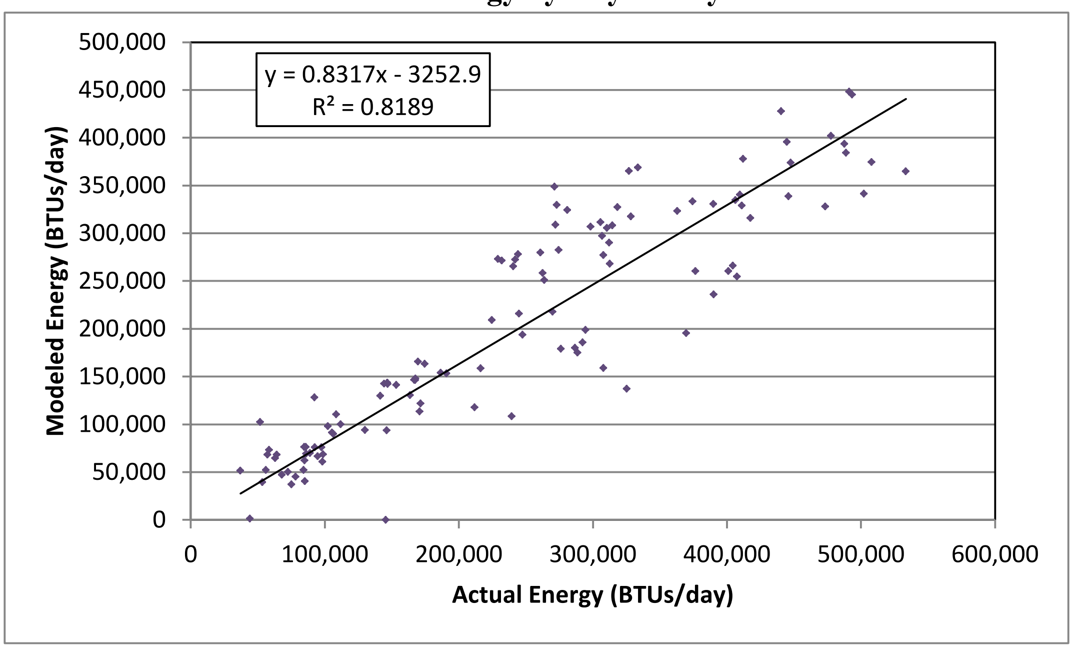


Figure 7-6-24
Modeled vs. Actual Household Energy by Day - Daily Direct Vent Heater BTUs



Hourly Model – The second and final component of the complete home heating energy model consisted of the development of a separate set of least-squares regression models of hourly energy use (one for each device type) that incorporated ambient temperature, weekday/weekend and diurnal variation influences unique to each device.

Since most wood-burning devices are not thermostatically controlled and require "manual" loading of fuel, their diurnal (and weekday/weekend) energy use patterns would be dictated by someone being home (and loading wood into the firebox). Depending on the size and burn duration range of each type of wood device, one might expect a different set of statistically fitted diurnal and weekday/weekend profiles than for oil devices.

Ambient temperature, an obvious explanatory variable for residential space heating energy use was incorporated into the Hourly model. (Incorporation of ambient temperature dependence was tested in both the Daily and Hourly models. It was determined that by incorporating it into the Hourly model rather than Daily model, device-specific responses to variations in ambient temperature could be better modeled.)

Thus, the set of Hourly models (one for each device type) was developed using the following equation form:

$$\boldsymbol{HH\ HrBTU_i = C_0 + C_{1,i} + C_2T + C_3DayType} \quad \textbf{(2)}$$

Where:

$HH\ HrBTU_i$ = predicted hourly household space heating energy use (BTU/hr) in hour i (ranging from 0 to 23);
T = daily ambient temperature (in °F);
$DayType$ = a dummy variable for weekday (value 0) and weekend (value 1) days and
$C_0 – C_3$ = least squares-fitted coefficients (C_0 is the intercept).

Daily, rather than hourly ambient temperature was found to produce marginally better fitted results for the set of Hourly regression models. This was attributed to the high degree of overall variance in the hourly measurement data (especially at the individual device level) and the fact that wood device are generally not thermostatically controlled and depending on the device and its settings, have a wide range in burn duration (over 12 hours for some devices) for a single fuel load. This diminishes correlation with hourly temperatures. Therefore, the set of Hourly models were fitted using daily ambient temperatures (i.e. averaged over 24 hours) developed from the hourly ambient temperature data.

Table 7-6-10 lists the set of Hourly model coefficients for each of the five heating devices determined using least-squares fitted regressions. The "intercept" coefficients (C_0) for each device reflect a baseline, or average hourly energy use for that device. The series of 24 C_1 coefficients (hourly index from 0 to 23) reflect fitted hour-specific adjustments to the baseline (C_0) level unique to each device type. In the fitted regression, the baseline was assigned to Hour 0 (midnight to 1 AM). This is why the C_1 value shown for Hour 0 in Table 7-6-10 is zero.

Table 7-6-10
Hourly Model (Temperature, Day, Diurnal Variation Model) Coefficients

Coefficient	Hour Index	Coefficient Values by Device				
		Woodstove	Fireplace	OWB	CentOil	DVOil
C_0 – Hourly, base	n/a	14952	11085	49737	29322	6047
C_1 - Hourly	0	0	0	0	0	0
	1	130	-1425	-1388	547	79
	2	-606	-2559	-1893	1108	130
	3	-2111	-3779	-1299	2050	89
	4	-3205	-4731	-2308	3351	421
	5	-4699	-4183	-3496	3849	-44
	6	-3477	-4026	-4218	5173	-95
	7	-1527	-3447	-4510	6640	-548
	8	-869	-1650	-2484	5774	-494
	9	1359	-1013	-1247	4562	-431
	10	1855	-1135	-257	4069	-157
	11	2702	-1383	-292	2979	-165
	12	1836	70	218	3001	185
	13	593	2822	1869	1774	-245
	14	1156	3418	-1223	2311	-21
	15	1531	2359	-2377	1762	-214
	16	2617	116	-5490	2411	-339
	17	1964	498	-6101	1719	-546
	18	3940	619	-7770	1328	-1676
	19	3561	-262	-8067	81	-1668
	20	5282	-19	-7050	359	-596
	21	3117	284	-5169	-1507	-1165
	22	571	1370	-3537	-817	-628
	23	1056	947	-1756	-457	-242
C_2 - Ambient Temp.	n/a	-263	-244	-175	-434	-170
C_3 - DayType	n/a	406	-655	-3548	-82	79

n/a – Not applicable

At the bottom of Table 7-6-10, the C_2 and C_3 coefficients are shown for each device reflecting daily ambient temperature and weekday/weekend differences, neither of which is modeled as varying by hour, but rather as an offset term that is constant over the day. As expected, the ambient temperature coefficients (C_2) are all negative, reflecting increasing energy use with decreasing outdoor temperature. The ambient temperature coefficient for Central Oil is the largest (negative) value compared to those for the other devices. This makes sense since central oil devices are the predominant source of "base level" or entire heating in a large majority of the instrumented sample (as well as Fairbanks residences in general) and thus reflect the greatest response to ambient temperature.

Finally, the DayType (C_3) coefficients in the bottom row of Table 7-6-10 reflect a mixture of positive and negative values across the range of instrumented devices. Since the DayType dummy variable is 0 for weekdays and 1 for weekends, a positive value indicates greater predicted energy use for that device on weekend days relative to weekdays. The two oil devices show a weaker variation between weekend and weekday energy use than the wood devices, likely due to the fact that the oil devices are thermostatically controlled.

Combined Application of Fitted Regression Models - The final step in the development of the home heating energy model consisted of serially combining the two models into a "composite" model as follows.

First, the Daily model is applied to generate estimates of daily household energy use by device as a function of dwelling size and the device use fractions in a household (or group of households as described later in the "Emission Calculation Details" section of the appendix. Next, the Hourly model is applied (with separate sets of coefficients for each applicable device) to estimate hourly energy use by device, factoring in ambient temperature, day of week and diurnal usage pattern effects.

In order to properly impose the variations addressed by the Hourly model, a reference temperature and a reference day type must be assumed to allow normalization of the second model results when combined with the Daily model predictions. The overall average temperature during the instrumented study sampling period was chosen as the reference temperature (-3.5°F), while weekdays were chosen as the reference day type.

Once daily energy use estimates have been generated using the Daily model and daily estimates are divided by 24 to represent an average hourly value, the Hourly model is then applied twice (for each device type), first using the selected input ambient temperature and day type and next with the reference ambient temperature (-3.5°F) and reference day type (weekday). Ratios of actual day to reference day energy use for each device in each hour are then calculated for each set of Hourly model estimates.

Finally, the results from the Daily and Hourly model regressions are combined by summing the product of the Daily model energy for each type, the Daily model device fraction for each type, and the ratio of the Hourly model energy for each type at the desired conditions and the Hourly model energy for each type at the reference conditions as shown in the following equation:

$$\boldsymbol{HH\ BTU_{d,i,t}} = {\boldsymbol{DayBTU_d}}/{\boldsymbol{24}} \times {\boldsymbol{HrBTU\ Actual_{d,i,t}}}/{\boldsymbol{HrBTU\ Ref_d}} \qquad \textbf{(3)}$$

Where:

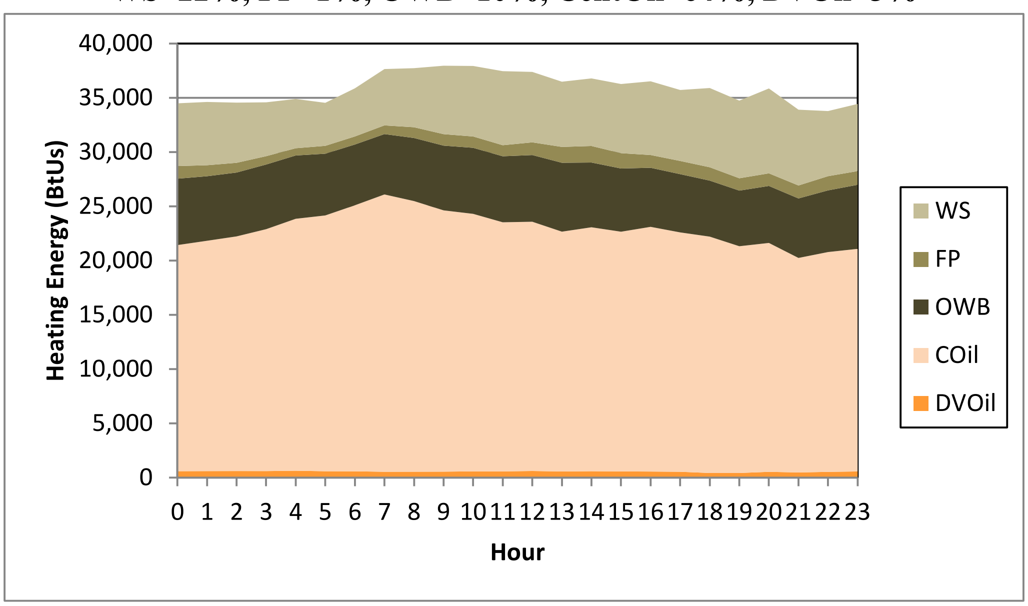
HH BTU$_{d,i}$ = Calculated household hourly energy use (BTU) for device type *d* and hour *i*;
Day BTU$_d$ = Daily model-predicted household energy use (BTU) for device type *d*;
HrBTU Actual$_{d,i,t}$ = Hourly model-predicted household energy use (BTU) for input ambient temperature (in °F) and day type (weekday or weekend);
HrBTU Ref$_d$ = Hourly model-predicted household energy use (BTU) averaged over all 24 hours for the reference temperature (-3.5°F) and reference day type (weekday); and

Device Type 1=Woodstove, 2=Fireplaces, 3=Outdoor Wood Boilers, 4=Central Oil, 5=Direct Vent Heaters, Hour *i* refers to the hour ending (1=midnight to 1 AM, 2=1 AM to 2 AM, etc.) and *t* is ambient temperature in °F.

Figure 7-6-25 through Figure 7-6-28 present estimates of hourly energy by device and hour for several sets of example conditions to illustrate how the combined space heating energy model responds to each of its input variables. In each figure, predicted household hourly energy use (in BTUs) is plotted by hour of the day (0 represents midnight to 1 AM) for each device type in a hypothetical household.

First, Figure 7-6-25 shows a case that represents a typical mix of household device usage splits identified in local home heating surveys, reflecting primary oil use and secondary wood use. It assumes a daily average ambient temperature of 0°F.

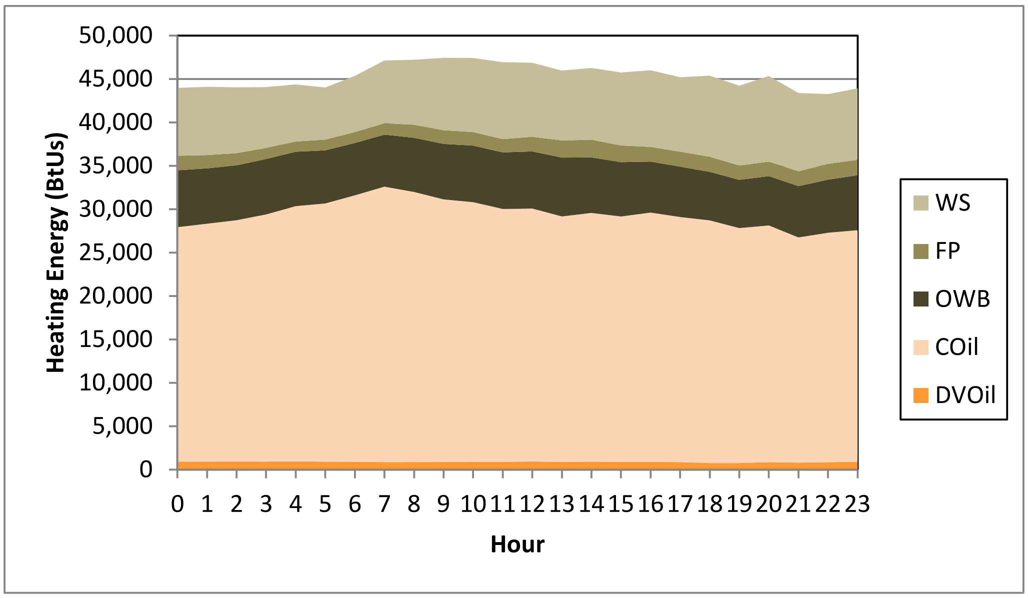
Figure 7-6-25
Combined Model Energy Use Case:
Dwelling Size = 2,129 ft^2, Temp = 0°F, Day Type = WD,
WS=22%, FP=1%, OWB=10%, CentOil=64%, DVOil=3%



(Although a single home is not likely to employ all five of these devices, the energy model was designed for use in space heating inventory calculations which as explained later in the "Emission Calculation Details" section of the appendix, is applied for large groups of households. The energy model can also look at more simplistic one- and two-device per home scenarios, but it was designed for the broader inventory use explained above.)

Figure 7-6-26 shows predicted household energy use for the same device mix as in Figure 7-6-25, but at a colder -20°F daily ambient temperature. Expectedly, predicted energy use is over 20% higher (note the difference in vertical axis scales between the two figures).

Figure 7-6-26
Combined Model Energy Use Case:
Dwelling Size = 2,129 ft^2, Temp = -20°F, Day Type = WD,
WS=22%, FP=1%, OWB=10%, CentOil=64%, DVOil=3%



Next, Figure 7-6-27 illustrates a case representing a household primarily heated by wood, again at -20°F. In this example, wood burning devices collectively comprise 70% of the average winter season household energy use with oil used for the remaining 30%. Compared to Figure 7-6-26, this shows higher overall energy use (due to the relative inefficiency of wood devices compared to oil) and a different diurnal pattern.

Finally, Figure 7-6-28 shows the typical "primary oil" device mix case from Figure 7-6-26, but for a smaller dwelling size (1,500 vs. 2,129 ft^2). Comparing its results to those in Figure 7-6-26, a reduction in overall energy use of about 10% is predicted for the smaller home.

Thus, this series of plots demonstrates how the space heating energy model works and responds reasonably to changes in its inputs.

Figure 7-6-27
Combined Model Energy Use Case:
Dwelling Size = 2,129 ft², Temp = -20°F, Day Type = WD,
WS=55%, FP=5%, OWB=10%, CentOil=28%, DVOil=2%

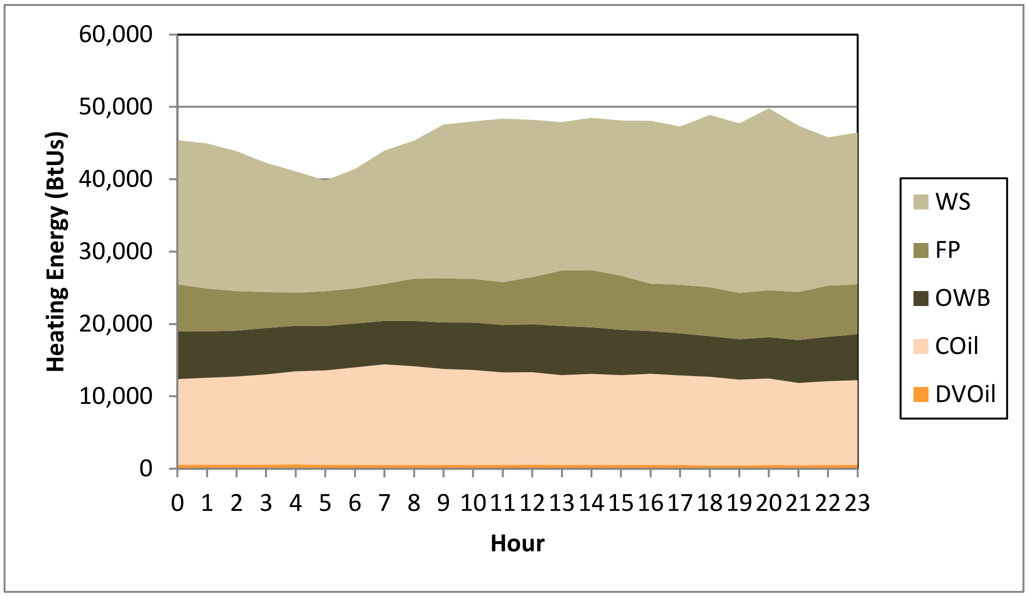
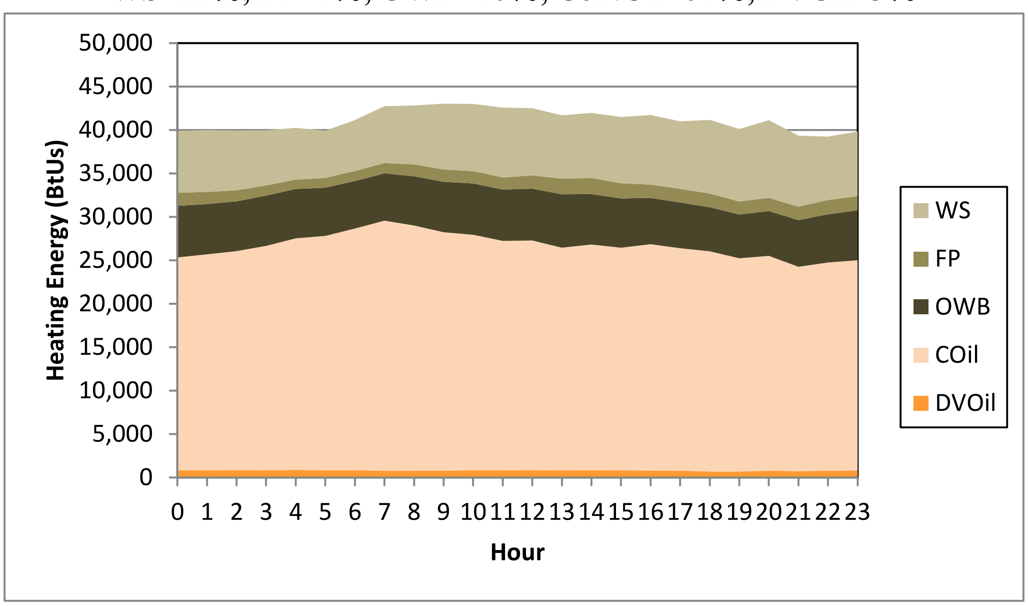


Figure 7-6-28
Combined Model Energy Use Case:
Dwelling Size 1,500 ft², Temp = -20°F, Day Type = WD,
WS=22%, FP=1%, OWB=10%, CentOil=64%, DVOil=3%



HOME HEATING – SPACE HEATING SURVEYS

One of the key sources of data use to drive the residential heating energy model was information developed from a series of residential "Home Heating" (HH) telephone surveys regularly conducted by DEC. These surveys have been conducted in 2006, 2007, and 2010-2015 and have been used by DEC and Borough to determine the mix of residential home heating devices and practices within the Fairbanks $PM_{2.5}$ nonattainment area.

In addition to these broader HH surveys, the agencies also funded and coordinated two special surveys in 2013 specifically targeting wood-burning households, one in which more details were obtained on rated emission levels for certified devices, the other which further examined wood purchase and usage practices.

This section of the Emission Inventory Technical Appendix describes each of these two sets of survey instruments and summarizes the key data extracted from these surveys and processing performed for use in calculating space heating emissions within the SIP inventories.

RESIDENTIAL HOME HEATING SURVEYS

Purpose – The primary purpose of these HH surveys was to collect up-to-date information on residential heating practices in Fairbanks during the winter season when extremely cold ambient temperatures cause a significant seasonal increase in fuel combustion for residential heating. Since the first surveys were conducted during the 2006 and 2007 winter seasons, DEC has continued to fund similar annual surveys beginning again in early 2010. The rationale behind these continued surveys is to ascertain whether trends in the devices/fuels used to heat homes have changed over time. DEC and the Borough also use the surveys to gauge public awareness about local air quality and control programs.

Basic Approach - The HH surveys were conducted by a specialized research survey firm, Hays Research Group (Hays), based in Alaska. Hays was directed to randomly sample residential households within the Fairbanks $PM_{2.5}$ non-attainment area, perform the telephone surveys and deliver the detailed, electronically recorded survey data results to DEC. The telephone surveys were generally toward the end of each winter (e.g., the 2010 survey was conducted during February 2010) to get responses about heating patterns/practices while fresh in the minds of the respondents.

Targeted sample sizes for the first three HH surveys (2006, 2007 and 2010) were set at 300 households for each survey. For the 2011-2015 surveys, the targeted sample size was more than doubled, to 700 households. Within each survey, ZIP code-specific sampling targets were established based on household data from the 2010 U.S. Census and used to select stratified samples of residential households by ZIP code. (For the 2010 and earlier HH surveys, stratified ZIP code sampling was based on 2000 Census data, then later re-weighted to be consistent with the 2010 Census weightings. Composite metrics tabulated across ZIP codes from all surveys could then be compared in an unbiased manner.)

In addition, the 2011 and later surveys utilized a different Fairbanks telephone database that included mobile phones. Given the growing use of cell phones, in some households as a replacement for land-line phones, concern emerged that the approach used to sample households using a land-line only phone number database may have unintentionally biased the resulting samples. As a result, the household selection process for the 2011 and later surveys was revised to include cell-sampled respondents. The cell phone respondents were contacted using known Fairbanks cell prefixes, and then verified to be within the boundaries of the survey. Sample sizes for the cell phone respondent subsets within each survey were "self-selecting." Hays simply used a combined list of phone numbers (land and cell) and randomly dialed from the list. Cell vs. land line phone status was later confirmed by the Hays interviewer during the survey of each respondent. The cell phone respondent fractions ranged from 5% to 12% across the three (2011 and later) HH surveys. No ZIP code or address location data were collected for these cell-based respondents, except within the 2012 survey[11]. For the other surveys, cell respondents were proportionally distributed across the non-attainment area ZIP codes based on the 2010 Census weightings.

Survey Content – The surveys focused on identifying the types and usage practices of different home heating devices used in residences within the nonattainment area during winter months. It was organized into a hierarchical series of roughly 70 separate questions that respondents were asked to answer based on the types of heating devices available and used within their homes. Key questions included the following:

- identifying the types of heating devices present in the household (including the specific type of wood-burning device if used);
- providing rough usage percentages for each device on both a winter season and annual basis; and
- estimating the amount of fuel used in each device (e.g., cords of wood or gallons of heating oil) both during winter and on an annual basis.

The survey questions were organized in a "branching" structure. An initial set of focused questions were asked to identify the types of heating devices present and used in the home. Then for each device applicable to the household, separate branches of further questions were asked about each device. The residential heating device types tracked under the surveys (for which separate question branching was conducted) are listed in Table 7-6-11. The surveyor navigates the homeowner through specific branches of the survey related to those devices that exist in the household. In addition to those devices explicitly listed in Table 7-6-11, the survey allows other types of heating devices to be identified and recorded into a generic "Other" group for which "verbatim" descriptions of the device provided by the homeowner were recorded into a separate file. Generally, the most common type of heating device in the Other category is portable electric heaters, which produce upstream or indirect emissions.

[11] For the 2012 HH survey only, address data were obtained by Hays, but not released. Hays used the addresses to locate the surveyed households within ZIP codes in material provided to DEC.

Table 7-6-11
Fairbanks Home Heating Survey Device Types

Fuel Group	Device Type
Wood-Burning	Fireplaces
	Woodstoves/Inserts
	Outdoor Wood Boilers
Oil-Burning	Central Oil Boilers/Furnaces
	Portable Fuel Oil/Kerosene Heaters
	Direct Vent Heaters
Gas	Natural Gas Heaters
Coal	Coal Heaters
Steam	Municipal (District) Heat[a]

[s] Municipal or District heat refers to steam heat circulated in underground pipes generated from the Aurora Energy coal plant.

After the branching portions of each survey are completed for the specific devices present in the home, a general section of questions are included at the end that were asked of all respondents. These questions typically focused on planned changes in heating devices/practices and also included elements related to Borough education and control programs. Summarized separately below are the key types of questions contained in each survey branch or section:

- *Initial Section* - types of devices present in the house and the homeowner's rough estimate of the percentages each device was used during winter (and annually in some surveys), later surveys also asked for dwelling size (heated space);

- *Fireplace Section* – winter season and annual wood use estimates; whether wood used is cut by the homeowner or purchased commercially, seasoning period before burning, estimated wood moisture content and annual wood expenditure;

- *Stove/Insert Section* – estimated age and installation date of device, winter season and annual wood use estimates, cordwood or pellet device, whether wood used is cut or bought, seasoning period before burning, estimated wood moisture content and annual wood expenditure;

- *Outdoor Wood Boiler Section* - winter season and annual wood use estimates, use of cordwood or pellets, whether wood used is cut or bought, seasoning period before burning, estimated wood moisture content and annual wood expenditure;

- *Central Oil Section* – size of fuel tank, gallons of heating oil used during winter and annually, yearly cost of fuel oil;

- *Portable Fuel Oil/Kerosene Heater Section* - similar to Central Oil section, plus questions asking whether the device burns fuel oil or kerosene;

- *Direct Vent Heater Section* – similar to Central Oil section;

- *Gas Section* – estimated winter season and annual expenditures for natural gas;

- *Coal Section* – estimated winter season and annual coal use and expenditure, whether used in indoor stove or outdoor boiler;

- *Municipal Heat Section* - estimated winter season and annual expenditures for municipal (i.e. District) heat; and

- *General/Future Use Section* – this final section included questions about future home heating practices, such as estimating the heating oil price that would trigger each respondent to stop burning wood, as well as questions designed to gauge public awareness about air quality in Fairbanks and wood-burning in particular.

Attachment A contains the interviewer survey script for the 2011 Home Heating survey which lists each of the questions and shows their order and the section branching summarized above. (The structure/content for the 2012 and later surveys was similar to that for the 2011 survey.)

<u>Survey Data Assembly and Quality Assurance Review</u> – Once the telephone surveys were completed by Hays Research (the survey firm used to conduct the surveys and assemble the response data) the survey data were then provided to DEC in a series of electronic files[12] for processing and quality assurance review as described below.

Assembly & Processing – For each survey, the as-received data were imported into a single spreadsheet; the primary response data were loaded into one sheet and the verbatim responses in a secondary sheet, with those responses organized into tables specific to each question of that form (verbatim rather than categorical/numeric responses). Each record in the primary data corresponded to completed and coded responses to all questions for a household. Each column contains the responses to a specific question. Respondent IDs, survey dates, and residence ZIP codes were also listed for each record. (Respondent IDs were also recorded for the verbatim responses so they could be properly linked to the primary data. Other basic processing steps included converting number values to numeric types and reassigning '999' missing data codes used by Hays to blank values within the spreadsheets so they would be properly treated during subsequent statistical tabulations performed in the spreadsheets.

Quality Assurance Review – Before response data were analyzed and tabulated into metrics used within the SIP inventories, a detailed set of data consistency and range checks were performed on the as-received data as provided by Hays. Examples of data consistency checks included comparing devices used in the household recorded in the initial section of the survey with completed, valid responses in the appropriate device-specific "branch" sections, or checking that annual fuel use was always greater than or equal to winter season (Oct-Mar) fuel use.

[12] The primary file contains categorical/numeric responses to most of the survey questions. Separate files were used to collect and provide "verbatim" responses to specific questions which did not involve categorical responses. For example, respondents were asked to briefly describe the types of devices that landed into the generic "Other" device category discussed earlier.

Range checks were also applied to responses for questions that involved numerical, rather than categorical responses. Plausible or theoretical limits were used to flag "outlier" values for specific questions (e.g., wood stove fuel use). Where possible, flagged values were compared to other related responses for corroboration. For example, fuel use entries (e.g., cords of wood or gallons of oil burned) were compared to responses in the initial section where the homeowner provided roughly percentage distributions of device usage for each equipped device. If there was a large inconsistency between the two elements, the usage data were invalidated. For example, if a respondent said they burned 10 cords of wood in the winter (a large amount) but listed their wood device providing only 20% of total winter usage, the wood use entry was marked invalid.

Most of the response data (generally 80% or higher) passed these consistency and range checks. For those that didn't, inconsistencies were reported to Hays. In some cases, transcription or survey logic errors were discovered. Transcription errors were then corrected. Survey logic errors (where the surveyor forgot to ask device specific questions for devices present in a household) were addressed by performing callbacks to specific respondents (or calling additional households when the initial respondents were not available) in order to develop valid samples that met sample size targets of the survey (300 households in 2010 and earlier surveys, 700 households in 2011 and later surveys).

<u>Surveys Used for 2020 Amendment Plan</u> – For this 2020 Amendment plan (and consistent with the earlier Serious SIP), area-specific wintertime heating device usage fractions and practices were developed from the more robustly-sampled 2011-2015 HH survey data, which encompassed a combined sample of over 3,500 households, and were used to develop space heating emissions for the 2019 Baseline inventory. These combined 2011-2015 survey results were used to develop estimates of the types and number of heating devices used during winter by 4 km square areas[13] within the nonattainment area. The survey data were also used to cross-check the energy model-based fuel use predictions as well as to identify and apportion wood use within key subgroups (certified vs. non-certified devices and purchased vs. user-cut wood, the latter of which reflects differences in moisture content that affects emissions).

"Special purpose" surveys were also conducted in support of this 2020 Amendment and the earlier Serious SIP and included:

1. 2013 "Wood Tag" and "Wood Purchase" surveys of wood-burning households that collected further detail on EPA-certified devices and wood sources;

2. a 2016 Postcard survey that sought to assess changes in wood use related to heating oil price decreases; and

3. a 2017 Commercial Business survey intended to identify and estimate solid fuel device space heating for commercial businesses within the nonattainment area.

[13] Modeling grid cells were 1.33 km square. Device and fuel usage distributions from the 2011-2015 survey data were calculated by 4 km square areas (which consist of 3 × 3 sets of modeling grid cells) in order to achieve a minimum statistically sufficient sample size of a least 50 households per 4 km square area across the majority of the nonattainment area.

(These specialized surveys are discussed in the "Specialized Wood Burning Surveys" sub-section that follows.)

The combined 2011-2015 HH survey sample was used to represent residential space heating device and fuel use for the 2013 Baseline inventory, as opposed to the 2013 survey data. The rationale behind this decision was twofold:

1. Calendar year 2013 was centered within the 2011-2015 survey period, and any trends over the period (e.g., wood use, uncertified device fractions would be reasonably represented by the combined average over the period); and

2. Use of the combined data provided a roughly five-fold increase in sample size, which as shown later in this sub-section provided much higher statistical confidence in the device/fuel usage fractions developed from the survey data, especially for smaller proportion device/fuel combinations such as Outdoor Wood Boilers.

And although useful for trends analysis, data from the more sample-limited 2010 and earlier HH surveys were not used to represent residential space heating patterns for the 2013 Baseline inventory.

Tabulation of Key 2011-2015 HH Survey Results – A series of basic cross-tabulations were prepared to examine results of the responses to each question in the surveys. Key results from these tabulations are presented separately below for the combined 2011-2015 HH survey data.

Households Sample Sizes and Multi-Device Usage - The first step in the analysis consisted of translating the cross-tabulated record counts into fractional or percentage distributions by device or fuel type so the survey results could be applied to update the emissions inventory. As described earlier, the initial section of the survey asked respondents to identify all of the specific type(s) of heating devices used in the household. Thus, the survey accounted for use of multiple heating devices within each household. These instances of multiple device use within a household had to be properly accounted for in tabulating the results to ensure that surveyed usage is correctly extrapolated to the entire population of Fairbanks households.

Table 7-6-12 shows the sample sizes by ZIP code (including cellphone households that could not be located by ZIP) in the first two rows. The number and percentage of sampled households are shown. In the highlighted row below, weighting factors developed from the percentage of households within each ZIP code based on the 2010 U.S. Census are shown. Comparing these weighting factors to the sample percentages just above, the sample percentages are in nominal, but not perfect agreement with the Census-based weightings. As described later, these weightings were used to adjust the sampled response data by ZIP (and unknown ZIP for the cellphone households) to generate Census-weighted composites in addition to sample self-weighted averages.

Table 7-6-12 2011-2015 HH Survey Sample Size and Multiple Use Types								
Parameter	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**
Sample Size, Households	183	906	114	787	1,150	359	15	3,514
Sample Size, % of Sample	5.2%	25.8%	3.2%	22.4%	32.7%	10.2%	0.4%	100.0%
2010 Census Household Weightings	-	24.6%	4.7%	23.9%	34.3%	12.0%	0.5%	100.0%
Multi-Type Household Factor	1.60	1.32	1.47	1.60	1.55	1.65	1.60	1.51
Multi-Type Household Use %	46.4%	27.5%	38.6%	51.6%	47.8%	55.2%	46.7%	43.8%

[a] Also includes Birch Hill area

Next, Table 7-6-12 lists the multiple device usage factors that were calculated from the validated survey data. This “Multi Type Household Factor” represents the ratio of the total number of devices used divided by the number of households. (For example, a factor of 2.0 would indicate an average of two devices in each household.) As seen in Table 7-6-12, there is a fairly consistent multi-type factor across all ZIP codes, with an average for the entire sample of 1.51. Finally, Table 7-6-12 shows the percentages of households with more than one heating device. As shown, nearly 44% of all surveyed households use multiple heating devices.

Device Counts and Usage Distributions – Table 7-6-13 summarizes the counts (number of households) of heating devices by device type and ZIP code from the survey sample. As seen in Table 7-6-13, central oil furnaces (2,803 total households) and wood-burning devices (1,339 total households) were the most commonly found home heating devices in the combined 3,514 household survey sample. The totals of all devices reported at the bottom of Table 7-6-13 reflect the fact that many households use more than one type of home heating device. These totaled counts, when divided by the number of households surveyed listed earlier in Table 7-6-12, match the Multi-Type Household Factors also reported in Table 7-6-12 (for example, within the Downtown area, 1,193 ÷ 906 = 1.32).

Table 7-6-14 presents the distributions of device usage percentages by ZIP code during the winter months (October-March). <u>These usage percentages were determined from the survey responses to Q9a-Q9h where the respondents were asked to roughly estimate the percentage of time each household device is used during winter</u>. The usage percentages in Table 7-6-14 <u>are not</u> based on either the counts of household devices or the amounts of fuel used queried in later sections of the survey. The usage percentages have been properly normalized to account for multiple device use within a household as described in the preceding sub-section. As shown in Table 7-6-14, central oil furnaces are used between 46% and 76% of the time across all ZIP code areas, with an average across the entire sample of 65.5%. Wood-burning devices represent 19.2% of total wintertime device usage across the entire sample, with higher percentages in the outlying areas (North Pole, Airport and Steese) than in those nearer the city center (Downtown, Wainwright). As seen in Table 7-6-14, households in the Wainwright/Birch Hill area have a much greater usage of District heating because of access to this underground infrastructure.

Table 7-6-13
2011-2015 HH Survey Counts of Heating Device Types
(Number of Surveyed Households with Device)

Heating Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**
Wood Burning	71	168	26	379	514	175	6	**1,339**
Central Oil Furnace	133	751	64	662	906	278	9	**2,803**
Portable Heat Device	11	23	3	23	27	12	2	**101**
Direct Vent Type	39	64	20	84	185	63	2	**457**
Natural Gas	7	37	25	10	23	5	3	**110**
Coal Heating	4	8	7	18	3	8	0	**48**
District Heating	6	43	17	4	11	3	0	**84**
Electric Heat	11	53	3	34	50	19	2	**172**
Other	10	46	3	45	61	30	0	**195**
TOTALS	**292**	**1,193**	**168**	**1,259**	**1,780**	**593**	**24**	**5,309**

[a] Also includes Birch Hill area

The rightmost column of Table 7-6-14 highlights composite average device usage percentages using the 2010 Census household ZIP code weightings listed earlier in Table 7-6-12. These weighted averages were calculated using the Census-based household fractions (rather than the survey sample fractions) by ZIP code. Cell households with no known ZIP code were weighted into the Census composite based on their proportion with the sample (i.e., they were assumed to be proportionally distributed into each ZIP code based on the Census weightings).

Table 7-6-14
2011-2015 HH Survey Distributions of Respondent-Estimated Winter Heating Usage Percentages by Device Type

Heating Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd.**
Wood Burning	20.0%	8.9%	11.9%	27.7%	20.2%	23.3%	26.3%	19.0%	**19.2%**
Central Oil Furnace	57.4%	75.6%	46.6%	62.5%	65.7%	61.6%	50.0%	66.0%	**65.5%**
Portable Heat Device	1.9%	0.8%	0.2%	0.5%	0.4%	0.9%	2.3%	0.7%	**0.6%**
Direct Vent Type	13.8%	3.8%	9.9%	4.7%	9.1%	10.4%	4.0%	7.1%	**7.2%**
Natural Gas	2.3%	3.6%	15.1%	0.8%	1.4%	0.7%	16.7%	2.3%	**2.4%**
Coal Heating	0.0%	0.5%	3.6%	1.3%	0.2%	0.5%	0.0%	0.7%	**0.7%**
District Heating	3.3%	4.1%	12.1%	0.2%	0.4%	0.2%	0.0%	1.8%	**1.8%**
Electric Heat	0.7%	1.2%	0.5%	0.8%	0.7%	0.8%	0.7%	0.9%	**0.9%**
Other	0.6%	1.6%	0.2%	1.6%	1.9%	1.7%	0.0%	1.6%	**1.6%**

[a] Also includes Birch Hill area

Wood-Burning Device Breakdowns – Despite the fact that the survey indicates wood-burning devices are used less than 20% of the time, they are a significant contributor to wintertime ambient $PM_{2.5}$ levels. Table 7-6-15 lists the breakdowns in the types of wood-burning devices used within each surveyed ZIP code area. As shown, woodstoves represent an overwhelming majority of wood-burning devices in Fairbanks. Over 86% of the wood burning devices according to the Census-weighted survey sample are woodstoves. This is not surprising given their heating efficiency and the ability to locate the stove within the interior of a residence.

Table 7-6-15
2011-2015 HH Survey Distribution of Wood-Burning Devices (% of Households Sampled)

Wood-Burning Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd.**
Fireplace	5.8%	8.0%	16.0%	3.2%	5.9%	9.1%	0.0%	6.0%	**5.4%**
Fireplace with Insert	4.3%	9.2%	8.0%	4.8%	5.1%	6.3%	16.7%	5.8%	**5.2%**
Woodstove	84.1%	79.8%	76.0%	87.4%	86.8%	79.4%	66.7%	84.7%	**86.3%**
Outdoor Wood Boiler	5.8%	3.1%	0.0%	4.5%	2.2%	5.1%	16.7%	3.6%	**3.0%**

[a] Also includes Birch Hill area

As also shown in Table 7-6-15, fireplaces represent most of the remaining wood-burning usage. Those with inserts constitute 5.2% of the overall sample. Fireplaces without inserts, which are extremely energy inefficient for space heating purposes, represent 5.4% of household wood devices. Outdoor boilers were only found in some areas and represent 3.0% of the weighted survey sample.

Table 7-6-16 provides a further breakdown of the splits between un-certified and certified fireplace inserts or woodstoves. It shows that uncertified stoves/inserts represent less than 20% of the overall sample. Though not shown, the uncertified stove/insert percentage has dropped consistently between the 2011 and 2015 surveys, from 25.7% in 2011 to 13.9% in 2015, which reflects on-going effects of the Borough's Wood Stove Change Out program.

Table 7-6-16
2011-2015 HH Survey Splits Between Uncertified and Certified Fireplace Inserts/Woodstoves (% of Households Equipped)

Insert/Woodstove Certification Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd.**
Un-Certified (<1988)	9.8%	18.4%	15.8%	15.9%	21.3%	14.6%	20.0%	17.8%	**19.1%**
Certified (≥1988)	90.2%	81.6%	84.2%	84.1%	78.7%	85.4%	80.0%	82.2%	**80.9%**

[a] Also includes Birch Hill area

These splits were compiled based on the responses to Q10a of the survey: "*Was your woodstove or insert installed before or after 1988?*" Beginning in 1988, EPA set mandatory New Source Performance Standards (NSPS) [14] for new woodstoves and inserts. Smoke emission levels of 1988 and newer stoves meeting these EPA limits are generally 50-80% lower than from older un-certified units, so the split between un-certified and certified stoves has a significant effect on particulate emissions.

This survey question based on the device installation date may not truly represent the split between EPA-certified and uncertified devices. Even though EPA established these NSPS, regulatory implementation still enabled device manufacturers to sell "woodstove-like" devices that were not subject to the NSPS. As described in the following sub-section, a specialized survey was conducted in 2013 to identify and quantify the fractions of these additional stove-like devices in use in Fairbanks that avoided NSPS certification.

Fuel Usage Rates and Costs - Table 7-6-17 summarizes average fuel usage rates (i.e., the amount of fuel used per season or year) and heating costs by device type for households equipped with or using each device/fuel. These are not averaged across all households.

As shown in Table 7-6-17, households using either fireplaces with inserts or woodstoves burn an average of 3.85 cords annually and 3.48 cords of wood during winter months (October through March) across the weighted survey sample. (These averages were compiled from a sample size of 1,194 households using fireplaces with inserts or stoves.) As also shown in Table 7-6-17, households equipped with fireplaces (without inserts) burned less, using 2.54 and 2.07 cords annually and in winter, respectively. This is not surprising given the significantly lower net heating efficiency of standard fireplaces compared to those with inserts or woodstoves. In contrast wood usage for outdoor wood boilers (OWBs) was much higher, averaging over 8 cords during winter. Although the sample size of OWBs in this survey was small (47 households), higher wood usage for these devices is consistent with the fact that they are generally used as a primary, rather than supplemental heating source.

As reported in Table 7-6-17, households using central oil furnaces consumed an average of 1,130 gallons of heating oil annually and 882 gallons during winter months alone. (These averages are based on a total of 2,803 central oil furnaces identified in the survey.)

Table 7-6-17 also lists similarly tabulated average fuel amounts or costs for portable/kerosene heaters, direct vent heaters, natural gas-based heating, and municipal heating. The sample sizes these device-specific averages were tabulated from were generally much smaller than for wood-burning and central heating devices. As such, they should be interpreted with caution.

[14] EPA certified woodstove smoke emission limits under the original 1988 NSPS were 7.5 grams/hour and 4.1 grams/hour for non-catalytic and catalytic stoves/inserts, respectively (http://www.epa.gov/burnwise/woodstoves.html). Under the new 2015 NSPS, these limits were dropped to 2.0 grams/hour or 2.5 grams/hour using cord wood, effective in 2020 and new limits were added for other wood burning devices.

Table 7-6-17
2011-2015 HH Survey Wood, Heating Oil and Other Fuel Usage Rates and Heating Costs per Equipped Household

Device Type	Usage Period	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd.**
Stove/Insert Wood Use (cords)	Annual	3.25	3.52	3.94	4.69	3.59	3.83	5.08	3.91	**3.85**
	Winter	2.96	3.14	3.32	4.20	3.32	3.49	4.67	3.55	**3.48**
Stove/Insert Wood Use (pellets, tons)	Annual	2.78	3.00	4.17	3.80	2.74	4.81	0.51	3.37	**3.33**
	Winter	2.41	2.66	3.33	3.29	2.44	3.04	0.46	2.86	**2.78**
Fireplace Wood Use (cords)	Annual	1.67	1.80	5.00	3.20	2.29	2.95	n/a	2.57	**2.54**
	Winter	0.75	1.60	4.75	2.40	2.02	2.11	n/a	2.07	**2.07**
Outdoor Wood Boiler Use (cords)	Annual	20.00	3.29	n/a	8.98	10.60	7.80	20.00	9.97	**8.62**
	Winter	17.33	2.70	n/a	8.58	10.52	7.00	15.00	9.21	**8.10**
Central Oil Use (gal)	Annual	1,038	1,130	1,067	1,121	1,160	1,144	730	1,133	**1,130**
	Winter	844	874	856	878	903	888	607	884	**882**
Portable Heater Fuel Use (gal)	Annual	270	442	28	261	342	277	n/a	315	**322**
	Winter	243	293	28	172	289	130	n/a	223	**231**
Direct Vent Heater Fuel Use (gal)	Annual	440	496	124	413	359	505	193	409	**413**
	Winter	371	430	112	363	310	471	154	359	**362**
Coal Heater Use (tons)	Annual	$2,733	$4,085	$2,132	$1,967	$2,692	$1,350	$1,320	$2,850	**$2,671**
	Winter	$2,277	$2,846	$1,675	$1,283	$2,156	$1,129	$915	$2,103	**$1,982**
Natural Gas Fuel Cost (dollars)	Annual	1.63	3.24	1.38	10.34	7.33	5.64	n/a	6.68	**6.30**
	Winter	1.08	3.19	0.71	8.18	5.67	5.64	n/a	5.52	**5.20**
District Heat Fuel Cost (dollars)	Annual	$1,429	$3,143	$801	$721	$4,000	$200	n/a	$2,412	**$2,342**
	Winter	$803	$1,811	$574	$505	$3,875	$200	n/a	$1,633	**$1,897**

[a] Also includes Birch Hill area
n/a – Not applicable (i.e., indicates where a device was not found in the sample for a specific ZIP code)

Extrapolation of Survey Sample to Nonattainment Area – An important element of the analysis consisted of extrapolating heating device counts and usage rates from the sample of 712 surveyed households to the entire household population within the Fairbanks $PM_{2.5}$ nonattainment area. The extrapolation was based on the 2010 U.S. Census-based occupied household counts by ZIP code within the nonattainment area. These Census-based household counts within the nonattainment area are listed in the first row of Table 7-6-18. Based on the share of Cell households in the survey sample, these Census counts were proportionally re-distributed to reflect this Cell share as shown in the second row of Table 7-6-18.

Table 7-6-18
2011-2015 HH Survey Extrapolated Survey Heating Device Counts to $PM_{2.5}$ Nonattainment Area

Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	$PM_{2.5}$ NA Area ZIP Sum	Extrap
Census-Based Households	*n/a*	*7,412*	*1,490*	*7,560*	*11,430*	*4,199*	*2*	***32,093***	***32,093***
Cell-Distributed Households	*3,876*	*6,517*	*1,310*	*6,647*	*10,049*	*3,692*	*2*	***32,093***	***32,093***
Extrapolation Factor	*9.36*	*8.48*	*12.72*	*9.47*	*9.31*	*10.44*	*9.45*	***n/a***	***9.36***
1 - Wood-Burning Device	665	1,424	331	3,590	4,788	1,827	57	**12,682**	**12,537**
1a - Fireplace without insert	39	114	53	115	283	167	0	**770**	**750**
1b - Fireplace with insert	29	131	26	173	245	115	9	**729**	**722**
1c - Woodstove	559	1,136	251	3,139	4,156	1,451	38	**10,731**	**10,619**
Stoves & Inserts (1b+1c)	588	1,267	278	3,312	4,401	1,566	47	**11,459**	**11,341**
Stove/Ins, Uncertified	132	394	79	946	1,495	427	15	**3,488**	**3,606**
Stove/Ins, Certified	455	873	199	2,366	2,906	1,139	32	**7,971**	**7,735**
Stove/Ins, Cord Wood	519	1,122	249	2,809	4,148	1,491	28	**10,366**	**10,364**
Stove/Ins, Pellets	69	145	29	503	254	76	19	**1,094**	**976**
1d - Outdoor Wood Boiler	39	44	0	163	104	94	9	**453**	**446**
2 - Central Oil Furnace	1,245	6,367	814	6,271	8,439	2,903	85	**26,124**	**26,245**
3 - Portable Heater	103	195	38	218	251	125	19	**950**	**946**
4 - Direct Vent Heater	365	543	254	796	1,723	658	19	**4,358**	**4,279**
5 - Natural Gas Heating	66	314	318	95	214	52	28	**1,087**	**1,030**
6 - Coal Heat	37	68	89	171	28	84	0	**476**	**449**
7 - District Heat	56	365	216	38	102	31	0	**809**	**787**
8 – Electric Heat[b]	103	449	38	322	466	198	19	**1,596**	**1,610**
9 - Other	94	390	38	426	568	313	0	**1,830**	**1,610**
All Heating Devices	2,734	10,114	2,138	11,927	16,580	6,192	227	**49,911**	**49,494**

[a] Also includes Birch Hill area
[b] Electric Heat households and extrapolated device counts developed from processing verbatim responses with "Other" generic device group in survey responses. The "Other" counts shown below this row reflect all non-electric heat devices listed as Other in the survey.

Extrapolation factors or multipliers were then calculated from the number of households in an area (either an individual ZIP code or the entire area) from the Cell-Distributed counts divided by the surveyed households for the same area. For example, the Downtown ZIP code (99701) area contains 6,517 households as listed in Table 7-6-18. Since a total of 906 households within that ZIP code were surveyed as reported earlier in Table 7-6-12, the calculated extrapolation factor is 8.48 (6,517 ÷ 181). The combined 2011-2015 survey sample represents roughly one-tenth of all occupied households within the nonattainment area.

Table 7-6-18 presents these extrapolated estimates of the number of heating devices by ZIP code area and across the entire Fairbanks $PM_{2.5}$ nonattainment area. The first row in the table lists the extrapolation factors calculated for each area to expand the survey sample to the entire population of households for each area. The remaining rows of the table present estimated counts of the number of devices by device type and ZIP code. The “short code” designations in the Device Type column of Table 7-6-18 identify each unique device type and clarify the sub-categories and sub-totals reported within the wood-burning sector. As explained in the note below Table 7-6-18, Electric Heat device counts were also broken out from the Other category.

The extrapolation of device counts from the survey sample to total households across the entire nonattainment area was performed two different ways: (1) by individual ZIP code and then summed; and (2) for the entire self-weighted sample. Table 7-6-18, these total device counts for the nonattainment area are reported in the two rightmost columns labeled “ZIP Sum” and “Extrap,” respectively. As seen in comparing these columns, the counts differ slightly. This is likely due to propagation of round-off error from small sample sizes within each ZIP code when summed across all ZIP code areas reflected in the survey sample.

On this basis, a total of 12,682 wood-burning devices were estimated to be in use within the nonattainment area. Of these, 10,731 are free-standing woodstoves and 729 are fireplaces with inserts. From the combined total of 11,459 stoves/inserts, 3,488 were estimated to be uncertified (pre-1988). Fireplaces without inserts and outdoor wood boilers represent the remaining wood-burning devices; their counts within the nonattainment area are 770 and 453, respectively, as shown in Table 7-6-18. As addressed below, the precision of device count estimates is not necessarily accurate to the whole integer values listed in Table 7-6-18. The whole integer values are simply shown in this table to illustrate how they were calculated from the sample-to-nonattainment area extrapolation factors.

Statistical Uncertainty Analysis – In extrapolating devices counted in the combined 2011-2015 HH survey sample to the entire nonattainment area, an additional issue that was addressed was the resulting statistical uncertainty. As shown in the preceding tables, very small numbers of households with certain devices were found. Thus, an analysis of the uncertainties associated with proportional extrapolation of the household sample to the entire nonattainment area was performed.

The results of this uncertainty analysis are presented in the next three tables. The estimates in these tables quantify the statistical uncertainty associated with extrapolating the device usage distributions in the surveyed sample represented earlier in Table 7-6-14 through Table 7-6-16 to all the households in the nonattainment area. In each of these tables, the standard error of proportion was used as the measure of statistical uncertainty. It represents the accuracy of each proportional (i.e., usage fraction) estimate in the sample, measured as the standard deviation of that proportion.

First, Table 7-6-19 presents standard errors of proportion associated with the respondent-estimated usage fractions of each major device type reported earlier in Table 7-6-14. The first value in each cell is the usage fraction from Table 7-6-14; the second value represents one standard deviation of this usage fraction.

Table 7-6-19
2011-2015 HH Survey Standard Error of Proportion for Respondent-Estimated Winter Heating Usage Percentages by Device Type

Heating Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	**All**	**Census Wtd**
Wood Burning	20.0% ±5.8%	8.9% ±1.9%	11.9% ±5.9%	27.7% ±3.1%	20.2% ±2.3%	23.3% ±4.4%	26.3% ±22.3%	19.0% ±1.3%	**19.2% ±1.3%**
Central Oil Furnace	57.4% ±7.2%	75.6% ±2.8%	46.6% ±9.2%	62.5% ±3.4%	65.7% ±2.7%	61.6% ±5.0%	50.0% ±25.3%	66.0% ±1.6%	**65.5% ±1.6%**
Portable Heat Device	1.9% ±2.0%	0.8% ±0.6%	0.2% ±0.7%	0.5% ±0.5%	0.4% ±0.4%	0.9% ±1.0%	2.3% ±7.6%	0.7% ±0.3%	**0.6% ±0.3%**
Direct Vent Type	13.8% ±5.0%	3.8% ±1.2%	9.9% ±5.5%	4.7% ±1.5%	9.1% ±1.7%	10.4% ±3.2%	4.0% ±9.9%	7.1% ±0.8%	**7.2% ±0.9%**
Natural Gas	2.3% ±2.2%	3.6% ±1.2%	15.1% ±6.6%	0.8% ±0.6%	1.4% ±0.7%	0.7% ±0.8%	16.7% ±18.9%	2.3% ±0.5%	**2.4% ±0.5%**
Coal Heating	0.0% ±0.3%	0.5% ±0.5%	3.6% ±3.4%	1.3% ±0.8%	0.2% ±0.3%	0.5% ±0.7%	n/a	0.7% ±0.3%	**0.7% ±0.3%**
District Heating	3.3% ±2.6%	4.1% ±1.3%	12.1% ±6.0%	0.2% ±0.3%	0.4% ±0.3%	0.2% ±0.4%	n/a	1.8% ±0.4%	**1.8% ±0.4%**
Electric Heating	0.7% ±1.2%	1.2% ±0.7%	0.5% ±1.2%	0.8% ±0.6%	0.7% ±0.5%	0.8% ±0.9%	0.7% ±4.1%	0.9% ±0.3%	**0.9% ±0.3%**
Other	0.6% ±1.1%	1.6% ±0.8%	0.2% ±0.9%	1.6% ±0.9%	1.9% ±0.8%	1.7% ±1.3%	n/a	1.6% ±0.4%	**1.6% ±0.4%**

[a] Also includes Birch Hill area
n/a – Not available

For example, the fraction of wood-burning devices used in winter for the entire sample was 19.2% (as listed earlier in Table 7-6-14). Assuming device usage is normally distributed, the value of ±1.3% listed in the upper right cell in Table 7-6-19 means that the actual wood-burning usage fraction lies between 17.9% (19.2 - 1.3) and 20.5% (19.2 + 1.3) with 95% probability.[15]

As expected, the usage fraction estimates within individual ZIP code areas have wider ranges of standard error than the overall estimate across all areas because the standard error estimates are related to sample size. As seen in the rightmost column in Table 7-6-19, the standard errors for heating device usage fraction are less than ±2% across the entire nonattainment area.

Similarly, Table 7-6-20 and Table 7-6-21 present Standard Error of Proportion estimates for proportional device usage within the wood-burning sector and between uncertified and certified woodstoves/inserts, respectively.

[15] 95% probability represents the probability of a normally-distributed sample within two standard deviations of its mean.

Table 7-6-20
2011-2015 HH Survey Standard Error of Proportion for
Distribution of Wood-Burning Devices (Percent of Households Sampled)

Wood-Burning Device Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	All	**Census Wtd**
Fireplace	2.3% ±3.5%	1.5% ±1.8%	3.6% ±7.2%	1.7% ±1.3%	2.6% ±1.4%	4.5% ±3.1%	n/a	2.3% ±0.8%	**2.1% ±0.8%**
Fireplace with Insert	1.7% ±3.0%	1.7% ±2.0%	1.8% ±5.1%	2.3% ±1.5%	2.3% ±1.3%	3.1% ±2.6%	6.7% ±20.0%	2.2% ±0.8%	**2.0% ±0.7%**
Woodstove	32.8% ±11.0%	14.8% ±5.4%	17.3% ±14.6%	42.0% ±5.0%	38.8% ±4.2%	38.7% ±7.2%	26.7% ±35.4%	32.2% ±2.5%	**33.2% ±2.5%**
Outdoor Wood Boiler	1.7% ±3.0%	0.6% ±1.1%	n/a	2.2% ±1.5%	1.1% ±0.9%	2.5% ±2.3%	6.7% ±20.0%	1.4% ±0.6%	**1.2% ±0.6%**

[a] Also includes Birch Hill area
n/a – Not available.

Table 7-6-21
2011-2015 HH Survey Standard Error of Proportion for
Uncertified and Certified Stove/Insert Splits (Percent of Households Equipped)

Insert/Woodstove Certification Type	Cell No ZIP	Dntown 99701	Wnwrt[a] 99703	Nth Pole 99705	Airport 99709	Steese 99712	Univ 99775	All	**Census Wtd**
Un-Certified (<1988)	9.8% ±7.5%	18.4% ±6.5%	15.8% ±16.4%	15.9% ±4.0%	21.3% ±3.8%	14.6% ±5.9%	20.0% ±35.1%	17.8% ±2.3%	**19.1% ±2.3%**
Certified (≥1988)	90.2% ±7.5%	81.6% ±6.5%	84.2% ±16.4%	84.1% ±4.0%	78.7% ±3.8%	85.4% ±5.9%	80.0% ±35.1%	82.2% ±2.3%	**80.9% ±2.3%**

[a] Also includes Birch Hill area
n/a – Not available.

<u>Comparisons Across Surveys</u> – Finally, Table 7-6-22 presents a comparison of key tabulations from each of the historical Fairbanks Home Heating surveys: 2006, 2007, 2010-2015. The tabulations from all the historical surveys were re-weighted by ZIP code using the 2010 Census weightings for consistency when comparing results.

As Table 7-6-22 shows, the normalized fractions of winter device are fairly consistent over time, except for the fact that wood use fractions have headed upward while usage in the generic Other category has trended down. It shows that wood stoves, and recently, outdoor wood boilers have exhibited increased usage within the wood-burning device sector. A large downward trend in the fraction of uncertified stoves/inserts can also be seen in Table 7-6-22.

Table 7-6-22 also shows increasing (but still modest) penetration of pellet-burning stoves, rising from near zero in the 2006 and 2007 surveys to over 10% of total stoves/inserts in the three latter surveys.

Table 7-6-22
Summary of Key Results from Historical Home Heating Surveys (2006-2015)

Statistic	Parameter	Survey Results								
		2006[a]	2007[a]	2010	2011	2012	2013	2014	2015	**2011-2015**
Average Winter Device Use by Type (% of Household Use)	Wood	10.8%	12.4%	18.2%	15.3%	19.2%	20.8%	22.4%	19.2%	**19.2%**
	Central Oil	68.6%	64.8%	67.2%	67.4%	68.1%	66.8%	60.4%	64.1%	**65.5%**
	Portable	0.7%	0.5%	0.1%	0.8%	0.1%	0.8%	0.9%	0.6%	**0.6%**
	Direct Vent	8.1%	7.0%	8.0%	9.5%	6.9%	5.6%	7.4%	7.0%	**7.2%**
	Natural Gas	2.4%	2.0%	4.2%	3.2%	3.0%	1.6%	1.6%	2.3%	**2.4%**
	Coal Heat	n/a	n/a	0.5%	0.6%	0.4%	1.1%	1.4%	0.2%	**0.7%**
	District Heat	2.0%	0.8%	1.1%	1.8%	1.9%	1.7%	0.9%	2.8%	**1.8%**
	Electric Heat	n/a	n/a	n/a	0.5%	0.1%	0.7%	1.7%	1.2%	**0.9%**
	Other	7.5%	12.5%	0.8%	0.9%	0.3%	0.8%	3.2%	2.6%	**1.6%**
Wood Burning Type (% of Wood-Burning Devices)	Fireplace	12.6%	17.1%	7.0%	5.2%	4.2%	5.4%	6.7%	5.2%	**5.4%**
	Insert	8.2%	5.6%	6.1%	4.3%	4.0%	4.7%	4.6%	8.4%	**5.2%**
	Woodstove	79.2%	77.2%	85.3%	87.2%	89.1%	88.9%	84.3%	82.3%	**86.3%**
	Wood Boiler	n/a	n/a	1.6%	3.2%	2.7%	1.0%	4.5%	4.1%	**3.0%**
Wood Stove/Insert Cert Type (% of Woodstoves/Inserts)	Uncertified	52.0%	46.7%	35.7%	25.7%	22.7%	20.1%	14.4%	13.9%	**19.1%**
	Certified	48.0%	53.3%	64.3%	74.3%	77.3%	79.9%	85.6%	86.1%	**80.9%**
Wood Stove/Insert Wood Type (% of Woodstoves/Inserts)	Cordwood	99.8%	100.0%	95.8%	96.9%	95.9%	88.3%	85.2%	89.1%	**91.0%**
	Pellet	0.2%	0.0%	4.2%	3.1%	4.1%	11.0%	13.5%	10.9%	**8.6%**
Wood Stove/Insert Wood Source (% of Woodstoves/Inserts)	Buy	27.0%	28.0%	36.5%	27.0%	36.1%	35.4%	32.3%	37.4%	**33.8%**
	Cut Own	71.1%	60.6%	50.2%	61.9%	49.1%	47.1%	54.3%	47.9%	**51.8%**
	Both	1.8%	11.4%	13.4%	11.0%	14.8%	17.5%	13.4%	14.7%	**14.4%**
Stove/Insert Wood Use (cords)	Winter	3.14	2.84	3.51	3.31	3.62	3.43	3.69	3.20	**3.48**
Fireplace Wood Use (cords)	Winter	0.82	0.81	4.09	3.94	2.51	1.73	1.41	1.87	**2.07**
Central Oil Use (gal)	Winter	n/a	n/a	6.00	17.80	12.01	5.67	2.30	4.56	**8.10**
Portable Heater Fuel Use (gal)	Winter	1,172	1,027	819	979	861	903	828	841	**882**
Direct Vent Heater Fuel Use (gal)	Winter	97.1	241.9	59.1	323.1	89.4	298.0	212.9	175.0	**231.1**
Coal Heater Fuel Use (tons)	Winter	470	514	487	413	367	342	361	337	**362**
Natural Gas Fuel Cost ($)	Winter	n/a	n/a	2.29	1.50	3.79	2.47	11.38	9.35	**5.20**
Municipal Heat Fuel Cost ($)	Winter	$1,414	$1,287	$1,346	$2,164	$1,836	$2,233	$1,713	$1,837	**$1,982**

[a] Winter usage in these surveys encompassed October-May; later survey winter usage spanned October-March.

In addition, the "Wood Source" section of Table 7-6-22 shows how the mix of where households acquire their wood has trended over time. Most wood-burning households cut their own wood (vs. purchasing it commercially), although the "Cut Own" fraction appears to have drifted downward in recent surveys as shown in Table 7-6-22.

Finally, as shown in the lower section of Table 7-6-22 winter season fuel use and heating cost trends are mixed across the list of devices shown. Although both wood stove/insert and fireplace usage in households equipped with those devices have trended upward, there is significant year to year oscillation in the averages compiled from the survey data.

As highlighted in the rightmost column in Table 7-6-22, the combined 2011-2015 survey data were largely used in the 2013 baseline inventory.

And as noted earlier, Table 7-6-22 shows the clear downward trend in the fraction of uncertified wood stoves and inserts, dropping from 52.0% in 2006 to 13.9% in 2015.which is believed to results from a combination of "natural" turnover in stoves from uncertified to newer, certified (and cleaner) stoves in the early survey years combined with the effects of the Borough's Wood Stove Change Out program that began in July 2010. Thus, as described in further detail later in the "Survey Data Use in SIP Inventories" sub-section, this downward trend in uncertified stoves/inserts was developed using data from all available Home Heating surveys.

Specialized Wood-Burning Surveys

2013 Wood Tag and Purchase Surveys - In additional the annual Home Heating surveys described in the preceding section, DEC and the Borough also commissioned two specialized surveys in early 2013 that focused on wood-burning devices and practices. Unlike the Home Heating surveys which randomly sampled all residential households, these specialized surveys targeted only wood-burning households and are summarized as follows:

1. *Wood Tag Survey* – A telephone survey of 216 households in which respondents were asked a series of questions about their wood devices related to establishing whether it was certified or not and if so, what emission rating (in grams/hour) and output (in BTU/hour) were stamped on the device's "tag" or certification label. Information was also collected on the make, model and installation date of the devices (when available) that was used in conjunction with EPA's published lists of certified stoves/inserts[16] and hydronic heaters[17] to look up emission ratings, technology type (catalytic vs. non-catalytic) and energy output. The survey also contained specific questions related to current participation in wood-related emission control programs, including existing Borough programs as well as likelihood of switching to natural gas under expanded availability of natural gas anticipated over the next several years. Finally, the survey also included questions about other devices and usages within the household beyond the wood-burning devices upon which the survey was primarily focused. As with the Home Heating surveys, the sampling was performed in a stratified manner, randomly sampling households within nonattainment area ZIP codes based on targeted sample sizes developed from 2010 Census household weightings by ZIP code.

2. *Wood Purchase Survey* – A separate survey of 217 wood-burning households within the nonattainment area (again with 2010 Census-weighted targeted sampling by ZIP code) was conducted to ascertain more detailed information about patterns in households that commercially purchase their wood and that cut it themselves. Much like the branching elements of the Home Heating surveys, specific sets of questions were asked in households that bought wood from those that cut their own. For wood buyers, questions centered around purchased wood: the supplier and their reasons for using them, whether

[16] http://www.epa.gov/Compliance/resources/publications/monitoring/caa/woodstoves/certifiedwood.pdf
[17] http://www.epa.gov/burnwise/owhhlist.html

wood was split or in rounds or whole logs, etc. For respondents who cut their wood, questions included the source (private or public land), whether a permit was obtained, etc. For both wood source types, respondents were also asked questions related to moisture content and the drying/seasoning period for their wood.

In addition to the specific questions asked within each of these two wood-burning surveys, respondents in both surveys were asked a series of questions about the price premium they would be willing to pay for purchase of pre-dried wood given that dry wood typically produces about 25% more heat per cord than wet wood. These questions were intended to gauge interest and potential participation in a local control program designed to expand use of fully-dry wood.

Attachment A lists the survey script and questions contained in the 2013 Wood Tag and Wood Purchase surveys (following the Home Heating survey script).

Key Findings Across Tag and Purchase Surveys – Before summarizing findings from the unique questions within each specialized wood household survey, tabulations of several key results common to both surveys are presented as follows.

Wood-Burning Device Distributions – Table 7-6-23 presents a side-by-side comparison of the mix of primary wood-burning devices used in sampled households from the Tag and Purchase surveys (each with sample sizes of over 200 households as noted earlier). As shown, distributions of wood devices between the two surveys are in general agreement.

Both surveys show that woodstoves represented well over 80% of primary wood-burning devices. (Pellet and cordwood stoves from the Tag survey totaled 87.8%, these splits were not available from the Purchase survey.). This is consistent with woodstove fractions from the Home Heating surveys shown earlier in Table 7-6-15 and Table 7-6-22. However, the 17.7% pellet stove fraction from the 213 Tag survey was noticeably higher than that observed in more recent Home Heating surveys (which averaged roughly 4%).

Both the Tag and Purchase surveys also exhibited slightly higher fractions of fireplaces, 7.8% and 9.5%, respectively than those seen in recent Home Heating surveys (roughly 5%), although higher fireplace fractions were seen in earlier surveys prior to 2010 as reported in earlier Table 7-6-22.

Table 7-6-23 2013 Wood Survey Wood-Burning Device Distributions (Percent of Households Sampled, Census Weighted)		
Wood-Burning Device Type	Wood Tag Survey	Wood Purchase Survey
Woodstove (cordwood)	70.1%	82.1%
Woodstove (pellet)	17.7%	
Fireplace Insert	0.4%	3.4%
Fireplace (no insert)	7.8%	9.5%
Outdoor Wood Boiler	3.6%	3.2%
Other	0.5%	1.7%

Wood Source Mix - Table 7-6-24 compares the splits in the source of household wood between the Tag and Purchase surveys. As shown, these splits are very consistent, with households that cut their own wood outnumbering those that purchase their wood commercially by about a 3-to-1 margin, with roughly 15-20% of sampled homes using a mixture of purchased and personally harvested wood. This relative 3-to-1 ratio of Cut vs. Buy group households represents a higher split of Cut households than reported from recent Home Heating surveys. As shown earlier in Table 7-6-22, the Cut vs. Buy household splits ranged from 1.5 to 2-to-1 in the 2010-2012 Home Heating surveys.

As explained later in the "Fairbanks Wood Energy and Moisture Content" section of this appendix, the Buy vs. Cut wood source splits are important because of evidence that indicates homeowners that cut their own wood tend to season (and dry) it longer than those who buy their wood. Thus this split affects the overall wood moisture level.

Table 7-6-24 2013 Wood Survey Wood Source Mix (Percent of Households Sampled, Census Weighted)		
Wood Source Group	Wood Tag Survey	Wood Purchase Survey
Buy	22.4%	19.9%
Cut Own	63.1%	57.7%
Both (Buy & Cut Own)	14.5%	22.3%

Cost of Firewood – In both the Tag and Purchase surveys, respondents in the Buy group (those that purchased some or all of their firewood) were also questioned about the price they paid (excluding any delivery fee). The results were very consistent across both surveys and are listed as follows.

Survey	Avg. Price ($/cord)	Range	Sample Size

Tag	$233	$100-$400	50
Purchase	$227	$89-$400	60

In these 2013 surveys, the average price paid for firewood was about $230 per cord (excluding delivery fee). Under the Purchase survey, Buy group respondents were also asked about delivery fees. About 72% paid no delivery fee (or picked up the wood themselves). For the remaining 28% that paid a fee, the average was $293 although values varied from $40 to $700 and the phrasing of the question was vague in specifying the price per cord, delivery or season.

Willingness to Pay More for Dried Wood – Both wood surveys also included a series of questions intended to measure willingness to spend more on commercially-purchased wood that is fully dried before being sold. The questions were identically phrased in both surveys and were directed to those households that buy all or a portion of their firewood. They were asked in a staged manner as follows: *"Knowing that dry wood provides 25 percent more heat than wet wood, would you pay $25 more per cord for dry wood?"* For those who answered yes, the question was then repeated with the threshold raised to $50, then $75, and finally $100.

Responses are summarized in Table 7-6-25. For each staged question, the percentage who responded affirmatively is shown. In parenthesis next to each percentage is the ratio that was used to calculate it (number answering "yes" divided by total definitive answers). The table shows that the percentage of people willing to pay each specified amount for dry wood was fairly consistent between both the Tag and Purchase surveys, but in no case was the difference statistically significant at the 95% confidence level.[18] Thus, the data from two surveys were combined in the rightmost column of Table 7-6-25 to provide the most robust estimate of the surveyed responses (129 combined households that buy wood).

[18] In general, large sample sizes are necessary to detect small differences between two percentages (see, for example, Snedecor et al, Statistical Methods, 1980).

Table 7-6-25 2013 Wood Survey Willingness to Pay for Dry Wood Distribution of Wood-Burning Devices (Percent of Households Sampled)			
Pay More for Dry Wood?	% Willing to Pay (#yes/total)		**Willingness to Pay Combined Surveys**
	Wood Tag Survey	Wood Purchase Survey	
$25/cord more	73.5% (36/49)	72.5% (58/80)	**72.8%**
$50/cord more (if 'yes' to above)	38.6% (17/44)	46.5% (33/71)	**43.5%**
$75/cord more (if 'yes' to above)	16.3% (8/44)	13.6% (9/66)	**15.5%**
$100/cord more (if 'yes' to above)	14.6% (7/43)	4.6% (3/65)	**9.3%**

Key Tag Survey Findings – As noted earlier, the Tag survey sampled 216 wood-burning households in the Fairbanks nonattainment area. The primary objective of the survey was to obtain a reasonably size subset of households with certified woodstoves/fireplace inserts (or Phase 1 or 2-qualified outdoor wood boilers) and have respondents provide certification information about the device such as its smoke rating (particulate emission rate in grams/hour), heating efficiency and heat output (BTU/hour) by reading these data from the certification label or "Tag" stamped on the device. Table 7-6-26 lists the distribution of primary wood-burning devices from the surveyed sample in the "All" column. For each device, it also shows the breakdown between devices identified as uncertified/unknown or EPA-certified based on the respondents' answers to the question: *"Is your device certified, or does it have a certification label?"* (Certification label information was only solicited for woodstoves, inserts and outdoor wood boilers. As noted with "n/a" in the "Certified" column of Table 7-6-26, certification data was not applicable to fireplaces or other devices not explicitly identified.)

Table 7-6-26 2013 Tag Survey Wood-Burning Device Distributions (Number of Households)				
Wood-Burning Device Type	Sample Size			
	All	Uncertified/ Unknown	Certified	**Certified, Label Read**
Woodstove (cordwood & pellet)	189	92	97	**18**
Fireplace Insert	1	1	0	
Fireplace (no insert)	17	17	n/a	**n/a**
Outdoor Wood Boiler	8	3	5	**1**
Other	1	1	n/a	**n/a**
Totals	216	114	102	**19**

As shown in the highlighted "Certified, Label Read" column in Table 7-6-26, once respondents were asked to actually read information from the device certification label (or provide via follow-up postcard solicitations) few could or did. Label visibility or access were likely the primary factors for getting few "Label Read" responses.

Fortunately, respondents were also asked to provide make, model and model year of their woodstoves, inserts or outdoor wood boilers. A total of 95 respondents were able to provide this information. These responses (where available) were then compared to EPA's published lists[19] of certified woodstoves/inserts and outdoor hydronic heaters (i.e. outdoor wood boilers). For devices that could be matched to EPA's lists (and are therefore certified), emission rate, efficiency and heat output data were looked up. Using this approach, the initial sample of 19 devices for which complete label data were available was expanded to a total of 68 certified devices (67 stoves/inserts, 1 outdoor wood boiler) with compiled emission rate, efficiency and heat output data.

Certified Woodstove/Insert Levels - Table 7-6-27 presents tabulated emission rates (in grams/hour) and heat output ranges (in BTU/hour) for those woodstoves/inserts for which certification data were available. Separate sample sizes and averages are shown by technology type (catalytic vs. non-catalytic). As shown, the analysis sample was split roughly 60%/40% for catalytic and non-catalytic certified woodstoves/inserts. Average particulate emission rates (i.e. certified smoke rating) are highlighted in the middle column. Across the entire sample, the average PM emission rate was found to be 2.48 grams/hour as shown at the bottom of Table 7-6-27. Based on this sample, Fairbanks certified woodstoves/inserts are quite clean compared to EPA's existing certified woodstove emission standards of 7.5 grams/hour and 4.1 grams/hour for non-catalytic and catalytic devices, respectively.

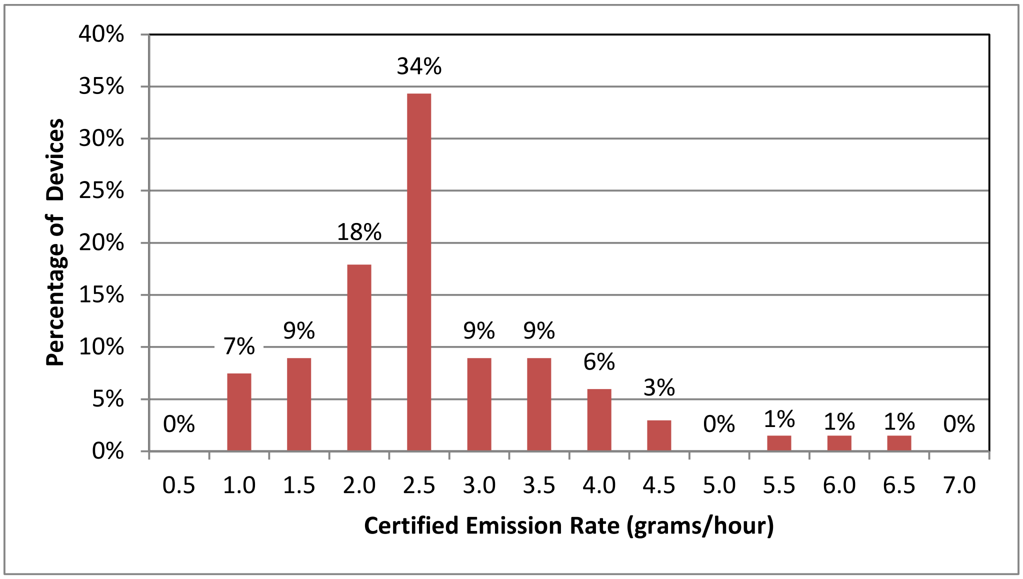
Table 7-6-27
2013 Tag Survey Certified Woodstove/Insert Emission Rates and Output by Technology Type

Technology Type	Sample Size		Avg. Emission Rate (grams/hour)	Avg. Output (BTU/hour)	
	N	Pct.		Minimum	Maximum
Catalytic	40	59.7%	**2.23**	10,740	36,541
Non-Catalytic	27	40.3%	**2.86**	10,871	34,714
Totals/Averages	67	100.0%	**2.48**	10,793	35,805

Figure 7-6-29 shows the distribution of emission rates for the certified stoves/inserts from the Tag survey sample. Each interval shows the percentage of devices in the survey sample between the indicated rate and that to its immediate left. For example, 34% of the devices (23 out of 67) had certified emission rates of 2.0 to 2.5 grams/hour. Summing the frequencies from Figure 7-6-29 cumulatively, 31% and 66% of the stoves/inserts were below 2.0 gram/hour and 2.5 gram/hour levels, respectively.

[19] http://www.epa.gov/burnwise/appliances.html, circa January 2013.

Figure 7-6-29
Distribution of Tag Survey Certified Stove Emission Rates (grams/hour)

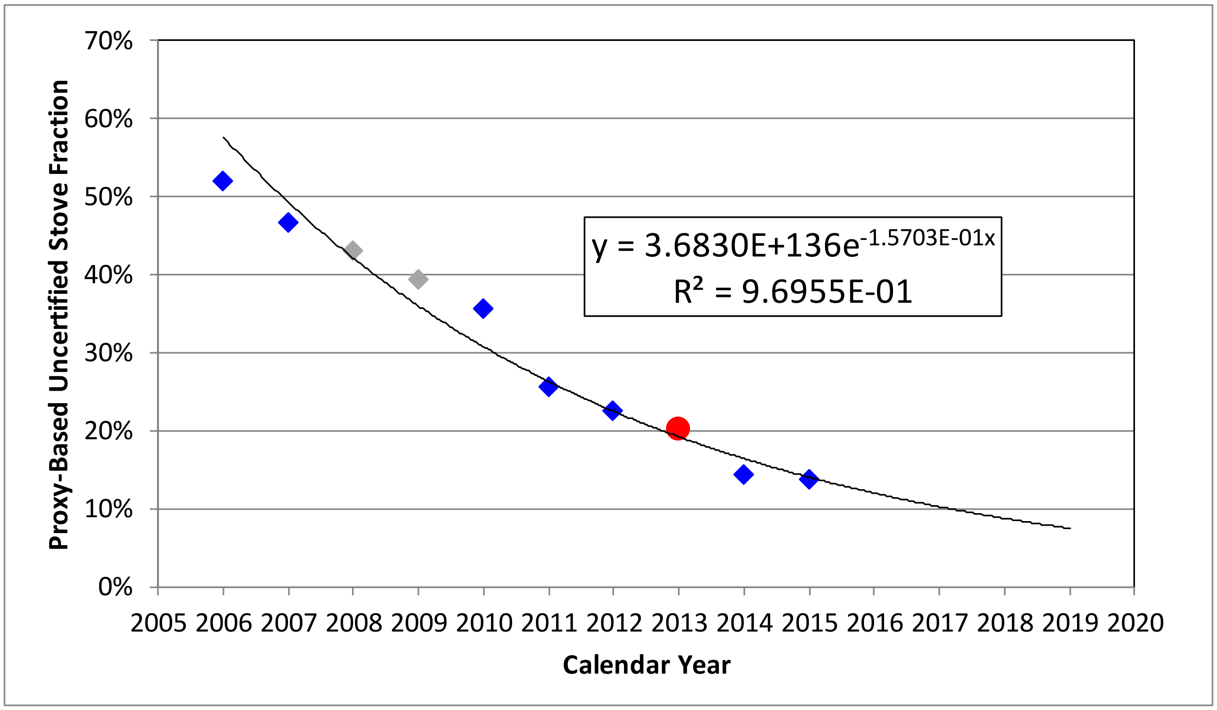


True Uncertified Device Fraction – Responses to specific questions from the Tag survey were also used to evaluate what is believed to be a biased (low) estimate of the percentage of uncertified woodstoves/inserts from the Home Heating surveys. As discussed earlier, the Home Heating surveys do not attempt to get respondents to examine their wood devices for the presence (or absence) of an EPA certification label. The installation date question (1988 and earlier vs. post-1988) from the Home Heating surveys is used as a "proxy" to estimate the fractions of woodstoves/inserts that are not EPA-certified, but as discussed earlier "woodstove-like" devices that are excluded from EPA's wood heater regulations have been observed for sale in Fairbanks retail outlets. Thus, the more definitive label information (or lack thereof) from the Tag survey presented an opportunity to estimate a true uncertified woodstove/insert fraction.

Out of 129 definitive responses (i.e. removing "don't know" responses) from Tag survey woodstove/insert households, 90 were found to have a certification label or tag (although as noted earlier not all could be read by the respondents). The remaining 39 when ZIP code Census-weighted represented a "true" uncertified stove/insert fraction of 31.8%.

As shown earlier in Table 7-6-22, the proxy-based uncertified stove fraction estimates from the Home Heating surveys have been on a steady downward decline (in part based on the fixed installation date cutoff). Thus in order to make an equivalent comparison to the true uncertified fraction from the 2013 Tag survey, this Home Heating proxy trend was fitted using a exponential curve approach illustrated in Figure 7-6-30. The diamond shaped marker points are the proxy-based uncertified stove fractions from Table 7-6-22. (Values for 2008 and 2009 shown as gray markers in were interpolated from the 2007 and 2010 survey fractions.)

Figure 7-6-30
Curve-Fitted Forecast of 2006-2015 Proxy-Based Home Heating Survey Uncertified Stove/Insert Fraction



A least-squares exponential curve was fitted to these data as shown by the line. The proxy-based uncertified fraction from the 2013 survey is shown as a red marker in Figure 7-6-30. This 2013 proxy-based uncertified stove fraction was 20.1%.

The difference between the two 2013 estimates (true vs. proxy) of the uncertified stove fraction was 12.7% (31.8% - 20.1%) and was assumed to represent the "offset" that accounted for the underreported uncertified stoves in the Home Heating proxy-based approach. (How this offset was used in the SIP inventory is discussed in the next sub-section.)

The 39 Tag survey responses used to represent the true uncertified stove/insert fraction were also further examined to cross-check the approach used to calculate this proxy offset. 34 of the 39 "true" uncertified device respondents provided installation/age information for their stoves/inserts; 18 (53.4%) were installed on or before 1988; 16 (46.6%) after 1988. The post-1988 split was then multiplied by the true uncertified stove fraction of 31.8% to produce a "proxy-equivalent" estimate of 14.8% (31.8% × 46.6%), which compares reasonably with the 12.7% offset estimated above.

Natural Gas Expansion – Two questions were included in the Tag survey to gauge willingness of existing wood-burning households to switch to using natural gas under a planned expansion of natural gas availability being guided by the Alaska Industrial Development and Export Authority (AIDEA).

The first question asked respondents to estimate the retail price gas would need to be offered at to get them to switch from wood (and heating oil). To make the question easier to understand and the answers more meaningful, the price question was asked on a heating oil equivalent basis: *"If natural gas becomes available, what gas price would get you to stop burning wood (in $/gal equivalent of heating oil)?"* Out of 140 definitive responses, the average gas price was $2.17 per gallon on an oil equivalent basis. 102 of the 140 respondents, or 72.8% indicated willingness to switch to gas if offered at $2.00/gallon equivalent, about half of the current heating oil price.

The second question dealt with the potential need of wood-burning households that switch to gas to continue to burn wood on extremely cold days (less than -30°F) for reasons such as ensuring particular rooms or areas of the house stayed warm. Of the 185 definitive responses to this question, 37.9% (71 respondents) indicated they may still feel the need to use their wood devices on cold days, even after switching their house to natural gas.

Wood Species Mix – Finally, responses were also tabulated from the question asking homeowners to identify the predominant species of firewood they burned. Out of a total of 191 valid responses, the ZIP code Census-weighted composite fractions (by volume) were as follows:

- Birch (paper birch) – 46.4%;
- Spruce (white spruce) – 34.1%; and
- "Aspen" (black/white poplar) – 18.5%.

These translate to mass fractions of 54.6%, 30.3% and 15.1%, respectively based on the unit mass[20] of each local wood specie published by the Alaska Department of Natural Resources.

Key Purchase Survey Findings – Beside results summarized earlier in conjunction with the Tag survey, a key finding from the Wood Purchase survey was the mix of whole logs (or round) versus pre-split logs purchased. At the time of purchase the 81 responses were split as follows:

- Split – 31 or 38.3%;
- Whole/Rounds – 40 or 49.4%; and
- Both – 11 or 12.3%.

A follow up question was asked of those purchasing whole logs/rounds about when they split their wood, 'as needed' or 'on delivery.' Roughly 44% said 'as needed', the remaining 56% responded 'on delivery.'

Normalizing these tabulations to remove the 'Both' responses and account for splitting by the homeowner after delivery, the mix of split vs. whole/round logs was calculated to be roughly 75% vs. 25%.

[20] "Purchasing Firewood in Alaska," Alaska Department of Natural Resources, Division of Forestry, http://forestry.alaska.gov/pdfs/firewood.pdf

2016 Postcard Survey - A postcard (rather than telephone) survey was conducted in 2016 to assess whether large drops in heating oil prices from 2013 to 2015 had any impact on wood use. Unlike the earlier telephone-based surveys under which a random sample was drawn from all residents in the nonattainment area, the 2016 Postcard survey targeted household respondents who had participated in the 2014 and 2015 HH surveys. Use of a postcard-type survey enabled respondents to more thoughtfully collect and estimate wood and heating oil usage data for winter 2015-2016 space heating that could be directly compared to similar data for the same set of households as sampled in the earlier 2014 and 2015 surveys. An analysis directed by DEC[21] found that winter season residential wood use dropped 30% on average in the 2016 survey for the same set of households sampled in the 2014 and 2015 surveys, and that most of this drop could not be explained by differences in heating demand due to year-to-year variations in winter temperatures.

DEC's Staff Economist then coordinated a study by University of Alaska Fairbanks[22] that evaluated the 2016 Postcard data to determine if a cross-price elasticity could be quantified between wood use and heating oil use and prices in Fairbanks. That economic study found a median cross-price elasticity between wood and heating oil of -0.318, meaning wood use drops by 0.318% for every 1% decrease in the price of heating oil. This wood vs. cross-price elasticity was then used to estimate changes in wood vs. oil use in projected baseline inventories relative to the difference between the forecasted oil price in the projection year vs. the 2013 Baseline.

2017 Commercial Business Survey – In 2017, DEC conducted a study of commercial businesses within the nonattainment area to determine which businesses, if any had and used solid fuel burning devices (wood or coal) during winter months. The first element of the study consisted of acquiring a spreadsheet database[23] of over 1,700 businesses within the nonattainment area from the Borough's Planning Department. The database included the name and type of each business as well as its location. Based on the business types, the data were then classified into a total of 12 categories spanning two groups, Possible Solid Fuel (SF) and Not Likely SF as follows:

- Possible SF – churches, dining/bars, hotels/motels, retirement centers, other;
- Not Likely SF – banks, fast food, grocery stores, gas stations, hospitals/medical, schools/day care, other.

A total of 608 out of 1,774 businesses were categorized within the Not Likely SF group. It was assumed that businesses categorized within this group did not operate solid fuel devices and were not further evaluated. For the remaining 1,116 classified within the Possible SF group, 140 were classified as either churches, dining/bars, hotels/motels or retirement centers. Each of these were surveyed by a combination of telephone and on-site inquiries. A total of 1,026 were classified as Other within the Possible SF group and a random survey of 50 business from this category was similarly conducted.

[21] T. Carlson, M. Lombardo, Sierra Research, R. Crawford, Rincon Ranch Consulting memorandum to Cindy Heil, Alaska Department of Environmental Conservation, January 17, 2017.
[22] "Estimating FNSB Home Heating Elasticities of Demand using the Proportionally-Calibrated Almost Idea Demand System (PCAIDS) Model: Postcard Data Analysis," prepared by the Alaska Department of Environmental Conservation in collaboration with the University of Alaska Fairbanks Master of Science Program in Resource and Applied Economics, December 10, 2018.
[23] Email from Kellen Spillman, FNSB Community Planning Department, October 12, 2016.

Figure 7-6-31 shows the survey form used by DEC to enter information regarding solid fuel devices, usage and related activity from these phone and on-site surveys.

Figure 7-6-31
Commercial Business Solid Fuel Survey Form

FAIRBANKS NON-RESIDENTIAL BUSINESS SPACE HEATING SURVEY

Business Name: ____ PAN: ___________

Business Address: ____ Date: ___________

1) Do you have a wood, coal or other solid fuel burning device that is used for space heating?
(Yes, No, Not Sure/Don't Know) ________________________

YES BRANCH

Y2) What is/are the device(s) and fuel(s)?

____

____

Y3) How many cords of wood or bags/tons of coal do you use:

In winter (October through March)

_______ cords of wood

_______ bags / tons of coal

Annually (entire year)

_______ cords of wood

_______ bags / tons of coal

Y4) What's a rough estimate of how much heating <u>during winter</u> is from this/these solid fuel device(s)?

____________ %

Y5) What's the size of the building space that's heated?

__________ square feet

NO (or Don't Know) BRANCH

N2) What fuel is your primary source of space heating during winter (October through March)?

- ☐ – Heating Oil
- ☐ – Natural Gas
- ☐ – Municipal/District Heat
- ☐ – Waste Oil
- ☐ – Electric
- ☐ – Other (not listed above)

Notes/Observations: ____

____

____

The resulting response data were entered into a spreadsheet and used to represent solid fuel-burning space heating emissions for commercial businesses. Out of over 1,700 businesses a total of ten were found to operate wood or coal burning devices and their usage estimates were applied within the baseline inventory. (Commercial solid fuel space heating accounted for about 0.01% of total $PM_{2.5}$ emissions within the nonattainment area.)

Survey Data Use in SIP Inventories

As pointed out in the preceding sections, a variety of telephone-based residential surveys have been conducted in Fairbanks dating as far back as early 2006 in order to ascertain information about local space heating practices, as well as their trends over time. This sub-section clarifies two specific elements of these surveys that were utilized to calculate space heating emissions within the SIP inventories. It also describes how they were applied as inputs in these calculations. Except where explicitly noted, these inputs were based on the combined 2011-2015 Home Heating survey data.

Device Energy Usage Splits by 4 km Grid Cell – As discussed earlier, the Home Heating survey data included tabulations of the mix of heating devices in sampled homes and rough estimates of wintertime use percentages provided by the respondent at the beginning of the telephone survey. Later in the device-specific sections of the survey, respondent provided estimates of winter season (and annual) fuel use (e.g., cords of wood or gallons of heating oil) or costs (amount spent per winter month on natural gas or District heat).

A key input to the home heating energy model as discussed earlier under the "Development of Energy Model" section of this appendix was the seasonal average device energy use mix in the household. In the SIP inventory application of the energy model, this winter average household device energy use split was developed and applied from ZIP code-specific tabulations of device energy use splits developed from the 2011-2015 HH survey data. However, instead of using the roughly estimated splits provided by respondents at the beginning of the survey, more robust splits were calculated from the seasonal fuel use data provided later in the survey.

These calculations were performed by converting average seasonal fuel use (for each equipped device in the household) into energy use by multiply by each fuel's specific energy content. Table 7-6-28 lists the energy contents assumed for each fuel and their data sources.

Multiplying by these fuel energy contents, average winter season fuel use estimates from the 2011-2015 HH surveys were then translated into winter season energy use estimates. These calculations were performed by 4 km square grid cell (each of which contains nine 3×3 1.33 km modeling grid cells). Average fuel use for each fuel and device type for all households within each 4 km cell was converted to average winter season energy use estimates by cell. For device categories such as natural gas and electric heat, fuel cost rather than fuel use data was collected in the survey since it was easier for respondents to provide cost rather than usage data for these categories. Table 7-6-28 lists the unit costs for these fuels that were used to translate the survey data into seasonal fuel use.

Table 7-6-28 Assumed Energy Contents of Space Heating Fuels in Fairbanks			
Fuel	Energy Content	Units	Source/Notes
Wood, baseline moisture	12.1	mmBTU/ton	Alaska Department of Natural Resources http://forestry.alaska.gov/pdfs/firewood.pdf, Wood density = 1.683 tons/cord
Heating Oil #1	125,000	BTU/gal	Cold Climate Housing Research Center (energy content for #1 oil in heating appliance survey)
Heating Oil #2	138,500	BTU/gal	North American Combustion Handbook, from http://en.wikipedia.org/wiki/Heating_oil
Fairbanks #1 & #2 Blend	135,000	BTU/gal	Fairbanks Community Research Quarterly, http://www.co.fairbanks.ak.us/cp/Pages/crq.aspx
Kerosene	135,000	BTU/gal	http://generatorjoe.net/html/energy.asp
Natural Gas	1,010	BTU/ft^3	Fairbanks Community Research Quarterly, http://www.co.fairbanks.ak.us/cp/Pages/crq.aspx Gas cost = \$2.34 per 100 ft^3
Coal	15.2	mmBTU/ton	http://www.usibelli.com/Coal-data.php
Electric	3,413	BTU/kWh	Fairbanks Natural Gas, http://www.fngas.com/calculate.html Electricity cost = \$0.180 per kilowatt-hour (kWh)

The results of these energy use calculations are presented in Table 7-6-29. Actual energy use (winter season BTUs per household) has been translated into normalized percentages in the table. Based on the availability of separate emission factors for specific device/fuel combinations, splits from the survey data were stratified into the categories shown in Table 7-6-29. (The energy use estimates for the cell phone households were proportionally distributed into each 4 km grid cell based on their share of the survey sample and 2010 Census weightings.)

The first six rows of Table 7-6-29 show calculated HH survey-based heating energy use splits by device/fuel for key 4 km grid cells within the Fairbanks portion of the nonattainment area, stretching from the area around Fairbanks International Airport (FAI) and the Chena Pump/Geist Road to the west to the downtown Fairbanks/Nordale and Southeast Fairbanks areas to the east.

The next four rows in Table 7-6-29 provide similar splits for the 4 km cells that comprise most of the North Pole area. As seen in Table 7-6-29, the usage splits for woodstoves/inserts and outdoor wood boilers in these North Pole cells are notably higher than those across most of Fairbanks cells, with the area southeast of the Richardson Highway as the exception.

Use of the combined 2011-2015 survey sample enabled the development of these more spatially resolved usage splits. (The Moderate SIP was based on a single survey and only resolved usage splits by ZIP code.)

Table 7-6-29
2011-2015 Home Heating Survey Winter Season Heating Energy Use Splits by Key 4 Km Grid Cell

Area Description	4 Km Grid Cell	Pct. Of Winter Season Heating Energy Use by Grid Cell									
		Wood			Heating Oil			Nat Gas	Coal	Steam	
		Stove/ Insert	Fireplace	Outdoor Boiler	Central Oil	Direct Vent	Portable	Natural Gas	Coal Heat	Muni. Heat	Total
FAI	137,136	25.32%	1.47%	2.08%	66.30%	1.89%	0.00%	0.00%	2.93%	0.00%	100%
Chena Pump/Geist	137,137	8.70%	1.36%	0.58%	84.63%	1.22%	1.72%	0.98%	0.08%	0.72%	100%
Mitchell/S. Fairbanks	138,136	17.88%	0.00%	1.07%	69.76%	2.17%	0.00%	8.26%	0.42%	0.44%	100%
W of Downtown	138,137	11.33%	0.27%	0.53%	80.92%	1.19%	0.37%	3.75%	0.00%	1.64%	100%
Mitchell/SE Fairbanks	139,136	11.51%	0.21%	0.44%	73.75%	2.37%	2.50%	7.08%	0.17%	1.96%	100%
Downtown/Nordale	139,137	9.14%	0.54%	0.23%	84.16%	1.83%	0.27%	0.73%	0.42%	2.69%	100%
NP/SE of Richardson	143,134	20.75%	1.03%	1.39%	72.57%	1.55%	0.07%	0.00%	2.64%	0.00%	100%
NP/N of Hurst	143,135	26.84%	0.35%	3.30%	62.82%	2.78%	0.93%	0.62%	2.35%	0.00%	100%
NP/S of Hurst	144,134	29.82%	0.71%	3.55%	63.00%	1.12%	0.92%	0.67%	0.22%	0.00%	100%
NP/Badger	144,135	24.53%	0.00%	1.88%	71.29%	0.85%	0.24%	0.00%	0.87%	0.35%	100%
Cells <50 Households	Low SS	28.89%	0.59%	1.46%	60.89%	5.90%	0.36%	0.35%	1.45%	0.10%	100%

However, even with five years of combined HH survey data, a number of 4 km cells in the outlying portions of the nonattainment area had sample sizes less than 50 households. As noted at the bottom of Table 7-6-29, all the data for these areas were combined and used to represent device/fuel usage in all of the outlying cells. The 50-household minimum was developed based on balancing explicit splits for more cells with a minimum statistically viable sample.[24]

Highlighted columns in Table 7-6-29 refer to those devices for which in-use measurements were collected under the aforementioned CCHRC study, and which were used to construct the home heating energy model. Emissions for those devices not represented in the CCHRC study (those not highlighted in Table 7-6-29) were calculated from their HH survey-based proportional energy use outside the energy model.

Forecasted Trends in Uncertified Stoves/Inserts – As discussed earlier in summarizing the key findings from the 2013 Wood Tag survey, EPA certification data obtained for devices sampled under that effort enabled development of an offset or correction factor to upwardly revise underreported fractions of uncertified stoves/inserts from the Home Heating surveys.

Table 7-6-30 illustrates how this offset was used in conjunction with development of trends in the split between certified and uncertified stoves/inserts over time that were applied in representing their effects in both 2013 (the centered year of the surveys) and future years.

[24] Alternative minimum sample sizes of 30 and 100 households were also evaluated. A 30-household minimum did not appreciably increase the number of 4 km cells meeting the requirement and for those that did, exhibited greater variations due to the smaller sample size. A 100-household minimum would have resulted in several of the cells shown in Table 7-6-29 not meeting the criteria and therefore not reflecting neighborhood-specific patterns.

Table 7-6-30
Corrected Splits and Trends in Uncertified and Certified Stoves/Inserts

Calendar Year	Home Heating Survey-Based Uncertified Pct.	Tag Survey Offset	Corrected Percentages			
			Uncertified	Certified, Non-Catalytic	Certified, Catalytic	Total
2006	52.0%	+12.7%	64.7%	26.3%	9.0%	100.0%
2007	46.7%		59.4%	31.0%	9.6%	100.0%
2008	43.1%		55.7%	31.1%	13.2%	100.0%
2009	39.4%		52.1%	30.7%	17.2%	100.0%
2010	35.7%		48.4%	29.9%	21.7%	100.0%
2011	25.7%		38.4%	37.4%	24.2%	100.0%
2012	22.7%		35.4%	40.3%	24.3%	100.0%
2013	20.1%		32.8%	36.6%	30.6%	100.0%
2014	14.4%		27.1%	40.3%	32.6%	100.0%
2015	13.9%		26.6%	42.3%	31.2%	100.0%
2016			*24.6%*	*47.1%*	*28.3%*	*100.0%*
2017			***22.9%***	***48.1%***	***29.0%***	***100.0%***
2018			*22.9%*	*48.1%*	*29.0%*	*100.0%*
2019+			*22.9%*	*48.1%*	*29.0%*	*100.0%*

The second column in Table 7-6-30 lists the uncorrected fractions of uncertified stoves/inserts tabulated from the annual Home Heating surveys dating back to the inaugural survey in 2006. (2008 and 2009 fractions were interpolated from 2007 and 2010 survey results.) The 12.7% correction factor determined from the Tag survey is shown in the next column and was assumed to be a constant offset over time. (In the absence of additional corroboratory data other than that collected in the 2013 Tag survey and given that the law under which uncertified woodstove-like devices was not changed through 2015, it was believed that a constant offset adjustment over time was reasonable.)

The remaining columns of Table 7-6-30 show the corrected splits between uncertified and certified (both non-catalytic and catalytic) stoves/inserts from the historical Home Heating surveys after applying the offset adjustment to the uncertified fractions. The shaded cells in the table highlight the corrections to the uncertified fractions from the Home Heating survey data over time. For example, in 2013 the Home Heating survey-based estimate of 20.1% was increased by 12.7% to yield a corrected estimate of 32.8%. After applying this correction for each historical calendar year, the splits for the remaining certified non-catalytic and catalytic were proportionally renormalized as shown in the next two columns of Table 7-6-30.

As shown in the *italicized* lower section of Table 7-6-30, estimates of uncertified stove/insert fractions over time out to 2019 and later years were forecasted to continue their natural downward trend observed from 2006 through 2017 survey data using the exponential curve and equation presented earlier in Figure 7-6-30 and the constant 12.7% additive adjustment.

However, as highlighted for calendar year 2017, the projected downward trend based on the exponential curve fit shown in in Figure 7-6-30 was capped, or held constant in subsequent years. The reason for this relates to the on-going effects of the Borough's Wood Stove Change Out (WSCO) program.

Under the earlier Moderate SIP, available data at the time suggested that the downward trend in uncertified stoves/inserts had two components: 1) the WSCO Program (which started in July 2010); and 2) "natural" turnover of older uncertified devices that preceded, and continued to occur outside the WSCO program. This analysis and its findings were revisited under the Serious SIP and the 2020 Amendment.

WSCO program transaction data for calendar years 2013 through 2016 were obtained from the Borough and tabulated under the earlier Serious SIP to determine if the Home Heating survey-based exponential trend curve continued to show greater drops in uncertified device fractions over time than explained by WSCO data for uncertified-to-certified wood device change outs.[25] A greater decrease in the uncertified device fractions than explained by the WSCO data over the same period would identify and provide an estimate for the natural turnover in uncertified devices occurring outside the WSCO program. However, analysis of the 2013-2016 WSCO uncertified-to-certified device change-outs showed a nearly identical decrease to that projected from the Home Heating survey data to 2017.

Therefore, it was estimated that little if any natural turnover was continuing outside the WSCO program. The Home Heating survey-projected downward trend in uncertified devices was held constant in 2017 and later years to reflect WSCO program activity through calendar year 2016 within projected baseline inventories to be consistent with controls included in the Moderate SIP that are now treated as part of the baseline in 2017 and later years.

The corrected splits and trends in Table 7-6-30 were applied to represent stove/insert uncertified/certified fractions in the baseline and projected baseline SIP inventories. As explained later in this appendix, a separate analysis of WSCO program data for later years beyond 2018 was conducted to estimate on-going effects from the WSCO program in later years that produce control benefits under the 2020 Amendment.

[25] During the 2013-2016 period and beyond, the WSCO program includes several types of incentivized change-outs including: 1) uncertified-to-certified wood device change-outs, 2) high-to-low emitting certified wood device change-outs, and 3) solid fuel (wood or coal) to liquid/gaseous fuel device conversions. Only the first of these change out-types impacts the uncertified device fractions over time.

HOME HEATING – FAIRBANKS WOOD ENERGY AND MOISTURE EFFECTS

For biofuels such as wood, the moisture level has a significant effect on the net heating energy when the fuel is burned as well as on resulting emission factors (mass emissions of pollutant per unit mass of fuel). Energy content of the locally-available firewood species must also be accounted for. This section of the Emission Inventory Technical Appendix describes how Fairbanks-specific wood energy and moisture effects were accounted for within the Residential Space Heating sector of the SIP inventories.

The section begins by summarizing the sources and methods used to estimate the energy content of Fairbanks-specific wood used in home heating. It also contains a discussion of basic concepts in representing and accounting for heating energy effects of wood as a function of its moisture content. Next, the data and sources used to estimate baseline moisture levels across the spectrum of Fairbanks wood burners are described. The final sub-section documents how these elements were combined to calculate effects of moisture content on wood-burning emissions within the SIP inventories.

FAIRBANKS WOOD ENERGY CONTENT

The energy content per unit volume of firewood varies by over a factor of two[26], depending on the species of the wood. Although energy content per unit mass shows much less variation across wood species, firewood is cut, purchased and stacked/stored on a volumetric basis (e.g., in cords) and therefore understanding the types/mix of Fairbanks firewood species is important.

Common woods in the conterminous U.S. typically exhibit an average energy content of roughly 8,500 BTU/lb on an oven dry (i.e. bone dry) basis. In EPA's AP-42 emission factor database, residential wood burning emission factors are based on an energy content of 17.3 mmBTU/ton[27] (equal to 8,650 BTU/lb).

(As discussed in the detail in following sub-section, wood moisture also has a significant effect on its effective energy content or heating value. Therefore, wood energy content is generally reported on a fully-dried basis, or at a reference moisture level. This sub-section deals solely with energy content variations by wood species, irrespective of moisture level.)

To better represent the energy content of firewood burned for space heating in Fairbanks, information on the relative usage of local wood species used in residential heating was collected from the 2013 "Wood Tag" survey of 216 randomly-selected wood-burning households located within the Fairbanks NAA. The three predominant local firewood species are: 1) Birch; 2) White Spruce; and 3) Aspen. Local firewood called "Aspen" is actually a mix of white poplar (American Aspen) and black poplar (Cottonwood) species that grow in the area.

[26] "Firewood BTU Content Charts," Chimney Sweep Online, http://www.chimneysweeponline.com/howood.htm.
[27] http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s10.pdf

Table 7-6-31 lists the relative usage fractions for each of the three primary local wood species (Birch, Spruce and Aspen) tabulated from the 2013 Wood Tag survey responses. It shows that Birch and Spruce are the most commonly used firewood species.

Table 7-6-31
Fairbanks Firewood Usage Splits and Energy Content by Species

Parameter	Local Wood Species			Composite
	Birch	Spruce	Aspen	
Usage Fraction, by volume	46.4%	35.1%	18.5%	100%
Usage Fraction, by mass	54.6%	30.3%	15.1%	100%
Energy Content (BTU/lb)[a]	8,126	8,518	8,252	**8,264**

[a] Assuming 0% moisture or oven dry basis.

Table 7-6-31 also shows energy contents assumed for each specie (on an oven dry basis), based on Alaska-specific data[20] published by the Alaska Department of Natural Resources (ADNR). The energy contents shown in Table 7-6-31 are adjusted to an oven-dry basis from the ADNR values, which reflect 20% moisture content, or "air dry" conditions. As highlighted in the rightmost column of Table 7-6-31, the composite energy content of Fairbanks firewood (weighted by the specie-specific usage percentages) was estimated to be 8,264 BTU/lb on an oven dry (OD) basis.

Wood Moisture and Energy Relationship

When harvested, wood has a certain amount of water or moisture suspended within its mass. The amount of moisture in wood is referred to as its moisture content (MC). Wood moisture content is generally defined on a percentage basis relative to either:

1. the mass of the wood including its water (wet basis, wb); or
2. the mass of the wood excluding the water (dry basis, db).

Wood moisture levels are rigorously measured in the laboratory by measuring the mass of wood before and after placing it in a drying oven (where all its suspended water is evaporated). For example, if a piece of wood had a wet mass (before drying) of 1.25 lb and a dry mass of 1.00 lb, its moisture content on both a wet or dry basis would be calculated as follows:

$$MC\ Wet\ (MC\ wb) = (Mass_{Wet} - Mass_{Dry}) \div Mass_{Wet} = (1.25 - 1.00) \div 1.25 = 0.20 \text{ or } 20\%$$
$$MC\ Dry\ (MC\ db) = (Mass_{Wet} - Mass_{Dry}) \div Mass_{Dry} = (1.25 - 1.00) \div 1.00 = 0.25 \text{ or } 25\%$$

Moisture levels also affect how wood energy content is reported, depending on what state the wood's suspended water molecules are in after being vaporized during combustion. Gross or Higher Heating Value (HHV) energy content includes energy associated with the latent heat of vaporization of moisture within the wood when condensed after combustion. Net or Lower Heating Value (LHV) energy content excludes this latent heat of vaporization. Under bone dry conditions, both heating values are the same. At moisture levels other than 0%, LHV energy content is lower than that based on the HHV. The equations below, excerpted from the U.S. Department of Energy Biomass Energy Data Book[28] and converted to English units, show how wood HHV and LHV vary by wood moisture content.

$$\boldsymbol{HHV = HHV_{dry} \times (1 - MC_{wb})} \quad \textbf{(4)}$$

$$\boldsymbol{LHV = HHV_{dry} \times (1 - MC_{wb}) - 1050\, MC_{wb}} \quad \textbf{(5)}$$

Where:

HHV = higher heating value (BTU/lb) which includes latent heat of vaporization;
LHV = lower heating value (BTU/lb) which excludes latent heat of vaporization;
HHV_{dry} = laboratory-measured energy content or bone dry HHV (BTU/lb);
MC_{wb} = wood moisture content (%, wet basis); and
1050 = a constant that represents the latent heat of vaporization (at 25°C).

Table 7-6-32 presents calculated Fairbanks wood energy content (on both an HHV and LVH basis) as a function of various moisture levels, expressed on both a wet and dry basis.

Table 7-6-32
Fairbanks Wood Energy Content (BTU/lb) vs. Moisture Content (%)

MC Wet (%)	MC Dry (%)	HHV (BTU/lb)	LHV (BTU/lb)	%HHV Reduction Relative to Oven Dry
0.0%	0.0%	8,264	8,264[a]	0%
5.0%	5.3%	7,851	7,798	5.0%
10.0%	11.1%	7,437	7,332	10.0%
15.0%	17.6%	6,886	6,711	15.0%
20.0%	25.0%	6,611	6,401	20.0%
25.0%	33.3%	6,198	5,935	25.0%
30.0%	42.9%	5,785	5,470	30.0%
35.0%	53.8%	5,371	5,004	35.0%
40.0%	66.7%	4,958	4,538	40.0%
45.0%	81.8%	4,545	4,073	45.0%
50.0%	100.0%	4,132	3,607	50.0%

[a] Based on composite bone-dry energy content for local firewood mix.

The specific value to use depends on the combustion device and application. Wood burning devices used in residential space heating cannot recover latent heat energy from water vapor

[28] B. Boundy, et al., "Biomass Energy Data Book: Edition 4," Oak Ridge National Laboratory, Report No. ORNL/TM-2011/446, September 2011.

produced during combustion. Therefore, their heating value or efficiency in the real world would be based on the LHV. This approach is used in Europe. In the U.S. however, residential wood device heating value specifications and efficiencies have traditionally been published on an HHV basis, including data reported through EPA's woodstove certification standards. In order to be consistent with U.S. published data and efficiency ratings (used later in emission inventory and control measure calculations), HHVs were used to account for moisture effects in residential wood burning.

Wood Moisture and Emissions – The energy content vs wood moisture relationship shown in Table 7-6-32 results in a commensurate or proportional impact on wood-burning emissions. Relative to any "reference" moisture level, the amount of additional wood that must be burned is directly related to the difference in energy content between the actual and reference moisture levels. The relative reduction in HHV-based energy content at any moisture level relative to 0% (Oven Dry) moisture content is shown in the highlighted column in Table 7-6-32. The reduction in relative HHV is mathematically equal to the wet-basis moisture content.

Beyond this proportional HHV vs. moisture content impact, emissions from wood-burning devices are also affected by factors that reduce optimum combustion conditions. Wood burning devices are tested for emissions and efficiency performance with "air dry" wood in a moisture content range of about 18% to 28% (15% to 22% wet basis) to represent the normal range most people use or should use. Both higher and lower moisture content can have significant negative consequences[29]. High moisture reduces efficiency and makes it harder to start and sustain good secondary combustion. This is due to its cooling effect that slows down combustion and cools the gases produced by pyrolysis. Very dry wood tends to burn faster and can evolve gases at a rate that outstrips the ability of most heating devices to supply adequate air, resulting in oxygen starvation. This can cause higher emissions, pulsating combustion and overheating.

Available literature that quantifies these moisture-driven combustion effects on resulting device emission levels is extremely limited. In a comparative analysis[30] of wood device testing results from both laboratory measurements and in-home instrumented studies, Houck (2012) observed that any clear relationship that wood moisture alone might have with emissions is clearly obscured by other real-world variables. Earlier studies[31,32] also note the difficulty in isolating the moisture-combustion effect on emission rates in historical test measurements and suggest its magnitude is smaller compared to other sources of variation in the data.

Although the observed literature acknowledges a moisture-combustion effect on device emission rates, a statistically significant relationship isolating this effect does not appear to have been

[29] R. Curkeet, "Wood Combustion Basics," Intertek Worldwide, EPA workshop presentation, March 2, 2011, http://www.epa.gov/burnwise/workshop2011/WoodCombustion-Curkeet.pdf

[30] J. Houck, "A Comparison of Particulate Emission Rates from the In-Home Use of Certified Wood Stove Models with U.S. EPA Certification Emission Values and A Comparison between In-Home Uncertified and Certified Wood Stove Particulate Emissions," prepared for Hearth, Patio & Barbecue Association, February 1, 2012. Docket EPA-HQ-OAR-2009-0734.

[31] R. Curkeet and R. Ferguson, "EPA Wood Heater Test Method Variability Study," prepared for Hearth, Patio and Barbecue Association, October 6, 2010.

[32] J. Houck and P. Tiegs, "Residential Wood Combustion Technology Review Volume 1. Technical Report," prepared for U.S. Environmental Protection Agency, Report No. EPA-600/R-98-174a, December 1998.

developed. Therefore, wood-burning emissions in the SIP inventories are based solely on the moisture-energy content effect described earlier.

Baseline Moisture Levels

Having developed estimates of local firewood species and their energy content and identifying effects of wood moisture content on effective energy content (or HHV), the next step consisted of assembling baseline wood moisture levels for firewood burned in Fairbanks during winter. Two primary data sources were used:

1. Usage splits developed from Fairbanks home heating surveys on fractions of households that purchase wood sold commercially vs. those that cut their own wood (Cut group);

2. Wood moisture measured from the wood-burning homes in the aforementioned CCHRC Home Instrumentation study (used to the develop the space heating energy model; and

3. Moisture measured in experimental wood piles under a second CCHRC study[33].

Wood Source Groups - In each of the residential home heating surveys, residents were asked to identify the source of wood used in their home categorized as follows:

- Buy - those that purchased wood commercially;
- Cut – those that cut their own wood; and
- Both – those using a mixture of wood they cut themselves and purchased commercially.

Table 7-6-33 shows the "Wood Source" results tabulated from the home heating surveys: the combined 2011-2015 HH surveys and the 2013 specialized Wood Purchase and Tag surveys. Data for the 2013 baseline inventory were developed from combined results of the Purchase and Tag surveys. (These survey targeted wood-burning households, had roughly twice the sample of wood burning respondents than in each home heating survey and were less lengthy. As a result, their wood source splits were chosen as better estimates than those from the combined HH survey data.)

Since the fraction of Buy vs. Cut wood sources in households that responded "Both" was not known from the surveys, this response was not used. As highlighted at the bottom of Table 7-6-33, the fractions of Buy and Cut wood source groups from each historical survey were then renormalized.

[33] "Wood Storage Best Practices in Fairbanks, Alaska," prepared by Cold Climate Housing Research Center, June 27, 2011.

Table 7-6-33 **Fairbanks Residential Survey Wood Source Fractions**			
Wood Source Group	2011-2015 HH Surveys	2013 Purchase Survey	2013 Tag Survey
Buy Wood	35.1%	19.9%	22.4%
Cut Own	60.2%	57.8%	63.1%
Both (Buy & Cut)	4.7%	22.3%	14.5%
Total	100.0%	100.0%	100.0%
Normalized, Buy	**36.8%**	**25.6%**	**26.2%**
Normalized, Cut	**63.2%**	**74.4%**	**73.8%**

Once the household fractions within each wood source group were tabulated, separate data sources were used to estimate average wood moisture levels within each group. This distinction was made to account for the fact that homeowners who cut their own wood tend to be those that have built storage sheds with ample capacity and season or dry their wood for longer periods than those purchasing wood commercially.

Cut Group Moisture – As noted earlier, homeowners who cut their own wood (rather than buying it commercially) tend to be those who pre-plan and generally have constructed wood storage sheds or areas on their property. During the CCHRC Home Instrumentation study, it was observed that a number of the wood-burning participants in that study (the Mixed and Wood households) appeared to fit this profile of homeowners that cut their wood and had on-site storage for it. The moisture content of the wood stacks from each of these Mixed and Wood households in the Instrumented study was measured at the time of the instrumentation (Dec 2010-Feb 2011).

In the absence of any additional detailed data, it was assumed that the average wood moisture content from these 20 households provided a reasonable estimate of the wood moisture for homeowners in the Cut group. Table 7-6-34 lists the measured moisture content (dry basis) from the wood samples taken from each of these households. Moisture levels ranged from a low of 17% to a high of 58%, with an average of 26.6% shown at the bottom of Table 7-6-34.

Half of the measured moisture levels were in the “air dry” range (from 17% to 21%). This is consistent with anecdotal evidence noted earlier that homeowners who cut their own wood tend to properly store their wood and allow for a drying period of at least several months. And since the moisture measurements were taken during mid-winter, they are representative of winter season modeling episodes.

Thus, the average moisture content from this sample of 26.6% was assumed to reasonably approximate wood moisture for the Cut group of households.

Table 7-6-34 Estimated Cut Group Moisture Content Based on CCHRC Instrumentation Study Wood Samples	
CCHRC Household ID	Moisture Content (%, db)
1	25%
2	18%
3	17%
4	27%
5	20%
6	18%
7	33%
8	18%
9	38%
10	20%
21	21%
22	31%
23	24%
24	24%
25	19%
26	32%
27	58%
28	20%
29	21%
30	48%
Sample Average	**26.6%**

Buy Group Moisture – Wood moisture content for the Buy group of wood-burning households was developed from CCHR's "Wood Storage Practices" study. This study consisted of experimental development and testing of moisture content for different types (wood species) and storage/covering practices. Wood was cut and stored at two different points during the year:

1) *Spring Harvest* – wood cut in late May, simulating those homeowners that plan ahead and allow wood to dry over summer; and

2) *Fall Harvest* – wood cut in mid-September, simulating those that wait until fall to cut wood for immediate use in winter.

After each harvest, the wood was stored in different configurations that included a simulated wood shed and tarp covered, and uncovered stacks. Both whole log and split log stacks were prepared. Moisture measurements were then taken from randomly selected logs within each stack at different durations after each initial harvest at roughly two-month intervals, from immediately after stacking to up to 12 months later.

Table 7-6-35 lists the moisture levels (dry basis) measured by CCHRC for the Spring and Fall harvest cuts by storage method, wood type and seasoning period (in months from cut shown in green shaded cells above the month each moisture measurement was conducted.).

Boldface yellow shaded cells in Table 7-6-35 were originally marked as "Dry" by CCHRC. A moisture level of 15% was assumed for these measurements. *Italicized* tan shaded cells denote moisture levels interpolated from adjacent measurements that were missing in the original data.

These data were used to develop separate estimates of Cut group wood moisture for the January-February and November modeling episodes within the SIP inventories by using measured moisture levels from each harvest in these months. Before doing so, it was necessary to estimate splits in wood use by harvest, log type and storage method.

In consultation with DEC, it was assumed that 25% of wood sold commercially was cut in spring, with the remaining 75% harvested during fall. Greater weight was given to the fall cut due to the short and yearly varying length of the spring wood cutting window, which is affected by the timing of the spring thaw and breakup. Summer months exhibit wet, boggy conditions that can be worsened by thunderstorms, which makes wood harvesting difficult. Early fall is generally when most wood cutting and harvesting occurs, and when commercial wood sellers have a better idea of firewood demand for the upcoming winter months.

Next, the fraction of whole versus split logs was assumed to be evenly divided: 50% whole and 50% split. Not that these are fractions that reflect the state of the logs over duration they are stored in a stack, not the state of logs when burned. (Data collected later under the 2013 Wood Purchase survey roughly corroborate this assumption. The resulting composite moisture level is not strongly sensitive to the mix between whole and split logs based on the CCHRC measurements listed in Table 7-6-35.)

In addition, to represent a composite estimate of storage method-driven difference in moisture content, the "Tarp Covered" values in Table 7-6-35 were used and assumed to represent a mid-range wood storage method in terms of its effectiveness in reducing moisture during seasoning. (For Aspen, moisture levels were based on the "Simulated Wood Shed" measurements since Tarp Covered data were not available for that wood species.)

Table 7-6-35
Moisture Content Measurements from CCHRC Wood Storage Practices Study

Spring Harvest Moisture Content by Sampling Month (%, db)

Storage Method	Seasoning Months →	0	1.5	3	8	10	12
	Wood and Log Type	Late May	July	Late Aug	Jan	March	May
Simulated Wood Shed	Birch – split	52%	20%	18%	**15%**	**15%**	**15%**
Simulated Wood Shed	Birch – whole)	52%	30%	25%	29%	28%	24%
Simulated Wood Shed	Spruce – split	86%	16%	17%	**15%**	**15%**	**15%**
Simulated Wood Shed	Spruce – whole	86%	28%	21%	23%	24%	17%
Simulated Wood Shed	Aspen – split	76%	26%	20%	**15%**	**15%**	**15%**
Simulated Wood Shed	Aspen – whole	76%	49%	44%	40%	*33%*	26%
Tarp Covered	Birch – split	49%	21%	20%	**15%**	**15%**	**15%**
Tarp Covered	Birch – whole	49%	28%	31%	32%	*29%*	25%
Tarp Covered	Spruce – split	86%	22%	22%	35%	*27%*	18%
Tarp Covered	Spruce – whole	86%	67%	30%	29%	*26%*	23%
Uncovered	Birch – split	57%	19%	35%	46%	38%	17%
Uncovered	Birch – whole	57%	29%	32%	52%	39%	25%
Uncovered	Spruce – split	77%	17%	19%	**15%**	**15%**	**15%**
Uncovered	Spruce – whole	77%	29%	27%	47%	29%	17%
Solar Kiln	Aspen – split	59%	24%	16%	**15%**	**15%**	**15%**
Solar Kiln	Aspen – whole	59%	38%	32%	34%	31%	27%

Fall Harvest Moisture Content by Sampling Month (%, db)

Storage Method	Seasoning Months →	0	4	6	8
	Wood and Log Type	Mid Sept	Jan	March	May
Simulated Wood Shed	Birch – split	80%	49%	42%	30%
Simulated Wood Shed	Birch – whole)	80%	55%	56%	47%
Simulated Wood Shed	Spruce – split	85%	63%	40%	37%
Simulated Wood Shed	Spruce – whole	85%	77%	72%	51%
Simulated Wood Shed	Aspen – split	83%	63%	51%	34%
Simulated Wood Shed	Aspen – whole	83%	65%	*57%*	48%
Tarp Covered	Birch – split	78%	63%	70%	49%
Tarp Covered	Birch – whole	78%	67%	*62%*	57%
Tarp Covered	Spruce – split	92%	117%	*101%*	84%
Tarp Covered	Spruce – whole	92%	80%	*85%*	89%

Given these weighting/selection assumptions, Table 7-6-36 presents average moisture levels by specie (birch, spruce, aspen) for January-February and November, with composites calculated across harvest, log type and storage method. For example, the moisture content for birch during the January-February period was calculated as follows:

$$MC_{birch,Jan} = 25\% \times (50\% \times MC_{spring,birch,Tarp,Jan,split} + 50\% \times MC_{spring,birch,Tarp,Jan,whole}) + 75\% \times (50\% \times MC_{fall,birch,Tarp,Jan,split} + 50\% \times MC_{fall,birch,Tarp,Jan,whole})$$
$$= 0.25 \times (0.50\times15\% + 0.50\times32\%) + 0.75 \times (0.50\times63\% + 0.50\times67\%)$$
$$= 54.6\%$$

Table 7-6-36
Average Buy Group Moisture Content by Wood Species and Modeling Episode

Episode	Measurement Month(s)	Moisture Content by Species (%, db)			Wtd. Avg. MC (%, db)
		Birch	Spruce	Aspen	
Jan-Feb	Jan	54.6%	81.9%	54.9%	62.9%
Nov	Interpolation from Aug/Sep and Jan	59.8%	78.7%	62.6%	65.9%

The highlighted column in Table 7-6-36 shows the weighted average moisture content for Buy group wood across all three wood species for each modeling episode. These averages were calculated using the relative usage factors for each species (listed earlier in Table 7-6-31) of 46.4%, 35.1% and 18.5% for birch, spruce and aspen, respectively.

Calculation of Moisture Effects

Once Fairbanks wood-specific energy content and moisture content estimates were developed for each type of wood source (Buy vs. Cut), wood moisture effects were calculated by combining elements from the preceding sub-sections to produce composite estimates for both the 2019 baseline and projected baseline inventories.

The normalized Buy vs. Cut wood fractions from the 2013 Purchase and Tag surveys shown earlier in Table 7-6-33 (24% and 74%, respectively) were used to represent wood source splits during 2013. (As noted earlier, these 2008 splits were interpolated from results tabulated from 2007 and 2010 Home Heating surveys). These wood source splits were combined with separate moisture levels estimated for each source group (Buy vs. Cut), to generate weighted composite moisture level across both source groups as shown below in Table 7-6-37. As seen in Table 7-6-37, the composite wood moisture contents (db) for the 2013 Baseline were 36.1% and 36.9% for the January-February and November episodes, respectively, with a composite average across all episode days of 36.5%. The nominally higher moisture content in November compared to January-February is due to the fact that wet wood cut earlier in the year has less time to season and dry by November compared to the following January-February.

Table 7-6-37 Calculation of Baseline Wood Moisture Effects			
Source Group	Usage Fraction (%)	Moisture Content (%, db) by Modeling Episode	
		Jan-Feb	Nov
Buy	26%	62.9%	65.9%
Cut	74%	26.6%	26.6%
Composite	**100%**	**36.1%**	**36.9%**
Energy Content (EC)			
HHV (BTU/lb)		**6,071**	**6,036**
EC Relative to Energy Model (26.6%, db)		**0.930**	**0.925**

The last two rows in Table 7-6-37 show the resulting moisture-affected energy content (as HHV in BTU/lb) and the energy content (EC) relative to the reference EC on which the earlier residential heating energy model is based. The moisture level-specific HHVs were calculated using the energy content vs. moisture relationship shown earlier in Equation (4) and Table 7-6-32. (As explained earlier, the energy model's reference EC is the same as that of the Cut group since that was how the Cut group moisture level was estimated.) These relative ECs highlighted in the bottom row of Table 7-6-37 were applied to the BTU estimates generated by the energy model to adjust effective heating energy to reflect composite wood moisture levels within each episode for 2008 Baseline conditions.

HOME HEATING – OMNI AND AP-42 EMISSION FACTORS

In support of more robust SIP emission estimates, the Borough and DEC have sponsored several local measurement studies designed to better quantify $PM_{2.5}$ and related emissions in Fairbanks in the winter. A key element of this coordinated effort was the FNSB-sponsored study[34] of emission factors from residential space heating appliances and fuels, which was conducted in 2011 by OMNI-Test Laboratories, Inc. (OMNI).

The OMNI study provided the first and most comprehensive systematic attempt to quantify Fairbanks-specific, current technology-based emission factors from space heating appliances and fuels. The laboratory-based emission testing study consisted of 35 tests of nine space heating appliances, using six typical Fairbanks fuels. Both direct PM emissions and gaseous emission precursors of PM (SO_2, NO_x, VOC and NH_3) were measured, along with PM elemental profiles. All emission tests were conducted at OMNI's laboratory in Portland, Oregon. Supporting solid fuel, liquid fuel, and bottom ash analyses were performed by Twin Ports Testing, Southwest Research Institute (SwRI), and Columbia Analytical Services, respectively. PM profiles of deposits on Teflon filters from dilution tunnel sampling were analyzed by the Research Triangle Institute using XRF, ion chromatography, and thermal/optical analysis.

This section focuses on how Alaska-specific emissions data from the OMNI study data were used to complement EPA's more generic AP-42 Compilation of Emission Factors database for space heating sources. As described in detail in the following sub-sections, the overall approach consisted of using the Fairbanks-specific OMNI emission factor data, where available and reasonable. Where OMNI measurement data were not available, AP-42 emission factors were used with one exception: PM emission factors for residential natural gas combustion. A review of the AP-42 emission factor assigned to residential natural gas determined that this emission factor was based on testing of industrial and utility boilers in the early 1990s.[35] In 2009, Brookhaven National Labs conducted a testing study[36] that included measurement of emissions from smaller-scale residential natural gas boilers and furnaces. The residential natural gas devices tested included both cast-iron and condensing residential boilers and a furnace. The PM emission factor from these three devices were averaged and used to represent PM emissions for residential natural gas use. This Brookhaven-based emission factor (4.88×10^{-5} lb/mmBTU) is over two orders of magnitude below that used in AP-42 and is believed to be more representative of PM emissions from residential natural gas combustion.

EMISSION FACTORS FOR WOOD-BURNING DEVICES

The main focus of the OMNI study was wood burning appliances and fuels because of their apparent significant contribution to $PM_{2.5}$ in the Fairbanks nonattainment area. Specific wood burning space heaters were selected for testing by OMNI either because they represented popular

[34] "Measurement of Space Heating Emissions," OMNI-Test Laboratories, Inc., May 23, 2013.

[35] Eastern Research Group, "Emission Factor Documentation for AP-42 Section 1.4 Natural Gas Combustion," March 1998.

[36] R. McDonald, "Evaluation of Gas, Oil and Wood Pellet Fueled Residential Heating System Emissions Characteristics," Brookhaven National Laboratory, BNL-91286-2009-IR, December 2009.

conventional models in interior Alaska or more advanced models, such as newer EPA-certified wood stoves and EPA-qualified Phase 2 Outdoor Wood Hydronic Heaters (OWHHs), that are expected to be representative of future trends. Additionally, one pellet heater was tested. In all, 20 of OMNI's 35 tests were conducted on wood-fired units.

OMNI's wood burning tests used fuel loadings and test protocols generally as prescribed by EPA Method 28 and related EPA sampling methods. However, to provide the most realistic representation of Alaskan wood burning, split cordwood was used, rather than "crib wood" (i.e., dimensional lumber) as prescribed in the test method. In addition, OMNI used White Spruce and Paper Birch (with bark), the two most common cordwood fuels in Fairbanks, rather than the Douglas Fir prescribed in the test method. Locally produced Alaska wood pellets were used for the pellet heater.

OMNI's emission factor results are expressed in various forms, including emissions per kg of dry wood (similar to AP-42 emissions factors). However, testing was performed using representative Fairbanks fuel samples with as-received moisture levels. More specifically, the cordwood and other solid fuels tested by OMNI were collected in Fairbanks under typical fuel storage conditions and preserved to maintain moisture levels prior to their use in testing. In addition, solid fuels were tested for moisture content by OMNI immediately prior to each test.

EPA test procedures were used as the basis for OMNI's emission testing, with adaptations as needed to improve the representativeness of testing or its practicality. (OMNI's study report provides more details.) EPA Method 28 was followed for solid fuel loadings and test duration. However, Method 28 specifies four different firing rates for each device, in effect requiring four different tests for each appliance/fuel combination and then weighting the results to obtain both annual and heating season average emission values. Unfortunately, this ideal approach of conducting four tests for each appliance/fuel combination was not affordable for Fairbanks due to the size of Alaska's required appliance/fuel test matrix.

The solution for Fairbanks was to conduct Method 28 testing for each appliance/fuel at either "low" firing rate or "low" and "max" firing rates only. The "low" firing rate was defined to be a nominal rate of 35% of maximum load. This load was selected by FNSB for two reasons. First, it is very close to and only slightly above the heating season average weighted load for a Method 28 test, which is 34%. Second, it is very close to, and only slightly below, the center of the range for the most frequent (i.e., most heavily weighted) mode of the Method 28 test, which is Category 3. (This Category has a firing rate of 25–50% of maximum, and it is weighted at 0.450 for the heating season average, i.e. it accounts for nearly half of the firing during the heating season.) By also including a maximum firing rate where practical (corresponding to Category 4 of Method 28), the Borough attempted to capture both the average (g/kg) emission factor (primarily for emission inventory purposes) and the maximum or near maximum (g/hr) emission rate for other evaluation purposes (e.g. estimation of near-field impacts from individual sources).

OMNI's study included limited testing to characterize the effect of cold starts, but to date the results of those tests have not been sufficient to quantify the cold start effect. (Because the data were limited, only an indirect estimate could be made of cold start using results from several runs. These data suggest cold starts may add up to 15% to the total $PM_{2.5}$ emissions, but additional testing with a more direct sampling method would be required to confirm this result.) Therefore, Alaska's wood burning and other space heating emission factors, like AP-42 factors, do not include a cold start effect. Recent survey data from Fairbanks suggest that ignoring this effect may be less serious in Fairbanks than locations outside of Alaska because the vast majority of Fairbanks households that burn wood are more than occasional burners (in a 2012 survey, only 9% of wood burners described their usage as "occasional"); rather, they tend to burn out of economic necessity and very regularly, essentially every day in most cases. In addition, as with cold start test attempts, OMNI performed limited testing to characterize the effectiveness of a solid fuel stove catalytic retrofit device, but those test results too were inconclusive.

Comparison of OMNI and AP-42 Representativeness - In contrast to the appliances and fuels selected for their representativeness of Fairbanks in winter and used in the OMNI study, the emissions studies of residential wood burning that underlie EPA's AP-42 average emission factors include, by design, a broad spectrum of devices, fuels, and conditions. Among the variables reflected in the more than 150 studies relied upon by AP-42 are appliance types, models, ages, and technologies; fuel types (including many wood, coal, and oil types that are either uncommon or not used at all in Fairbanks); fuel conditions (e.g., moisture content), and form factors (crib vs. cordwood); these reflect test methods and field test conditions that are used throughout North America under a much wider variety of circumstances (not all of which are necessarily appropriate for Alaska). These and other features of the OMNI and AP-42 testing are summarized in Table 7-6-38.

An element not directly compared in Table 7-6-38 is measurement of particle size in reporting PM emission test results. While not correct, total PM, PM_{10}, and $PM_{2.5}$ are often used interchangeably. As noted by Houck[37] (2008), AP-42 states "PM-10 is defined as equivalent to total catch by EPA method 5H train." Most inventories treat the AP-42 values as either PM_{10} or $PM_{2.5}$ and essentially equivalent to each other. Research into the size distribution of particles from a certified catalytic model showed that PM_{10} averaged about 88% of the total particulate catch and $PM_{2.5}$ averaged about 80%; similar research with a certified non-catalytic model showed that PM_{10} averaged about 94% and $PM_{2.5}$ about 92% of the total catch.[38] OMNI's reported test results are size-segregated $PM_{2.5}$ measurements. As noted above, AP-42 published rates do not distinguish particle size.

As a compendium of generic emission factors, AP-42 is both relatively large in scope and a reliable information resource. However, there are several and serious technical challenges to applying the AP-42 average emission factors to Fairbanks wood burning. One of the first problems is lack of geographic specificity. AP-42 does not specify the exact mix of wood types that were used for its testing, but it is known from reviews of AP-42 that they are not dominated by either Paper Birch or White Spruce, the two most common types in Fairbanks. Furthermore, the current woodstove population and technology in Fairbanks and represented in the OMNI study is almost certainly newer than the AP-42 database. This is true not only because the AP-42

[37] J.E. Houck, et al., "Emission Factors for New Certified Residential Wood Heaters," presented at EPA's 17th Annual International Emissions Inventory Conference, June 2008, http://www.epa.gov/ttnchie1/conference/ei17/session4/houck.pdf.
[38] McCrillis, R.C., Wood Stove Emissions: Particle Size and Chemical Composition, U.S. Environmental Protection Agency, Research Triangle Park, NC, 2000, EPA-600/R-00-050.

database tends to be much older, but also because wood burning in Fairbanks has increased sharply in recent years due to escalating heating oil prices and some of the nation's highest home heating costs (average about $3,700/year). This means (and recent DEC-sponsored telephone surveys tend to support) that the Fairbanks wood burning device population has not only a higher fraction of certified wood burning devices, but also more of the newest (and lowest-emitting) of the certified devices. Finally, while many of the AP-42 wood appliance tests were reportedly conducted under "field conditions," presumably using representative wood moisture levels for those locations and seasons, we do not know whether the fuel moistures and firing rates in those tests were representative of Fairbanks in winter. In the case of OMNI's testing, OMNI and the Borough took steps to ensure the representativeness of Fairbanks fuel samples and the preservation of sample moisture prior to testing. In addition, OMNI measured and reported the fuel moisture levels (except for liquid fuels) before each test, and they used appropriate heating season average (and selected maximum) firing rates.

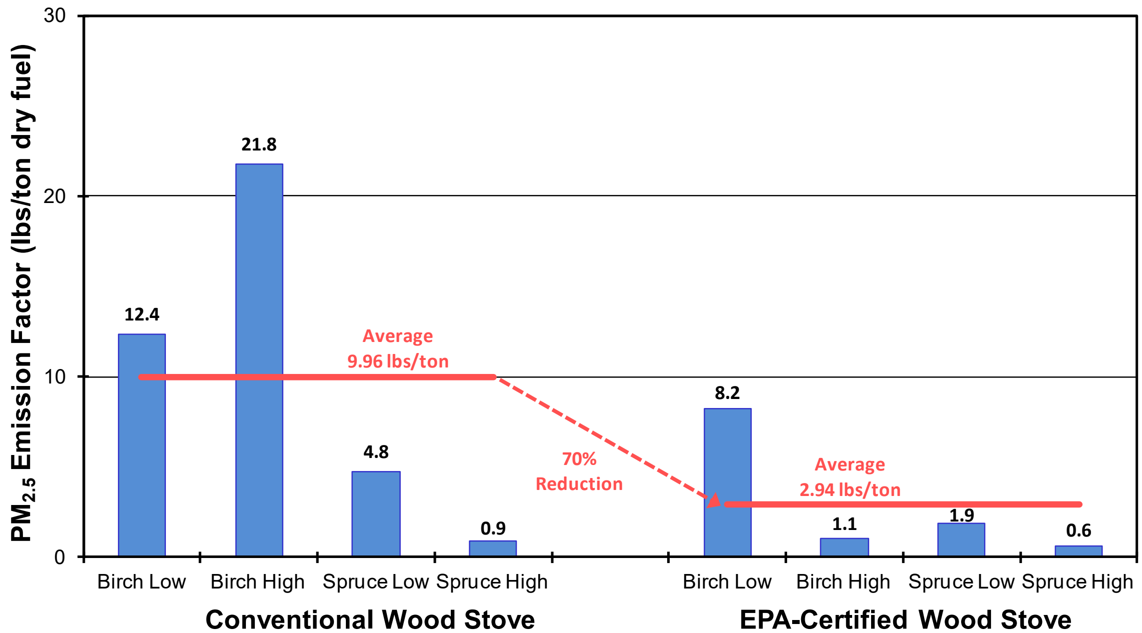
Table 7-6-38 Comparison of OMNI Heating Device Testing and AP-42 Emission Factors		
Features	OMNI Test Program	AP-42
Geographic Representation	Testing specific to interior Alaska appliances/fuels/winter conditions;	Testing designed to be representative of average emissions nationwide
Currency	2011 test program, supported by concurrent usage and measurement data (fuel type & moisture, in-use stack temperature monitoring, etc.)	Pertinent sections of AP-42 date from October 1996 or earlier; references dated 1972-2001
Appliances	"Conventional" and "advanced" wood stoves and outdoor hydronic heaters; pellet stove; coal stove; auger-fed coal OHH; fuel and waste oil burners (total: 9 appliances)	Large number and variety of appliances
Sample Size	35 tests conducted	More than 150 studies; hundreds of tests
Fuel Selection	Paper Birch & White Spruce (most common Fairbanks woods); locally produced wood pellets; Usibelli (Alaska) coal; local #1& #2 fuel & waste oil	Wide variety consistent with nationwide averages (hardwood dominates in most states)
Fuel Moisture	Wood fuels sampled in Fairbanks in winter with typical seasoning & moisture; samples preserved for testing; wood sampled for moisture prior to testing; resulting EFs reported "dry basis" (db)	Varies by study ("equilibrium wood moisture" varies by local condition); resulting AP-42 EFs understood to be db, but not reported explicitly; wood heater field studies report 24% avg (db)
Sampling Methods	EPA "Other Test Method 27" for $PM_{2.5}$ (in accordance with EPA proposed changes to method 201A); other EPA methods for gases	Wide variety of primarily EPA methods; most commonly reported as Method 5H or "5H equivalents"
Fuel Loadings: Wood Liquid Fuels Coal	 Method 28 for wood fuel amounts & handling but used Alaskan cord woods rather than Douglas Fir crib wood; No EPA test method; followed manufacturers' operating instructions; extended test duration to collect sufficient PM for analysis No EPA test method for stoves; followed manufacturers' operating instructions	Fuel loadings & form factor vary by study (AP-42 predates Method 28)
Firing Rates	OMNI targeted 35% & max firing rates (OMNI's "low" and "high" firing generally corresponds to Method 28 categories 3&4, respectively; category 3 is predominant mode for "winter season heating")	Varies by study; may be skewed toward "higher than average in-home burn rate"

One important limitation of the OMNI test program was the number of tests, which was limited by budget constraints to 35. This is far less than the AP-42 sample, which may number in excess of 1,000 tests. However, unlike AP-42, all of the OMNI tests used Alaska-specific fuels and the appliances tested were specifically chosen by OMNI to represent the Alaskan appliance population. Thus, there is a tradeoff between sample size, which favors using AP-42 emission factors, and data specificity, which favors the available OMNI test results.

A second limitation of the OMNI testing was the lack of replicate tests. However, this was partially compensated by the study design, which provided for multiple tests of individual appliances using different fuels and firing rates.

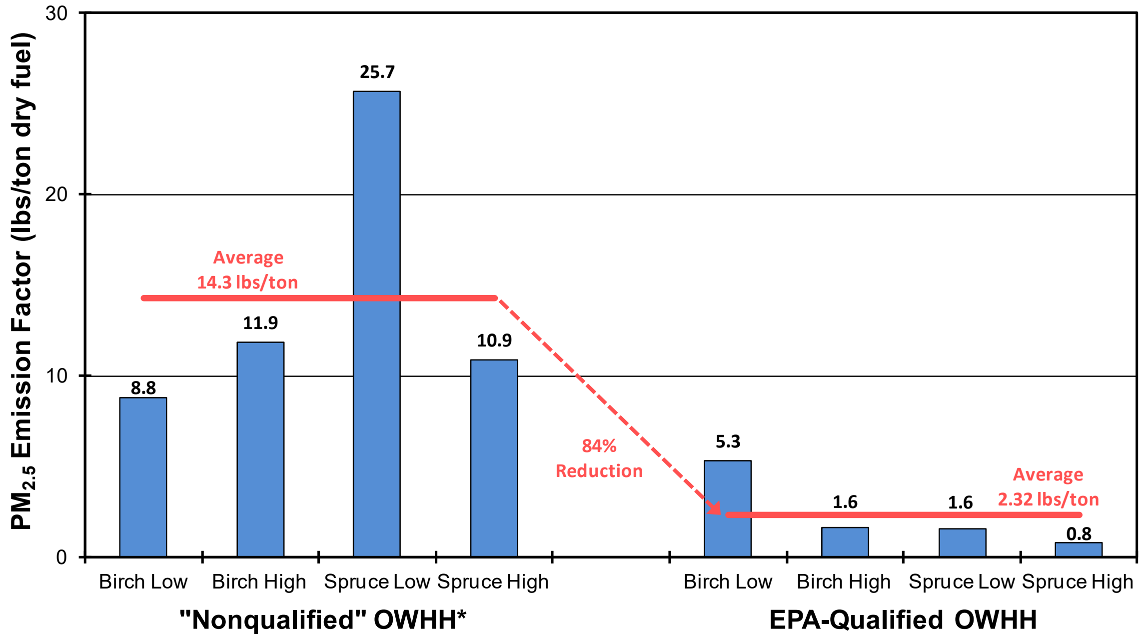
Summary of OMNI Test Results - As shown in Figure 7-6-32 and Figure 7-6-33, the OMNI study design allowed for suspected systematic variations in emissions to be tested and documented, and the observed patterns in the test results give confidence about the repeatability of testing. The figures show not only that EPA-certified wood stoves and EPA-qualified OWHHs emit about 70% less and 84% less $PM_{2.5}$ than their non-certified/nonqualified counterparts, but also that the patterns of reductions are similar for each fuel and firing rate.

Figure 7-6-32
$PM_{2.5}$ Emission Factors from OMNI Testing for
Conventional (left) & EPA-Certified (right) Wood Stoves by Wood Species and Firing Rate



Several apparent deviations from a completely systematic variation, such as higher Spruce vs. Birch emissions for the non-qualified OWHH in Figure 7-6-33, are discussed further in the OMNI report[34]. It should also be noted that the figures each show simple averages across the set of high and low firing rate tests.

Figure 7-6-33
$PM_{2.5}$ Emission Factors from OMNI Testing for
Non-Qualified (left) & EPA-Qualified (right) OWHHs by Wood Species and Firing Rate



Based on the greater specificity and applicability to Fairbanks and the greater amount of current supporting detail available, the OMNI emission factors were selected for use in the Fairbanks $PM_{2.5}$ SIP to represent average emissions from residential wood burning units, except for fireplaces (which OMNI did not test). In particular, the average $PM_{2.5}$ emission factors for "low" firing rate tests of birch and spruce were used to characterize the average emission factors for conventional woodstoves and outdoor hydronic heaters, advanced (i.e., more modern) EPA-certified woodstoves, EPA Phase 2 qualified OWHHs; and results from OMNI testing with locally produced Alaska wood pellets were used to characterize pellet stoves. The low firing rate tests were used to develop the SIP emission factors because the low firing rate (35% of maximum) was close to that of the winter season average Method 28 firing rate of 34% as explained earlier and based on local evidence suggesting wood burning devices tend to have their air dampers set at a low/mostly closed position to extend burn durations of a fuel load (e.g. to avoid waking up at night to add more wood to a stove).

The birch and spruce test results were weighted together based on splits in commercial timber sales within the Borough obtained from the Alaska Department of Natural Resources, Division of Forestry. These relative splits were 52% birch, 6% spruce and 42% aspen. (The normalized relative splits between birch and spruce were 90% and 10%, respectively).

EMISSION FACTORS FOR OIL-FIRED DEVICES

The vast majority of households in Fairbanks have central oil furnaces and, according to recent telephone survey data, about two-thirds of the residential heating in Fairbanks (BTU basis) is by central oil burning systems. Therefore, despite its relatively low PM emissions factor compared to wood, testing of a central heater with Nos. 1 and 2 heating oils (used in Fairbanks in about a 1:3 ratio) and of a waste (motor) oil-fired space heater were included in OMNI's test program.

The same suite of pollutants was sampled for oil burners as for wood, but the key pollutant of interest for oil burners was SO_2, due to both the much higher concentration of sulfur found in oil and the predominance of oil burning in Fairbanks. EPA's emission factor guidance document, AP-42, states: "On average, more than 95% of the fuel sulfur is oxidized to SO_2, about 1 to 5 percent is further oxidized to sulfur trioxide (SO_3), and 1 to 3 percent is emitted as sulfate particulate." According to EPA's $PM_{2.5}$ SIP guidance, SO_2 is presumed to be a precursor of secondary $PM_{2.5}$. Thus, oil burning appliances may contribute to both primary and secondary $PM_{2.5}$ sulfate in the atmosphere.

Samples of Nos. 1 and 2 fuel oil and waste oil sample were collected by FNSB staff, analyzed for OMNI by SwRI, and found to have sulfur contents of 896, 2566, and 3020 ppm by weight, respectively as shown in Table 7-6-39. Also shown in the table are three alternative SO_2 emission factors (Columns 1–3), all of which are in units of grams of SO_2 emitted per kg of oil burned.

Table 7-6-39
Fuel Sulfur and SO_2 Emission Factors for Three Fairbanks Oil Samples

		Alternative SO_2 Emission Factors: (grams of SO_2 per kg of fuel burned)		
Fuel	ppm Sulfur (by weight) from SwRI	Column 1 Range, assuming 95-100% of fuel S emitted as SO_2	Column 2 All fuel S Emitted as SO_2 except as measured in reduced form on $PM_{2.5}$ filters by XRF	Column 3 EF from OMNI SO_2 (and other) measurements
No. 1 Fuel Oil	896	1.70 - 1.79	1.77	1.25
No. 2 Fuel Oil	2,566	4.88 - 5.13	5.12	2.10
Waste Motor Oil	3,020	5.74 - 6.04	5.93	4.76

Column 1 shows the range of emission factors based strictly on the SwRI-measured sulfur contents and on the 95-100% S to SO_2 conversion rate for oil combustion documented in AP-42. Column 2 shows the corresponding emission factor based on 100% oxidation of sulfur but after first subtracting the PM reduced, elemental sulfur contributions on OMNI's PM filter samples (measured by Research Triangle Institute). These data are confirmatory regarding the SO_2 fraction in that they fall within the range anticipated based on AP-42. The third column shows an independent measure of the SO_2 emission factor by OMNI, although in this case, the EFs for all three oils are below the levels anticipated based on fuel sulfur content, suggesting these measurements are suspect. The precise reason for the lower values in OMNI's SO_2 measurement-based factors is not known, but it is recognized that the latter approach is a more complex estimate because it requires accurate calibration and measurement of not only SO_2 in the dilution tunnel, but also the same for a tracer gas in both the hot appliance stack and the dilution tunnel, along with accurate alignment of all measurement traces.

Two final points are worth noting with respect to oil combustion emission factors. First, the emission factors for SO_2 and SO_3 shown in AP-42's Table 1.3-1 imply a slightly higher proportion of fuel S emitted as SO_2 for residential furnaces (98.9%) than for other fuel burning sources. This is consistent with and lends credence to the relatively high SO_2 fractions (i.e., small PM correction) observed from the OMNI/SwRI/RTI measurements. Second, the oil burners were designed for and emission tested by OMNI at a single firing rate (there were no firing rate issues such as occurred with the wood burning appliances).

Based on the above findings, it was concluded that the simplest and most consistent emission factor for SO_2 is that derived from the direct fuel sulfur-based method as reflected in AP-42. Accordingly, application of the fuel sulfur-based method with 100% SO_2 oxidation and using the SwRI fuel sulfur measurements for oil, has been assumed in developing the Fairbanks SIP emissions inventory. By comparison, the emission factor measurement of SO_2 by OMNI is more complicated and may be less reliable than the above method. Furthermore, considering the closeness of the OMNI PM sulfur adjusted values (column 2) to the 100% S conversion based EFs (upper range limit of Column 1), the latter were used for the SIP-based inventory without adjustment for sulfur in the PM.

Emission Factors for Coal-Burning Devices

In addition to wood and oil fuels, OMNI emission tested Alaskan (Usibelli) subbituminous coal (wet, dry, lump, and stoker) in several residential heaters. Currently, coal is not widely used as a residential heating fuel in Fairbanks, and no EPA source test methods exist for residential coal stoves. The only AP-42 emission factor data available are from testing of much larger coal-fired boilers.

Under contract to OMNI, Twin Ports Testing (TPT) analyzed Alaskan coal samples that had been collected by Borough staff, stored in sealed drums to maintain moisture, and then shipped and stored by OMNI for use in testing. TPT reported that lump and stoker coal have sulfur content of 0.086 and 0.101 weight % S (dry basis), respectively. Fuel moisture contents for the eight coal test charges measured by OMNI immediately prior to testing ranged from 11.20–33.50%.

With regard to $PM_{2.5}$ emissions, coal emission factors were (unlike cordwood emission factors) somewhat variable, depending upon the device tested, wet vs. dry fuel, fuel form factor, firing rate, and other test conditions.

For lack of any information from AP-42 on residential coal burning, emission factors used to develop the Fairbanks inventory were taken from the OMNI test results, using the average of all valid tests at low firing rate (which is close to the expected heating season average firing rate).

EMISSION FACTORS FOR OTHER POLLUTANTS

In addition to measuring $PM_{2.5}$ and SO_2, OMNI also measured and developed emission factors for VOC, CO, NO, NO_2, NO_x, and NH_3 for all wood-burning devices and oil furnaces. For those cases where the OMNI study has provided more specific and applicable measurements than what is available from AP-42, Sierra has recommended the use of the former, with the two exceptions of SO_2 (discussed above) and VOC. For VOC, OMNI's measurements and emission factor are presented on a carbon mass-basis, whereas AP-42 shows mass emissions for TOC, methane, TNMOC, selected organic species, PAHs, and more. Absent more detailed information about the C-mass fraction of both sources, comparison of the VOC emission factors is problematic. Thus, no attempt was made to compare OMNI's emission factors with those in AP-42, nor consider substitution of the OMNI EF's for those in AP-42.

SIP INVENTORY EMISSION FACTORS

Table 7-6-40 and Table 7-6-41 provide tabulations of the emission factors used to estimate space heating emissions for the SIP inventories. These tables respectively show emission factors for wood-burning (in lbs/ton) and for other heating types (in lbs/1000 gals). The first column in each table lists the device type/technology. The next seven columns list the emission factors for VOC, NO_x, SO_2, primary PM_{10} and $PM_{2.5}$, NH_3 and CO.

The last column in each table lists the data source(s) and, in several cases, provides additional details about the emission factor calculations. Further details are provided in the footnotes to individual emission factor entries. Highlighted cells in each table show emission factor entries that are based on OMNI results. Unshaded cells refer to "default" AP-42 based emission factors that were used where OMNI data were not available or insufficient.

Table 7-6-40
Emission Factors for Wood-Burning Devices (lbs/ton) - EPA Method 5H Except Where Noted (OMNI Factors in Highlighted Cells)

Device and Technology	VOC	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3	CO	Data Source(s)
Fireplace, no insert	229.0	2.6	0.4	34.6	34.6	1.8[39]	252.6	AP-42, Table 1.9-1; for SO2, OMNI fuel S for spruce gave same EF as AP-42
Fireplace insert, non-EPA certified	53.0	2.8	0.4	30.6	30.6	1.7	230.8	Assumed equal to uncertified woodstove EFs
Fireplace insert, EPA-certified, non-catalytic.	12.0[40]	2.0[40]	0.4[40]	12.0	12.0	0.9[40]	140.8[40]	AP-42, Table 3 for PM EFs www.epa.gov/ttnchie1/ap42/ch01/related/woodstoveapp.pdf
Fireplace insert, EPA-certified catalytic	15.0[40]	2.0[40]	0.4[40]	13.0	13.0	0.9[40]	107.0[40]	AP-42, Table 3 for PM EFs www.epa.gov/ttnchie1/ap42/ch01/related/woodstoveapp.pdf
Woodstove, non-EPA certified	53.0	1.4	0.4	11.60[41]	11.60[41]	0.379	115.8	AP-42, Table 1.10-1 for VOC&SO_2; others use avg of OMNI runs 14&15, conventional wood stove, spruce & birch, low firing rate
Woodstove, EPA-certified, non-catalytic	12.0	1.5	0.4	7.57[41]	7.57[41]	0.239	118.1	AP-42, Table 1.10-1,assmd Phase II (1990 stds) for VOC&SO_2; others use avg OMNI runs 5&6 for birch & spruce; EPA (non-cat) woodstove low firing rate
Woodstove, EPA-certified, catalytic	15.0	1.5	0.4	8.40[41]	8.40[41]	0.239	118.1	same as immediately above, except OMNI avgs for PM_{10}&$PM_{2.5}$ scaled by the ratio of cat to non-cat (16.2/14.6)
Pellet Stove, exempt	2.4[42]	4.0	0.32	2.96	2.96	0.072	9.9	AP-42, Table 1.10-1for VOC; all others OMNI run #1, pellet stove, except SO_2 which is based on dry pellet S content from OMNI
Pellet Stove, EPA-certified	2.4[42]	4.0	0.32	2.96	2.96	0.072	9.9	AP-42, Table 1.10-1for VOC; all others OMNI run 1, pellet stove, except SO_2 which is based on dry pellet S content from OMNI
Hydronic Heater, weighted 80/20	*45.4*	*1.5*	*0.4*	9.43	9.43	0.233	*57.9*	80% / 20% weighting of OWB unqualified&OWB-Ph2 qualified
Hydronic Heater, Unqualified	*53.0*	*1.4*	*0.4*	10.55[41]	10.55[41]	0.261	*52.8*[43]	EPA/NY for VOC&SO_2; others use avg of OMNI runs 30&32, OWHH birch &spruce, low firing rate OMNI dry S content for spruce same EF as AP-42
Hydronic Heater, Phase 1	*12.0*	*2.1*	*0.4*	9.303[41]	9.30[41]	0.120	*102.7*	set rates for VOC to those for woodstoves; others from avg of OMNI runs 9&11, spruce & birch, EPA qualified OWHH, low firing rate, but for PM&CO scaled by phase 1&2 ratio;SO_2 based on OMNI content of dry spruce
Hydronic Heater, Phase 2	*15.0*	*2.1*	*0.4*	4.94[41]	4.94[41]	0.120	*78.01*	set rates for VOC to those for woodstoves; others from avg of OMNI runs 9 and 11, spruce & birch, EPA qualified OWHH, low firing rate, but PM & CO scaled by ratio for phase 1&2;SO_2 based on OMNI S content of dry spruce

[39] NH_3 EF from Pechan “Estimating Ammonia Emissions from Anthropogenic Non-Agricultural Sources”, Draft Final Report, April 2004.
[40] No separate EF data for this pollutant; assumed equal to corresponding certified woodstove EFs from AP-42.
[41] Entries reflect weighting of spruce and birch EFs from wood-specific OMNI tests based upon spruce vs. birch sales split from US Forest Service timber sales data
[42] From http://www.epa.gov/burnwise/pdfs/EPA_stove_emis_reduct.pdf, converted from kg/tonne to lbs/ton.
[43] CO is lower limit because instrument pegged.

Table 7-6-41
Emission Factors for Other Devices (lbs/1000 gal except where noted, OMNI Factors in Highlighted Cells)

Other Heating Types	VOC	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3	CO	Data Source(s)
Central Oil (Wtd #1 & #2), Residential	0.713	11.2	30.71[44]	0.457	0.457	0.024	0.448	AP-42 Table 1.3-1 for VOC; OMNI fuel S content for SO_2; all others OMNI run#17,SwRI for fuel (lower) heating value,AP-42 for fuel oil density
Central Oil (#1 distillate), Residential	0.713	11.2	12.72[45]	0.457	0.457	0.024	0.448	AP-42 Table 1.3-1 for VOC; OMNI fuel S content for SO_2; all others OMNI run#17, SwRI for fuel (lower) heating value,AP-42 for fuel oil density
Central Oil (#2 distillate), Residential	0.713	11.2	36.44[46]	0.457	0.457	0.024	0.448	AP-42 Table 1.3-1 for VOC;OMNI fuel S content for SO_2; all others OMNI run#17, SwRI for fuel (lower) heating value,AP-42 for fuel oil density
Central Oil (Wtd #1 & #2), Commercial	0.713	18	30.71[6]	0.457	0.457	0.024	0.448	AP-42 Table 1.3-1 for NO_x; for all others, assume same as above
Portable Heater: 43% Kerosene & 57% Fuel Oil	0.713	18	30.71[6]	0.4	0.4	0.024	0.4	EFs for portable heaters w. kerosene/fuel oil #2 blend assumed equal to central oil (#2); all except SO_2, NH_3 and CO, assumed same as above
Direct Vent	0.713	11.2	12.72	0.5	0.5	0.024	0.4	EFs for DV w. #1 assumed equal to central oil (on #2) in absence of actual data; except SO_2, NH_3 and CO assumed same as above
Natural Gas-Residential (lb/million ft^3)	5.5	94	0.6	0.0495[36]	0.0495[36]	20	40	AP-42 Tables 1.4-1 & 1.4-2 for all but PM and NH_3; shaded PM factors from 2009 Brookhaven, EPA/Pechan for NH_3
Natural Gas-Commercial, small uncontrolled (lb/million ft^3)	5.5	100	0.6	7.6	7.6	20	40	AP-42 Tables 1.4-1 & 1.4-2 for all but NH_3, EPA/Pechan for NH_3
Coal Boiler (lb/ton)	10	4.7	9.3[47]	8.0	8.0	1.266	130.6	AP-42 Table 1.1-19 for VOC, (w. Usibelli S content) SO_2; OMNI runs 21,23,37&38 for other, coal stove, wet & dry stoker & lump coal, low firing rate
Waste Oil Burning	1	52.2	36.97	5.2	5.2	0.036	12.4	AP-42 Table 1.11-1 for VOC; all others OMNI run#18, SwRI for heating value, AP-42 for No. 2 fuel oil density

[44] Assumes fuel S content of 2,163 ppm by weight; reflects approximate 76/24 split of #2/#1 per information from Polar & Sourdough Fuels; DEC email 1/31/12.
[45] Assumes S content of 896 ppm of #1from SWRI analysis of Fairbanks fuel sample as reported by OMNI Labs.
[46] Assumes S content of 2566 ppm of #2 from SWRI analysis of Fairbanks fuel sample as reported by OMNI Labs.
[47] Assumes coal S content of 0.3% by weight per www.Usibelli.com/coal_data.asp .

Space Heating – Emission Calculation Details

Home heating (and commercial space heating) emissions were calculated in a manner that optimized the use of locally-collected survey data, in-use device activity and fuel use measurements, and emission factor data that were described in detail in the preceding sections of this technical appendix. This section of the appendix explains how these local data were used in conjunction with the Fairbanks space heating energy model to generate estimates of pollutant emissions used in the episodic inventories. Thus, a key element in these emission inventory calculations consisted of utilizing spatially- and temporally resolved data or relationships based on them to generate gridded, day and hour-specific estimates of space heating emissions over the modeling domain.

These calculations were performed in a series of complex “Space Heating” spreadsheets.

Energy Model Implementation

The first step in building the Space Heating emission calculation spreadsheets consisted of loading in the Fairbanks Home Heating Energy Model in order to compute needed household heating energy as a function of device/fuel mix, building size, average daily ambient temperature and day type (weekday vs. weekend). The *Coeffs* tab in the spreadsheet contains the daily and hourly energy model coefficients listed earlier in Table 7-6-9 and Table 7-6-10.

The energy model is then implemented within the *HtEnergy* tab to calculate heating energy by modeling grid cell for each of the 1.33 km square cells across the modeling domain based on the number of residential households in each cell determined from block-level 2010 U.S. Census data (and grown forward or backward to each inventory year based on population projections). The summed space heating energy over all households in each grid cell was calculated separately by day and hour for each based on 4 km grid cell specific winter season energy use splits by device/fuel type developed the 2011-2015 Home Heating Survey data.

Table 7-6-42 (identical to Table 7-6-29 shown earlier) shows these winter season energy use splits for selected 4 km grid cells. Space heating energy use for those device/fuel types not highlighted (Portable Oil Heaters, Natural Gas, Coal and Electric Heat) was estimated from their Home Heating Survey-based splits shown in Table 7-6-42 in proportion to their Survey-based energy use outside the energy model.

In practice, this was applied across the entire nonattainment area with the 4 km cells mapped to the smaller 1.33 km modeling grid cells. Those device/fuel types highlighted in Table 7-6-42 represent those for which space heating energy use is estimated from the energy model.

Table 7-6-42
2011-2015 Home Heating Survey Winter Season Heating Energy Use Splits by Key 4 Km Grid Cell

Area Description	4 Km Grid Cell	Pct. Of Winter Season Heating Energy Use by Grid Cell									
		Wood			Heating Oil			Nat Gas	Coal	Steam	
		Stove/ Insert	Fireplace	Outdoor Boiler	Central Oil	Direct Vent	Portable	Natural Gas	Coal Heat	Muni. Heat	Total
FAI	137,136	25.32%	1.47%	2.08%	66.30%	1.89%	0.00%	0.00%	2.93%	0.00%	100%
Chena Pump/Geist	137,137	8.70%	1.36%	0.58%	84.63%	1.22%	1.72%	0.98%	0.08%	0.72%	100%
Mitchell/S. Fairbanks	138,136	17.88%	0.00%	1.07%	69.76%	2.17%	0.00%	8.26%	0.42%	0.44%	100%
W of Downtown	138,137	11.33%	0.27%	0.53%	80.92%	1.19%	0.37%	3.75%	0.00%	1.64%	100%
Mitchell/SE Fairbanks	139,136	11.51%	0.21%	0.44%	73.75%	2.37%	2.50%	7.08%	0.17%	1.96%	100%
Downtown/Nordale	139,137	9.14%	0.54%	0.23%	84.16%	1.83%	0.27%	0.73%	0.42%	2.69%	100%
NP/SE of Richardson	143,134	20.75%	1.03%	1.39%	72.57%	1.55%	0.07%	0.00%	2.64%	0.00%	100%
NP/N of Hurst	143,135	26.84%	0.35%	3.30%	62.82%	2.78%	0.93%	0.62%	2.35%	0.00%	100%
NP/S of Hurst	144,134	29.82%	0.71%	3.55%	63.00%	1.12%	0.92%	0.67%	0.22%	0.00%	100%
NP/Badger	144,135	24.53%	0.00%	1.88%	71.29%	0.85%	0.24%	0.00%	0.87%	0.35%	100%
Cells <50 Households	Low SS	28.89%	0.59%	1.46%	60.89%	5.90%	0.36%	0.35%	1.45%	0.10%	100%

These calculations were performed within the context of the gridded modeling inventories in a manner in which space heating energy use is not calculated by individual device (or household), but rather based on the total number of households in each grid cell and the average device/fuel usage splits across all surveyed households within each grid cell. For grid cells not represented in the Home Heating Survey (which sampled households only within the non-attainment area), the Census weighted average splits at the bottom of Table 7-6-42 were used.

Another element considered in calculating space heating energy use by episode day and hour for each grid cell was the use of occupied vs. total (which includes occupied and vacant households) households counts from the 2010 Census. Based on discussions with Borough staff, wood and coal burning energy use was calculated based on occupied households, while energy use for other devices/fuel was based on total (occupied and vacant) households. The central assumption here was that thermostatically controlled devices (central oil, natural gas) would still be operated at some lower heating level to ensure interior pipes and other infrastructure would not freeze and crack. No adjustment was estimated to account for the lower heating level for these devices in vacant households.

Finally, parcel level GIS data developed by the Borough from tax assessment data was used to calculate the average building size (in heated interior area) separately for both residential and commercial parcels within each grid cell. These average building sizes for each grid cell were required to drive the energy model calculations (along with average daily temperature, device usage mix and day type).

Application of Energy-Specific Emission Factors

The next step in the calculation of space heating emissions consisted of converting the device and technology specific emission factors presented earlier in Table 7-6-40 and Table 7-6-41 from pounds emitted per fuel use unit to pounds emission per unit energy (i.e., pounds per million BTU or lb/mmBTU). This conversion was necessitated by two factors:

1. *BTU-Based Energy Model* - The energy model was configured to predict space heating energy use (in BTUs), rather than fuel use across all of the devices. (This made it easier to utilize relative energy use splits calculated from the Home Heating Survey to augment energy use estimates for device not addressed directly within the energy model.)

2. *Treatment of Wood Moisture Effects* – Unlike other fuels used for space heating, the effective or "heating" energy of wood is directly related to its moisture content as discussed earlier in the "Home Heating – Fairbanks Wood Energy and Moisture Effects" section. The space heating emission calculation workflow (and adjustments for wood moisture) was made much simpler by starting with emission factors for wood devices assuming zero or oven dry moisture content and then applying a multiplicative adjustment that accounted for the heating energy effect as a function of moisture content. (This also made the process for calculating future inventories reflecting either trends in moisture content or effects from planned or adopted control measures more straightforward.)

The emission factor conversions were performed by dividing fuel specific energy content presented earlier in Table 7-6-28 (in BTU/fuel unit) into the pound per fuel unit emission factors in Table 7-6-40 and Table 7-6-41. For example, the $PM_{2.5}$ emission factor for residential heating oil (with mix of #1 and #2 oil) from Table 7-6-41 of 0.457 lb/1000 gal was divided by the energy content for heating oil (with the #1 and #2 mix) of132,000 BTU/gal (or 132 mmBTU/1000gal) listed in Table 7-6-28 to yield an energy-specific emission factor of 0.000346 (3.46×10^{-3}) lb/mmBTU.

Table 7-6-43 and Table 7-6-44 present the results of these emission factor conversions for all wood and non-wood burning devices and technologies, respectively. As noted above, energy-specific wood burning emission factors in Table 7-6-43 are represented on an over dry or 0% moisture basis. In both tables, highlighted cells refer to emission factors based on local device/fuel measurements from the OMNI Labs testing study and the 2009 Brookhaven study; AP-42 factors were used for pollutant/device combinations in un-highlighted cells. SCC codes and assumed net heating efficiencies for each device are also shown in both tables. Although the heating efficiencies were not used in calculating baseline emissions, they are used later in Control inventory calculations where efficiency were accounted for in scenarios where heating devices are replaced by other devices, such as switching from wood to heating oil.

Table 7-6-43
Heating Energy-Specific Emission Factors for Wood-Burning Devices (lbs/mmBTU), Oven Dry (0%) Moisture Basis (OMNI-Based Factors in Highlighted Cells)

Device and Technology	SCC Code	Heating Efficiency	Emission Factors (lb/mmBTU)						
			VOC	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3	CO
Fireplace, no insert	2104008100	7%	13.237	0.150	0.023	2.000	2.000	0.104	14.601
Fireplace insert, non-EPA certified	2104008210	40%	3.064	0.162	0.023	1.769	1.769	0.098	13.341
Fireplace insert, EPA-certified, non-catalytic.	2104008220	66%	0.694	0.116	0.023	0.694	0.694	0.052	8.139
Fireplace insert, EPA-certified catalytic	2104008230	70%	0.867	0.116	0.023	0.751	0.751	0.052	6.185
Woodstove, non-EPA certified	2104008310	54%	3.064	0.085	0.023	0.714	0.714	0.023	7.129
Woodstove, EPA-certified, non-catalytic	2104008320	68%	0.694	0.095	0.023	0.466	0.466	0.015	7.274
Woodstove, EPA-certified, catalytic	2104008330	72%	0.867	0.095	0.023	0.517	0.517	0.015	7.274
Pellet Stove, exempt	2104008410	56%	0.139	0.247	0.020	0.182	0.182	0.004	0.612
Pellet Stove, EPA-certified	2104008420	78%	0.139	0.247	0.020	0.182	0.182	0.004	0.612
Hydronic Heater, weighted 80/20	2104008610	43%	2.624	0.095	0.023	0.581	0.581	0.014	3.563
Hydronic Heater, Unqualified	2104008610	43%	3.064	0.087	0.023	0.650	0.650	0.016	3.253
Hydronic Heater, Phase 1	2104008610	43%	0.694	0.127	0.023	0.573	0.573	0.007	6.321
Hydronic Heater, Phase 2	2104008640	43%	0.867	0.127	0.023	0.304	0.304	0.007	4.804

Table 7-6-44
Heating Energy-Specific Emission Factors for Other Devices (lbs/mmBTU) (OMNI/Brookhaven-Based Factors in Highlighted Cells)

Device and Technology	SCC Code	Heating Efficiency	Emission Factors (lb/mmBTU)						
			VOC	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3	CO
Central Oil (Wtd #1 & #2), Residential	2104004000	81%	5.40E-03	8.46E-02	2.33E-01	3.46E-03	3.46E-03	1.86E-04	3.39E-03
Central Oil (#1 distillate), Residential	2104004000	81%	5.70E-03	8.94E-02	1.02E-01	3.65E-03	3.65E-03	1.96E-04	3.58E-03
Central Oil (#2 distillate), Residential	2104004000	81%	5.15E-03	8.07E-02	2.63E-01	3.30E-03	3.30E-03	1.77E-04	3.23E-03
Central Oil (Wtd #1 & #2), Commercial	2103004001	81%	5.15E-03	1.30E-01	2.22E-01	3.30E-03	3.30E-03	1.77E-04	3.23E-03
Portable Heater: 43% Kerosene & 57% Fuel Oil	2104004000	81%	5.20E-03	1.31E-01	2.24E-01	2.92E-03	2.92E-03	1.79E-04	3.27E-03
Direct Vent	2104007000	81%	5.70E-03	8.94E-02	1.02E-01	3.65E-03	3.65E-03	1.96E-04	3.58E-03
Natural Gas-Residential	2104006010	81%	5.42E-03	9.26E-02	5.91E-04	4.88-05	4.88E-05	1.97E-02	3.94E-02
Natural Gas-Commercial, small uncontrolled	2103006000	81%	5.42E-03	9.85E-02	5.91E-04	7.49E-03	7.49E-03	1.97E-02	3.94E-02
Coal Boiler	2104002000	43%	6.54E-01	3.08E-01	6.08E-01	5.22E-01	5.22E-01	8.27E-02	8.53E+00
Waste Oil Burning	2102012000	n/a	7.22E-03	3.77E-01	2.67E-01	3.76E-02	3.76E-02	2.63E-04	8.97E-02

n/a – Not available

OMNI factors are highlighted in gray, Brookhaven factors are highlighted in green

In applying these energy-specific emission factors in the Space Heating calculation spreadsheets, it was necessary to apply additional usage splits or allocations for each of the technologies listed in Table 7-6-43 and Table 7-6-44. For example, to calculate separate emission estimates for wood devices burning cordwood versus pellets and to allocate the splits of uncertified and certified wood stoves and inserts Table 7-6-29 and Table 7-6-30 presented earlier in the "Home Heating – Space Heating Surveys" section contain these cordwood/pellet and uncertified/certified device splits.

Notwithstanding wood moisture adjustments discussed separately in the next sub-section, space heating emissions were then calculated within each grid cell (by day and hour) by multiplying the total BTUs by device in the cell by the device and technology-specific energy emission factors listed in Table 7-6-43 and Table 7-6-44.

Wood Moisture Adjustment Calculations

As explained earlier in the "Home Heating – Fairbanks Wood Energy and Moisture Effects" section, wood moisture effects were accounted for using a linear relationship of heating BTUs vs. moisture content. This adjustment was necessary in calculation of 2008 Baseline and 2015 and 2019 Projected Baseline space heating emissions because of trends in average moisture content developed from survey data as described in that earlier section. Thus, with emission factors for wood devices expressed on a lb/mmBTU oven dry basis, it was relatively straightforward to apply the moisture adjustments, given an "input" or assumed average moisture level across all grid cells.

The *Moisture* tab in the Space Heating emission calculation spreadsheets contains the wood moisture content adjustment calculations based on the methods described in the earlier "Home Heating – Fairbanks Wood Energy and Moisture Effects" section. It also accounts for the fact that wood use measurements (and heating energy estimates developed from them embedded in the Home Heating Energy Model are associated with a specific wood moisture content of 26.6% (on a dry basis). Thus, the energy estimates from the model had to be adjusted to an oven dry basis from this 26.6% "reference" moisture level. In addition, the *Moisture* tab also includes an adjustment to account for the difference between the assumed wood energy content when the energy model was developed (6,053 BTU/lb) and that developed later in the SIP inventory process from the aforementioned 2013 Wood Tag Survey (6,413 BTU/lb at the 26.6% reference moisture level).

Commercial Space Heating Emissions

Due to differences in energy efficiency, ceiling heights and overall building size the residential Home Heating Energy Model was not used to estimate space heating energy use and emissions within commercial buildings.

Instead commercial sector heating energy was calculated based on an estimate of commercial building space energy intensity in Alaska provided by CCHRC.[48] CCHRC compared an energy model they developed using the ASHRAE "Energy Standard for Buildings Except Low Rise

[48] Email from Colin Craven, Cold Climate Housing Research Center, April 27, 2009.

Residential Buildings" Standard 90.1. Using the ASHRAE minimum standard (referred to as ECB) our Research Testing Facility, which is primarily office space, CCHRC found an energy intensity of about 89,000 $BTU/ft^2/yr$ for its office building in Fairbanks.

Looking at the 2003 US Commercial Building Energy Consumption Survey (CBECS) published by the U.S. Energy Information Administration, commercial building energy loads in Climate Zone 1 (Alaska) CCHRC found the most representative estimate to be 90,690 $BTU/ft^2/yr$, which closely agrees with the estimate for their own office building. This CBECS value of 90,690 was assumed to best represent average annual heating energy intensity of commercial structures in Fairbanks.

To use this annual intensity within the episodic inventory, the average of number of heating degree days (HDD) referenced to 65°F in Fairbanks was estimated to be 14,274 HDD based on data compiled for Fairbanks International Airport by Weather Underground[49]. Dividing this local HDD into the annual commercial building intensity for Fairbanks yields an estimate of 6.35 $BTU/HDD/ft^2$. This HDD-normalized building energy intensity was then used to calculate commercial heating energy demand within each grid cell. This was done by summing the total building space of all commercial structures within each grid cell developed from parcel-level Assessor data supplied by the Borough and then multiplying by the daily HDD for each day in the historical modeling episodes and the HDD-normalized intensity as follows:

$$Energy_{x,y} = 6.35\ BTU/HDD/ft^2 \times HDD_i \times Buildings \times Avg\ Size\ (ft^2)$$

Where: $Energy_{x,y}$ is the total commercial building heating energy estimated for grid cell (x,y) on episode day i (in BTU/day), HDD_i is the heating degree days for day i (referenced to 65F), *Buildings* represent the number of commercial structures in the grid cell and *Avg Size* is the average commercial building size (in ft^2).

These daily estimates for each grid cell were then apportioned to hourly values using an average hourly energy use profile for oil-heating devices within the energy model (assuming commercial building are similarly thermostatically controlled).

For non-solid fuel burning, commercial space heating energy use was assumed to be allocated to two fuel types: 1) heating oil; and 2) natural gas. Based on usage data compiled for Fairbanks under the aforementioned "Big 3" inventory study a split of 98% oil and 2% natural gas was assumed. The commercial device emission factors for oil and natural gas heating shown earlier in Table 7-6-44 were then used to compute commercial space heating emissions within each grid cell.

As noted earlier in the "Specialized Wood Burning Surveys" sub-section, a limited number of commercial businesses were found to burn wood and coal. Their emissions were calculated using the emission factors for residential wood and coal devices and allocated to appropriate grid cells where these businesses were located.

[49] www.degreedays.net (using temperature data from www.wunderground.com)

Calculation Workflow

Given the calculation complexity of the Space Heating emission spreadsheet, it was set up in a manner in which the following "inputs" were specified in two shaded cells within the *Emis* tab:

- *Calendar Year* – The inventory calendar year (2019 through 2029); and
- *Price Case* – This input allows selection of EIA future fuel oil price forecast cases. "R" uses the Reference or consensus fuel oil price case, "H" uses the High Price case and "L" uses the EIA Low Price case. (The Reference case was used for the mainstream inventory development, the High and Low Price cases were used to evaluate sensitivity.)

A Visual Basic for Applications (VBA) program written within the spreadsheet was then used to cycle through and calculate emissions for each day of the two modeling episodes. When emissions for each day were calculated within the *Emis* tab, they were translated to data structures in two other sheets in formats required by the SMOKE inventory processing model and then exported by the VBA program to external fixed-length ASCII files for subsequent input to SMOKE. In addition, emission estimates were automatically copied by the VBA program to a series of tabulation sheets (e.g., *DevTabs, ZipTabs, GridTabs, DevSumOut*) as calculations were being performed for each episode day.

Use of Episodic Emissions in SMOKE Model

A re-written version of the SMOKE Version 2.7.1 was used to provide space heating emissions to the pre-processor model on an episodic day and hour basis. Although the SMOKE model as originally written allowed point source emissions to be input by individual day and hour, area source emission categories (such as space heating) had to be temporally allocated using a combination of monthly, weekday and hourly profiles that would have lost the individual day- and hour-specific resolution reflected in the calculation of space heating emissions.

In short, the source code was modified in several locations to allow SMOKE to utilize space heating emission inputs by day and hour identically to its handling of episodic point source emissions.

In addition a small Fortran program was written and applied within the SMOKE processing workflow to allocate space heating emissions into the defined vertical layers used for the modeling domain. The program calculated plume heights for single and multi-story residential buildings and used these heights to allocate space heating emissions into the lower layers of the three-dimensional modeling domain. Attachment B describes the methodology behind these calculations.

OTHER AREA SOURCES

Emission contributions from other area sources in Fairbanks during winter are relatively modest compared to those from space heating. As a result, the methods used to estimate emissions for all other sources within the area source sector (besides space heating) were less complex. However, they still relied on local data where it was available, rather than national defaults or a "top-down" approach. The data sources used to estimate "Other" area source emissions were as follows:

1. DEC's Minor Stationary Source emissions database (for calendar year 2014);
2. Locally-collected data for coffee roasting facilities within the nonattainment area; and
3. EPA's 2014 National Emission Inventory (NEI).

This section of the technical appendix describes the data sources and methods used to estimate emissions from other non-space heating sources within the area source sector, beginning with the DEC's Minor Stationary Source database.

DEC MINOR STATIONARY SOURCES

Emissions for sources within the Fairbanks North Star Borough were extracted from the 2014 Minor Source database for the following source types and SCCs:

- Batch Mix Asphalt Plant (SCC 30500247);
- Drum Hot Mix Asphalt Plants (SCC 30500258);
- Gold Mine (SCC 10200502);
- Hospital (SCC 20200402);
- Refinery (SCC 30600106);
- Rock Crusher (SCC 30504030); and
- Wood Production (SCC 10300208).

Emissions for these sources from the 2014 Minor Source file were actual emissions in tons per year and are summarized in Table 7-6-45. In the Arctic, asphalt plants are not operated during winter. For these source categories along with Rock Crushers, winter nonattainment season activity and emissions were assumed to be zero. For all other source categories listed above, emissions were assumed to be constant throughout the year.

Table 7-6-45 2014 DEC Minor Stationary Source Emissions within Fairbanks North Star Borough by SCC Code						
		2014 Emissions (tons/year)				
Source Category	SCC Code	CO	NOx	SO_2	PM[a]	VOC
Batch Mix Asphalt Plants	30500247	0.18	0.39	0.05	0.04	0.03
Drum Hot Mix Asphalt Plants	30500258	0.99	11.41	1.23	2.23	2.11
Gold Mines	10200502	5.50	1.40	4.20	1.90	0.00
Hospitals	20200402	6.14	14.30	0.01	0.00	4.24
Refineries	30600106	13.77	23.80	0.50	3.00	9.50
Rock Crushers	30504030	76.31	61.79	5.86	49.08	17.87
Wood Production	10300208	0.00	5.38	0.00	5.94	7.32
Total Minor Sources		**102.90**	**118.47**	**11.85**	**62.19**	**41.08**

[a] DEC's database did not separately report $PM_{2.5}$ and PM_{10}. All PM emissions were assumed to be $PM_{2.5}$.

COFFEE ROASTERS

A Fairbanks Business database (with confirmation from Borough staff) was used to identify a total of four facilities within the nonattainment area that use on-site coffee roasters. These businesses were contacted and two of the four provided data on annual roasting throughput (tons of beans roasted). Throughput was conservatively estimated for the two non-reporting facilities based on the maximum from those that reported their throughput. Emission factors for PM, VOC and NOx from EPA's WebFIRE AP-42 database for batch roasters were used to calculate emissions. (No emission factors were available for SO_2 or NH_3). Uncontrolled emission factors were applied to three of the four facilities. The other facility utilizes a thermal oxidizer; its emission factors were based on WebFIRE factors for a batch roaster with a thermal oxidizer. Coffee roasting emissions were assumed to be constant throughout the year.

Table 7-6-46 shows the resulting emissions tabulated for the coffee roasters within the nonattainment area. It was assumed that the 2017 activity data for coffee roasters was identical to that in 2019; the estimates in Table 7-6-46 were applied directly within the 2019 Baseline inventory.

Table 7-6-46 Coffee Roasting Emissions within the Fairbanks Nonattainment Area				
		2017 Emissions (tons/year)		
Source Category	SCC Code	PM[a]	VOC	NOx
Coffee Roasters	30200220	0.0101	0.0021	0.0003

[a] DEC's database did not separately report $PM_{2.5}$ and PM_{10}. All PM emissions were assumed to be $PM_{2.5}$.

REMAINING SOURCES - 2014 NEI

The 2014 NEI was used to represent SCC-level annual emissions for all other remaining area source categories that included fugitive dust, commercial cooking, solvent use, forest and structural fires and petroleum project storage and transfer. A number of source categories within the Other Area Source sector from the NEI were estimated to have no emissions during episodic wintertime conditions. These "zeroed" wintertime source categories are listed below (with SCC codes in parentheses).

- Fugitive Dust, Paved Roads (2294000000)
- Fugitive Dust, Unpaved Roads (2296000000)
- Industrial Processes, Petroleum Refining, Asphalt Paving Materials (2306010000)
- Solvent Utilization, Surface Coating, Architectural Coatings (2401001000)
- Solvent Utilization, Miscellaneous Commercial, Asphalt Application (2461020000)
- Miscellaneous Area Sources, Other Combustion, Forest Wildfires (2810001000)
- Miscellaneous Area Sources, Other Combustion, Firefighting Training (2810035000)
- Waste Disposal, Open Burning (2610000100-500, 2610030000)

Some of these source categories, notably those for fugitive dust and forest wildfires, have significant summer season (and annual average) emissions; however, emissions from these categories do not occur during winter conditions in Fairbanks when road and land surfaces are covered by snow and ice.

For all other categories except Construction Dust (SCC 2311010000) emissions were assumed constant throughout the year. Based on discussions with Borough staff, constructions dust was split 37% in winter months (October-March) and 63% in summer months (April-September).

Table 7-6-47 provides a listing of annual emissions (tons/year) by SCC code for these remaining other area source categories for the Fairbanks North Star Borough that were extracted from the 2014 NEI. (Though not shown, similar data were extracted for the other three counties within the modeling domain, Denali, Southeast Fairbanks and Yukon-Koyukuk.)

2014 emissions from the Minor Stationary Source database and the NEI were then forecasted to 2019 using employment growth rates from ADOT/Kittelson socio-economic forecasts for the FMATS (now Fast Planning) 2045 Metropolitan Transportation Plan The 2014-2019 employment growth factor for Fairbanks from the historical ADLWD data was 1.059, reflecting a 1.2% annualized increase from 2014 to 2019. Thus, 2014 NEI emissions were forecasted to 2019 by multiplying 2014 emissions by 1.059.

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Dust - Paved Road Dust - Mobile Sources - Paved Roads - All Paved Roads - Total: Fugitives	2294000000	0.0	0.0	0.0	0.0	114.3	114.3	0.0
Dust - Unpaved Road Dust - Mobile Sources - Unpaved Roads - All Unpaved Roads - Total: Fugitives	2296000000	0.0	0.0	0.0	0.0	1651.3	1651.3	0.0
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Charbroiling - Conveyorized Charbroiling	2302002100	0.6	0.0	0.0	0.0	2.5	0.0	2.5
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Charbroiling - Under-fired Charbroiling	2302002200	2.0	0.0	0.0	0.0	16.1	0.0	16.0
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Frying - Clamshell Griddle Frying	2302003200	0.2	0.0	0.0	0.0	0.2	0.2	0.0
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Frying - Deep Fat Fying	2302003000	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Commercial Cooking - Industrial Processes - Food and Kindred Products: SIC 20 - Commercial Cooking - Frying - Flat Griddle Frying	2302003100	0.3	0.0	0.0	0.0	3.3	0.0	3.3
Industrial Processes - Petroleum Refineries - Industrial Processes - Petroleum Refining: SIC 29 - Asphalt Paving/Roofing Materials - Total	2306010000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Non-Industrial Surface Coating - Solvent Utilization - Surface Coating - Architectural Coatings - Total: All Solvent Types	2401001000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Commercial - Asphalt Application: All Processes - Total: All Solvent Types	2461020000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 2: Spillage	2501060103	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47 Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code								
		2014 ANNUAL EMISSIONS (tons/year)						
SOURCE DESCRIPTION	SCC	VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 2: Displacement Loss/Controlled	2501060102	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Storage and Transfer - Storage and Transport - Petroleum and Petroleum Product Storage - All Storage Types: Working Loss - Gasoline	2501995120	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Storage and Transfer - Storage and Transport - Petroleum and Petroleum Product Storage - All Storage Types: Breathing Loss - Gasoline	2501000120	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fires - Wildfires - Miscellaneous Area Sources - Other Combustion - Forest Wildfires - Wildfires	2810001000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Miscellaneous Area Sources - Other Combustion - Structure Fires - Unspecified	2810030000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Miscellaneous Area Sources - Other Combustion - Firefighting Training - Total	2810035000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Comb - Industrial Boilers, ICEs - Coal - Stationary Source Fuel Combustion - Industrial - Bituminous/Subbituminous Coal - Total: All Boiler Types	2102002000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Comb - Industrial Boilers, ICEs - Oil - Stationary Source Fuel Combustion - Industrial - Distillate Oil - Total: Boilers and IC Engines	2102004000	23.7	66.1	4.9	0.0	5.9	1.6	4.3
Fuel Comb - Industrial Boilers, ICEs - Oil - Stationary Source Fuel Combustion - Industrial - Residual Oil - Total: All Boiler Types	2102005000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Comb - Industrial Boilers, ICEs - Natural Gas - Stationary Source Fuel Combustion - Industrial - Natural Gas - Total: Boilers and IC Engines	2102006000	29.0	528.2	3.2	16.9	2.3	0.6	1.7
Fuel Comb - Industrial Boilers, ICEs - Oil - Stationary Source Fuel Combustion - Industrial - Kerosene - Total: All Boiler Types	2102011000	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Industrial Processes - Oil & Gas Production - Industrial Processes - Oil and Gas Exploration and Production - All Processes - Total: All Processes	2310000000	9.9	23.7	1.0	0.0	3.0	3.0	0.0
Industrial Processes - Oil & Gas Production - Industrial Processes - Oil and Gas Exploration and Production - All Processes : On-shore - Total: All Processes	2310001000	9.9	23.7	1.0	0.0	3.0	0.0	0.0
Dust - Construction Dust - Industrial Processes - Construction: SIC 15 - 17 - Residential - Total	2311010000	0.0	0.0	0.0	0.0	0.5	0.5	0.0
Dust - Construction Dust - Industrial Processes - Construction: SIC 15 - 17 - Industrial/Commercial/Institutional - Total	2311020000	0.0	0.0	0.0	0.0	55.4	55.4	0.0
Solvent - Industrial Surface Coating & Solvent Use - Solvent Utilization - Surface Coating - Traffic Markings - Total: All Solvent Types	2401008000	21.6	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Industrial Surface Coating & Solvent Use - Solvent Utilization - Surface Coating - Machinery and Equipment: SIC 35 - Total: All Solvent Types	2401055000	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Industrial Surface Coating & Solvent Use - Solvent Utilization - Surface Coating - Miscellaneous Manufacturing - Total: All Solvent Types	2401090000	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Degreasing - Solvent Utilization - Degreasing - All Processes/All Industries - Total: All Solvent Types	2415000000	49.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Dry Cleaning - Solvent Utilization - Dry Cleaning - All Processes - Total: All Solvent Types	2420000000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Graphic Arts - Solvent Utilization - Graphic Arts - All Processes - Total: All Solvent Types	2425000000	36.6	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Personal Care Products - Total: All Solvent Types	2460100000	99.5	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Household Products - Total: All Solvent Types	2460200000	109.5	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Automotive Aftermarket Products - Total: All Solvent Types	2460400000	67.7	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Coatings and Related Products - Total: All Solvent Types	2460500000	47.3	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All Adhesives and Sealants - Total: All Solvent Types	2460600000	28.4	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - All FIFRA Related Products - Total: All Solvent Types	2460800000	88.6	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Consumer and Commercial - Miscellaneous Products (Not Otherwise Covered) - Total: All Solvent Types	2460900000	3.5	0.0	0.0	0.0	0.0	0.0	0.0
Solvent - Consumer & Commercial Solvent Use - Solvent Utilization - Miscellaneous Non-industrial: Commercial - Emulsified Asphalt - Total: All Solvent Types	2461022000	9.6	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Permeation	2501011011	2.5	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

SOURCE DESCRIPTION	SCC	2014 ANNUAL EMISSIONS (tons/year)						
		VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Evaporation (includes Diurnal losses)	2501011012	2.8	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Spillage During Transport	2501011013	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Refilling at the Pump - Vapor Displacement	2501011014	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Residential Portable Gas Cans - Refilling at the Pump - Spillage	2501011015	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Permeation	2501012011	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Evaporation (includes Diurnal losses)	2501012012	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Spillage During Transport	2501012013	3.0	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Refilling at the Pump - Vapor Displacement	2501012014	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous Non-Industrial NEC - Storage and Transport - Petroleum and Petroleum Product Storage - Commercial Portable Gas Cans - Refilling at the Pump - Spillage	2501012015	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-6-47
Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code

		2014 ANNUAL EMISSIONS (tons/year)						
SOURCE DESCRIPTION	SCC	VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Bulk Gasoline Terminals - Storage and Transport - Petroleum and Petroleum Product Storage - Bulk Terminals: All Evaporative Losses - Gasoline	2501050120	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 1: Submerged Filling	2501060051	29.3	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 1: Splash Filling	2501060052	8.5	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Stage 1: Balanced Submerged Filling	2501060053	12.7	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Gasoline Service Stations - Underground Tank: Breathing and Emptying	2501060201	8.6	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Airports : Aviation Gasoline - Stage 1: Total	2501080050	38.2	0.0	0.0	0.0	0.0	0.0	0.0
Gas Stations - Storage and Transport - Petroleum and Petroleum Product Storage - Airports : Aviation Gasoline - Stage 2: Total	2501080100	3.9	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Storage and Transfer - Storage and Transport - Petroleum and Petroleum Product Transport - Truck - Gasoline	2505030120	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Storage and Transfer - Storage and Transport - Petroleum and Petroleum Product Transport - Pipeline - Gasoline	2505040120	7.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Processes - Mining - Industrial Processes - Mining and Quarrying: SIC 14 - All Processes - Total	2325000000	3.0	17.8	1.0	0.0	3.9	3.9	0.0
Waste Disposal - Waste Disposal, Treatment, and Recovery - Open Burning - All Categories - Yard Waste - Leaf Species Unspecified	2610000100	1.9	0.4	0.1	0.0	1.2	1.2	0.0

Table 7-6-47 Remaining 2014 NEI-Based Other Area Source Emissions in Fairbanks North Star Borough by SCC Code								
		2014 ANNUAL EMISSIONS (tons/year)						
SOURCE DESCRIPTION	SCC	VOC	NOx	SOx	NH3	PM25-PRI	PM25-FIL	PM-CON
Waste Disposal - Waste Disposal, Treatment, and Recovery - Open Burning - All Categories - Yard Waste - Brush Species Unspecified	2610000400	1.3	0.3	0.1	0.0	1.0	1.0	0.0
Waste Disposal - Waste Disposal, Treatment, and Recovery - Open Burning - All Categories - Land Clearing Debris (use 28-10-005-000 for Logging Debris Burning)	2610000500	73.0	31.5	10.4	0.0	82.5	82.5	0.0
Waste Disposal - Waste Disposal, Treatment, and Recovery - Open Burning - Residential - Household Waste (use 26-10-000-xxx for Yard Wastes)	2610030000	12.7	8.9	1.5	0.0	51.4	51.4	0.0
Waste Disposal - Waste Disposal, Treatment, and Recovery - Landfills - Municipal - Total	2620030000	0.0	2.0	3.0	0.0	0.1	0.1	0.0
Miscellaneous Non-Industrial NEC - Miscellaneous Area Sources - Other Combustion - Charcoal Grilling - Residential (see 23-02-002-xxx for Commercial) - Total	2810025000	1.4	1.7	0.0	0.0	4.4	0.0	0.0
Totals, 2014 NEI Sources		**858**	**704**	**26.1**	**16.9**	**2002**	**1967**	**27.8**

On-Road Mobile Sources

This section of the Emissions Inventory Technical Appendix describes the data/sources, methods and tools/workflow used to estimate on-road vehicle emissions across the Fairbanks SIP modeling domain. EPA's MOVES2014b vehicle emissions model was used to generate detailed fleet emission rates and was combined with EPA's SMOKE-MOVES integration tool to pass the highly-resolved and emission process-specific emission rates into SMOKE-ready input structures for use in preparation of gridded, episodic on-road mobile source emissions.

The sequence of steps in generating gridded episodic on-road mobile emissions using the SMOKE-MOVES Tool[50] consists of: 1) MOVES model processing; 2) meteorological data pre-processing; and 3) SMOKE model processing. This process does not create emission estimates (e.g., in tons/day) as is the case with other sectors of the inventory, but instead emission lookup tables are produced which are used by SMOKE to create photochemical model-ready emission fields. Local inputs were used where available when configuring each of the tools used in the steps of this process. The MOVES input data, resulting look-up tables and final processed emissions fields were developed to reflect episode specific conditions in the Fairbanks region during the spans of the two modeling episodes examined in the SIP's attainment analysis:

- Episode 1 - January 23rd – February 12th, 2008; and
- Episode 2 - November 2nd – November 17th, 2008.

The first sub-section discusses MOVES model processing, documenting assembly of model input data. It also describes the meteorological data pre-processing and emission rate processing performed using SMOKE-MOVES sources. The next sub-section explains the importing and model execution workflows used to generate vehicle emission rates processed through SMOKE-MOVES, including generation of lookup tables and processing performed within SMOKE.

Development of MOVES Inputs

Following EPA guidance for use of MOVES in SIP inventory applications, local data were assembled and analyzed to supply regional vehicle fleet and travel activity inputs to the model. Prior to detailed explanations of how the data inputs were developed, the key sources of local data are summarized below.

Key Data Sources - MOVES vehicle activity inputs were based primarily on data gathered as part of the conformity analysis for the Fast Planning (formerly FMATS) 2045 Metropolitan Transportation Plan (MTP)[51]. FMATS is the Metropolitan Planning Organization (MPO) for Fairbanks (In 2019, FMATS transitioned to the Fairbanks Area Surface Transportation Planning organization – FAST Planning). The 2045 MTP was based on the same 2013 baseline travel

[50] B. Baek, A. DenBleyker, "User's Guide for the SMOKE-MOVES Integration Tool", prepared for U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, July 14, 2010. http://www.cmascenter.org/smoke/documentation/smoke_moves_tool/SMOKE-MOVES_Tool_Users_Guide.pdf
[51] M. Malchow, T. Carlson, "Conformity Analysis for the FMATS 2045 Metropolitan Transportation Plan (MTP), prepared for Fairbanks Metropolitan Area Transportation System, January 23, 2019.

modeling network as its predecessor, the 2040 MTP. Inputs from that conformity analysis were derived from local transportation modeling efforts, vehicle registration data, and other local data, each of which is discussed separately below.

Regional Travel Demand Modeling - Vehicle activity on the FMATS transportation network was based on the TransCAD travel demand modeling performed for 2045 MTP (identical to the 2040 MTP base network as noted above). The TransCAD modeling network covers the entire FNSB $PM_{2.5}$ Non-Attainment Area (NAA) and its major links extend beyond the nonattainment area boundary as illustrated below in Figure 7-6-34.

Figure 7-6-34
FMATS TransCAD Modeling Network

The TransCAD model was configured using 2010 U.S. Census-based socioeconomic data. TransCAD modeling was performed for a 2013 base year and a projected 2045 horizon year. Population and employment forecasts were based on an average of historical growth rates, combined with Alaska Department of Labor population forecasts and studies conducted by Woods & Poole Economics. These projections explicitly accounted for increased travel associated with the population and employment growth triggered by the F-35 deployment at Eielson Air Force Base.

Attachment C provides further details on the travel demand model development.

Link-level TransCAD outputs were processed to develop several of the travel activity related inputs required by MOVES. Vehicle miles traveled (VMT) tabulated across the TransCAD network for key years for which Final 2045 MTP travel model outputs were available are presented below in Table 7-6-48**Error! Reference source not found.**.

Table 7-6-48
TransCAD Average Daily VMT by Year and Daily Period, Final 2045 MTP Forecast

Daily Period	2013	2019	2024	2025	2029	2035	2045
Entire TransCAD Modeling Network							
AM Peak	253,497	276,312	309,883	315,267	335,153	363,142	414,901
PM Peak	501,870	558,215	634,785	646,926	692,378	756,436	866,833
Off Peak	1,374,276	1,524,386	1,730,719	1,762,352	1,882,479	2,051,737	2,337,955
Daily Total	**2,129,642**	**2,358,912**	**2,675,387**	**2,724,546**	**2,910,010**	**3,171,315**	**3,619,689**
VMT Growth (2013=1.0)		1.108	1.256	1.279	1.366	1.489	1.700
PM Nonattainment Area							
AM Peak	205,465	220,221	244,801	248,669	262,920	282,982	320,515
PM Peak	400,283	439,227	495,365	504,213	536,915	582,865	662,054
Off Peak	1,092,896	1,195,145	1,345,403	1,368,250	1,453,659	1,573,484	1,774,618
Daily Total	**1,698,644**	**1,854,594**	**2,085,569**	**2,121,132**	**2,253,495**	**2,439,331**	**2,757,187**
VMT Growth (2013=1.0)		1.092	1.228	1.249	1.327	1.436	1.623

Vehicle Activity Beyond FMATS Network – The geographic extent of the FMATS network covers a small portion of the entire Grid 3 attainment modeling domain. Traffic density in the broader Alaskan interior is likely to be less than that concentrated in Fairbanks (and have less impact on ambient air quality in Fairbanks). Nevertheless, for completeness link-level travel estimates for major roadways beyond the FMATS network (and FNSB PM NAA) were developed using a spatial (ArcGIS-compatible) "Road Centerline" polyline coverage for the Interior Alaska region developed by the Alaska Department of Transportation and Public Facilities (ADOT&PF). This GIS layer identified locations of major highway/arterial routes within the Grid 3 domain broken down into individual milepost (MP) segments.

These road centerline segments are shown in red in Figure 7-6-35 along with the smaller FMATS link network (green lines) and the extent of the SIP Grid 3 modeling domain (blue rectangle). Annual average daily traffic volumes (AADT) and VMT (determined by multiplying volume by segment length) were assigned to each segment based on a spreadsheet database of calendar year 2013 traffic volume data compiled by ADOT&PF's Northern Region office. A Linear Reference System (LRS) approach was used to spatially assign volume and VMT data for each segment in the spreadsheet database to the links in the Road Centerline layer based on the route identifier number (CDS_NUM) and lineal milepost value.

Figure 7-6-35
Additional ADOT&PF Roadway Links beyond FMATS Network

DMV Registration Data – DEC obtained a dump or snapshot of statewide vehicle registrations from the Alaska Division of Motor Vehicle (DMV) as of April 2018. The Alaska DMV database includes vehicle make, model, model year, Vehicle Identification Number (VIN), vehicle class code, body style, registration status, expiration date and owner/operator address information. A subset of valid data for the FNSB NAA was created by extracting records from the statewide database based on current registration status and owner/operator ZIP codes located within the NAA.

As described in greater detail later under "MOVES Fleet Inputs", DEC also applied a licensed VIN decoder to the VINs for the FNSB NAA subset that provided additional vehicle attribute information that was used along with the DMV attributes to classify vehicles into the MOVES Source Use Type fleet classification scheme.

Seasonal Vehicle Activity Surveys – DEC has conducted a series of wintertime vehicle surveys in parking lots for commonly-frequented businesses (e.g., shopping centers) in Fairbanks in part as a cross-check to vehicle Inspection and Maintenance (I/M) program enforcement conducted by the Borough and to identify any seasonal variations in vehicle use. In conducting the surveys, personnel are stationed at various locations within the surveyed lots (over multiple days) and record license (and make/model) information for vehicles passing/parking within their viewing area. The results are then bounced against the DMV database to determine each vehicle's model year.

The most recent set of parking lot surveys was conducted in early 2009. As described in detail later, this and similar earlier surveys (with sample sizes of several thousand vehicles each) have found a clear, recurrent pattern that older vehicles tend to be driven less during winter because of drivability concerns under the harsh Arctic conditions.

MOVES Fleet Inputs - Outputs from several of the sources summarized earlier were used to develop the vehicle fleet-related inputs to the MOVES model runs. Each of these fleet-related MOVES inputs is described separately below. (The names of the individual inputs within MOVES are listed in parentheses.)

Vehicle Populations (Source Type Population & Age Distribution) - DMV registrations from the Alaska Division of Motor Vehicles (DMV) and 2009 Fairbanks Parking Lot Survey data provided the basis for the vehicle fleet populations and age distributions used to model the Fairbanks vehicle fleet with MOVES. As noted earlier, the DMV database includes vehicle make, model, model year, Vehicle Identification Number (VIN), vehicle class code, body style, registration status and expiration date.

Using a VIN decoding tool licensed by DEC, supplemental information such as vehicle class, gross vehicle weight, vehicle type, body type and fuel type (e.g., gasoline vs. diesel) were also determined in order to help classify each vehicle into one of the 13 MOVES Source Use Type categories. Vehicle attribute fields from the DMV database (Class Code, Body Style), and VIN decoder outputs (Vehicle Class, GVWR Class, Vehicle Type, Body Type) were used to categorize each vehicle record into one of the 13 usage-based "Source Type" categories as defined in MOVES to characterize the vehicle fleet.

Table 7-6-49 lists each of these "Source Type" categories and identifies the primary vehicle attribute fields in either the DMV database itself (DMV) or output from the VIN decoder (Decoder) that were used to determine the Source Type for each vehicle record.

For nearly all the records, the Source Type could be conclusively determined from specific combinations of these attributes. In some cases, such as Source Types 51 (Refuse Trucks) and 54 (Motorhomes), single values of the Body Style field in the DMV database were used to discern the appropriate Source Type. In other cases, Source Types were assigned based on categorical values in several attribute fields as noted in Table 7-6-49. In a few cases, vehicle make and model fields were also examined and then fed to a web-based search engine to identify whether the vehicle was a single or combination-unit truck.

Table 7-6-49 MOVES Vehicle Fleet Source Type Categories		
Source Type ID	Source Type Description	Primary Attributes/Sources
11	Motorcycle	Class Code (DMV), Body Style (DMV) – Categories MB and MC, Vehicle Type (Decoder), Vehicle Class (Decoder)
21	Passenger Car	Class Code (DMV), Vehicle Type (Decoder) , Vehicle Class (Decoder)
31	Passenger Truck	Class Code (DMV), Vehicle Type (Decoder) , Vehicle Class (Decoder)
32	Light Commercial Truck	Class Code (DMV), Vehicle Class (Decoder), GVWR Class (Decoder) – up to Class 4 (14,001-16,000 lb)
41	Intercity Bus	Class Code (DMV), Body Style (DMV), Vehicle Type (Decoder), Vehicle Class (Decoder)
42	Transit Bus	Class Code (DMV), Body Style (DMV), Vehicle Type (Decoder), Vehicle Class (Decoder)
43	School Bus	Class Code (DMV), Body Style (DMV), Vehicle Type (Decoder), Vehicle Class (Decoder)
51	Refuse Truck	Body Style (DMV) – Category GG
52	Single Unit Short-haul Truck	Class Code (DMV), Body Style (DMV), Vehicle Class (Decoder), GVWR Class (Decoder) – Class 6 and above
53	Single Unit Long-haul Truck	Apportioned from MOVES default 52/53 splits
54	Motor Home	Body Style (DMV) – Category MH
61	Combination Short-haul Truck	Class Code (DMV), Body Style (DMV), Vehicle Class (Decoder) – Category "Truck Tractor", GVWR Class (Decoder), Fuel Type (Decoder)
62	Combination Long-haul Truck	Apportioned from MOVES default 61/62 splits

As also noted in Table 7-6-49, the DMV and VIN decoder attribute data were not sufficient to distinguish between short-haul trucks (Source Types 52 and 61) and long-haul trucks (Source Types 53 and 62). All of the single and combination-unit truck records were assigned short-haul Source Type categories of either 52 or 61. The *SourceTypeYear* table in the MOVES database was then queried to extract nationwide vehicle populations for Source Type categories 52, 53, 61 and 62. Relative splits between short- and long-haul vehicle fractions in these categories were then calculated and used to estimate the populations of long-haul single-unit (53) and combination-unit (62) vehicles in the Fairbanks fleet.

Table 7-6-50 shows the resulting summation of vehicles by their sourceTypeID as determined from the VIN decoder and DMV data for the year 2018. The 2018 population data were scaled to 2019 values by forecasting the vehicle population based on the VMT rates of growth from 2013 to 2019. The VMT growth rates are derived for each individual HPMS vehicle type ID and then translated to MOVES source type ID. For the light duty vehicle fleet the annual rate of change in VMT was found to be 1.4%. The 2019 forecasted populations are shown in the rightmost column of Table 7-6-50.

Table 7-6-50
Fairbanks Baseline Vehicle Populations by MOVES Source Type

Source Type ID	Source Type Description	Vehicle Populations	
		2018 DMV	2019 Forecast
11	Motorcycle	4,194	4,254
21	Passenger Car	22,196	22,511
31	Passenger Truck	60,781	61,645
32	Light Commercial Truck	5,171	5,245
41	Intercity Bus	172	174
42	Transit Bus	103	104
43	School Bus	176	179
51	Refuse Truck	45	46
52	Single Unit Short-haul Truck	1,267	1,285
53	Single Unit Long-haul Truck	54	55
54	Motor Home	1,938	1,966
61	Combination Short-haul Truck	621	630
62	Combination Long-haul Truck	734	745
Total Vehicle Fleet		**97,452**	**98,837**

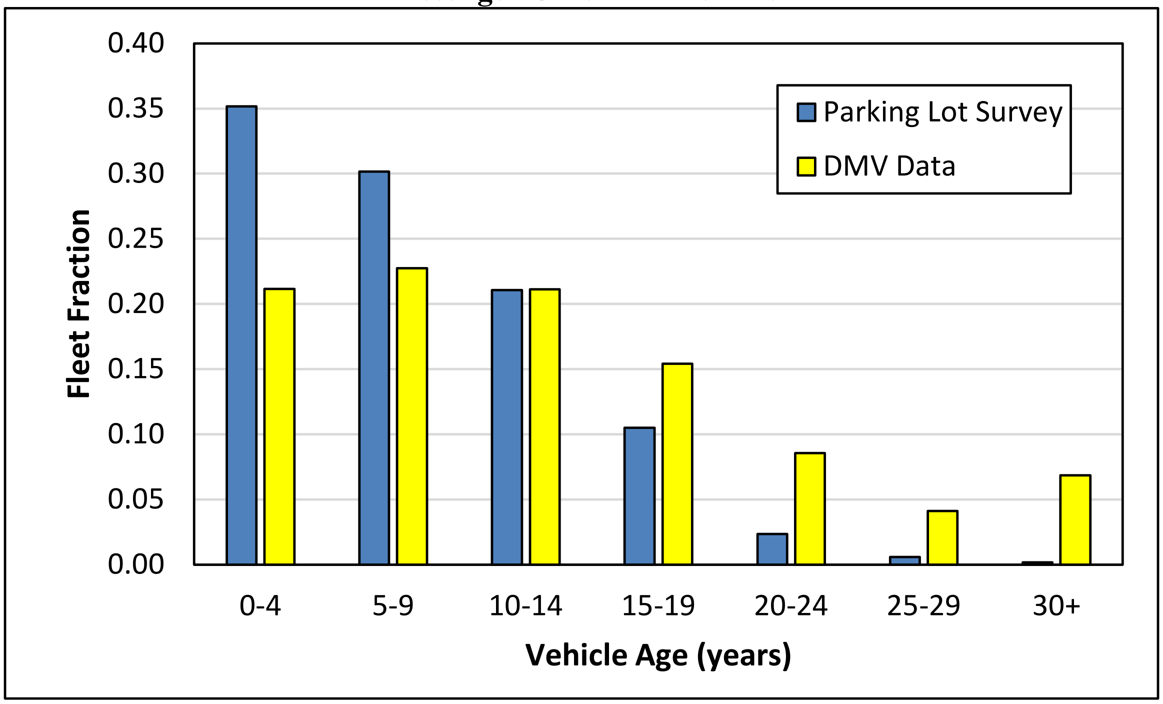
[a] As explained later, motorcycle activity in Fairbanks during the winter months was assumed to be zero.

The DMV registration data also identified the model year of the vehicle, which enabled distributions of populations by vehicle age[52] to be calculated for each Source Type and input to MOVES. For the three light-duty passenger vehicle types (11-motorcycles, 21-passenger cars, and 31-passenger trucks), vehicle age distributions from winter parking lot surveys[53] conducted by DEC in Fairbanks during January and February 2009 were used instead of those based on DMV registrations. This is because it was found in both these 2009 surveys as well as similar parking lot surveys conducted earlier by DEC in 2005 and 2000 that older passenger vehicles are driven less during harsh winter conditions in Fairbanks.

[52] Vehicle age in years was simply calculated by subtracting the model year from 2010, the calendar year in which the DMV database obtained.
[53] The purpose of the surveys was to collect data for assessing the performance of the I/M Program. A review of the location of the surveys found broad representation beyond the boundary of the CO nonattainment area in Fairbanks, North Pole, and Chena Ridge areas. While no data were collected in Goldstream Valley, the results sufficiently represent the $PM_{2.5}$ nonattainment area to be used in the analysis.

Figure 7-6-36 compares the vehicle age fractions (by age group) for light-duty passenger cars in Fairbanks developed from the DMV registrations and the Parking Lot Surveys. As Figure 7-6-36 clearly shows, vehicle fractions in the newer groups (< 15 years) from the Parking Lot Surveys are distinctly higher than from the DMV registrations. This pattern is reversed for the older vehicle groups (15 or more years old).

Figure 7-6-36
Comparison of DMV and Survey-Based Vehicle Age Distributions of Passenger Cars in Fairbanks



Another expected finding from the Fairbanks parking lot surveys is that motorcycles are simply not operated during cold wintertime conditions. Although motorcycles make up roughly 5% of the Fairbanks-registered vehicle fleet, as shown earlier in Table 7-6-50, only a single motorcycle was identified in the entire sample of over 8,500 vehicles from the 2009 Fairbanks surveys (which represents 0.01% of the survey sample).

Thus, for Source Type categories 11 (motorcycles), 21 (passenger cars) and 31 (passenger trucks), vehicle age distributions were based on the Parking Lot Survey data to reflect well-documented winter season shifts toward greater use of newer vehicles in the passenger car and passenger truck fleets as well as non-use of motorcycles during winter months. These survey-based winter seasonal adjustments for Fairbanks have been employed in wintertime emission inventories developed in previous CO SIPs and transportation conformity determinations that have been approved by EPA and FHWA.

For the remaining MOVES source type categories (32 and above), age distributions were based on the DMV registration data for Fairbanks These age distributions developed for the 2019 Baseline fleet were projected to future calendar year fleets using EPA's MOVES2014-based Age

Distribution Projection Tool.[54]

Gasoline vs. Diesel-Fueled Vehicle Fractions (AVFT Strategies) – MOVES provides users the ability to override its default nationwide based travel splits between different fuels and technologies. These Alternative Vehicle Fuel and Technology (AVFT) inputs are supplied to MOVES through the Strategies panel in the user interface, not the County Data Manager.

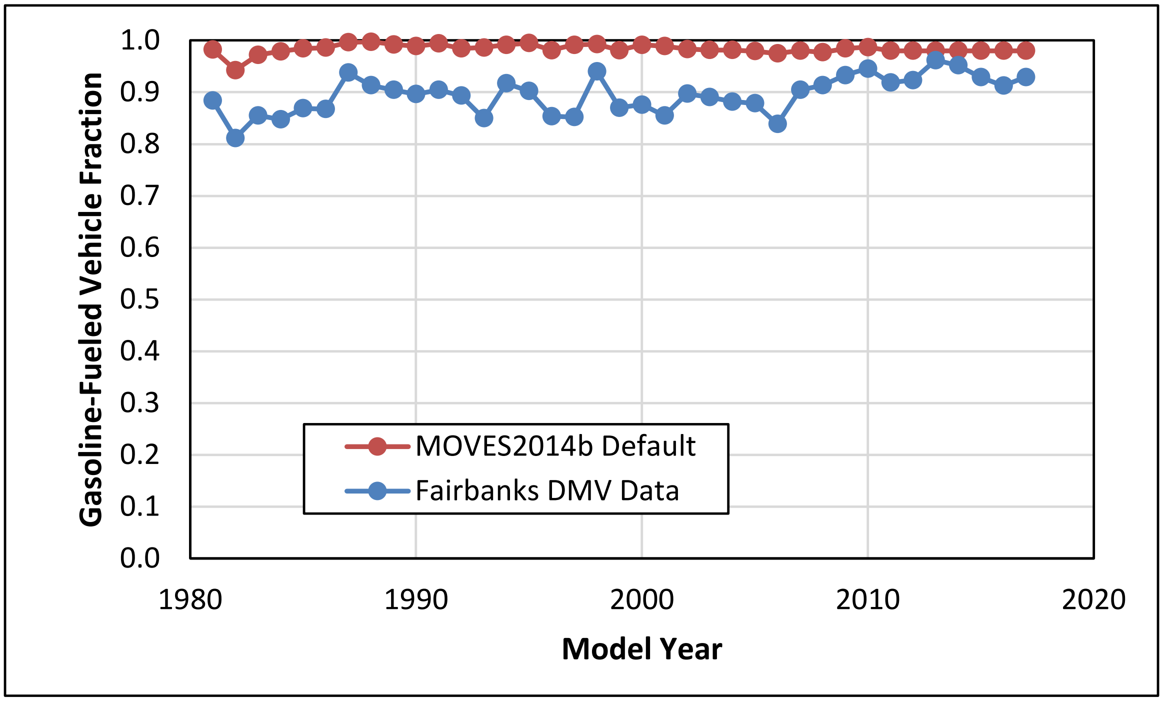
In order to account for differences in splits between gasoline- and diesel-fuel vehicles in the Fairbanks fleet compared to the U.S. as a whole, fuel fraction tables by source type and model year were also constructed using the DMV VIN decoded data described earlier. Not surprisingly, the MOVES default splits between gasoline and diesel vehicles was not representative of the Fairbanks fleet. Gasoline fractions were found to be lower in Fairbanks than the nationwide-based MOVES defaults (and diesel fractions were commensurately higher).

This is illustrated in Figure 7-6-37, which compares the gasoline vehicle fractions by model year for passenger trucks (MOVES Source Type 31) from the Fairbanks DMV data against the default fractions contained in MOVES. As seen in Figure 7-6-37, actual gasoline vehicle fractions for passenger trucks in Fairbanks are roughly 10% lower than the MOVES defaults (meaning diesel fractions are roughly 10% higher). Modest differences were also observed for some of the commercial vehicle categories as well.

As illustrated by the range of model years compared in Figure 7-6-37, DMV VIN decoder-based gasoline vs. diesel vehicle fractions were available only for model years 1981 through 2009 (the VIN decoder only operates on 1981 and later models). In setting up the AVFT fuel split input to MOVES, the fuel fractions must be specified by model year, not vehicle age. For earlier model years prior to 1981, the MOVES default fractions were used. For model years 2014 and later, the DMV-based fuel type fractions from model year 2014 were generally assumed to remain constant in future model years except in the passenger truck category where the MOVES defaults reflect a modest increase in diesel penetration in future model years. For passenger trucks in model years 2014 and later, the MOVES defaults were used.

[54] https://www.epa.gov/moves/tools-develop-or-convert-moves-inputs#fleet

Figure 7-6-37
Comparison of Passenger Truck Gasoline-Fuel Vehicle Fractions by Model Year
Fairbanks DMV Data vs. MOVES Defaults



Travel Activity (VMT) – Estimates of VMT over the FMATS modeling network (covering the entire $PM_{2.5}$ NAA) from the TransCAD travel model link output files were processed and input to MOVES through the "Vehicle Type VMT" input within the County Data Manager. The Vehicle Type VMT input must be in units of VMT per year, not VMT per day. The annual VMT must also be supplied by "HPMS Vehicle Type"[55] which is essentially an aggregated version of the 13-category MOVES Source Type scheme. Since states are required to provide periodic travel (i.e., VMT) estimates to FHWA via the Highway Performance Monitoring System (HPMS), EPA has designed MOVES to accept VMT input by these HPMS Vehicle Type categories.

Table 7-6-51 shows the mapping of Source Type to HPMS Vehicle Type categories. These mappings were based on FHWA's "VM-1" allocations as listed in EPA's latest MOVES2014 User's Guide.[56] It also shows how the Fairbanks baseline vehicle populations shown earlier in Table 7-6-50 were aggregated into the HPMS Vehicle Type categories.

[55] Although MOVES2014b allows VMT input by either the 13-category Vehicle Type scheme or the 5-category HPMS Type scheme, SMOKE-MOVES only supports the latter.
[56] "MOVES2014a User's Guide," U.S. Environmental Protection Agency, Report No. EPA-420-B-15-095, November 2015.

Table 7-6-51
MOVES Source Type to HPMS Vehicle Type Mapping

Source Type ID	Source Type Description	HPMS VehType ID	HPMS Vehicle Type Description	2018 DMV Vehicle Popn.
11	Motorcycle	10	Motorcycles	4,194
21	Passenger Car	25	Light-duty vehicles	22,196
31	Passenger Truck			60,781
32	Light Comm. Truck			5,171
41	Intercity Bus	40	Buses	451
42	Transit Bus			
43	School Bus			
51	Refuse Truck	50	Single Unit Trucks	3,304
52	Single SH Truck			
53	Single LH Truck			
54	Motor Home			
61	Comb. SH Truck	60	Combination Trucks	1,355
62	Comb. LH Truck			
Total Vehicle Fleet				**97,452**

HPMS data for the Fairbanks urban planning area provided by ADOT&PF[57] were analyzed and used to determine the locally-based VMT split between light- and heavy-duty vehicles. This local VMT split was found to be 93% "Passenger/Light-Duty" and 7% "Commercial/Heavy-Duty". Since the ADOT&PF classifications separate passenger from commercial vehicles; their "Light-Duty Passenger" category includes only MOVES Source Types 11, 21 and 31 (but not 32) as shaded in green in Table 7-6-51. The remaining "Commercial/Heavy Duty" category includes MOVES Source Types 32 through 62 as highlighted in tan within Table 7-6-51. Thus prior to aggregating activity data into the five-category HPMS scheme, VMT allocations were performed at the more resolved Source Type level since it maps into the two groups of local VMT splits obtained from ADOT&PF.

The first step in generating these VMT allocations by Source Type consisted of running MOVES2014b in "default" mode to generate MOVES default-based annual mileage accumulation rates (miles/year/vehicle) by Source Type for calendar year 2018, the year for which DMV-based populations were obtained. Table 7-6-52 shows the calendar year 2018 default mileage rates and vehicle populations along with the ADOT&PF-based Passenger/Light-Duty vs. Commercial/Heavy-Duty VMT splits in the leftmost columns. The cell shading is used within Table 7-6-52 to show which Source Types these VMT splits apply to.

[57] Email from Jennifer Anderson, Alaska Department of Transportation, Fairbanks 2018 HPMS Sections (csv file), November 2, 2018.

Table 7-6-52 Allocation of Local VMT Splits by Source Type for DMV Year 2018								
Source Type ID	ADOT&PF HPMS VMT Split	DMV Vehicle Popn.	MOVES Annual Default Mileage (miles/year-veh)	Default VMT (miles/day)	Aggregated VMT/Day			Allocated TransCAD VMT/Day
					Default	TransCAD	Ratio	
11	93.0%	4,194	2,191	25,172	2,689,655	1,700,600	1.582	15,915
21		22,196	10,756	654,064				413,548
31		60,781	12,073	2,010,419				1,271,137
32	7.0%	5,171	12,132	171,882	536,914	128,002	4.194	40,977
41		172	84,726	39,926				9,518
42		103	45,526	12,847				3,063
43		176	14,065	6,782				1,617
51		45	22,704	2,799				667
52		1,267	14,649	50,852				12,123
53		54	19,564	2,891				689
54		1,938	2,086	11,077				2,641
61		621	33,899	57,651				13,744
62		734	89,581	180,207				42,962
Totals	100%	97,452		3,226,569		**1,828,602**[a]		**1,828,602**

[a] 2018 VMT interpolated from 2013 and 2019 TransCAD travel model outputs.

As shown in Table 7-6-52, the next step consisted of calculating "Default" VMT by Source Type as the product of population and the MOVES-based annual mileage rates. For Source Type 21 for example:

$$Default\ VMT_{21} = Popn_{21} \times Mileage_{21} = 22{,}196 \times 10{,}756 / 365\ days/year = 654{,}064\ miles/day$$

The Default VMT was then aggregated into the Passenger vs. Commercial groups and compared to the VMT based on the local TransCAD travel model. As noted at the bottom of Table 7-6-52, 2018 travel model VMT was interpolated from TransCAD outputs for 2013 and 2019. This value, 1,828,602 miles/day for the nonattainment area, was then apportioned into the Passenger vs. Commercial groups using the 93% and 7% splits to yield the values of 1,700,600 and 128,002 VMT/day shown in the "Aggregated/TransCAD" column of Table 7-6-52. The ratio between the Default and TransCAD aggregated VMT in each group was then computed and used to allocate the total TransCAD-based VMT by individual Source Type shown in the rightmost column of Table 7-6-52. For Source Type 21 for example:

$$TransCAD\ VMT_{21} = Default\ VMT_{21} / Ratio_{Passenger} = 654{,}064 / 1.582 = 413{,}548\ miles/day$$

With this approach, the MOVES-based mileage rates are essentially used to scale VMT by Source Type within the larger Passenger and Commercial groups and yet preserve travel model-based total fleet VMT. VMT allocations by Source Type for other calendar years were similarly generated starting with TransCAD travel model VMT split into the Passenger and Commercial groups based on the 93%/7% splits from ADOT&PF.

Table 7-6-53 shows the resulting VMT allocations by Source Type for the key analysis years that preserve total fleet VMT produced by the TransCAD travel model outputs. The total daily fleet VMT at the bottom of Table 7-6-53 matches that for each calendar year presented earlier in Table 7-6-48.

Table 7-6-53
Fairbanks Nonattainment Area Allocated VMT by Calendar Year and Source Type

Source Type ID	Source Type Description	Nonattainment Area VMT (miles/day)				
		2019	2020	2023	2024	2026
11	Motorcycle	16,142	16,544	17,750	18,152	18,751
21	Passenger Car	419,426	429,873	461,215	471,662	487,223
31	Passenger Truck	1,289,205	1,321,317	1,417,653	1,449,765	1,497,595
32	Light Comm. Truck	41,560	42,595	45,701	46,736	48,278
41	Intercity Bus	9,654	9,894	10,616	10,856	11,214
42	Transit Bus	3,106	3,184	3,416	3,493	3,608
43	School Bus	1,640	1,681	1,803	1,844	1,905
51	Refuse Truck	677	694	744	761	786
52	Single SH Truck	12,296	12,602	13,521	13,827	14,283
53	Single LH Truck	699	716	769	786	812
54	Motor Home	2,678	2,745	2,945	3,012	3,111
61	Comb. SH Truck	13,940	14,287	15,328	15,676	16,193
62	Comb. LH Truck	43,573	44,658	47,914	48,999	50,616
Total Vehicle Fleet		**1,854,594**	**1,900,789**	**2,039,374**	**2,085,569**	**2,154,375**

As explained earlier, these VMT data were then mapped to the 5-category HPMS scheme for compatibility with SMOKE/MOVES VMT input requirements.

Scaling of Base Populations – Based on the allocated VMT for each calendar year, vehicle populations by Source Type were then scaled from the relationship between DMV populations and VMT in 2018 keeping annual mileage rates constant. (MOVES2014b default mileage rates from 2013-2032 were examined and found to exhibit very modest variation, so this approach was assumed to be reasonable.)

Beyond Network VMT - VMT on roadways outside the FMATS travel modeling network was calculated using the aforementioned spatial roadway VMT layer developed from merging the ADOT&PF Road Centerlines shapefile with 2013 AADT traffic volumes for those roads published by ADOT&PF's Northern Region office. Within ArcGIS, a masking operation was performed to discard the Road Centerlines layer segments corresponding to roadways already in and accounted from the FMATS travel model network. For 2013, total "outside FAST/FMATS network" VMT was 560,923 miles per annual average day, which was about three times lower than the total daily VMT within the FAST Planning/FMATS network. VMT growth in future years was applied based on county specific Alaska Department of Labor and Workforce

Development (ADLWD) population forecasts.[58] Annualized growth rates from 2019-2024 based on these ADLWD forecasts were as follows: FNSB=+1.6%, Denali=-0.4%, Southeast Fairbanks=+0.7% and Yukon-Koyukuk=-0.8%. The distributions by HPMS vehicle type were assumed to be the same as that within the FMATS network.

Vehicle populations beyond the nonattainment area were developed from the same statewide 2018 DMV database. Separate queries of vehicle registrations by county and zip code were used to extract just those withing the Fairbanks nonattainment area, versus those in the four counties spanning the entire modeling domain. The "beyond nonattainment area" 2018 vehicle populations were similarly projected as performed within the nonattainment area.

Other MOVES Inputs – The remaining MOVES modeling inputs representing the FNSB $PM_{2.5}$ nonattainment area included seasonal, daily and diurnal travel fractions; travel activity by speed range (or bin) and roadway type; freeway ramp fractions; ambient temperature profiles; I/M program inputs; and fuel specifications. Each of these inputs was supplied to MOVES to represent Fairbanks specific conditions through the model's County Data Manager Importer and are discussed separately below.

Monthly, Day-of-Week and Hourly VMT Fractions – In conjunction with VMT by HPMS Vehicle Type, MOVES also requires inputs of monthly, weekday/weekend, and hourly travel fractions. Based on data assembled by ADOT&PF from 2013 seasonal traffic counts, traffic within the FMATS modeling area exhibits a seasonal variation such that roughly 92% of annual average daily travel within the $PM_{2.5}$ nonattainment area occurs on average winter days (with 108% occurring on average summer days). These seasonal variations were incorporated into the MonthVMTFraction input table.

Day-of-week and hourly VMT fractions were similarly developed from the 2013 ADOT&PF data. The day-of-week fractions were then converted into Weekday vs. Weekend fractions as required for input to MOVES.

Travel by Speed Bin and Roadway Type (Average Speed & Road Type Distributions) – Link-level TransCAD model output files were processed to prepare these two sets of MOVES inputs for each analysis year.

The roadway type classification scheme employed in MOVES consists of the following five categories:

1. Off-Network;
2. Rural, Restricted Access;
3. Rural, Unrestricted Access;
4. Urban, Restricted Access; and
5. Urban, Unrestricted Access.

[58] http://live.laborstats.alaska.gov/pop/projections.cfm, as of May 2020.

The "Off-Network" category is used by MOVES to represent engine-off evaporative or starting emissions that occur off of the travel network. For SIP and regional conformity analysis, EPA's MOVES guidance indicated that the user must supply Average Speed Distribution and Road Type Distribution inputs for the remaining on-network road types (2 through 5), but direct MOVES to calculate emissions over all five road types. In this manner, starting and evaporative emissions are properly calculated and output.

The first of the two sets of inputs, Average Speed Distributions, consists of time-based[59] (not distance-based) tabulations of the fractions of travel within each of MOVES' 16 speed bins (at 5 mph-wide intervals) by road type and hour of the day. These inputs were calculated from the TransCAD link outputs by time of day. The TransCAD outputs consisted of travel times, average speeds and vehicle volumes for each link in the expanded modeling network for each of three daily periods:

1) AM Peak (7-9 AM);
2) PM Peak (3-6 PM); and
3) Off-Peak (9 AM-3 PM, plus 6 PM-7 AM).

Spreadsheet calculations were performed on the TransCAD link outputs to calculate time-based travel (multiplying link travel time by vehicle volume to get vehicle hours traveled or VHT) across all links. The link VHT was then allocated by MOVES road type and average speed bin. (The link classification scheme employed in the TransCAD modeling could easily be translated to the MOVES Rural/Urban and Limited/Unlimited Access road types.) Normalized speed distributions (across all 16 bins) were then calculated for each road type and time of day period and formatted for input into MOVES.

Similar spreadsheet calculations were also performed to tabulate distance-based (i.e., VMT-based) Road Type Distribution inputs to MOVES.

Freeway Ramp Fractions (Ramp Fraction) – MOVES uses default values of 8% (or 0.08) to represent the fraction of time-based limited access roadway travel (Road Types 2 and 4) that occur on freeway ramps. Fairbanks-specific ramp fraction values were tabulated from the TransCAD link level outputs and were supplied to MOVES in the Ramp Fraction input section of the County Data Manager to override the nationwide-based defaults.

Ambient Temperature Profiles (Meteorology Data) – Episodic average temperature profiles were created per the guidance in the SMOKE-MOVES model documentation using the MET4MOVES. Some MET4MOVES code modifications were made to allow for sub-monthly temperature profiles to be generated. Code changes are detailed in the SMOKE modeling appendix. Different temperature profiles are required as inputs for a number of MOVES runs to create lookup tables for rate per distance, rate per vehicle and rate per profile activities. The modified MET4MOVES program was operated using a version of the run_met4moves.csh script included with the 2.7.1 version of SMOKE. The dates of the episode days, surrogates and ASSIGNS file were updated to reflect the SMOKE configuration for the baseline modeling

[59] MOVES requires Average Speed Distribution inputs on a time-weighted basis and Road Type Distribution inputs on a distance-weighted basis.

episodes. Two script runs of the *run_met4moves.csh* file were performed to generate different average meteorology profiles for each episode. The MET4MOVES program requires the met field inputs already be processed through the Meteorology-Chemistry Input Processor (MCIP) software.

The domain-wide ground level average relative humidity (RH), minimum and maximum temperatures for each modeling episode are presented in Table 7-6-54. These outputs have been rounded down to the nearest 5-degree increment in the case of the minimum temperature and up to the nearest 5-degree increment in the maximum temperature case.

Table 7-6-54
Fairbanks Model Domain Episodic Meteorology Conditions

Episode	Relative Humidity	Min. Temperature (F)	Max.Temperature (F)
Episode 1 (Jan - Feb)	72.3%	-50.0	30.0
Episode 2 (Nov)	82.3%	-20.0	35.0

Daily temperature profiles for each of the episodes are presented in Table 7-6-55. These profiles have been scaled to reflect the maximum and minimum temperatures for those respective episodes. These profiles form the basis of the RPV and RPP MOVES simulation meteorology inputs that are generated by the RunSpec generator script.

The RunSpec generator script has been rewritten to use the average RH, minimum temperature, maximum temperature and average profiles to create the RPD, RPV and RPP meteorology input fields.

Table 7-6-55 Fairbanks Model Domain Episodic Average Temperature Profiles		
Hour	Episode 1 Temperature (F)	Episode 2 Temperature (F)
1	-33.7	-17.8
2	-38.0	-20.0
3	-42.9	-18.5
4	-47.2	-13.1
5	-48.2	-16.2
6	-46.4	-17.1
7	-46.6	-15.6
8	-48.5	-19.8
9	-50.0	-18.8
10	-48.9	-18.2
11	-48.7	-9.0
12	-36.5	4.7
13	-10.6	14.7
14	15.7	26.6
15	30.0	35.0
16	29.1	32.3
17	12.3	19.7
18	-3.0	8.9
19	-11.6	0.8
20	-18.1	1.4
21	-22.1	-2.1
22	-26.2	-9.8
23	-31.4	-14.0
24	-29.2	-17.4

I/M Program Data (I/M Programs) – Since the Fairbanks Inspection and Maintenance (I/M) program was terminated at the end of 2009, the “Use I/M Program” input element to MOVES was set from “Yes” to “No” to account for the elimination of the program.

Fuel Property Inputs – Fuel property inputs (e.g., fuel volatility, sulfur level, ethanol volume, aromatic, olefins and benzene content, etc.) were based on MOVES defaults for Fairbanks with one exception discussed below. In MOVES2014b, Fairbanks is grouped within Fuel Region 6, which includes Alaska and rural portions of California, Nevada, Arizona and Hawaii where Reformulated Gasoline (RFG) is not required. In consultation with EPA, the defaults were chosen over industry-based survey data[60] collected in Fairbanks which tend to be limited to a small number of fuel samples. The MOVES default fuel properties for this non-RFG region assume a 10% ethanol blend level in gasoline. Although this “E10” blend level is used for gasoline in the lower-48, there is no ethanol blending in Alaska. Thus, the MOVES2014b “Fuel Wizard” tool was used to zero the gasoline ethanol content and properly adjust the other fuel properties that would be affected by this change. The Fuel Wizard has been designed in MOVES2014b to be consistent with EPA refinery modeling based on the Tier 3 Motor Vehicle Emissions and Fuel Standards rulemaking.

[60] Bi-annual fuel surveys across 30 U.S. cities conducted by the Alliance of Automobile Manufacturers 1999-2017.

Table 7-6-56 shows the MOVES2014b gasoline fuel properties used for Fairbanks for calendar years 2017 and later (2017+) before and after the Fuel Wizard-based ethanol adjustment to the defaults. (The "Null" values for T50 are as extracted from the MOVES database, indicating this value is not defined in the default database.) Diesel fuel defaults for Fuel Region 6 were not changed.

Table 7-6-56
MOVES2014b Gasoline Fuel Properties Before and After Ethanol Adjustment

Fuel Property	MOVES2014b Defaults Calendar Year 2017+	Fuel-Wizard Adjusted Calendar Year 2017+
RVP (psi)	11.4	10.4
Sulfur Level (ppm)	10.0	10.0
Ethanol (% vol)	10	0
Aromatic Content (% vol)	21.4	25.0
Olefin Content (% vol)	6.7	8.7
Benzene Content (% vol)	0.7	0.7
e200 (% vol)	53.7	48.8
e300 (% vol)	87.4	86.8
T50 (deg F)	Null	202.2
T90 (deg F)	192.2	312.0

Plug-In Adjustments to $PM_{2.5}$ Emissions – Finally, starting exhaust $PM_{2.5}$ emissions for light-duty gasoline vehicles were adjusted to account for the effects of wintertime vehicle plug-in block heater use in Fairbanks.

Table 7-6-57 summarizes the reductions in starting exhaust $PM_{2.5}$ developed from measured data in the Fairbanks 2010-2011 Plug-In Testing program resulting from use of plug-ins while a vehicle is parked or "soaked." The column "Default Daily Soak Dist" lists the daily average soak time fractions extracted from MOVES2014b model for light-duty vehicles. The next column, "% $PM_{2.5}$ Redn" shows relative starting exhaust $PM_{2.5}$ emission reductions developed from the measurement data as a function of soak time. The plug-in reductions are expressed as percentages relative to the emissions of the vehicle if it had not been plugged in when parked. Only reductions for $PM_{2.5}$ are shown. (Although plug-in effects were also measured for gaseous pollutants, only directly emitted $PM_{2.5}$ reductions are being applied for the SIP inventory adjustments.)

Table 7-6-57
Local Measurement-Based Starting Exhaust $PM_{2.5}$ Emission Reductions from Plug-In Use

OpMode ID	Soak Time Intervals (min.)	Default Daily Soak Dist.	% $PM_{2.5}$ Redn	% Plug-In Use as a Function of Soak Time (minutes) and Daily Ambient Temperature (°F)					
				-50°F	-40°F	-30°F	-20°F	-10°F	0°F
101	Soak Time < 6	0.185	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
102	6 ≤ to < 30	0.205	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
103	30 ≤ to < 60	0.096	4.4%	25.9%	14.0%	2.4%	0.0%	0.0%	0.0%
104	60 ≤ to < 90	0.058	7.3%	44.4%	32.5%	20.8%	9.4%	0.0%	0.0%
105	90 ≤ to < 120	0.042	10.3%	56.6%	44.7%	33.1%	21.6%	10.4%	0.0%
106	120 ≤ to < 360	0.162	23.5%	86.8%	74.9%	63.2%	51.8%	40.6%	29.6%
107	360 ≤ to < 720	0.114	53.0%	100.0%	100.0%	93.1%	81.7%	70.5%	59.5%
108	720 ≤ Soak Time	0.139	70.8%	100.0%	100.0%	100.0%	100.0%	89.4%	78.4%
Daily Composite Plug-In Trip Fraction (%)				39.9%	35.9%	31.3%	27.4%	22.6%	18.5%
Daily Composite Plug-In $PM_{2.5}$ Reduction (%)				16.4%	15.9%	15.1%	14.1%	12.2%	10.4%

The six rightmost columns in Table 7-6-57 show plug-in usage fractions (percentage of trips) as a function of both soak time and ambient temperature (daily average temperature). The soak time intervals correspond to those defined in EPA's MOVES2014b model. The ambient temperature range is shown from -50°F to 0°F in 10-degree increments. At the bottom of Table 7-6-57, daily composite plug-in usage fractions and $PM_{2.5}$ starting exhaust reductions are shown.

The average ambient temperature over the modeling episode days was -11.8°F, which yields a plug-in $PM_{2.5}$ reduction (applied to starting exhaust light-duty gasoline vehicles) of 12.5% based on the analysis spreadsheet developed to compute plug-in benefits as a function of soak time and ambient temperature.

These adjustments were applied using an EPA- accepted approach that consisted of modifying the MOVES soak time distribution inputs for light-duty vehicles contained in *OpModeDistribution* table in the model's default database. Attachment D describes this process in further detail.

MOVES Data Importing and Execution and SMOKE Processing

Once all of the inputs were assembled, MOVES command input or "RunSpec" files and input importer scripts and processing workflows were set up to generate model runs and feed outputs to SMOKE as summarized below.

RunSpec and Importer Generation (SMOKE-MOVES) – Version 0.20 of the RunSpec generator script from the SMOKE-MOVES tool was used to create the MOVES RunSpec and import files for the RPD, RPV and RPP simulations in the baseline. Modifications to the script were made to allow for the use of Excel files and spreadsheet tabs in the importing process with the exception of the meteorology inputs. AVFT data was added through a separate text file via a change to the RunSpec configuration script. The RunSpec run control input for POLLUTANTS was set to both OZONE and PM in order to output pollutants for direct $PM_{2.5}$, precursor pollutants and CO.

The met profile inputs for the RPD, RPV and RPP rates are created in the RunSpec generator script based on the outputs from the modified MET4MOVES program. A new meteorology type was added to signal the creation of RPD and RPV temperature profiles from the temperature maximums, minimums and profiles extracted from the episode-processed meteorology files. Table 7-6-58 lays out the number of temperature profiles created for each of the model episodes and rates calculations.

Table 7-6-58
Fairbanks MOVES Rates Temperature Profile Count

Rates Scenario	Episode 1	Episode 2
RPD	1	1
RPV	8	11
RPP	66	36
Total Profiles	**75**	**48**

The RPD, RPV and RPP inventory importer scripts were run to import each of these different profiles with the 2008 baseline vehicle activity, population and fleet characteristics.

<u>MOVES Simulations</u> – Following the importing of the RPD, RPV and RPP input data the RunSpec scripts were configured to execute a series of 75 MOVES runs for episode 1 and 48 MOVES runs for Episode 2. These simulations were performed with MOVES version 20100826 installed on a custom-built Linux computer (Intel i7 950 4 core/8 thread, 8 GB system memory, 1 TB hard disk drive) running Ubuntu 10.04 OS.

Non-Road Mobile Sources

Non-road sources encompass all mobile sources that are not on-road vehicles. They include recreational and commercial off-road vehicles and equipment as well as aircraft, locomotives, recreational pleasure craft (boats) and marine vessels.

This section of the appendix discusses the data and methodologies used to estimate emissions for the non-road source sector. (No information on either commercial marine or recreational vessel emissions is presented, as they do not operate in the arctic conditions experienced in the Fairbanks modeling domain during the winter.) The following sub-sections are organized based on the models or tools used to develop emission estimates for specific sources within the inventory sector.

Non-Road Vehicles and Equipment

EPA's MOVES2014b model includes the capability to model both on-road and non-road vehicle emissions. MOVES2014b was used to model non-road vehicle/equipment emissions for the following categories:

- Recreational vehicles (e.g., all-terrain vehicles, off-road motorcycles, snowmobiles);
- Logging equipment (e.g., chain saws);
- Agricultural equipment (e.g., tractors);
- Commercial equipment (e.g., welders and compressors);
- Construction and mining equipment (e.g., graders and backhoes);
- Industrial equipment (e.g., forklifts and sweepers);
- Residential and commercial lawn and garden equipment (e.g., leaf and snow blowers);
- Locomotive support/railway maintenance equipment (but not locomotives); and
- Aircraft ground support equipment[61] (but not aircraft).

It is important to note that none of these non-road vehicle and equipment types listed above were federally regulated until the mid-1990s. (As parenthetically noted for the last two types of equipment in the list above, MOVES/NONROAD was used to estimate emissions of support equipment for the rail and air sectors, but emissions from locomotives and aircraft were calculated separately using other models/methods as described in the sub-sections that follow.)

Default equipment populations and activity levels in the MOVES/NONROAD are based on national averages, then scaled down to represent smaller geographic areas on the basis of human population and proximity to recreational, industrial, and commercial facilities. EPA recognizes the limitations inherent in this "top-down" approach and realizes that locally generated inputs to the model will increase the accuracy of the resulting output. Therefore, in some cases locally derived inputs which more accurately reflect the equipment population, growth rates, and wintertime activity levels in the Fairbanks area were substituted for EPA's default input values.

[61] Although NONROAD can be configured to also estimate emissions from airport ground support equipment (GSE), GSE emissions were estimated using the AEDT model as described under the "Aircraft" sub-section.

Calculation Methodology – MOVES/NONROAD model calculates emissions from each source category according to the following methodology:

$$\boldsymbol{Emissions = EF \times DF \times P \times LF \times Hours \times Units}$$

Where:

EF = emission factor in g/hp-hr;
DF = deterioration factor (dimensionless);
P = engine power in horsepower;
LF = load factor (dimensionless);
Hours = annual operating hours for each engine (unit); and
Units = total population of engines operating in a given year.

The above calculation yields emissions in grams per year, which MOVES/NONROAD then converts to tons per year. For seasonal or daily emissions estimates, the calculated annual emissions for each source are then distributed over a given number of calendar months. For example, NONROAD assumes by default that all snowmobile activity takes place during the winter months, which are defined by the model to be December, January, and February. For this analysis, several modifications were made to equipment population growth rates, seasonal activity distribution, and annual operating hours and equipment populations. Summarized below are the specific modifications made to EPA's default MOVES/NONROAD inputs.

Equipment Growth Rates – MOVES/NONROAD model predicts future equipment populations using national growth rates that have been determined using nationwide historical engine population estimates (i.e., for 1989 through 1996) from the Power Systems Research (PSR) PartsLink database. Given the relatively flat, and in some cases negative population growth predicted for Alaska's interior region, it is believed that the default NONROAD growth rates do not provide an accurate representation of equipment population growth trends in the 2013 through 2019 timeframe. For example, the default NONROAD growth factor results in a 2.8% annual increase in the snowmobile population in Fairbanks between 2010 and 2025—a figure that is well above the annual human population growth rate predicted by the Alaska Department of Labor and Workforce Development[58] for this area over the same period of time.

As shown in Table 7-6-59, a relatively flat annual growth rate of 0.1% for the total population of Alaska's interior region is predicted through 2025, which includes a negative growth rate in some of the smaller areas surrounding the Fairbanks nonattainment area. Therefore, to better reflect 2019 and later year equipment populations in the Fairbanks nonattainment area, the human population projections for the individual interior regions as shown in Table 7-6-59 were used as surrogate equipment population growth rates for all non-road equipment modeling performed for this inventory.

Table 7-6-59 Alaska Interior Region Human Population by Area (2010 to 2020)					
Interior Region	July 1, 2010 (Census)	July 1, 2015 (Estimated)	July 1, 2020 (Projection)	July 1, 2025 (Projection)	Annualized Growth Rate (2010-2025)
Denali Borough	1,826	1,781	1,819	1,850	0.1%
Fairbanks North Star Borough	97,581	98,645	97,080	100,724	0.2%
Southeast Fairbanks Census Area	7,029	6,899	6,823	6,886	-0.1%
Yukon-Koyukuk Census Area	5,588	5,493	5,100	4,929	-0.8%
Interior Region Total	112,024	112,818	110,822	114,389	0.1%

Modifications to Snowmobile Inputs – Because the overwhelming majority of the wintertime non-road emissions in the Fairbanks area are associated with snowmobile activity, it was important to utilize all available FNSB-specific input NONROAD modeling parameters for this equipment category. This analysis was performed using the following modifications to NONROAD's snowmobile inputs:

Snowmobile Populations – The current version of EPA's NONROAD model predicts a calendar year (CY) 2010 population of 12,193 snowmobiles in the Borough, which is very close to the 12,420 snowmobiles registered in FNSB for that same year.[62] However, snowmobile populations in the areas surrounding FNSB did not approximate DMV registration data as closely as in the Borough, as shown in Table 7-6-60 below. Consequently, the CY2014 DMV registration totals shown below were substituted for the default NONROAD snowmobile population. (The 2018 DMV database did not include snowmobiles.)

Table 7-6-60 Alaska Interior Region Snowmobile Population by Area for CY 2014		
Interior Region	NONROAD Default Population	Alaska DMV Registrations
Denali Borough	168	410
Fairbanks North Star Borough	12,193	12,420
Southeast Fairbanks Census Area	518	1,115
Yukon-Koyukuk Census Area	567	808

Snowmobile Activity – Snowmobile use inside the urban nonattainment area is largely banned because of public safety ordinances that prohibit their use on public trails and on public roadways. To address the fact that most snowmobile activity takes place outside the nonattainment area, the NONROAD default annual activity rate of 57 hours/year/unit was

[62] Data obtained from the Alaska Division of Motor Vehicles (DMV).

applied to only half of the FNSB snowmobile population. In addition, to account for loading, unloading, and maintenance activities that presumably take place inside the nonattainment area, an additional 1 hour/year/unit of snowmobile activity was assumed for the entire snowmobile population. All other snowmobile activity is assumed to occur in areas outside the Borough and/or the nonattainment area.

Snow Blowers – For purposes of this analysis, emissions from this equipment source were assumed to be zero. $PM_{2.5}$ violations (and consequently, $PM_{2.5}$ design days) always occur when there is a strong inversion layer over the region, rather than during periods of snow activity when snow blowers are typically used. Therefore, since snow blowers are not typically in use on the $PM_{2.5}$ design day, we have discounted their emissions from this analysis.

Nonexistent Wintertime Activity – Due to the severe outdoor weather conditions present in Fairbanks during the winter months, FNSB staff has determined that there is zero wintertime activity for a number of different equipment categories. Therefore, all activity and corresponding emissions for the following non-road equipment categories have been removed from this analysis:

- Lawn and Garden;
- Agricultural Equipment;
- Logging Equipment;
- Pleasure Craft (i.e., personal watercraft, inboard and sterndrive motor boats);
- Selected Recreational Equipment (i.e., golf carts, ATVs, off-road motorcycles); and
- Commercial Equipment (i.e., generator sets, pressure washers, welders, pumps, A/C refrigeration units).

Selected equipment from the following categories was retained, as follows:

- Construction and Mining – Graders, off-highway trucks, rubber tire dozers, and rubber tire loaders were retained to represent snow removal equipment activity.

- Industrial Equipment – Equipment that primarily operates indoors (such as forklifts, aerial lifts, and terminal tractors) was retained.

Equipment Not Included in NONROAD Model – Discussions with FNSB staff[63] indicate that indirect-fired temporary Diesel and propane heaters are commonly used in FNSB in connection with any indoor construction or repair work performed during the winter months. These heaters are in constant use (24 hours/day, 7 days/week) during the six-month FNSB winter period while regular indoor heating systems at construction sites are non-operational. Because these heaters are not included on the NONROAD model equipment list, we have calculated emissions from this source separately, as shown below in Table 7-6-61 and Table 7-6-62.

FNSB staff has estimated that a total of 30 heaters (10 small propane and 20 large Diesel units) operate continually at various construction sites during the winter months. Unit heating capacity

[63] Personal communication between Glenn Miller (FNSB) and Bob Dulla (Sierra Research), 3/4/2013.

was obtained from vendor specifications.[64]

Table 7-6-61 Emissions from Indirect-Fired Temporary Heaters - Diesel							
# units	Unit Heating Capacity (Btu/hr)	Fuel Heat Value (Btu/gallon)	Emission Factors (lb/1000 gallons) (AP-42, Table 1.3-1)				
			NO_x	CO	PM	TOC	SO_x
20	2,000,000	138,500	10	5	2	0.556	0.61
Tons/Year from All Units:			6.3	3.2	1.3	0.35	0.39

Table 7-6-62 Emissions from Indirect-Fired Temporary Heaters - Propane							
# units	Unit Heating Capacity (Btu/hr)	Fuel Heat Value (Btu/ft^3)	Emission Factors (lb/10^6 ft^3) (AP-42, Table 4-1)				
			NOx	CO	PM	TOC	SO_x
10	450,000	2,500	100	21	4.5	5.8	0.426
Tons/Year from All Units:			0.39	0.08	0.02	0.02	0.002

These indirect-fired temporary heater emissions were added to the inventory and assumed to occur only during winter months. The Source Classification Codes (SCCs) assigned to these heaters were as follows:

- SCC 2270002000 – Mobile Sources, Off-highway Vehicle Diesel, Construction and Mining Equipment, Total; and
- SCC 2267002000 – Mobile Sources, LPG, Construction and Mining Equipment, All.

Fuel and Temperature Inputs – NONROAD modeling runs were executed for the four counties within the $PM_{2.5}$ modeling domain:

1. Fairbanks North Star Borough (FNSB);
2. Denali Borough;
3. Southeast Fairbanks Census Area; and
4. Yukon-Koyukuk Census Area.

[64] http://www.etopp.com/indirect-fired-temporary-heaters.html.

For each of these counties, calendar year 2019 and later wintertime fuel parameters for both gasoline and diesel fueled equipment were set to correspond to the levels EPA has assumed in the MOVES2014b model for FNSB. This reflects the fact that mobile source fuel in interior Alaska is refined locally. So the same gasoline and diesel refinery blends are used in both on-road and non-road sources in Fairbanks. Table 7-6-63 below shows both the NONROAD default values and the FNSB fuel parameters and temperature inputs used in this MOVES/NONROAD modeling effort.

Table 7-6-63
NONROAD Modeling Wintertime Fuel and Temperature Inputs

Fuel Parameter	MOVES/NONROAD Default	CY 2019 & Later
Gasoline RVP	8.0	14.7
Gas Oxygen Weight (%)	2.44	0.0
Gas Sulfur (%)	0.0339	0.0028
Diesel Sulfur (%)	0.0351	0.0011
Marine Diesel Sulfur (%)	0.0435	0.0011
CNG/LPG Sulfur (%)	0.003	0.003
Stage II Control (%)	0	0
EtOH Blend Market (%)	75.1	0
EtOH Volume (%)	9.3	0
Minimum Temperature (^oF)	-	-15.7
Maximum Temperature (^oF)	-	4.0
Average Temperature (^oF)	-	-6.0

Annual and Seasonal Model Runs – As explained earlier, the NONROAD model was executed to generate average winter season emissions, overriding seasonal variation defaults in the model where local data were available. The winter season emissions were tabulated into winter daily averages over model runs for the six winter months (October through March). In addition, annual (12-month) model runs were also executed because of the way in which emissions must be formatted for input to the SMOKE emissions processing model to support the attainment modeling. For non-road sources, SMOKE requires annual average emission inputs (in tons/year) coupled with monthly temporal allocation factors. These temporal allocations were developed from the winter season average and annual emission estimates. Although non-road sources are not the dominant sector for direct $PM_{2.5}$ and precursor emissions in the modeling domain during the winter non-attainment season, several of the sources (e.g., snowmobiles) exhibit strong seasonal activity variations which needed to be accounted for in the inventory workflow feeding the attainment modeling.

Summary of Emissions – Calendar year 2019 non-road emissions tabulated by equipment category totaled across the four-county modeling domain are presented below in Table 7-6-64. (These tabulations also include emissions from temporary heaters which were added to the nonroad model outputs as noted earlier.)

Table 7-6-64
Calendar Year 2019 MOVES/NONROAD Emissions by Equipment Category

Equipment Category	Grid 3 Domain MOVES/NONROAD Emissions (tons/year)						
	VOC	CO	NO_x	SO_x	PM10-PRI	PM25-PRI	NH3
Recreational Equipment	1,189.8	3,277.9	97.3	0.0	36.5	33.5	0.6
Construction & Mining Equipment	24.1	179.8	122.9	0.4	11.1	10.8	0.3
Industrial Equipment	1.5	29.9	13.8	0.0	0.5	0.5	0.0
Lawn & Garden Equipment (Res)	41.5	739.0	8.3	0.0	2.0	1.8	0.0
Lawn & Garden Equipment (Com)	4.6	66.3	1.1	0.0	0.4	0.4	0.0
Agricultural Equipment	1.6	13.3	13.7	0.0	1.0	1.0	0.0
Commercial Equipment	15.3	427.3	16.4	0.0	1.3	1.2	0.0
Logging Equipment	2.9	22.3	1.1	0.0	0.4	0.4	0.0
Pleasure Craft	97.2	595.2	59.7	0.0	1.8	1.7	0.1
Railroad Equipment	0.1	1.5	0.6	0.0	0.1	0.1	0.0
TOTALS	**1,378.8**	**5,352.5**	**334.9**	**0.4**	**55.0**	**51.3**	**1.1**

Spatial Allocation – In the absence of well-developed, source-specific surrogates for Alaska[65], MOVES/Non-road outputs were spatially allocated to individual grid cells in the modeling domain based on apportionment factors developed from block-level occupied household counts obtained from the 2010 U.S. Census. It was assumed that relative density of occupied households was a reasonable surrogate for allocating all SCC-specific categories from the MOVES/Non-road modeling runs with the exception of snowmobiles, which used a modified version of the Occupied Household surrogate based on allocations of snowmobile activity inside and outside the $PM_{2.5}$ non-attainment area that were discussed earlier in this sub-section.

Locomotives

Emissions for two types of locomotive activity were included in the emissions inventory:

1) *Line-Haul* – locomotive emissions along rail lines within the modeling domain (from Healy to Fairbanks and Fairbanks to Eielson Air Force Base); and

2) *Yard Switching* – locomotive emissions from train switching activities within the Fairbanks and Eielson rail yards.

Information on wintertime train activity (circa 2013) was obtained from the Alaska Railroad

[65] EPA has developed a detailed set of SMOKE-ready surrogate files for use in spatial allocation down to 4 km grid cell sizes as described here: http://www.epa.gov/ttn/chief/emch/spatial/index.html. However, although the domain over which these surrogates were developed convers much of North American, is does not extend to Alaska.

Corporation[66] (ARRC), the sole rail utility operating within the modeling domain, providing both passenger and freight service. These activity data were combined with locomotive emission factors published by EPA[67] to estimate rail emissions within the emissions inventory.

Table 7-6-65 lists the train activity data by line segment and switching yard supplied by ARRC. Conversations with ARRC indicated that these November 2013 estimates were reasonably representative of the broader six-month winter season.

Table 7-6-65
Winter 2013 Train Activity by Line Segment and Yard

Line Segment or Switching Yard	November Avg. (# of trains/day)[1]	Hours of Operation	Miles (per train)	Locomotives (per train)[2]	Fuel Cons. (gal/train)[3]
Healy to Fairbanks	4.29	0001 - 1800	108	4	1210
Fairbanks to North Pole	1.7	2100 - 0800	17	2	95
North Pole to Eielson	1	0800 - 1600	12	1.5	50
Eielson to Ft. Greely	Zero	n/a	80	0	Zero
Fairbanks Yard	1	24 Hours	10	1.5	42
Eielson Yard[4]	1	8 Hours	5	1	14

Notes:
[1] The Healy to Fairbanks segment is based on average number of trains run in a week divided by seven days. The North Pole to Eielson value is an average number. ARRC does not go to Eielson from Fairbanks every day.
[2] Locomotive numbers from Fairbanks Operations Chief
[3] Fuel consumption from Mechanical Manager (~2.8 gallons/mi at average throttle speed)
[4] Eielson AFB has their own yard locomotives

Source: Alaska Railroad Corporation.

ARRC staff also indicated that train activity in this part of the state has been fairly flat from year to year. Thus, these 2013 estimates were assumed to be reasonably representative of future years. Given the modest rate of future economic growth forecasted for the Alaskan interior, the train activity shown in Table 7-6-65 was assumed constant in future year inventories through 2019.

These train activity data were combined with EPA-published locomotive emission factors which are presented in Table 7-6-66. In the absence of detailed locomotive age data from ARRC, the calendar year specific emission factors shown in Table 7-6-66 were based on Tables 5 through 7 of the cited EPA locomotives publication.

[66] Email from Matthew Kelzenberg, Alaska Railroad Corporation to Alex Edwards, Alaska Department of Environmental Conservation, July 19, 2016.
[67] "Emission Factors for Locomotives," U.S. Environmental Protection Agency, Office of Transportation and Air Quality, EPA-420-F-09-025, April 2009.

Table 7-6-66 EPA Emission Factors (g/gal) for Locomotives by Calendar Year and Activity Type							
Calendar Year	Activity Type	HC	CO	NO_x	PM_{10}	$PM_{2.5}$	SO_2
2013	Large Line-Haul	6.5	26.6	139.0	3.8	3.7	0.09
2013	Large Switch	13.3	38.1	225.0	5.0	4.9	0.09
2019	Large Line-Haul	3.9	26.6	103.0	2.5	2.4	0.1
2019	Large Switch	11.4	38.1	200.0	4.4	4.3	0.1

Source: U.S. Environmental Protection Agency, EPA-420-F-09-025.

Emission factors for CO are constant across calendar year since the CO standard is the same across all locomotive Tier categories. Per EPA guidance, $PM_{2.5}$ emission factors were scaled from those for PM_{10} using a 97% scaling factor. SO_2 emission factors were also developed based on EPA guidance using estimates of diesel fuel density (3200 g/gal), sulfur to SO_2 conversion rate (97.5%) and fuel sulfur (15 ppm in 2012 and later from Alaska Ultra Low Sulfur Diesel[68] phase in).

Table 7-6-67 shows the 2013 locomotive emissions calculated by combining activity and emission factor data in the preceding two tables, multiplying fuel consumption by the gram per gallon emission factors.

[68] https://dec.alaska.gov/air/anpms/ulsd/ulsdhome.htm

Table 7-6-67 Calendar Year 2019 Locomotive Emissions by Line Segment and Yard						
Line Segment or Switching Yard	HC	CO	NO_x	PM_{10}	$PM_{2.5}$	SO_2
Healy to Fairbanks (lb/day)	74.39	304.41	1590.72	43.49	42.18	1.03
Fairbanks to North Pole (lb/day)	2.31	9.47	49.49	1.35	1.31	0.03
North Pole to Eielson (lb/day)	0.72	2.93	15.32	0.42	0.41	0.01
Eielson to Ft. Greely (lb/day)	0	0	0	0	0	0
Fairbanks Yard (lb/day)	1.23	3.53	20.83	0.46	0.45	0.01
Eielson Yard (lb/day)	0.41	1.18	6.94	0.15	0.15	0.00
Total Locomotive Emissions (lb/day)	79.06	321.52	1683.31	45.88	44.50	1.08
Total Locomotive Emissions (tons/year)	**14**	**59**	**307**	**8**	**8**	**0**

Spatial Allocation – Line-haul locomotive emissions over each of the rail segments listed in the preceding tables were spatially allocated to individual grid cells in the modeling domain using GIS software and a statewide rail line shapefile developed by the U.S. Department of Transportation. The allocations assumed a constant line-haul speed and thus were proportional to the lineal track length within each grid cell.

Yard-switching emissions were allocated to specific grid cells that encompassed the Fairbanks and Eielson rail yards using estimated apportionment factors that corresponded to the amounts of switching track lines within each cell.

AIRCRAFT

Emissions were estimated from aircraft operations at three regional airfields within the modeling domain: 1) Fairbanks International Airport (FAI); 2) Fort Wainwright Army Post[69] (FBK); and 3) Eielson Air Force Base (EIL). The aircraft emissions were developed using the Federal Aviation Administration's (FAA) AEDT2c aircraft/airfield emissions model. AEDT considers the physical characteristics of each airport along with detailed meteorological and operations information in order to estimate the overall emissions of aircraft, ground support equipment (GSE) and auxiliary power units (APUs) at each airport. At the time the analysis was performed, AEDT2c was the latest available version.

AEDT Methodology Summary - The AEDT model requires as input detailed information on landings and take-offs (LTO) for each aircraft type in order to assign GSE and estimate the associated emissions. Each LTO is assumed to comprise six distinct aircraft related emissions modes: startup, taxi out, take off, climb out, approach, and taxi in. The AEDT modeled defaults for time in mode and angle of climb out and approach were used for purposes of this analysis. In order to properly allocate aircraft emissions to each vertical layer of analysis (elevation above ground level), aircraft emissions were estimated for each mode and ascribed to a specific vertical layer. The vertical grid structure established for the Fairbanks $PM_{2.5}$ attainment modeling

[69] Formerly Ladd Air Force Base.

consists of 38 vertical layers ranging between ground level and 100,000 feet as shown in Table 7-6-68. The current version of AEDT allows the user to vary the mixing height over a range from 1,000 feet to a maximum of 10,000 feet. Thus, the tan-shaded layers (1 through 21) in Table 7-6-68 represent those for which AEDT emissions were assigned or distributed as described below.

Table 7-6-68
Vertical Layer Boundaries Included in the Emissions Analysis

Layer	Meters	Feet	Layer	Meters	Feet
1	0	0	20	2,408.84	7,903.01
2	4.00	13.13	21	2,922.27	9,587.47
3	8.00	26.26	22	3,470.92	11,387.50
4	12.81	42.03	23	4,059.98	13,320.13
5	23.63	77.54	24	4,695.90	15,406.45
6	46.94	153.99	25	5,386.76	17,673.05
7	67.89	222.73	26	6,142.97	20,154.05
8	112.79	370.05	27	6,978.19	22,894.28
9	177.96	583.87	28	7,910.89	25,954.32
10	276.73	907.91	29	8,966.86	29,418.78
11	410.35	1,346.28	30	10,126.79	33,224.30
12	546.23	1,792.09	31	11,416.93	37,457.05
13	684.46	2,245.61	32	12,875.50	42,242.38
14	825.13	2,707.10	33	14,512.04	47,611.59
15	968.31	3,176.85	34	16,445.80	53,955.93
16	1,150.96	3,776.12	35	18,747.26	61,506.62
17	1,375.80	4,513.78	36	21,744.80	71,341.08
18	1,646.36	5,401.43	37	25,751.01	84,484.76
19	1,987.69	6,521.28	38	32,139.07	105,442.93

Emissions associated with aircraft start up, taxi in or out, and take off, were assigned to Layer 2 (approximately 13 feet above ground level) to reflect average engine heights above ground. GSE and APU emissions were assigned to Layer 1. Climb out and approach emissions were ascribed proportionately between layers 2 and 11 (from 13 to approximately 1,300 feet) based upon the relative size of the distance between layer boundaries. Separate AEDT runs were made for each of the remaining 10 layers (Layers 12-21) with boundaries between 1,000 and 10,000 feet.

All AEDT runs assumed the minimum temperature allowable in default mode of -9.08°C (15.7°F). The following sub-sections separately describe the data sources, assumptions and methods used to generate AEDT-based aircraft emission estimates for each airfield.

Fairbanks International Airport - Fairbanks International Airport is a state-owned public-use airport located three miles (5 km) southwest of the central business district of Fairbanks in the Fairbanks North Star Borough of Alaska. Given the fact that FAI is positioned only 9.5 hours from 90% of the northern industrialized hemisphere and considering that the airport is open 24 hours a day (including holidays), FAI is convenient for servicing cargo airlines as a refueling stop for aircraft on trans-polar routes. FAI is also served by a number of passenger airlines.

Annual LTOs for FAI in 2013, 58,621, were obtained from the Alaska International Airport System (AIAS)[70]. However, these AIAS data did not include the distribution of LTOs by aircraft type. The LTO distribution by aircraft types was derived from the FAI Statistics System.[71] A report generated for January of 2013 included the activity of 45 air carriers utilizing 39 different types of aircraft. 92% of the reported LTOs were attributable to aircraft types that were included in the AEDT model. The remaining LTOs were either ascribed to similar aircraft with respect to manufacturer, size and purpose, or proportionately distributed among those aircraft types present in the model. Table 7-6-69 presents the distribution of 2013 LTOs by airframe for FAI used in the modeling.

Table 7-6-69
2013 LTOs by Aircraft Type for Fairbanks International Airport (FAI)

Airframe	LTOs
ATR 42-200, "-300", -400, and -500	15
ATR 72-"200", ATR 72-500	259
Airbus A319-100 Series	74
Raytheon Beech 1900-C, Raytheon Beech 1900-D	2297
Raytheon Super King Air 200	1
Raytheon Beech Bonanza 36	144
Raytheon Beech 18	287
Boeing 727-200 Series	1
Boeing 737-100 Series, Boeing 737-200 Series	3
Boeing 737-400 Series	3141
Boeing 737-700 Series	524
Boeing 737-800 Series	708
Boeing 737-900 Series	293
Boeing 747-400 Series	0
Boeing 757-200 Series	207
Boeing 767-300 Series, Boeing 767-300 ER	0
CASA 212-200 Series, "CASA 212-300 Series", CASA 212-400 Series	2
Cessna 208 Caravan	4806
Cessna 206, Cessna 210 Centurion	395
Boeing C-118	54
DeHavilland DHC-8-100	2152
Embraer EMB120 Brasilia	66
Helio U-10 Super Courier	115
Lockheed C-130 Hercules	61
Boeing DC-6	175
Boeing DC-9-30 Series	36
Boeing MD-11	2

[70] Alaska International Airport System – Statistics, Alaska Department of Transportation and Public Facilities, http://dot.alaska.gov/aias/stat2557scascca.shtml.
[71] http://dot.alaska.gov/faiiap/index.shtml.

Table 7-6-69 2013 LTOs by Aircraft Type for Fairbanks International Airport (FAI)	
Airframe	**LTOs**
Pilatus PC-12	186
Piper PA-31 Navajo	6266
Piper PA-32 Cherokee Six	282
HS125-8	1
Saab 340-B	1
Shorts 330	148
Boeing C-118	1404
Boeing DC-9-10 Series	117
Raytheon Beech 1900-C	273
Cessna 206	1170
Cessna 208 Caravan	546
Cessna 210 Centurion	117
Helio U-10 Super Courier	351
Piper PA-31 Navajo	936
Raytheon Beech 18	195
Piper PA-32 Cherokee Six	390
Raytheon Beech Bonanza 36	117
Cessna 150 Series	2612
Cessna 172 Skyhawk	8539
Cessna 182	6238
Cessna 310	117
Cessna 337 Skymaster	117
Piper PA-23 Apache/Aztec	10839
Piper PA-24 Comanche	39
Piper PA-28 Cherokee Series	312
Piper PA-30 Twin Comanche	195
Piper PA-34 Seneca	39
Piper PA46-TP Meridian	78
Raytheon Beech 60 Duke	39
Lockheed C-130 Hercules	934
Boeing C-17A	47
Boeing 707-300 Series	16
Lockheed Martin F-16 Fighting Falcon	24
Boeing F/A-18 Hornet	8
Boeing KC-135 Stratotanker	55
Lockheed P-3 Orion	47
Lockheed S-3 Viking	8
TOTAL	**58,621**

In default mode, AEDT automatically assigns GSE and auxiliary power units (APU) to each LTO based upon airframe type. GSE include air conditioning units, air starts, aircraft tractors, baggage tractors, belt loaders, bobtails, cabin service trucks, cargo loaders, carts, catering trucks, deicers, fork lifts, fuel trucks, generators, ground power units, hydrant carts, lavatory trucks, lifts, passenger stands, service trucks, sweepers, water service trucks, and any other vehicles or equipment that tend to the aircraft while at the gate. Although APUs are most often on-board generators that provide electrical power to the aircraft while its engines are shut down, many aircraft utilize external generators. For purposes of this analysis, the AEDT defaults for GSE and APU age distribution, motive power and operating time per LTO were used. All GSE and APUs emissions were assigned to ground level as noted earlier.

The AEDT estimated 2013 emission inventory for FAI is presented in Table 7-6-70 below.

Table 7-6-70
2013 FAI Emissions Inventory by Source Category (Metric Tons per Day)

Source	CO	THC	TOG	VOC	NOx	SOx	PM2.5	PM10
Aircraft	5.358	0.233	0.234	0.204	0.256	4.780	0.114	0.114
APU	0.009	0.001	0.001	0.001	0.004	0.001	0.001	0.001
GSE	0.127	0.000	0.005	0.005	0.020	0.000	0.001	0.001
Totals	**5.493**	**0.233**	**0.239**	**0.210**	**0.280**	**4.781**	**0.115**	**0.116**

Fort Wainwright/LADD Army Airfield **-** Fort Wainwright (FBK) is located adjacent to Fairbanks in the interior of Alaska in the Fairbanks North Star Borough about 365 miles north of Anchorage. Information regarding 2008 LTOs was obtained from FBK in the form of monthly average flights by group. (Annual LTOs were developed by multiplying the monthly averages by a factor of 12.)

Summaries of the type of aircraft in each of these groups are provided below:

- *Military/Local* - denotes activity by Army-owned aircraft stationed at Ladd Army Airfield which are all rotary-wing aircraft; CH-47 Chinook, UH-60 Blackhawks and OH-58 Kiowa Warriors. The monthly LTOs for this group were distributed according to the proportion of available aircraft.

- *Military/Transient* - reflects activity by military aircraft that utilize the airspace/airfield that are not stationed at Ladd Army Airfield. The aircraft inventory includes the A-10 Warthog, C-12 Huron, C-130 Hercules, C-17 Globe Master, F-16 Falcon and KC-135 Strato-Tanker. The monthly LTO for this group were assumed to be evenly distributed across the available airframes.

- *General Aviation/Local* - represents activity by Bureau of Land Management (BLM) owned aircraft stationed at Ladd Army Airfield. The aircraft mix in this group includes the Bell 212, Euro-Copter AS-350, Canadair CL-215 Scooper, CASA C-212 Avio-car, Cessna 206 Sky Wagon, Dornier 228 and Short Sherpa. The LTOs for this group were evenly distributed across all airframes.

- *General Aviation/Transient* - denotes activity by non-military aircraft not stationed at Ladd Army Airfield. The mix of aircraft in this group includes the Beech King Air 350, Boeing 737, Citation Cessna 552, Gulfstream Jet V, and Bell 206 Jet-Ranger.

As was the case with FAI, some of the aircraft in use at FBK were not found in the AEDT database. In these instances, alternative airframes were selected according to similarity, or the LTOs associated with those missing aircraft were proportionately distributed among the remainder of the fleet. The LTOs by aircraft used in the Fort Wainwright modeling are presented in Table 7-6-71.

Table 7-6-71
2013 LTOs by Aircraft Type for Fort Wainwright/LADD Army Airfield (FBK)

Airframe	LTOs
Boeing CH-46 Sea Knight	2286
Sikorsky UH-60 Black Hawk	4382
Bell 206 JetRanger	5715
Cessna 182	0
Boeing C-17A	670
Boeing KC-135 Stratotanker	670
F16	670
Lockheed C-130 Hercules	167
Beechcraft C-12 Huron	167
Raytheon Beech 1900-C, Raytheon Beech 1900-D	167
Bell 214B-1	57
Eurocopter AS 355NP	57
Bombardier CL-415	57
CASA 212-200 , -300 and -400 Series	57
Cessna 206 and 210 Centurion	57
Dornier 228-200 Series	57
Shorts 330	57
Raytheon Super King Air 300	962
Boeing 737-400 Series	962
Cessna 552 T-47A	962
Gulfstream V-SP	962
Bell 206 JetRanger	962
Total	**40,206**

GSE and APU assignment and emissions were modeled using the AEDT defaults. The resulting inventory for FBK is summarized in Table 7-6-72 as follows.

Table 7-6-72
2013 FBK Emissions Inventory by Source Category (Metric Tons per Day)

Source	CO	THC	TOG	VOC	NOx	SOx	PM2.5	PM10
Aircraft	0.112	0.035	0.040	0.040	0.416	4.094	0.078	0.078
APU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GSE	0.042	0.000	0.002	0.002	0.011	0.000	0.001	0.001
Totals	**0.154**	**0.035**	**0.042**	**0.042**	**0.428**	**4.094**	**0.078**	**0.078**

Eielson Air Force Base - Eielson Air Force Base (EIL) is located approximately 26 miles (42 km) southeast of Fairbanks, Alaska in central Alaska's Fairbanks North Star Borough. North Pole is the nearest community to the base, located nine miles away. Established in 1943 as Mile 26 Satellite Field, Eielson is home to the 354th Fighter Wing which is part of the Eleventh Air Force (11 AF) of Pacific Air Forces (PACAF).

Eielson played an important role because of its strategic location. Aircraft movement information including take off, landings, touch-and-go, low approach, or aircraft passing though EIL airspace were provided by AFB personnel for February of 2008. It was estimated that some 1,100 aircraft movements per month (13,200 annual LTOs) were attributable to AFB operations with an approximately 60% / 40% military / civilian distribution.

The airframes assigned to EIL include the A-10 Thunderbolt II, C-123, F-4 Phantom II, F-16 Fighting Falcon, KC-135 Strato-Tanker, and the OV-10 Bronco. Lacking aircraft specific LTO information, it was assumed that each aircraft was equally likely to have contributed to overall emissions for the purposes of this analysis. Civilian traffic was attributed to the Piper PA-31 as the most frequent flyer found in the analysis of FAI. The assumed LTOs by aircraft type for EIL are included in Table 7-6-73.

Table 7-6-73 2013 LTOs by Aircraft Type for Eielson Air Force Base (EIL)	
Airframe	LTOs
Rockwell Commander 500	1
Raytheon Super King Air 200	53
Raytheon King Air 90	1
Boeing DC-10-10 Series	5
Boeing DC-6	2
Boeing DC-9-30 Series	2
Boeing 707-300 Series	6
Boeing 737-700 Series	8
Boeing 737-800 Series	4
Boeing 747-400 Series	6
Boeing 757-200 Series	1
Boeing 767-200 Series	3
Boeing 767-300 Series, Boeing 767-300 ER	2
Boeing 777-200 Series	2
Boeing F-15 Eagle	220
Boeing C-17A	90
Boeing KC-135 Stratotanker	459
Bombardier Challenger 600	1
Cessna 208 Caravan	1
Cessna 560 Citation V	6
Cessna 172 Skyhawk	6
Convair CV-580	2
Fairchild A-10A Thunderbolt II	148
Fokker F27 Friendship	2
Rockwell Commander 690	1
Gulfstream G500	2
Gulfstream G100	1
Lockheed C-130 Hercules	116
Lockheed C-5 Galaxy	7
Lockheed Martin F-16 Fighting Falcon	1465
Lockheed P-3 Orion	10
Shorts 330-100 Series	6
Boeing F/A-18 Hornet	145
Pilatus Turbo Trainer PC-9	1
Gulfstream G300	7
F-16	0
F-16	0
Total	**5,580**

As for the other airfields, GSE and APU assignment and emissions were also modeled using the AEDT defaults. The resulting inventory for Eielson is presented in Table 7-6-74.

Table 7-6-74 2013 EIL Emissions Inventory by Source Category (Metric Tons per Day)								
Source	CO	THC	TOG	VOC	NOx	SOx	PM2.5	PM10
Aircraft	0.171	0.114	0.132	0.131	0.137	1.876	0.048	0.048
APU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GSE	0.003	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Totals	**0.174**	**0.114**	**0.132**	**0.131**	**0.140**	**1.876**	**0.048**	**0.048**

Combined Airfield Emissions Inventory - Taken in the aggregate, the three airfields included in the current analysis contribute only modestly to the overall emissions of the region. The vast majority of emissions associated with aircraft take off, landing and related ground support equipment occur near ground level which may result in increased exposure. Table 7-6-75 presents the combined emissions of the three analyzed airfields stratified by vertical layer.

The emission units in Table 7-6-75 differ from those in the earlier airfield-specific tables. AEDT output units of metric tons were used in those tables. They have been converted to tons in Table 7-6-75 for comparison with other sectors of the emissions inventory. AEDT does not estimate ammonia (NH_3) emissions for aircraft; thus, they were assumed to be zero.

Table 7-6-75 2013 Combined Emissions Inventory of Aircraft Operations (Tons/Day)							
Layer	VOC	CO	NO_x	SO_x	NH_3	PM_{10}	$PM_{2.5}$
1	0.0085	0.2000	0.0425	0.0013	0	0.0026	**0.0027**
2	0.1472	0.6319	0.0873	1.2878	0	0.0470	**0.0470**
3	0.0015	0.0241	0.0042	0.0665	0	0.0023	**0.0023**
4	0.0009	0.0145	0.0025	0.0399	0	0.0014	**0.0014**
5	0.0021	0.0325	0.0057	0.0900	0	0.0030	**0.0030**
6	0.0045	0.0701	0.0122	0.1937	0	0.0066	**0.0066**
7	0.0040	0.0630	0.0110	0.1741	0	0.0059	**0.0059**
8	0.0086	0.1350	0.0235	0.3732	0	0.0126	**0.0126**
9	0.0125	0.1959	0.0342	0.5417	0	0.0183	**0.0183**
10	0.0189	0.2970	0.0518	0.8209	0	0.0278	**0.0278**
11	0.0256	0.4017	0.0700	1.1105	0	0.0376	**0.0376**
12	0.0134	0.3179	0.0419	0.5978	0	0.0230	**0.0230**
13	0.0125	0.3170	0.0349	0.4942	0	0.0190	**0.0190**
14	0.0132	0.3174	0.0353	0.4954	0	0.0190	**0.0190**
15	0.0143	0.3231	0.0429	0.5640	0	0.0082	**0.0082**
16	0.0186	0.4086	0.0528	0.6647	0	0.0075	**0.0075**
17	0.0686	0.8585	0.0592	0.8806	0	0.0050	**0.0050**
18	0.0192	0.5035	0.0571	0.7014	0	0.0040	**0.0040**
19	0.0147	0.4810	0.0725	0.8012	0	0.0046	**0.0046**
20	0.0057	0.3754	0.0867	0.8687	0	0.0050	**0.0050**
21	0.0072	0.4494	0.1060	1.0832	0	0.0062	**0.0062**
Totals	**0.4217**	**6.4173**	**0.9341**	**11.8509**	**0**	**0.2666**	**0.2667**

Spatial Allocation – In addition to the vertical layer allocations represented in Table 7-6-75, simple horizontal allocations of aircraft emissions were developed within a GIS system based on a map overlay of each of the three airfields and the modeling domains grid cells. Ground-based and elevated (climb out and approach) emissions were distributed into the 3-5 specific grid cells that encompassed the runway and taxiway/terminal apron areas of each airfield. (Refined allocations of climb out and approach emissions by horizontal and vertical cell reflecting typical in-air flight trajectories at each airfield were not developed given the magnitude of airfield emissions relative to the entire emissions inventory and significance of ground-based sources under the limited vertical mixing characterizing winter $PM_{2.5}$ episodes in Fairbanks.)

INVENTORY SUMMARY TABULATIONS

Based on the source-specific data, assumptions and methodologies described in detail in the preceding section, episodic "Modeling" inventories (across the entire Grid 3 modeling domain and "Planning" inventories (for the $PM_{2.5}$ nonattainment area) are summarized by source sector in this section.

Table 7-6-76 through Table 7-6-78 present these summaries for the 2019 Baseline, 2024 Projected Baseline and 2024 Control/Attainment inventories, respectively. For directly-emitted $PM_{2.5}$, condensable and filterable components are separately reported (along with the combined total). The splits between condensable and filterable $PM_{2.5}$ emissions were developed from SCC-level emission factor data in EPA's latest WebFIRE emission factor database[72] (dated September 2016). As shown in Table 7-6-76 through Table 7-6-78, condensable and filterable components were only available for all SCCs within the Point Source sector. For the remaining sectors, there were few SCC source categories for which condensable/filterable emissions were listed in WebFIRE (Area Sources), or for which emissions are developed directly from EPA models (MOVES for Mobile Sources) that do not report the separate PM components. Thus in Table 7-6-76 through Table 7-6-78, sector-summed condensable and filterable $PM_{2.5}$ emissions are only given for the Point Source sector.

In addition to these summary tables, a spreadsheet is included in the electronic Appendix III.D.7.06. This spreadsheet reports emissions for all sources at the SCC-level and shows which SCCs outside the Point Source sector for which separate condensable and filterable $PM_{2.5}$ emissions could be determined. These SCC-level spreadsheets are provided for both the 2019 Baseline and 2024 Control/Attainment inventories.

Table 7-6-76
2019 Baseline Episode Average Daily Emissions (tons/day) by Source Sector

	Modeling Inventory Grid 3 Domain Emissions (tons/day)							*Planning Inventory Nonattainment Area Emissions (tons/day)*						
Source Sector	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NOx**	**SO_2**	**VOC**	**NH_3**	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NO**	**SO_2**	**VOC**	**NH_3**
Point Sources	0.59	0.48	0.11	10.36	5.87	0.03	0.073	0.57	0.46	0.11	10.31	5.68	0.03	0.073
Area, Space Heat	2.21	n/a	n/a	2.61	4.16	9.55	0.145	1.91	n/a	n/a	2.43	3.88	8.60	0.132
Area, Other	0.24	n/a	n/a	0.38	0.03	2.25	0.050	0.22	n/a	n/a	0.36	0.03	2.10	0.046
On-Road Mobile	0.27	n/a	n/a	2.30	0.01	4.90	0.055	0.22	n/a	n/a	1.70	0.01	3.83	0.040
Non-Road Mobile	0.36	n/a	n/a	1.75	7.78	5.26	0.003	0.26	n/a	n/a	0.94	5.41	4.16	0.002
TOTALS	**3.67**	**n/a**	**n/a**	**17.40**	**17.85**	**22.00**	**0.325**	**3.17**	**n/a**	**n/a**	**15.73**	**15.01**	**18.72**	**0.293**

n/a – Not available

[72] https://cfpub.epa.gov/webfire/index.cfm?action=fire.downloadInBulk

Table 7-6-77 2024 Projected Baseline Episode Average Daily Emissions (tons/day) by Source Sector														
	Modeling Inventory Grid 3 Domain Emissions (tons/day)							*Planning Inventory Nonattainment Area Emissions (tons/day)*						
Source Sector	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NOx**	**SO_2**	**VOC**	**NH_3**	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NO**	**SO_2**	**VOC**	**NH_3**
Point Sources	0.64	0.52	0.12	11.21	6.35	0.04	0.079	0.62	0.50	0.12	11.16	6.16	0.03	0.079
Area, Space Heat	2.48	n/a	n/a	2.87	4.53	10.52	0.156	2.14	n/a	n/a	2.43	4.20	8.60	0.132
Area, Other	0.26	n/a	n/a	0.41	0.03	2.42	0.053	0.24	n/a	n/a	0.38	0.03	2.24	0.050
On-Road Mobile	0.20	n/a	n/a	1.67	0.01	4.45	0.058	0.16	n/a	n/a	1.25	0.01	3.55	0.043
Non-Road Mobile	0.36	n/a	n/a	1.79	8.88	4.60	0.003	0.24	n/a	n/a	1.02	5.59	3.64	0.002
TOTALS	**3.93**	**n/a**	**n/a**	**17.95**	**19.80**	**22.02**	**0.350**	**3.40**	**n/a**	**n/a**	**16.24**	**15.98**	**18.06**	**0.306**

n/a – Not available

Table 7-6-78 2024 Control Episode Average Daily Emissions (tons/day) by Source Sector														
	Modeling Inventory Grid 3 Domain Emissions (tons/day)							*Planning Inventory Nonattainment Area Emissions (tons/day)*						
Source Sector	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NOx**	**SO_2**	**VOC**	**NH_3**	**$PM_{2.5}$ Total**	**$PM_{2.5}$ Cond.**	**$PM_{2.5}$ Filt.**	**NO**	**SO_2**	**VOC**	**NH_3**
Point Sources	0.64	0.52	0.12	11.21	3.01	0.04	0.079	0.62	0.50	0.12	11.16	2.81	0.03	0.079
Area, Space Heat	1.09	n/a	n/a	2.87	2.58	10.52	0.156	0.74	n/a	n/a	2.43	2.27	8.60	0.132
Area, Other	0.26	n/a	n/a	0.41	0.03	2.42	0.053	0.24	n/a	n/a	0.38	0.03	2.24	0.050
On-Road Mobile	0.20	n/a	n/a	1.67	0.01	4.45	0.058	0.16	n/a	n/a	1.25	0.01	3.55	0.043
Non-Road Mobile	0.36	n/a	n/a	1.79	8.88	4.60	0.003	0.24	n/a	n/a	1.02	5.59	3.64	0.002
TOTALS	**2.54**	**n/a**	**n/a**	**17.95**	**14.51**	**22.02**	**0.350**	**1.99**	**n/a**	**n/a**	**16.24**	**10.71**	**18.06**	**0.306**

n/a – Not available

Attachment A

Fairbanks Home Heating & Wood Household Survey Scripts

Fairbanks 2011 Home Heating Survey

Final Script

Phone # ______________ Survey # _________
Interviewer Name _________________
Date ______________

(Location of Home)

Good evening, I am calling from Hays Research Group; we are conducting a brief survey on behalf of the Alaska Department of Environmental Conservation (DEC) and the Fairbanks North Star Borough (BURR-oh) regarding home space heating options. May I please speak to the person most knowledgeable about the heating devices in your home? (IF NOT AVAILABLE – When would be the best time to reach him/her? Set a callback and get a name.)

Q1-Q8) Please tell me which of the following devices provide space heat for your home?

Q1) A wood burning device?

1. Yes
2. No
3. DK/REF

Q2) A central Oil furnace?

1. Yes
2. No
3. DK/REF

Q3) Portable Fuel Oil/Kerosene heating device?

1. Yes
2. No
3. DK/REF

Q4) Toyo (TOY-oh), Monitor or other direct vent type heater?

1. Yes
2. No
3. DK/REF

Q5) Natural Gas Heat?

1. Yes
2. No
3. DK/REF

Q6) Coal Heat

1. Yes
2. No
3. DK/REF

Q7) Municipal Heat?
1. Yes
2. No
3. DK/REF

Q8) Other not listed? ___________________

QQ) And can you please tell me how many square feet are in your home, not including any garage space?

1. ________________sq. ft.
2. DK/REF

(At least one of the questions between Q1-Q7 must = 1 yes, otherwise terminate)

(Ask Q1a if Q1=1, otherwise skip to Q9)

Q1a) Is your wood burning device a fireplace, a fireplace with insert, a wood burning stove or outdoor wood boiler?

1-Fireplace
2-Fireplace with insert
3-Wood burning stove
4-Outdoor Wood Boiler (note could called hydronic heater by some)
5-DK/REF

Q9) (Q9 answers must total 100%) What percentage of your heating is done by each of the following devices during the winter months, from October to March?

a. Wood Burning Device	%
b. Central Oil furnace	%
c. Portable Fuel Oil/Kerosene	%
d. Direct Vent type	%
e. Natural Gas Heat	%
f. Coal Heat	%
g. Municipal Heat	%
h. Other	%

We'll now get into some usage details of each type of heating.

(Section 1: Wood burning stove/Fireplace insert)

(Ask Q10-Q12 if Q1a = 2) "Fireplace with insert" or 3) "Wood burning stove", otherwise skip to Q13)

Q10a) Was your wood burning stove or insert installed before or after 1988?

1) Before
2) After
3) DK/REF

Q11a) How old is your wood burning stove or insert? Allow multiple responses

1) Less than 1 year
2) 1-5
3) 5-10
4) 10-15
5) 15+ years
6) DK/REF

Q11b) Is your wood stove or insert catalytic or non –catalytic?

1) catalytic
2) non-catalytic
3) DK/REF

Q12) Does your stove or insert burn pellets or cord wood? Allow multiple responses

1)Pellets
2)Cord Wood
3) DK/REF

(Ask Q13-Q14 if Q12=2 "Cord wood", otherwise skip to Q15)

Q13) What best describes your use of wood heat during the winter months, October to March?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don't know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Q14) Where do you get the wood for your heating? Allow multiple responses
1. Buy wood
2. Cut your own
3. DK/REF

(Ask Q15-Q17a if Q14=2 "Cut your own", otherwise skip to Q18)

Q15) When cutting wood do you get a permit?

1. Yes
2. No
3. DK/REF

Q16) How many months do you season your wood before burning it?

1.________Months
2. DK/REF=9999

Q17) Do you know what the moisture content of your wood is, and if so, what is it?

1.________Percent
2. DK/REF=9999

(Ask Q18-Q19 if Q12 =2 "Cord wood", otherwise skip to Q20)

18) In cords, how much wood do you burn in your wood burning stove or insert annually? (If the respondent asks, one cord of wood is four feet wide, four feet high, and eight feet long stacked)

1. Wood in cords _______
2. DK/REF=9999

Q19) In cords, how much do you burn from October to March?

1. Wood in cords _______
2. DK/REF=9999

(Ask Q20-Q21 if Q12=1 “pellets”, otherwise skip to Q22)

Q20) How many 40 lb bags of pellets do you burn in your wood burning stove or insert annually?

1. 40 lb bags of pellets ________
2. DK/refused=9999

Q21) How many bags do you burn from October to March?

1. 40 lb bags of pellets ________
2. DK/refused=9999

(Ask Q22 if q18 or q19= DK/REF, otherwise skip to Q23)

Q22) How much do you spend per year on wood?

1. $__________
2. DK/refused=9999

(Ask q23 if q20 or q21 = DK/REF, otherwise skip to Q24)

Q23) How much do you spend per year on pellets?

1. $__________
2. DK/refused=9999

Q23a) Is there a pellet source that you prefer?

1. Yes
2. No
3. DK/REF

(Ask Q23b if Q23a=”Yes”, otherwise skip to Q24)

Q23b) Why do you prefer that source?

Specify ___________

(Section 2: Wood burning Fireplace)

(Ask Q24-Q25 if Q1a = 1 “Fireplace”, otherwise skip to Q32)

Q24) From this list, what best describes your use of wood heat during the winter months, from October to March?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don't know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Q25) Where do you get the wood for your heating? (Allow multiple responses)

1. Buy wood
2. Cut your own
3. DK/REF

(Ask Q26-Q31 if Q25=2, otherwise skip to Q32)

Q26) When cutting wood do you get a permit?

1. Yes
2. No
3. DK/REF

Q27) How many months do you season your wood before burning it?

1. Months ______
2. DK/refused=9999

Q28) Do you know what the moisture content of your wood is, and if so, what is it?

1. Percent ______
2. DK/refused=9999

Q29) In cords, how much wood do you burn in your fireplace annually?

1. ________cords
2. DK/refused = 9999

Q30) How much do you burn from October to March?

1. ________cords
2. DK/REF=9999

Q31 How much do you spend per year on wood?

1. $__________
2. DK/REF=9999

(Section 3: Outdoor Wood Boiler)

(Ask Q32-Q33 if section if Q1a = 4 "outdoor wood boiler", otherwise skip to Q34)

Q32) What best describes your use of wood heat during the winter months, from October to March?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don't know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Q33) Where do you get the wood for your heating? (allow multiple responses)

1. Buy wood
2. Cut your own
3. Purchase Pellets
4. DK/REF

(Ask Q34-Q36 if Q33=2 "cut your own", otherwise skip to Q37)

Q34) When cutting wood do you get a permit?

1. Yes
2. No
3. DK/REF

Q35) How many months do you season your wood before burning it?

1. Months ______
2. DK/REF=9999

Q36) Do you know what the moisture content of your wood is, and if so, what is it?

1. Percent ______
2. DK/REF=9999

Q37) How much wood do you burn in your outdoor wood boiler annually?

1. ________cords
2. ________ pellets
3. DK/REF=9999

Q38) How much do you burn from October to March?

1. ________cords
2. ________ pellets

3. REF=9999

(ask Q39 if Q33= 1 “Buy wood”, otherwise skip to Q40)

(ask Q38a if Q33= 3 “Purchase Pellets”, otherwise skip to Q40)

Q38a) Is there a pellet source that you prefer?

1. Yes
2. No
3. DK/REF

(Ask Q38b if Q38a=”Yes”, otherwise skip to Q40)

Q38b) Why do you prefer that source?

Specify ___________

Q39) How much do you spend per year on wood?

1. $__________
2. DK/REF=9999

Q40) What is the brand name of your outdoor wood boiler? (open ended)

(Section 4: Central Oil)

(ask Q41-Q44 of Q2=1 “yes”, otherwise skip to Q45)

Q41) How large is your fuel oil tank, in gallons?

1. _______Gallons
2. DK/REF=9999

Q42) In gallons, how much oil do you use annually?

1. _______Gallons
2. DK/REF=9999

Q43) How many gallons do you use during the winter months (October – March)?

1. _______Gallons
2. DK/REF=9999

Q44) How much do you spend per year on fuel oil?

1. $__________
2. 9999=No/DK/REF

(Section 5: Portable Fuel Oil/Kerosene Heating Device)

(Ask Q45-Q46 if Q3=1 “YES”, otherwise skip to Q47)

Q45) You mentioned using a Portable Fuel Oil or Kerosene Heating Device, does the device use Fuel Oil?

1. Yes
2. No
3. DK/REF

Q46) Does the device use Kerosene?

1. Yes
2. No
3. DK/REF

(If Q45 OR Q46 = 1 “yes”, read Q47-Q48, otherwise skip to Q49)

Q47) In gallons, how much oil/kerosene do you use annually?

1. ________gallons
2. DK/REF=9999

Q48) How many gallons do you use during the winter months (October – March)?

1. ________gallons
2. DK/REF=9999

Q49) How much do you spend per year on oil/kerosene? No/DK/REF=9999

1. $________
2. DK/REF=9999

(Section 5.1
For homes using Central Oil, and/or Portable Fuel Oil/Kerosene Heating Devices, and/or Other devices)

(Ask Q50 if Q2=1 “yes” or Q3=1 “yes” or Q7=1 “yes”, otherwise skip to Q51

Q50) From this list please tell me what best describes your use of fuel oil and kerosene burning devices during the winter months, from October to March?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don't know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Section 6: Toyo, Monitor, or other Direct Vent Type of Heater if uses fuel oil and direct vent fuel consumption question

(Ask this section if Q4=1 "yes", otherwise skip to Q55)

If Q2=1 and Q4=1 skip Q 51 & Q52

Q51) In gallons, how much oil do you use annually?

1. _______Gallons
2. 9999=DK/refused

Q52) How many gallons do you use during the winter months (October – March)?

1. _______Gallons
2. 9999=DK/REF

Q53) How much do you spend per year on oil?

1. $________
2. 9999=DK/REF

Q54) What best describes your use of direct vent heating device during the winter months, from October to May?

a. Day time only	d. Weekend only	g. Not currently using any device
b. Evening only	e. Evening and Weekend only	h. Don't know (do not read)
c. Daytime and evening	f. Occasional use	i. Refused (do not read)

Section 7: Natural Gas Heating Device

(if Q5=1 "yes", ask Q55-Q56, otherwise skip to Q57)

Q55) How much do you spend on natural gas annually?

1. $________
2. DK/REF=9999

Q56) How much do you spend during the winter months, from October to March?

1. $________

2. DK/REF=9999

Section X: Coal Heating Device

(if q6=1 "yes", ask Q57-Q60, otherwise skip to Q61)

Q57) How much coal do you use annually?

1.__tons
2.__bags
3. DK/refused

Q58) How much did you pay for the coal?

1.___$/bag
2.___$/ton
3. DK/refused

Q59) How much coal do you use during the winter (October – March)?

1.__tons
2.__bags
3. DK/refused

Q60) Is your coal burned in an indoor stove or an outdoor boiler?

1. Indoor stove
2. Outdoor boiler
3. DK/refused

(Section F: Municipal Heat)

If Q7=1 "yes", ask Q61-Q62, otherwise skip to Q63)

Q61) How much do you spend on municipal heat annually?

1. $________
DK/refused =9999

Q62) How much do you spend on municipal heat during the winter months, October to March?

1. $________
DK/REF=9999

Future Section (to be completed for every survey)

Q63) Do you anticipate acquiring a new or different type of heating device within the next 2 years?

1. Yes
2. No
3. DK/refused

(If Q63=1 “yes”, ask Q64, otherwise skip to

Q64) What type of device do you plan to acquire? READ LIST

a. Wood Stove	d. Fuel Oil		h. Don’t know (do not read)
b. Wood Pellet	e. Kerosene		i. Refused (do not read)
c. Outdoor Wood Boiler	f. Coal stove	g. Outdoor coal boiler	j Other (Specify)

(If Q64= a. ‘Wood stove”, ask Q64a, otherwise skip to Q65)

Q64a) Newer EPA certified stoves are more efficient and require less chimney cleaning than older stoves. These benefits ultimately offset the purchase price, particularly if you hire chimney sweepers. How quickly would a new stove need to pay for itself in order for you to buy one?

1. 1 year
2. 2 years
3. 3 years
4. 4 years
5. 5 years or more
6. None
7. Don’t Know/Refused (do not read)

Q64b) Would you invest in a new more efficient stove if you were to receive a price incentive paid by either state or local government of $250? (like a rebate)

1. Yes
2. No >> ask 64c

if answer to 64 b is no then proceed to 64c:
Q64c) What if the price incentive was $500?

1. Yes
2. No >> ask 64d

if answer to 64 c is no then proceed to 64 d:

Q64d) And if the price incentive were $750, would you invest in a new stove?

1. Yes
2. No >> ask 64e

if answer to 64 d is no then proceed to 64 e:
Q64e) What if the incentive were $1,000?

1. Yes
2. No >> ask 64f

if answer to 64e) is no then proceed to 64f)

Q64f How much of an incentive would it take for you to invest in a new stove?

1. $1000 – 1200
2. $1201 – 1500
3. $1501 – 1750
4. $1751 – 2000
5. $2001 or more
6. DK/refused

(If Q1a=1 or Q12=2 ask Q65-Q68, otherwise skip to Q69)

Q65) Did you burn more wood this winter to minimize the cost of heating oil?

1. Yes
2. No
3. DK/REF

Q66) What fuel oil price would cause you to shift away from using wood for heating?
(If respondent is unclear of question ask: If fuel oil prices decline, at what price will you shift to using more fuel oil to heat and decrease the use of wood?)

Specify:____________

Q67) Natural gas is currently priced at $2.34/hundred cubic feed which is equivalent to $3.04 of #2 Heating Oil. How much lower would natural gas need to be priced to cause you to shift away from fuel oil? (If respondent is unclear of the question, ask what the equivalent fuel oil price per gallon that would cause them to shift away from fuel oil?)

Specify:____________

(ASK Q68 ONLY IF ZIP=99709, otherwise skip to Q69)

Q68) Can you please tell me whether you live inside of Chena Ridge (to the east of the ridge) or outside of Chena Ridge (to the west of the ridge).

1. Inside Chena Ridge
2. Outside Chena Ridge
3. DK/REF

(ASK Q69 ONLY IF ZIP=99712, otherwise skip to Q70)

Q69) Can you please tell me if you live inside of Farmers Loop Road or outside of Farmers Loop Road?

1. Inside Farmers Loop Road
2. Outside Farmers Loop Road
3. DK/REF

(ASK ALL)

Q70) Are you being impacted by wood smoke from your neighbors?

1. Yes
2. No
3. DK/REF

Q71) Does the Borough have a winter time air quality problem?

1. Yes
2. No
3. DK/REF

Q72) How do you keep abreast of current issues is it (read list, allow more than one answer)

1. TV
2. Radio
3. Newspaper
4. Internet
5. Other
6. DK/refused

Thank you, that is all the questions I have this evening. If you have questions or comments about this survey, I can give you the contact information for Hays Research Group. Again, thank you for your time.

2013 Wood-Burning Household Tag Survey

Intro / Screener

Hello, this is ___________ calling from Hays Research Group, an Alaskan research firm. We are conducting a survey today on behalf of the State and The Fairbanks Northstar Borough to gather information about specific models of heating devices to help us better understand the air quality issues in the area. Your number was selected at random, and all information collected will be kept confidential, your name address and phone number will not be included in any of the information given to the State or Borough. Can I speak to the person in the household who would be most knowledgeable about heating methods in your home?

Q1) Do you use any wood-burning heating devices in your house during winter?

(this could include wood stoves, fireplaces, hydronic heaters, outdoor wood boilers and pellet stoves)

1. Yes (continue)
2. No or Don't know / Refused (terminate "the survey today deals with wood heating devices, so you are ineligible to participate, thanks for your time")

Q2) What type of wood device(s) do you use? Read list (multiple answers OK)

1. Wood Stove
2. Pellet Stove
3. Insert
4. Fireplace
5. Hydronic heater (sometimes referred to as an outdoor wood boiler)
6. Other (specify) – removed 20913
7. (Don't know/Refused) - terminate

[IF Q2=1. WOOD, ASK Q3-Q9]

WOOD STOVE SECTION

Q3) I am going to ask you a few questions about your wood stove. Are you able to look at it to give me some specific information?

1. Yes
2. No (ask if there is a better time to call back)

Q4) What year was the wood stove installed in your home? (date range between 1950-2013)

1. (open ended)
2. Don't know=9998, Refused=9999 (ask Q4 again after Q9 if DK/REF)

Q5A-B) Do you know the make and model of your wood stove?

Q5A) Make

1. (open-end)
3. Don't know / Refused (ask Q5 again after Q9 if DK/REF)

Q5B) Model
1. (open-end)
2. Don't know / Refused (ask Q5 again after Q9 if DK/REF)

Q6) If you have a wood stove and it is EPA certified, it should have an EPA-certification label on the back or side. Please take a look at it as the next questions I will ask you are specific to the information written on the label.

<u>If the respondent refuses or is unable to see the label</u> - ask if you can set up a call back time to speak with someone who can or a time that is more convenient – be sure to reread the list of information you will be calling back for.

<u>If respondent refuses to set up a call back time</u> - ask if you can send them a postcard to be returned by mail with the requested information. (GO TO Q22 IF Q2=1 or 3 only and Q6=3 (Refused-YES TO POSTCARD). IF Q2=1 AND Q6=3 (Refused-YES TO POSTCARD) GO TO Q22. IF Q2=1 & 5 AND Q6=3 (Refused-YES TO POSTCARD) GOT TO Q10)

1=Continue
2=Set callback
3= Refused (YES TO POSTCARD)
4=Refused (NOT TO POSTCARD) – terminate
5=Wood stove not EPA Certified (go to Q22 if Q2=1 only, If Q2=1, 3 & 5, go to Q3I, then DQ10)
6=Label no longer available/Unreadable ((go to Q22 if Q2=1 only, If Q2=1, 3 & 5, go to Q3I, then DQ10)

Is it Catalyst Equipped or Non Catalytic?

1. Yes
2. No
3. Don't Know / Refused

Q7) What is the Smoke Rating (grams/hour)? – (range = 0.5 – 8 grams per hour)

______ (DK=98/REF=99)

Q8) What is the Efficiency (50% - 100%)?

1. Open ended (in percent)
2. Don't know=998, Refused=999

Q9) What is the Heat Output range (Btu/Hr.)? (range = 1000-80,000 btu)

1. Open ended (defined as range in # Btu/Hr eg "7000-30000")
2. Don't know=99998, Refused=99999

[IF Q2=3. INSERT, ASK Q3I-Q9I]

INSERT SECTION

Q3I) I am going to ask you a few questions about your Insert heating device. Are you able to look at it to give me some specific information?

3. Yes
4. No (ask if there is a better time to call back)

Q4I) What year was the Insert heating device installed in your home? (date range between 1950-2013)

4. (open ended)
5. Don't know=9998, Refused=9999 (ask Q4 again after Q9 if DK/REF)

Q5AI-Q5BI) Do you know the make and model of your Insert heating device?

Q5AI) Make

1. (open-end)
6. Don't know / Refused (ask Q5AI again after Q9I if DK/REF)

Q5BI) Model
1. (open-end)
2. Don't know / Refused (ask Q5BI again after Q9I if DK/REF)

Q6I) If you have an Insert heating device and it is EPA certified, it should have an EPA-certification label on the back or side. Please take a look at it as the next questions I will ask you are specific to the information written on the label.
<u>If the respondent refuses or is unable to see the label</u> - ask if you can set up a

call back time to speak with someone who can or a time that is more convenient – be sure to reread the list of information you will be calling back for.

<u>If respondent refuses to set up a call back time</u> - ask if you can send them a postcard to be returned by mail with the requested information. (GO TO Q22 IF Q2=1 or 3 only and Q6=3 (Refused-YES TO POSTCARD). IF Q2=3 AND Q6I=3 (Refused-YES TO POSTCARD) GO TO Q22. IF Q2=3 & 5 AND Q6I=3 (Refused-YES TO POSTCARD) GOT TO Q10)
1=Continue
2=Set callback
3= Refused (YES TO POSTCARD)
4=Refused (NOT TO POSTCARD) – terminate
5= Insert stove not EPA Certified (go to Q22 if Q2=3 only. If Q2=3 & 5, go to DQ10 before Q22)
6=Label no longer available/Unreadable (go to Q22 if Q2=3 only. If Q2=3 & 5, go to DQ10 before Q22)

Is it Catalyst Equipped or Non Catalytic?

4. Yes
5. No
6. Don’t Know / Refused

Q7I) What is the Smoke Rating (grams/hour)? – (range = 0.5 – 8 grams per hour)

______ (DK=98/REF=99)

Q8I) What is the Efficiency (50% - 100%)?

3. Open ended (in percent)
4. Don’t know=998, Refused=999

Q9I) What is the Heat Output range (Btu/Hr.)? (range = 1000-80,000 btu)

3. Open ended (defined as range in # Btu/Hr eg “7000-30000”)
4. Don’t know=99998, Refused=99999

[IF Q2=5 Hydronic heater, ASK Q10-Q21]

HYDRONIC HEATER SECTION

Q10) If you have a hydronic heater and it is "Phase 1 or Phase 2 Qualified", it will have a white label. Please take a look at it as the next questions I will ask you are specific to the information written on the label.

If the respondent refuses or is unable to see the label - ask if you can set up a call back time to speak with someone who can or a time that is more convenient – be sure to reread the list of information you will be calling back for.

If respondent refuses to set up a call back time - ask if you can send them a postcard to be returned by mail with the requested information. (GO TO Q22 IF Refused=Yes to Postcard, terminate if Q2=5 only and Q10=4 Refused-No to Postcard)
1=Continue
2=Set callback
3= Refused (YES TO POSTCARD)
4=Refused (NOT TO POSTCARD) – terminate
5= Hydronic heater not Phase 1/Phase 2 (go to Q22)
6= Label no longer available/Unreadable (go to Q22)

What is the Smoke Emissions This Model number (0.xx lbs/million btu)?

(IF NEEDED, read: This will be shown as a triangle along the bottom of a line. The number we are looking for is the one that says "this model")
(range = 0 - 0.5 lbs / million btu)

1. Open ended (in lbs/million Btu)
2. Don't know=98 / Refused=99

Q11) If it is not too difficult, please provide information on the following items:

Manufacturer (of the hydronic heater)
1. Open ended
2. Don't know / Refused

Q12) Model Number (of the hydronic heater)

1. ENTER MODEL NUMBER
2. Don't know / Refused

Q13) 8-Hour Heat Output Rating (Btu/Hr)

- (range = 1,000-400,000 btu/hr, answer will be in a range such as “10,000-40,000”

1. Open ended (in Btu/Hr)
2. Don’t know=999998, Refused=999999

Q14) 8-Hour Average Efficiency (in %)

- We will set this as a numeric open-end with 0-100% range then we can code DK as 101 and REF as 102 or both with 101

1. Open ended (in %)
2. Don’t know=101, Refused=102

Q15) Is your hydronic heater tag orange or white ?

1. Orange with a white border
2. White with an orange border
3. Don’t know / Refused (skip to Q19)

Q16) (ask Q16 only if Q15 = 1. Orange)

What is the Average emissions in Grams per Hour? This is denoted as blank grams per hour average

- (range = 5-30 grams /hr)

1. Open ended (in GRAMS/HR)
2. Don’t know / Refused

Q17) (ask Q17 – Q18 only if Q15 = 2 White)

What are the average emissions in grams per hour?
(range = 0-15 grams / hr)

1. Open ended (in GRAMS/HR)
2. Don’t know=98 / Refused=99

Q18) What is the maximum test run emissions? (IF NEEDED, read: This is denoted as blank grams per hour maximum test run).

- (range = 0-20 grams/hr)

1. Open ended (in GRAMS/HR)
2. Don’t know=98 / Refused=99

Q19) The next number down should be blank lbs per million BTU heat input. Can you read me that number?

- (range = 0-1 lbs/million btu)

1. Open ended (in LBS/MILLION BTU)

2. Don't know=98 / Refused=99

Q20) The next number down should be blank lbs per million BTU heat output. Can you read me that number?

- (range = 0-3 lbs/million btu)

1. Open ended (in LBS/MILLION BTU)
2. Don't know=98 / Refused=99

Q21) The last number on the bottom should read blank grams per hour per ten thousand BTU output. Can you read me that number?

- range = 0-2 grams / hr)

1. Open ended (in GRAMS/HR/10000BTU OUTPUT)
2. Don't know=98 / Refused=99

ALL DEVICE SECTION

ASK ALL

Q22) What other heating devices do you use?

1. A central oil furnace
2. Portable fuel oil or kerosene heating device
3. Toyo (toy-oh), Monitor, or other direct vent type heater
4. Natural gas heat
5. Coal heat
6. Municipal heat
7. Other (specify)
8. Don't Know / Refused
9. No other heating device (go to Q27)

ASK ALL

Q23A-Q23B) Roughly how much of your winter heating is done with wood versus other heating methods? For instance would you say you heat with 20% wood and 80% heating oil? (Should equal to 100%)

1. % Fuel oil
2. % Wood
3. DK=998
4. Refused=999

Q24) (For multi-device HHs) Do you always burn wood at colder temps as a secondary source of heat?

1. Yes
2. No
3. Don't know / Refused

Q25) Ask only if Q24 = 1. Yes, otherwise skip to Q27)

Is that because

1. You need the extra heat to keep all areas of the house warm
2. To save money?
3. Both?
4. Other specify
5. (Don't know/Refused)

Q26) (ask only if Q25 = 1. Yes, otherwise skip to Q27)
At what temperature do you have to start burning wood to keep all of the areas of the house warm?

1. Open ended (in degrees Fahrenheit) = (range: -60 to 100 degress)
2. Don't Know=998 / Refused=999

Q27) Have you participated in any of the following programs? (allow multiple responses)

1. Borough's Wood Stove Change Out Program
2. AHFC Home Rebate
3. AHFC Weatherization
4. No
5. Don't Know / Refused

(AHFC = Alaska Housing Finance Corporation)

ALL DEVICES, NEVER PARTICIPATED IN OTHER PROGRAMS SECTION

Q28) (ask only if Q27 = 4. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

If you did not participate in these programs, would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 75% of the cost of installing a new replacement device?

1. Yes
2. No
3. Don't Know / Refused

Q29) (ask if Q28= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 80% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q30) (ask if Q29= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 85% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q31) (ask if Q30= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 90% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q32) (ask if Q31= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 95% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q33) (ask if Q32= 2. No, otherwise skip to Q34, if Q2=2 Pellet, skip to Q37)

Would you change out the wood burning device you currently operate to a cleaner device if the Borough reimbursed you 100% of the cost of installing a new replacement device?
1=YES
2=NO
3= (Don't know/Refused)

Q34) Do you cut your own firewood or buy it from someone else?

1= Cut your own (go to Q37)
2= Buy it from someone else
3= Both
4= Don't Know / Refused

Q35A-Q35B) Ask if Q34 = 3. Both, otherwise skip to Q36)

How much of your wood do you buy versus cutting. For instance would you say you cut 75% and buy 25%?

1 = open ended (answer in terms of % cut / % bought)
2 = Don't know=998 / Refused=999

Q36) (ask only if Q34 = 2. Buy it from someone else, or 3. Both)

Where do you buy your firewood? Be as specific as possible as in the name of the person or company if possible.

1 = Open ended
2 = Don't Know / Refused

Q36A) What price, per cord, did you pay for wood this winter? (in $/cord of wood)

(Open ended) (99998=Don't know/99999=Refused)

Q36B) Does that price include the cost of delivery?

Yes
No
Don't know / Refused

[ASK Q37 ONLY IF Q2=1, 3-5]

ALL DEVICES, CORDWOOD SECTION

Q37) What types/species of wood do you burn? What's the share of each type? (read list) (IF 1 type of wood only/Other type of wood – do not ask follow up question but auto code it as 100%)
Birch (x%)
Spruce (y%)
Alder (z%)
Other type of wood (a%)

Q38A) (Ask Q38A only if Q2 = 1 "wood stove", 3. "insert" , 4 . "Fireplace" or 5. "Hydronic Heater/ Outdoor wood boiler", otherwise skip to Q38B)

In cords, how much wood do you burn from October to March?

1. ________cords
2. DK=9998/Refused = 9999

ALL DEVICES, PELLETS SECTION

Q38B) (Ask Q38B only if Q2 = 2 "pellet stove", otherwise skip to Q38C)For Pellet Stoves:

Q38) How many 40 lb bags of pellets do you burn in your wood burning stove or insert from October to March?

1. 40 lb bags of pellets ________
2. DK=9998/refused=9999

Q38C) How long do you season your wood, if at all? (range: 0 to 120 months)

(open ended) (record answer in number of months) code Don't know as 998 and Refused as 999

Q39) Knowing that dry wood provides 25 percent more heat than wet wood, would you pay $25 more per cord for dry wood?

1 = Yes
2 = No
3 = Don't Know / Refused

Q40) (ask if Q39 = 1. Yes, otherwise skip to Q43)

Would you pay 50 dollars more per cord for dry wood?

1 = Yes
2 = No
3 = Don't Know / Refused

Q41) (ask if Q40 = 1. Yes. Otherwise skip to Q43)

Would you pay 75 dollars more per cord for dry wood?

1 = Yes
2 = No
3 = Don't Know / Refused

Q42) (ask if Q41 = 1. Yes. Otherwise skip to Q43)

Would you pay 100 dollars more per cord for dry wood?

1 = Yes
2 = No
3 = Don't Know / Refused

Q43) On a scale of zero to a hundred with zero being wide open and a hundred being completely shut, where do you typically set the air damper on your wood stove or insert? (0-100% for min/max)?

Open ended (%)
Don't know=101 / Refused=102

Q44) Is there a difference between your nighttime and daytime setting?

1 = Yes
2 = No
3 = Don't Know / Refused

Q45) (Ask if Q44 = 1. Yes, otherwise skip to Q 47)

On a scale of zero to a hundred with zero being wide open and a hundred being completely shut, where do you set your air damper at night?

1. Open ended (%)
2. Don't know / Refused

Q46) (Ask if Q44 = 1. Yes, otherwise skip to Q 47)

On a scale of zero to a hundred with zero being wide open and a hundred being completely shut, where do you set your air damper during the daytime?

3. Open ended (%)
4. Don't know / Refused

Q47) If natural gas becomes available in Fairbanks, What natural gas price would get you to stop burning wood? This is a little bit difficult, but if you could, please phrase it in terms of dollars per gallon of heating fuel. For example you could say I would stop burning wood if natural gas cost the equivalent of four dollars a gallon of heating oil, or three dollars a gallon, etc.

1. Open ended (in $/GALLON) (range: 0-20 dollars)
2. Don't know / Refused

Q48) If natural gas were available in Fairbanks, would you still need to burn wood at lower temperatures to keep your house warm regardless of how gas is priced?

1. Yes
2. No
3. Don't know / Refused

IF RESPONDENT AGREED TO BE SENT A POSTCARD IN Q6, Q6I OR Q10, ASK the following information before terminating the call:

Name to send the Postcard to (full name)
Full Address

(END)
Those are all the questions I have today. Thank you for your time and participation. Have a good day/evening.

2013 Fairbanks Wood Purchasing Survey Questionnaire

Hello, this is ___________ calling from Hays Research Group, an Alaskan research firm. We are conducting a survey today on behalf of the State and The Fairbanks Northstar Borough to gather information about house heating devices to help us better understand the air quality issues in the area. Your number was selected at random, and all information collected will be kept confidential, your name address and phone number will not be included in any of the information given to the State or Borough. Can I speak to the person in the household who would be most knowledgeable about heating methods in your home?

Q1) Do you use any wood-burning heating devices in your house during the winter?

1. Yes (continue)
2. No (end call)

Q2) What type of wood device(s) do you use? Read list (allow multiple responses)

1. Stove
2. Insert
3. Fireplace
4. Hydronic heater (also known as an outdoor wood boiler)
5. Other (specify)
6. Don't know / Refused

Q3) Do you cut your own firewood, or buy it?

1. Cut
2. Buy
3. Both
4. Don't Know / Refused

Q4) (ask only if Q3 = both) How much of your wood do you buy versus cutting. For instance would you say you cut 75% and buy 25%?

1. open ended (answer in terms of % cut / % bought)
2. Don't know / Refused

PURCHASED WOOD (WOOD BUYERS) SECTION

Q5) (ask only if Q3 = 2. Buy, or 3. Both, otherwise skip to Q14) Regarding the firewood you purchase, do you have the wood delivered or do you pick it up?

1. Delivered
2. Pick It Up
3. Both
4. Don't know / Refused

Q6) Do you have a consistent firewood supplier?

1. Yes
2. No
3. Don't know / refused

Q7) (ask Q7 only if Q6 = 1. Yes, otherwise skip to Q09) How many years have you bought wood from them?

1. 1 year
2. 2 years
3. 3 years
4. 4 years
5. 5 years
6. 6 years
7. 7 years
8. 8 years
9. 9 years
10. 10 or more years
11. Don't know / Refused

Q8) What do you like most about the supplier? (multiple responses OK)

1. Price
2. Reliability
3. Honesty
4. Wood is split
5. Wood is dry
6. Delivery (when and where you want it dumped)
7. Other (please specify)
8. Don't know / Refused

Q9) (ask Q9 only if Q6 = 2. No, or 3, Don't know / Refused, otherwise skip to Q10) How do you choose a firewood supplier?

1. Advertisement (e.g., newspaper, Craigslist, etc.)
2. Word of mouth
3. Review old supplier info
4. Other (describe)
5. Don't know / Refused

Q10) Is the wood you buy already split or in the round?

1. Split
2. In the round
3. Both
4. Don't know / Refused

Q11) (ask Q11 only if Q10 = 2. In the round, or 3. Both, otherwise skip to Q12)

If the wood is in the round, when do you split it? (READ OPTIONS)

1. As needed
2. Upon delivery
3. Don't know / Refused

Q12) Do you know where your suppliers are getting their wood from?

1. Yes
2. No
3. Don't know / Refused

Q13) Where do they get their wood from?

(OPEN ENDED)

Q14) Are you aware of firewood theft?

1. Yes (from newspaper and news articles)
2. Yes (from personal experience)
3. No
4. Don't know / Refused

Q15) Do you ask suppliers what the moisture content of the firewood is that they are selling?

1. Yes
2. No
3. Don't know / Refused

Q16) Do the suppliers tell you the moisture content of the firewood they are selling?

1. Yes
2. No
3. Don't know / Refused

Q17) (ask Q17, only if Q16 = yes, otherwise skip to Q18)

Are they truthful about the moisture content when they tell you? Is it as dry as they say it is?

1. Yes
2. No
3. Don't Know / Refused

Q18) (Ask Q18 only if Q5 = 1. Yes, or 3. Both, otherwise skip to Q19) What is the delivery fee you pay for your wood? This is not the price of the wood, but only the delivery charge.

1. $__
2. Don't Know / Refused

CUT WOOD (WOOD BUYERS) SECTION

Q19) (ask Q19 only if Q3 = 1. Cut, or 3. Both, otherwise skip to Q20) With regard to the wood that you cut, where do you cut it (read list) (accept multiple answers)

1. State Lands
2. Military Bases
3. Railroad Land
4. Personal Property
5. Other (Please specify)
6. Don't Know / Refused

Q20) How long do you season your wood, if at all?

(open ended) (record answer in number of months)

Q21) (ask Q21 only if Q3 = 2. Buy or 3. Both, otherwise survey is complete)

What price did you pay for your wood this winter per cord? ($/cord)?

Q22) Knowing that dry wood provides 25 percent more heat than wet wood, would you pay $25 more per cord for dry wood?

1. Yes
2. No
3. Don't Know / Refused

Q23) (Ask Q23 if Q22 = 1. Yes, otherwise survey is complete)

Would you pay 50 dollars more per cord for dry wood?

1. Yes
2. No
3. Don't Know / Refused

Q24) (Ask Q24 if Q23 = 1. Yes, otherwise survey is complete)

Would you pay 75 dollars more per cord for dry wood?

1. Yes
2. No
3. Don't Know / Refused

Q25) (Ask Q25 if Q24 = 1. Yes, otherwise survey is complete)

Would you pay 100 dollars more per cord for dry wood?

4. Yes
5. No
6. Don't Know / Refused

(END OF SURVEY)

Attachment B

Residential Space Heating Source Plume Rise Calculations

Residential Space Heating Source Plume Rise Calculations

The approach described below is used to calculate the effective stack height of different home heating sources present in Fairbanks. The three stack types are described as stack 1) wood stove, stack 2) central oil, and stack 3) fireplace. These stack types vary by their exit temperature, diameter, flow rate and exit velocity. Table 1 presents a summary of the variables related to the stack parameters used for the plume rise calculations.

Table 1
Inputs for Plume Rise Calculation

Variable	Value	Units	Converted Value	Units	Description
G	9.81	g/m	9.81	m/s2	gravitational acceleration
Ts1min	250	F	394.2611	Kelvin	Temperature Stack 1 min
Ts1max	1000	F	810.9278	Kelvin	Temperature Stack 1 max
Ts2	400	F	477.5944	Kelvin	Temperature Stack 2 avg
Ts3min	250	F	394.2611	Kelvin	Temperature Stack 3 min
Ts3max	500	F	533.15	Kelvin	Temperature Stack 3 max
D1	6	inches	0.1524	meters	Diameter Stack 1
D2	5	inches	0.127	meters	Diameter Stack 2
D3	8	inches	0.2032	meters	Diameter Stack 3
Fr1min	5	CFM	0.00236	m3/s	Flow Rate Stack 1 min
Fr1max	50	CFM	0.023597	m3/s	Flow Rate Stack 1 max
Fr2	27	CFM	0.012743	m3/s	Flow Rate Stack 2
Fr3min	100	CFM	0.047195	m3/s	Flow Stack 3 min
Fr3max	200	CFM	0.094389	m3/s	Flow Stack 3 max
Vs1min	n/a	n/a	0.129361	m/s	Exit Velocity Stack 1 min
Vs1max	n/a	n/a	1.293611	m/s	Exit Velocity Stack 1 max
Vs2	n/a	n/a	1.005912	m/s	Exit Velocity Stack 2
Vs3min	n/a	n/a	1.455313	m/s	Exit Velocity Stack 3 min
Vs3max	n/a	n/a	2.910626	m/s	Exit Velocity Stack 3 max
U	n/a	n/a	2	m/s	Wind Speed (stable default)
Height1	15	feet	4.572	m	Stack Height 1
Height2	25	feet	7.62	m	Stack Height 2

Estimates for the exit temperature, diameter and flow rate were provided by Omni-Test Laboratories, Inc. Exit velocity was calculated from the flow rate. Parcel data for residences in Fairbanks showed that the majority of homes are either one or two stories tall. The stack heights for these different homes were provided from Fairbanks North Star Borough.

The formula used to calculate plume rise is presented below.

$$He = Hs + 21.425 * F^{3/4} / U$$

(source : *Air Pollution Its Origin and Control* , Wark et al. 1998)

Where *He* is effective stack height, *Hs* is the physical stack height, *U* is the wind speed and *F* is buoyancy flux as calculated below.

$$F = \frac{1}{4} * g * d^2 * V_s * (T_s - T)/T_s$$

Where *g* is gravitational acceleration, *d* is stack diameter, V_s is stack exit velocity, T_s is the stack exit temperature and *T* is ambient temperature.

The plume rise calculation was performed using the hourly ambient temperature for the 2008 episodes January 23rd to February 10th and November 2nd through November 17th. The minimum, average and maximum effective stacks were calculated for wood stoves, central oil heaters and fireplaces at 15' and 25'. Table 2 presents the resulting minimum, average and maximum effective stacks calculated across the two-episode period for both the default SMOKE wind speed of 2m/s and the average wind speed in the two episodes of 0.563 m/s.

Table 2
Effective Stack Height

Stack Device Type	Stack Height	Value Type	Effective Height (2m/s wind speed)	Effective Height (0.563 m/s wind speed)
Wood Stove	15 ft.	min	15.378 ft.	16.344 ft.
Wood Stove	15 ft.	avg	17.127 ft.	22.556 ft.
Wood Stove	15 ft.	max	18.871 ft.	28.753 ft.
Wood Stove	25 ft.	min	25.378 ft.	26.344 ft.
Wood Stove	25 ft.	avg	27.127 ft.	32.556 ft.
Wood Stove	25 ft.	max	28.871 ft.	38.753 ft.
Central Oil	15 ft.	min	16.694 ft.	21.018 ft.
Central Oil	15 ft.	avg	16.800 ft.	21.395 ft.
Central Oil	15 ft.	max	16.914 ft.	21.800 ft.
Central Oil	25 ft.	min	26.694 ft.	31.018 ft.
Central Oil	25 ft.	avg	26.800 ft.	31.395 ft.
Central Oil	25 ft.	max	26.914 ft.	31.800 ft.
Fireplace	15 ft.	min	18.579 ft.	27.714 ft.
Fireplace	15 ft.	avg	21.353 ft.	37.570 ft.
Fireplace	15 ft.	max	24.210 ft.	47.718 ft.
Fireplace	25 ft.	min	28.579 ft.	37.714 ft.
Fireplace	25 ft.	avg	31.353 ft.	47.570 ft.
Fireplace	25 ft.	max	34.210 ft.	57.718 ft.

The effective heights of the plume from the three wood devices for the different stack heights will be used to determine the layering of the area emissions from the home heating sector. Based on the home heating surveys in Fairbanks, one can determine the fraction of area sources that are due to each of the three heating devices listed above. Using the effective stack heights calculated above the emissions from the home heating devices can then be placed in the appropriate model layer. The first three model layers are 0-4 meters, 4-8 meters, and 8-12 meters. The fraction of the plume in a given layer will be calculated based on a normal distribution centered at the average effective stack height with the min and max values serving as the 3rd standard deviation or 99th percentile range of this distribution. A small Fortran program or NCL script can then be written to generate a layered area emissions file from the original single layer file in Netcdf format and ready for CMAQ input.

Attachment C

FMATS Regional Travel Demand Modeling Documentation

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING / PLANNING
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MEMORANDUM

Fairbanks North Star Borough Updated Population and Employment Forecasts

Date: November 22, 2017 Project #: 13520.10

To: ADOT&PF

From: Mike Aronson and Anais Malinge

SUMMARY

Kittelson and Associates, Inc. (KAI) recommends the use of population and employment forecasts for the Fairbanks North Star Borough (FNSB) based on an average of historical growth rates, the Alaska Department of Labor population forecasts and studies conducted by Woods & Poole Economics. Base population and employment totals were estimated for each five year increment between 2015 and 2050.

Forecasts may be affected by potential changes at Eielson Air Force Base (EAFB) or the Alaska Liquid Natural Gas (LNG) Project. The recommended forecasts include additional activity associated with the proposed F-35A deployment at EAFB, but do not include population or employment changes related to the LNG project.

The resulting average annual growth rates are 0.82% annual growth for population and 1.34% annual growth for total employment. Without the EAFB deployment, the resulting average annual growth rates would be 0.66% annual growth for population and 1.16% annual growth for total employment.

DIFFERENCES FROM PRIOR FORECASTS

Prior population and employment forecasts for the FNSB were documented in memoranda dated August 4, 2016 and March 1, 2017. The base population and employment forecasts (without F-35A deployment) are identical in all of the forecasts. The March 1, 2017 forecast added a small amount of supporting non-military employment based on the F-35A deployment, and also added additional temporary employment for the EAFB construction period. This November 2017 update incorporates newer EAFB projections, and includes the following changes from prior forecasts:

- Decrease in direct EAFB employment from 1,563 to 1,474
- Increase in dependents from 1,202 to 1,798

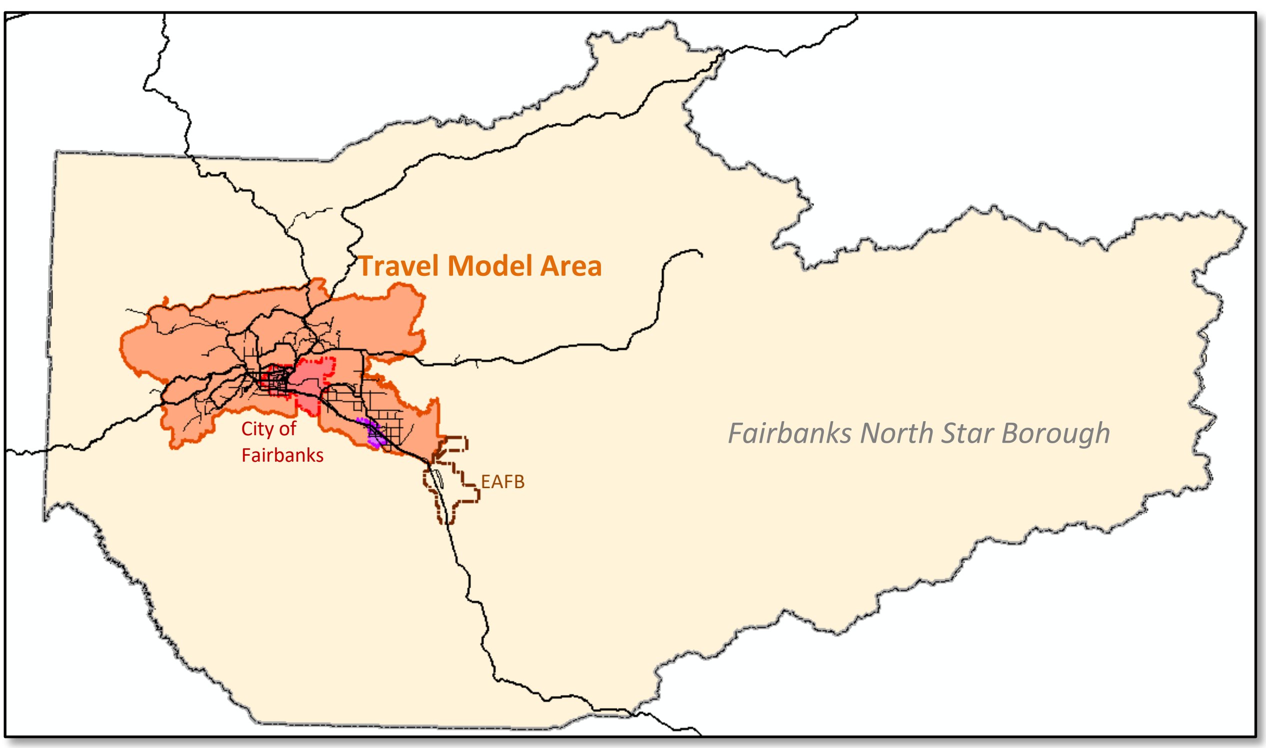
- Estimate of additional induced population growth due to births and supporting activity, with 2,152 additional population estimated by 2030
- Revised estimates of temporary construction activity, with a peak of 852 employees in 2020
- Increased estimates of induced employment growth related to serving the increased population, with 2,123 additional employees projected by 2045

Compared to the forecasts documented March 1, 2017, the 2045 FNSB population estimate would increase from 122,706 to 125,541 (+2.3%). The 2045 FNSB employment estimate would increase from 81,317 to 83,080 (+2.2%).

STUDY AREA

The Alaska Department of Labor and Woods & Poole Economics data reflect forecasts for the entire FNSB. However, the travel model area encompasses a smaller area within the larger FNSB, as shown in Figure 1. The travel model area contains approximately 35,000 out of the 39,000 total households in the FNSB (90 percent), and includes about 45,000 out of the 59,000 total FNSB employees (76 percent), with EAFB contributing most significantly to the differences. The forecasts documented in the subsequent sections represent the projected growth in population and employment for the larger FNSB area. The forecast growth rates for each land use type and time period will be applied to the smaller travel model area.

Figure 1: Fairbanks Model Area



DATA SOURCES

Alaska Department of Labor and Workforce Development

The Alaska Department of Labor and Workforce Development (Alaska DOL) produces population estimates and projections for the State of Alaska and its regions. Population estimates and projections are reported in the April 2016 *Alaska Population Projections* report from 2015 to 2045. The Alaska DOL population forecast uses the cohort component method, which accounts for in- and out-migration, births, and deaths as the primary factors for population fluctuations.

In addition, the Alaska DOL produces a ten-year industry forecast for the State of Alaska. The ten-year forecast for the State of Alaska is documented in the October 2014 *2012 to 2022 Alaska Economic Trends* article.

Woods & Poole

Woods & Poole Economics, Inc. is a private firm that specializes in long-term county economic and demographic projections. Woods & Poole industry and population projections for the FNSB were purchased in June 2016 and used as a basis for comparison with the DOL forecasts.

The Woods & Poole forecast methodology applies a regional projection technique which captures regional economic flows at the county, state and regional levels and constrains the results with an estimated United States total. The Woods & Poole employment forecast is founded on an export- based approach for Economic Areas (EA) as defined by the Bureau of Labor Statistics which is then used to estimate earnings. The employment and earnings projections become explanatory variables to estimate population and households, essentially assuming net migration rates projected from employment opportunities. The EA projections are then disaggregated to counties and used as control totals.

HISTORICAL TRENDS

The following shows historical trends from 1985 to 2015 for population and employment by industry growth, as summarized by Woods & Poole.

Population Trends

Table 1 and Figure 2 show the historical population trend for the FNSB. As calculated and shown in Table 1, population for the 30 year period between 1985 and 2015 experienced an average increase of 950 persons per year, corresponding to a 1.3% annual growth rate compared to the 1985 population or a 1.0% annual growth rate compared to the 2015 population. The population growth for the five year period prior to 1985 was faster, averaging nearly 3,400 persons per year.

Table 1: Historical FNSB Population Trends (1980-2015)

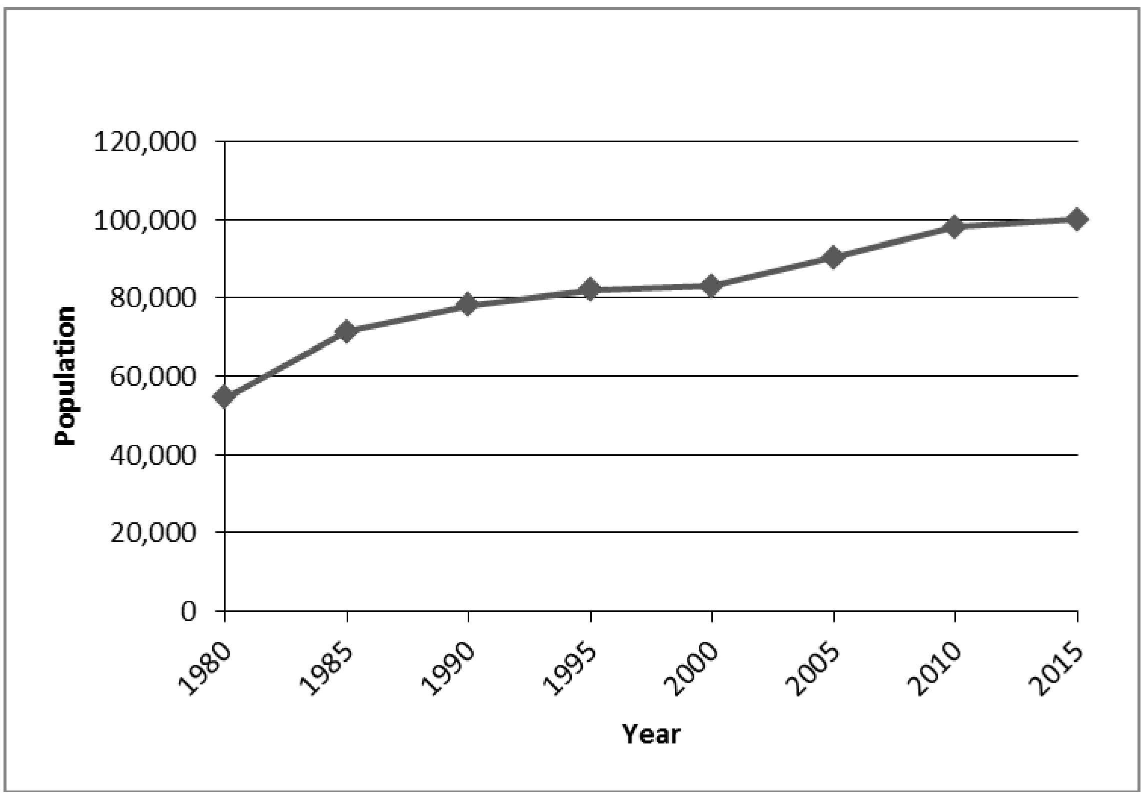
Year	1980	1985	1990	1995	2000	2005	2010	2015	Average Annual Growth Rate (%)
Population	54,503	71,435	78,067	81,941	83,005	90,431	98,279	100,000	0.96%
Households	18,445	22,725	26,862	28,927	29,831	35,224	36,704	39,060	1.37%

Note: Annual growth rate calculated relative to 2015 totals for the 30 year period, 1985-2015.

Source: Woods & Poole Economics, 2016.

Figure 2 indicates that there were several different growth rates during the past 30 years. Population grew at a rate of 1,325 persons per year between 1985 and 1990, then less than 800 per year between 1985 and 2000. Using the most recent 10 year period from 2005 to 2015, the growth rate has averaged 955 persons per year. This rate is similar to the 30-year average.

Figure 2: Historical FNSB Population Trends (1985-2015)



Employment Trends

Table 2 shows the historical employment trends for the period between 1980 and 2015 for industry sectors in the FNSB. The largest employment sectors in 2015 were Government, Military and Professional Services.

The FNSB region added an average of 530 jobs per year for the 30-year period between 1985 and 2015. The sectors with the highest increases were Health Services (115 jobs per year), Professional Services (95 jobs per year), and Leisure/Hospitality and Government (each 75 jobs per year).

In terms of growth rates compared to 2015 totals, the average annual growth rate was 0.8%, similar to the population growth rate during the same 30-year period. The industry sectors that experienced the greatest annual growth rates were the Health Services sector (1.9%) and the Leisure and Hospitality sector (1.4%).

Table 2: Historical Industry Trends in FNSB (1980-2010)

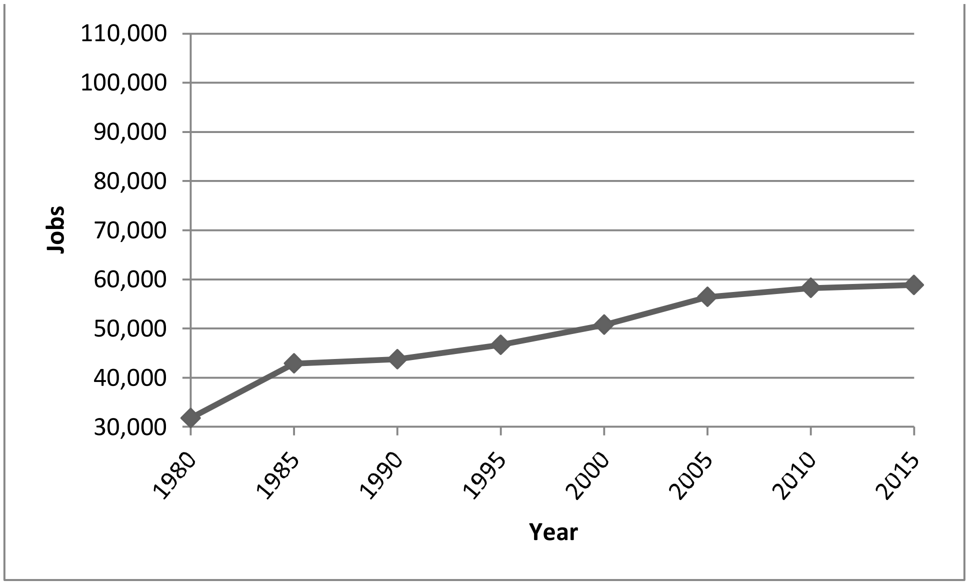
Industry Sector	1980	1985	1990	1995	2000	2005	2010	2015	Average Annual Growth Rate (%)
Agriculture	169	232	219	221	216	205	213	271	0.5%
Resources/Mining	896	1,436	1,370	1,679	1,835	1,733	1,924	3,081	1.8%
Construction	1,969	4,221	2,172	2,732	2,729	4,117	3,754	3,623	-0.6%
Manufacturing	826	757	853	946	902	930	905	938	0.6%
Wholesale	483	725	602	629	608	757	780	885	0.6%
Retail	2,728	4,310	4,612	5,326	5,242	6,222	5,751	5,956	0.9%
Trans/Ware/Utility	2,253	2,523	1,978	2,184	2,833	2,577	2,900	2,501	-0.03%
Prof Services	4,442	5,314	5,371	5,881	7,206	8,120	8,619	8,142	1.2%
Health Services	1,694	2,457	2,855	3,320	4,119	4,995	5,540	5,854	1.9%
Leisure/Hospitality	2,139	3,210	3,609	4,233	4,725	5,277	5,261	5,439	1.4%
Other Services	1,161	1,713	1,994	2,323	2,408	2,524	2,440	2,336	0.9%
Government	7,400	9,246	9,735	9,640	10,351	10,982	11,550	11,470	0.6%
Military	5,622	6,738	8,368	7,569	7,562	7,983	8,591	8,355	0.6%
Total Employment	**31,782**	**42,882**	**43,738**	**46,683**	**50,736**	**56,422**	**58,228**	**58,851**	**0.9%**

Note: Annual growth rate calculated relative to 2015 totals for the 30 year period, 1985-2015..

Source: Woods & Poole Economics, 2016.

Figure 3 shows the historical trend for total employment for the 30 year period. As shown, the largest growth in total employment occurred between 1980 and 1985, when the region added an average of 2,220 jobs per year. During the most recent 10-year period from 2005 to 2015, employment increased by an average of 240 jobs per year (0.4% compared to the 2015 total).

Figure 3: Historical Trend for FNSB Total Employment (1980-2015)



FORECAST COMPARISON

The following section provides updated population and employment forecasts as well as comparisons with the prior forecasts used for the 2040 Metropolitan Transportation Plan (MTP) and documented in the 2014 *Recommended Population and Employment Forecast* Memorandum ("2014 Memo"). The 2014 Memo was informed by 2013 Woods & Poole data and 2012 Alaska DOL data, while the updated forecasts are informed by updated 2016 Woods & Poole data and updated 2014 Alaska DOL data.

Population Forecast

Table 3 and Figure 4 provide the long-term population forecast comparison between Woods & Poole and Alaska DOL projections. The DOL and Woods & Poole start at similar 2010 population levels. As shown, the prior 2012 DOL population projections assumed a notably higher average annual growth rate (1.41%) than those assumed in the more current 2014 DOL population projections (0.34%). Woods & Poole estimates an average annual population growth rate of 0.60% to the year 2050, which is higher than the new DOL forecast but lower than the prior 2012 DOL forecast.

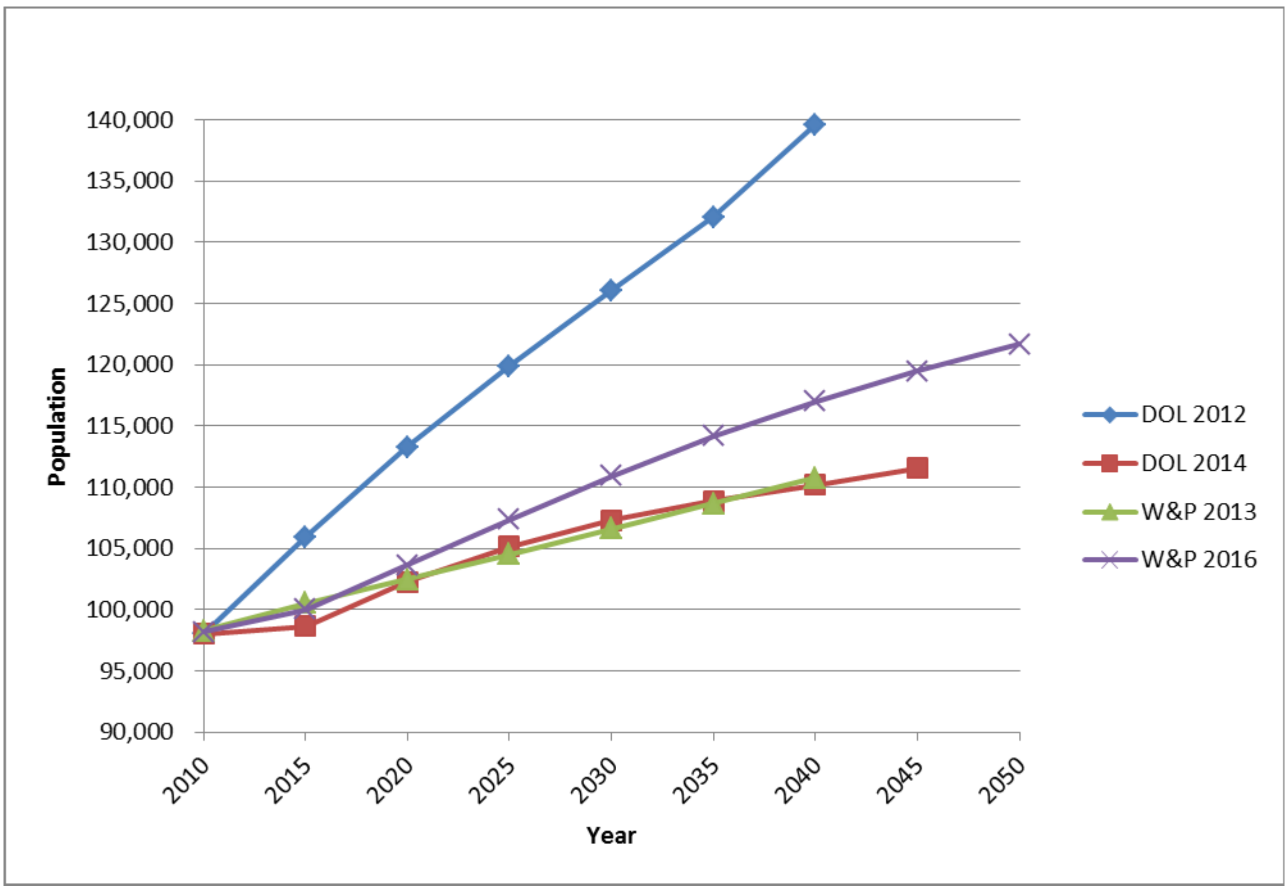
Table 3: Comparison of FNSB Population Forecasts (2010-2050)

Projection Series	2010	2015	2020	2025	2030	2035	2040	2045	2050	Average Annual Growth Rate[1]
2012 DOL[1]	98,000	105,928	113,275	119,910	126,067	132,076	139,620	n/a	n/a	1.41%
2014 DOL[1]	98,000	98,645	102,237	105,139	107,276	108,869	110,197	111,562	n/a	0.34%
2013 W&P[1]	98,279	100,539	102,471	104,528	106,596	108,656	110,764	n/a	n/a	0.42%
2016 W&P	98,174	100,000	103,643	107,326	110,933	114,192	117,009	119,460	121,664	0.60%
Compare 2016 W&P to 2014 DOL	-1.4%	-1.4%	-2.0%	-3.3%	-4.7%	-5.8%	-6.6%	-7.9%	n/a	

[1] Annual growth rates based on linear trend lines for population forecasts between 2010 and 2040.

Source: Alaska DOL, 2012; Alaska DOL, 2014; Woods & Poole, 2013; Woods & Poole, 2016.

Figure 4: Comparison of FNSB Population Forecasts (2010-2050)



Employment Forecast

Table 4 shows the current long-term forecast for industry sectors as projected by Woods & Poole. The forecast assumes a total employment change of 44% between 2015 and 2050, corresponding to a 0.87% annual growth rate. Table 4 also documents the annual growth rate for each industry sector. As shown, the Retail (114%), Wholesale (82%), Agriculture (58%), and Professional Services (58%) sectors are projected to experience the greatest growth rates. In particular, Woods & Poole projects virtually no growth in military employment in the Fairbanks area.

Table 4: Employment Projections, 2015-2050

Industry Sector	2015	2020	2025	2030	2035	2040	2045	2050	Growth (%)	Annual Growth Rate (%)
Agriculture	271	294	317	340	363	386	408	429	58.3%	1.06%
Resources/Mining	3,081	3,288	3,505	3,730	3,962	4,201	4,446	4,697	52.5%	0.98%
Construction	3,623	4,060	4,444	4,712	4,914	5,106	5,327	5,574	53.9%	0.95%
Manufacturing	938	1,009	1,062	1,107	1,148	1,187	1,225	1,262	34.5%	0.71%
Wholesale	885	993	1,093	1,197	1,302	1,406	1,507	1,609	81.8%	1.28%
Retail	5,956	6,783	7,567	8,426	9,369	10,401	11,531	12,766	114.3%	1.51%
Trans/Ware/Utility	2,501	2,554	2,652	2,750	2,835	2,901	2,948	2,980	19.2%	0.49%
Prof Services	8,142	8,828	9,535	10,247	10,945	11,618	12,258	12,875	58.1%	1.06%
Health Services	5,854	6,340	6,856	7,383	7,884	8,333	8,714	9,034	54.3%	1.03%
Leisure/Hospitality	5,439	5,785	6,135	6,441	6,669	6,897	7,152	7,406	36.2%	0.74%
Other Services	2,336	2,470	2,614	2,763	2,915	3,067	3,217	3,363	44.0%	0.88%
Government	11,470	12,125	12,694	13,171	13,554	13,855	14,098	14,298	24.7%	0.56%
Military	8,355	8,380	8,405	8,429	8,454	8,479	8,504	8,529	2.1%	0.06%
Total Employment	**58,851**	**62,909**	**66,879**	**70,696**	**74,314**	**77,837**	**81,335**	**84,822**	**44.1%**	**0.87%**

Source: Woods & Poole, 2016.

Table 5 and Figure 5 provide the long-term (2040) employment forecast comparison between the previous and current Woods & Poole projections. The comparison of growth rates only extends to 2040, as 2040 was the last forecast year for the 2013 Woods & Poole projections. The newer forecasts result in 4.2 percent more jobs by 2040 compared to the prior forecasts.

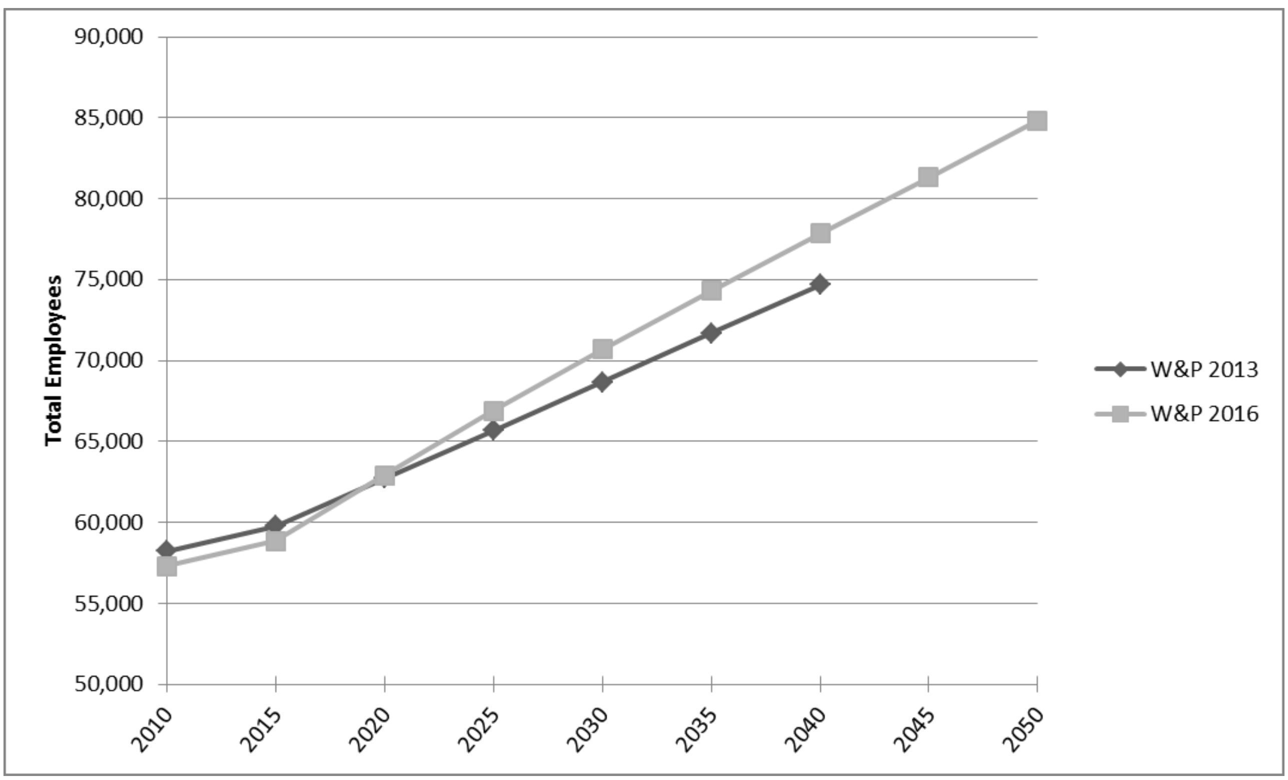
The most significant increases between the growth rates in the prior and current forecasts are in the Resource/Mining and Retail sectors. Large percentage changes are projected for the Agriculture and Manufacturing sectors, but the increases in numbers of employees are relatively small (change in 30-year employee growth from 37 to 120 for agriculture and from 53 to 336 for manufacturing). The newer forecasts result in slower growth in the Health Services sector.

Table 5: Comparison of FNSB Employment Growth by Sector

Industry Sector	2013 Woods & Poole			2016 Woods & Poole		
	2010	2040	Growth (%)	2010	2040	Growth (%)
Agriculture	213	250	17.4%	266	386	45.1%
Resources/Mining	1,924	2,552	32.6%	2,175	4,201	93.1%
Construction	3,754	5,223	39.1%	3,665	5,106	39.3%
Manufacturing	905	958	5.9%	851	1,187	39.5%
Wholesale	780	1,350	73.1%	758	1,406	85.5%
Retail	5,751	8,331	44.9%	5,616	10,401	85.2%
Trans/Ware/Utility	2,900	3,756	29.5%	2,414	2,901	20.2%
Prof Services	8,619	11,584	34.4%	8,500	11,618	36.7%
Health Services	5,540	9,632	73.9%	5,572	8,333	49.6%
Leisure/Hospitality	5,261	7,017	33.4%	5,192	6,897	32.8%
Other Services	2,440	3,153	29.2%	2,101	3,067	46.0%
Government	11,550	12,535	8.5%	11,561	13,855	19.8%
Military	8,591	8,344	-2.9%	8,621	8,479	-1.6%
Total Employment	**58,228**	**74,685**	**28.3%**	**57,292**	**77,837**	**35.9%**

Source: Woods & Poole, 2013; Woods & Poole, 2016.

Figure 5: Comparison FNSB Employment Forecasts



RECOMMENDED FORECASTS

Recommendations are provided for a "base forecast" and for additional potential activities which would increase the population and employment forecasts above the base. The "base forecast" refers to the population and employment forecasts based on documented sources, and without explicit consideration of changes due to EAFB or the LNG project. The potential changes due to EAFB and the LNG project are also described.

Recommended Base Forecasts without Additional Activity

The base total population and employment forecasts are summarized in Table 6, excluding the effects of potential changes at EAFB and the LNG Project. The average annual growth rates are not strictly the averages of the individual growth rates, but are instead summarized annual growth rates based on a statistical analysis of the recommended forecasts by 5-year increments described in the following sections.

Table 6: Comparison of FNSB Growth Rates without Additional Activity

Forecast	Population	Employment
Historic	0.96%	1.05%
Alaska Department of Labor	0.37%	n/a
Woods & Poole	0.51%	1.26%
Recommended	**0.66%**	**1.15%**

Source: Kittelson & Associates, 2016

Base Population Forecast

It is recommended that the base population forecast use an average of the three available sources: historical trends, Alaska DOL and Woods & Poole. The historical trends were extrapolated from the 2015 population using the average 0.96% annual growth rate from 1985-2015. The recommended base forecast for each five year increment is the average of the extrapolated historical growth, the Woods & Poole forecast and the DOL forecast (Table 7). A statistical analysis of the average population numbers results in a 0.66% annual population growth rate.

Table 7: Recommended Base Population Forecast

	2015	2020	2025	2030	2035	2040	2045	2050	Growth (%)
Historical	100,000	104,800	109,600	114,400	119,200	124,000	128,800	133,600	0.96%
W&P Forecast	100,000	103,643	107,326	110,933	114,192	117,009	119,460	121,664	
DOL Forecast	98,645	102,237	105,139	107,276	108,869	110,197	111,562	111,993	
Average	99,548	103,560	107,355	110,870	114,087	117,069	119,941	122,419	0.66%

Base Employment Forecast

Woods & Poole projects a higher employment growth rate than the historical employment growth rate. For employment forecasts, it is recommended that an average of the historical trends and Woods & Poole be used (Table 8). The historical trends were extrapolated from the 2015 employment using the average 1.05% annual growth rate from 1985-2015. A statistical analysis of the averages results in a 1.15% annual employment growth rate.

Table 8: Recommended Base Employment Forecast

	2015	2020	2025	2030	2035	2040	2045	2050	Growth (%)
Historical	58,851	61,945	65,039	68,132	71,226	74,320	77,414	80,508	1.05%
W&P Forecast	58,851	62,909	66,879	70,696	74,314	77,837	81,335	84,822	1.26%
Average	58,851	62,427	65,959	69,414	72,770	76,079	79,374	82,665	1.15%

Once the total employment forecasts are established, it is recommended that the percentages from the Woods & Poole forecasts be used to allocate employment type by sector for each five year time period.

ADDITIONAL POPULATION AND EMPLOYMENT GROWTH

Additional population and employment growth beyond the "base forecasts" may occur related to the basing and operation of two F-35A squadrons at EAFB and to the LNG Project.

Eielson Air Force Base

The expansion of the EAFB will involve phased workforce increases during construction and at full build-out. Construction activity is anticipated to start in 2017 and continue through 2022, while the EAFB workforce is anticipated to be phased across a five year period, between 2017 and 2022.

An initial estimate of population and employment growth associated with the F-35A deployment was documented in the United States Air Force, "F-35A Operational Beddown – Pacific Environmental Impact Statement," February, 2016 (EIS) as summarized in FNSB, Baseline and Projected Populations for EAFB Memorandum, June 29, 2016. Since the publication of the EIS, the Air Force has conducted additional studies of potential effects in the Fairbanks area. The most recent available projections were prepared by Northern Economics on October 31, 2017. The newer projections use a more comprehensive forecast model by Regional Economics Models, Inc. (REMI) which consider a wide variety of induced population and employment effects.

Table 9 provides a summary of the anticipated growth in population and employment related to the EAFB expansion.

Table 9: EAFB Additional Population and Employment Growth

	2015	2020	2022	2025	2030	2035	2040	2045
Population								
EAFB Personnel	0	569	1,353	1,353	1,353	n/a	n/a	n/a
EAFB Contractors	0	n/a	121	121	121	n/a	n/a	n/a
EAFB Dependents	0	n/a	1,798	1,798	1,798	n/a	n/a	n/a
EAFB Induced	0	n/a	n/a	n/a	2,152	n/a	n/a	n/a
TOTAL	0	n/a	n/a	n/a	5,424	n/a	n/a	n/a
Total Employment	0	620	1,474	1,474	1,474	n/a	n/a	n/a

Source: Northern Economics, "F-35A Beddown and Military Construction," October 31, 2017.

A summary of the population and employment growth assumptions are provided below:

- Total population increase of 3,272 military personnel, civilian personnel, and their dependents phased in between 2017 and 2022);
- An additional induced population (births, etc… associated with increased population) of 2,152 by 2030

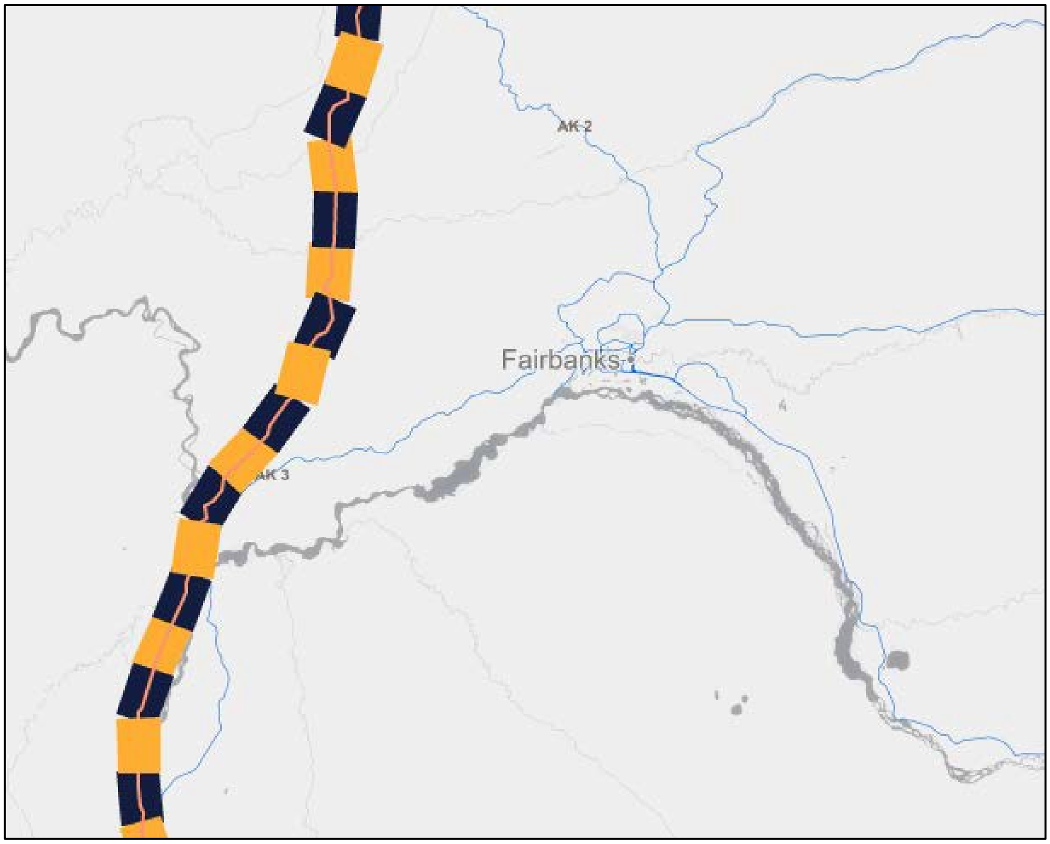
The Northern Economics summary did not include several components of growth. These have been estimated separately based on proportions from the information provided:

- EAFB personnel, contractors and dependents are assumed to remain at 2030 levels for years beyond 2030.
- The numbers of contractors for years prior to 2022 are estimated based on the 2022 proportions of contractors to Air Force personnel.
- The numbers of dependents for years prior to 2022 are estimated based on the 2022 proportions of dependents to Air Force personnel.
- The induced population growth for years prior to 2030 is estimated based on the proportions to Air Force personnel. The induced population after 2030 is assumed to grow at the same rate as the base (non-EAFB) population forecast.
- EAFB construction jobs were estimated based on an earlier Northern Economics projection dated September 22, 2017.
- Additional induced employment was estimated to serve the additional population, based on the proportion of base (non-EAFB) employment to base (non-EAFB) population.

Alaska Liquid Natural Gas Project

Potential construction of the proposed LNG Project could have temporary and permanent impacts on population and employment in the Fairbanks area. The proposed alignment of the LNG pipeline would be along the western edge of the Fairbanks North Star Borough (Figure 6).

Figure 6: Potential Alaska LNG Pipeline Alignment



Source: http://alaska-lng.com/project-overview/map/

The LNG project is still under study, and the schedule for its implementation is uncertain at this time. A feasibility study prepared by Wood Mackenzie in August 2016[1] stated that, "currently the competitiveness of the Alaska LNG project ranks poorly when compared to competing LNG projects…. This ranking also means that not only will the project not make sufficient returns for investors at current LNG market prices, but it may struggle to make acceptable returns even under a US $70/barrel price. There are certain levers that could be used to improve the competitiveness of the Alaska LNG project and potentially also improve the competitiveness compared with other

[1] Wood Mackenzie, Alaska LNG Competitiveness Study (presentation), August 2016.

jurisdictions." As of December, 2016, the Alaska Gasline Development Corp. (AGDC), a state entity, was taking over the technical and regulatory activities associated with the LNG project.[2]

A set of resource reports were prepared for the LNG in 2016, with one of them covering potential impacts on population and employment[3]. The report states that, "Project data are not yet available for modeling. These data would be incorporated when available. As a result, Draft 2 of Resource Report No. 5 provides a qualitative discussion of potential Project effects by affected resource."

Resource Report 5 provides the following information:

- The first phase of construction was projected for 2019 to 2025 and would include most of the pipelines, liquefaction facilities and marine facilities.
- Operations and the second phase of construction would start in 2025.
- The new local resident population increases caused by Project construction would likely be highest in the main economic activity centers of Fairbanks, Anchorage, or around other identified pick up locations, the Kenai Peninsula Borough (KPB), and the Matanuska-Susitna Borough (MSB).
- Fairbanks and Anchorage would be the primary locations in Alaska where goods and services for the Project would be purchased from local businesses during the construction phase. The additional temporary economic activity and jobs these purchases would generate are expected to result in an increase in the populations of the two cities. In addition, Fairbanks and Anchorage, together with the KPB and MSB, would be where many of the persons directly and indirectly working on the Project would spend a portion of their incomes on consumer goods and services. The additional jobs this spending would generate are expected to also result in temporary population increases in the affected areas.
- Project construction would create temporary and seasonal increases in jobs in Alaska. The employment effects of construction would be felt primarily from 2019 through 2027.
- The additional economic activity and jobs that would be generated by the Project in Fairbanks and Anchorage would temporarily result in a substantial increase in local demand for housing in absolute terms, but the increase in percentage terms would be minor due to the large existing supply of temporary accommodations in the municipalities.
- Most permanent employment after construction would be in the Anchorage area or near the liquefaction facility in the KPB. Of the approximately 700 operations personnel projected for the Project, approximately 400 are anticipated to be located in Anchorage.

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[2]Natural Gas Intelligence website, http://www.naturalgasintel.com/articles/108904-state-of-alaska-taking-over-pipeline-lng-project-from-producers, December 30, 2016.

[3] Alaska LNG Project, "Draft Resource Report No. 5, Socioeconomics," July, 2016

Potential Temporary LNG Effects

Temporary changes would occur during the pipeline construction period and would be expected to be greater than the permanent changes. These would include Fairbanks' role as a base for residences of construction workers, materials suppliers and their employees, and auxiliary businesses that support the construction activity. Changes in population and employment during construction may affect a focused five to ten year period but would not necessarily significantly revise the long-term population and employment forecasts to the year 2045.

Potential Long Term LNG Effects

Permanent changes in population and employment would depend on Fairbanks' role in the ongoing operation and maintenance of a LNG pipeline. Although most of the permanent employment would be in Anchorage or KPB, it would be reasonable to assume that there would be some ongoing presence of LNG and LNG-related employees in the Fairbanks area. That number would not be expected to significantly change the overall population and employment growth rates.

Recommendation

It is recommended that the current population and employment forecasts for FNSB not include any adjustments for the LNG project. This is due to the following considerations:

- The long-term effects of LNG operation in the Fairbanks area are expected to be minimal after the construction period.
- The financing and implementation of the project is uncertain at this time.
- Quantification of the population and employment changes associated with construction are not yet available.

RECOMMENDED FORECASTS WITH ADDED ACTIVITY

Table 10 and Table 11 show the recommended FNSB population and employment forecasts, respectively, for each five year increment, and for several interim years required for air quality analysis. The recommended forecasts assume a base population and employment forecast, and the added growth resulting from the EAFB expansion.

Indirect employment associated with EAFB would represent additional employment to serve the additional population. The indirect employment was estimated based on maintaining the ratio of total employment to total population, increasing the total employment associated with the additional population compared to the base population, then subtracting the additional employment that would be directly employed at EAFB. This maintains the overall proportions of total employment to total population.

Table 10: Recommended Population Forecast

		2015	2017	2019	2020	2021	2022	2023	2024	2025	2030	2035	2040	2045	2050	Growth (%)	Annual Growth Rate (%)
Base Population		99,548	101,153	102,758	103,560	104,319	105,078	105,837	106,596	107,355	110,870	114,087	117,069	119,941	122,419	22.97%	0.66%
Eielson AFB Personnel		0	18	104	569	1,186	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353		
Eielson AFB IContractors		0	2	9	51	106	121	121	121	121	121	121	121	121	121		
Eielson AFB Dependents		0	24	138	756	1,576	1,798	1,798	1,798	1,798	1,798	1,798	1,798	1,798	1,798		
Eielson AFB Induced		0	4	44	302	755	1,004	1,148	1,291	1,435	2,152	2,152	2,152	2,152	2,152		
Alaska LNG																	
Total Population		**99,548**	**101,200**	**103,053**	**105,238**	**107,942**	**109,354**	**110,257**	**111,159**	**112,062**	**116,294**	**119,573**	**122,613**	**125,541**	**128,067**	**28.65%**	**0.82%**
5-Year Growth					5,689					6,824	4,232	3,280	3,040	2,928	2,526		
5-Year Growth Rate (%)					5.72%					6.48%	3.78%	2.82%	2.54%	2.39%	2.01%		

Table 11: Recommended Employment Forecast

Industry Sector	Category	2015	2017	2019	2020	2021	2022	2023	2024	2025	2030	2035	2040	2045	2050	Growth (%)	Annual Growth Rate (%)
Agriculture	Industrial	271	279	288	292	296	300	304	308	313	334	355	377	398	418	54.28%	1.55%
Resources/Mining	Industrial	3,081	3,154	3,226	3,263	3,302	3,340	3,379	3,418	3,457	3,662	3,880	4,106	4,339	4,578	48.57%	1.39%
Construction	Industrial	3,623	3,785	3,948	4,029	4,100	4,170	4,241	4,312	4,383	4,627	4,812	4,991	5,199	5,432	49.94%	1.43%
Manufacturing	Industrial	938	963	989	1,001	1,010	1,020	1,029	1,038	1,047	1,087	1,124	1,160	1,195	1,230	31.12%	0.89%
Wholesale	Industrial	885	925	965	985	1,004	1,022	1,041	1,059	1,078	1,175	1,275	1,374	1,471	1,568	77.18%	2.21%
Retail	Retail	5,956	6,266	6,576	6,731	6,877	7,024	7,170	7,317	7,463	8,273	9,174	10,166	11,253	12,441	108.89%	3.11%
Trans/Ware/Utility	Industrial	2,501	2,514	2,528	2,534	2,551	2,567	2,583	2,599	2,616	2,700	2,776	2,835	2,877	2,904	16.12%	0.46%
Prof Services	Office	8,142	8,389	8,637	8,760	8,889	9,018	9,146	9,275	9,404	10,061	10,718	11,356	11,963	12,548	54.11%	1.55%
Health Services	Office	5,854	6,029	6,204	6,291	6,385	6,480	6,574	6,668	6,762	7,249	7,720	8,145	8,504	8,804	50.40%	1.44%
Leisure/Hospitality	Retail	5,439	5,560	5,680	5,741	5,803	5,865	5,927	5,989	6,051	6,324	6,530	6,741	6,980	7,218	32.70%	0.93%
Other Services	Industrial	2,336	2,382	2,428	2,451	2,476	2,502	2,527	2,553	2,578	2,713	2,854	2,998	3,139	3,277	40.30%	1.15%
Government	Office	11,470	11,695	11,920	12,032	12,130	12,227	12,324	12,422	12,519	12,932	13,272	13,542	13,758	13,934	21.49%	0.61%
Military	Military	8,355	8,339	8,324	8,316	8,310	8,305	8,300	8,295	8,289	8,276	8,278	8,287	8,299	8,312	-0.51%	-0.01%
Total Base		**58,851**	**60,281**	**61,712**	**62,427**	**63,133**	**63,840**	**64,546**	**65,252**	**65,959**	**69,414**	**72,770**	**76,079**	**79,374**	**82,665**	**40.46%**	**1.16%**

Eielson AFB Military	Not in Model	0	20	113	620	1,292	1,474	1,474	1,474	1,474	1,474	1,474	1,474	1,474	1,474		
Eielson AFB Construction	Not in Model	0	235	821	852	783	701	564	443	339	109	109	109	109	109		
Eielson AFB Indirect	Retail	0	0	0	0	27	98	153	205	253	433	467	504	545	590		
Eielson AFB Indirect	Industrial	0	0	0	0	32	114	177	235	289	483	507	532	556	582		
Eielson AFB Indirect	Office	0	0	0	0	59	211	328	436	537	897	942	985	1,022	1,059		
Alaska LNG	Industrial	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Total Employment		**58,851**	**60,536**	**62,646**	**63,899**	**65,326**	**66,438**	**67,241**	**68,046**	**68,851**	**72,810**	**76,270**	**79,682**	**83,080**	**86,479**	**46.95%**	**1.34%**
5-Year Growth					5,048					4,952	3,960	3,460	3,412	3,399	3,398		
5-Year Growth Rate (%)					8.58%					7.75%	5.75%	4.75%	4.47%	4.27%	4.09%		

Construction jobs estimated from Northern Economics, "Updated Population Forecasts," September 22, 2017 - difference between Approved + Pending with and without military construction projects.
Indirect employment estimated as ratio of base employment/base population * revised population.

Note: Forecasts directly from the Northern Economics forecasts from October 31, 2017 are shown in grey shading. Other EAFB forecasts are estimated based on these inputs.

Attachment D

MOVES Operating Mode Distribution Adjustments to Reflect Plug-In Benefits

Approach Used to Account for Plug-In Block Heater Emission Effects Using MOVES in Fairbanks $PM_{2.5}$ SIP Inventories

Overview

Engine block heaters or "plug-ins" are widely used in Fairbanks during winter to ensure engine startup and drivability during harsh ambient conditions. Based on chassis dynamometer emission testing conducted in Fairbanks during winter 2010-2011, they also provide a significant reduction in vehicle starting emissions by keeping the engine warmer than the ambient environment when parked with the engine off. Within the Fairbanks $PM_{2.5}$ SIP, the effects of these plug-in reductions are not being accounted for as a control measure but rather as an adjustment to baseline (and projected baseline) light-duty vehicle starting exhaust emissions.

EPA's MOVES2014b vehicle emissions model is being used to generate vehicle emissions for the on-road mobile source portion of the SIP inventory. Despite MOVES' far-reaching scalability and the complex set of conditions it is designed to address, the model's input structure does not explicitly incorporate support for cold temperature plug-in effects. However, an approach was conceptually designed and informally presented to EPA/OTAQ that accounts for measured plug-in effects by iteratively adjusting MOVES' default *OpModeDistribution* table in a manner that when executed, generates reductions in output start exhaust emissions that equal those from the local measurement study (as a function of ambient temperature).

The processes for assembling local fleet, activity, ambient and other SIP-level inputs to MOVES and running the model follow EPA guidance and are explained elsewhere in the Fairbanks SIP. This document focuses on describing how measured emission reductions from block heater plug-in use in Fairbanks during winter were accounted for via iterative adjustment to the starting operating mode distributions used within the model. The approach specifically adheres to OTAQ's requirement that it be applied within MOVES' inputs and design structure, rather than as an off-model adjustment. The following explanation provides a "proof of concept" of these procedures for the 2013 baseline calendar year fleet and a single winter daily average temperature of -20°F. Within the SIP inventories, similar procedures are being applied for a range of daily average ambient temperatures from -50°F to 0°F at 10°F increments to cover the entire range of ambient conditions across the SIP attainment modeling episodes.

Measurement-Based Plug-In Reductions

Table 1 summarizes the reductions in starting exhaust $PM_{2.5}$ developed from measured data in the Fairbanks 2010-2011 testing program resulting from use of plug-ins while a vehicle is parked or "soaked." The column "Default Daily Soak Dist" lists the daily average soak time fractions extracted from MOVES for light-duty vehicles. The next column, "% $PM_{2.5}$ Redn" shows relative starting exhaust $PM_{2.5}$ emission reductions developed from the measurement data as a function of soak time. The plug reductions are as expressed percentages relative to the emissions of the vehicle if it had not been plugged in when parked. Only reductions for $PM_{2.5}$ are shown. (Although plug-in effects were also measured for gaseous pollutants, only directly emitted $PM_{2.5}$ reductions are applied for the SIP inventory adjustments.) The rightmost columns show plug-in usage fractions (percentage of trips) as a function of both soak time and ambient temperature.

OpMode ID	Soak Time Intervals (min.)	Default Daily Soak Dist.	% $PM_{2.5}$ Redn	% Plug-In Use as a Function of Soak Time (minutes) and Daily Ambient Temperature (°F)					
				-50°F	-40°F	-30°F	-20°F	-10°F	0°F
101	Soak Time < 6	0.185	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
102	6 ≤ to < 30	0.205	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
103	30 ≤ to < 60	0.096	4.4%	25.9%	14.0%	2.4%	0.0%	0.0%	0.0%
104	60 ≤ to < 90	0.058	7.3%	44.4%	32.5%	20.8%	9.4%	0.0%	0.0%
105	90 ≤ to < 120	0.042	10.3%	56.6%	44.7%	33.1%	21.6%	10.4%	0.0%
106	120 ≤ to < 360	0.162	23.5%	86.8%	74.9%	63.2%	51.8%	40.6%	29.6%
107	360 ≤ to < 720	0.114	53.0%	100.0%	100.0%	93.1%	81.7%	70.5%	59.5%
108	720 ≤ Soak Time	0.139	70.8%	100.0%	100.0%	100.0%	100.0%	89.4%	78.4%
Daily Composite Plug-In Trip Fraction (%)				39.9%	35.9%	31.3%	27.4%	22.6%	18.5%
Daily Composite Plug-In $PM_{2.5}$ Reduction (%)				16.4%	15.9%	15.1%	**14.1%**	12.2%	10.4%

Table 1
Local Measurement-Based Starting Exhaust $PM_{2.5}$ Emission Reductions from Plug-In Use

At the bottom of Table 1, daily composite plug-in usage fractions and $PM_{2.5}$ starting exhaust reductions are shown. Table 2 shows the adjusted OpMode Distribution that leads to a 14.1% reduction in direct $PM_{2.5}$ starting emissions for gasoline LDVs at -20°F in Fairbanks. The steps leading to the formulation of that adjusted MOVES *OpModeDistribution* table are explained in detail in the following section.

Table 2
OpMode Distribution Adjustment to Achieve 14.1% Direct $PM_{2.5}$ Start Emission Reductions for Gasoline LDVs at -20°F

OpMode ID	Soak Time Intervals (minutes)	Adjusted OpMode Distribution
101	Soak Time < 6	0.225
102	6 ≤ Soak Time < 30	0.247
103	30 ≤ Soak Time < 60	0.116
104	60 ≤ Soak Time < 90	0.069
105	90 ≤ Soak Time < 120	0.050
106	120 ≤ Soak Time < 360	0.108
107	360 ≤ Soak Time < 720	0.082
108	720 ≤ Soak Time	0.103
Resulting Start Exh. Direct $PM_{2.5}$ Reduction		14.1%

MOVES Modeling Steps

1. *Enable Save Generators in Base RunSpec* - An existing Fairbanks MOVES RunSpec was loaded reflecting 2008 vehicle activity and population. This run was configured to span weekends and weekdays. The run configuration was modified to run in inventory mode and the input temperature was set to a fixed -20°F for all hours of the day. The "Start Operating Mode Distribution Generator" option within the Advanced Performance Features Panel was enabled (checking Save Data) to save the model's "default" OpModeDistribution values that are dynamically generated during execution for the baseline run. General output options were set to capture starts and population and units were configured for grams, joules and miles for the mass, energy and distance respectively. Output emissions details for time and location were set to "Hour" and "County". All other fields in the "Output Emission Detail" panel were left at defaults except the Fuel Type, Emission Process and Source Use Type options were all checked.

2. *Execute Baseline Run* - The MOVES model was then executed to generate and output emissions reflecting the baseline or unadjusted operating mode distributions. MOVES outputs were exported to a processing spreadsheet in which daily starting exhaust emissions were tabulated for gasoline passenger cars (SourceTypeID=21) and passenger trucks[73] (SourceTypeID=31) to determine baseline starting exhaust emissions prior to adjusting operating mode distributions.

3. *Export Baseline Operating Mode Distributions* - The data in the Start Operating Mode Distribution Generator were exported into a spreadsheet in order to adjust the *OpModeDistribution* table for light duty vehicle starts (source types 21 and 31) using fuel type 1 (gasoline) for the $PM_{2.5}$ pollutant processes (polprocid 11102 and 11202).

4. *Adjust Starting Operating Mode Distributions* - Adjustments to the baseline distributions were performed by reducing the frequencies in the longer soak categories and increasing fractions in the shorter soak categories to simulate the effects of reduced start exhaust emissions. The cutoff between long and short soak categories was arbitrarily set at OpModeID 106 (2 to 6-hour soaks). Frequencies for OpModeIDs 106,107,108 were decreased using a constant multiplier for each of these three soak categories. Once those soak categories were reduced all of the soak categories for source types 21 and 31 for the $PM_{2.5}$ pollutant processes were then renormalized to sum to 1. The initial adjustment multiplier was set to 80% (0.80). A new set of starting OpMode distributions were then calculated in this manner. These adjustment multipliers were applied universally over all hours of the day for the aforementioned source types, but using the hour-specific soak fractions reflected in the baseline *OpModeDistribution* table.

[73] The analysis and adjustments were restricted to gasoline-fueled cars and passenger trucks because the plug-in measurement study was limited to these vehicle types. Although plug-in reductions may occur for other vehicle types, those reductions were not measured. Therefore, adjustments made within MOVES were restricted to those vehicle and fuel types for which test measurements were collected.

5. *Load Adjusted Operation Model Distributions* - The adjusted OpMode distributions were exported from Excel and then imported into a new separate MySQL database and *OpModeDistribution* table matching the structure required by MOVES.

6. *Create RunSpec for Adjusted Distributions and Re-Run MOVES* - The MOVES model was then configured with the existing default inputs with the adjusted *OpModeDistribution* table imported through the Manage Inputs Data Sets panel of the MOVES GUI. No other configuration changes from the baseline RunSpec were made except to change the output database name. The model was then executed again to generate start emission outputs using the new *OpModeDistribution* table.

7. *Tabulate and Compare Starting Exhaust Emission Outputs* - The MOVES outputs were exported for this revised simulation and compared against the original emissions outputs from the baseline run.

Steps 4 through 7 were repeated a number of times until the start emission outputs from Source Types 21 and 31 using Fuel Type 1 showed an emission reduction of 14.1% from the baseline MOVES run based on the default OpMode distributions. (As shown earlier in Table 1, 14.1% is the daily composite $PM_{2.5}$ reduction from plug-in use for the proof-of-concept test case at -20°F.)

Table 3 shows the results of these iterations for the multipliers, daily OpMode distribution composites and emissions reductions. After five iterations, the adjusted OpMode distributions using a 51.4% multiplier yielded a targeted 14.1% reduction in starting exhaust $PM_{2.5}$.

Table 3
Iterative Approach to OpMode Distribution Adjustments and Start Emission Reductions for Gasoline LDVs at -20°F[74]

OpMode ID	Soak Time Intervals (minutes)	Default Distribution	Iterations				
			1	2	3	4	5
101	Soak Time < 6	0.185	0.199	0.239	0.227	0.226	0.225
102	6 ≤ Soak Time < 30	0.205	0.220	0.260	0.248	0.247	0.247
103	30 ≤ Soak Time < 60	0.096	0.103	0.123	0.117	0.117	0.116
104	60 ≤ Soak Time < 90	0.058	0.062	0.072	0.069	0.069	0.069
105	90 ≤ Soak Time < 120	0.042	0.045	0.052	0.050	0.050	0.050
106	120 ≤ Soak Time < 360	0.162	0.143	0.092	0.106	0.108	0.108
107	360 ≤ Soak Time < 720	0.114	0.103	0.072	0.081	0.082	0.082
108	720 ≤ Soak Time	0.139	0.126	0.090	0.101	0.102	0.103
OpMode Distribution Adjustment Multiplier			80%	40%	50%	51%	51.4%
Resulting Start Exh. Direct $PM_{2.5}$ Reduction			5.1%	18.5%	14.6%	14.3%	**14.1%**

Adjustments to the OpMode distributions were restricted to directly emitted $PM_{2.5}$ for light-duty

[74] See Table 1 for the measurement-based daily-composite $PM_{2.5}$ reduction target for -20°F along with the range of $PM_{2.5}$ reduction targets spanning temperatures -50°F to 0°F.

passenger vehicle source types 21 and 31. As explained earlier, no plug-in adjustments were developed for gaseous pollutants. Therefore a separate set of MOVES runs based on the default soak distributions were used to estimate emission rates for gaseous pollutants within the SIP on-road inventory workflow. This separate MOVES run was also require to calculate the $PM_{2.5}$ emissions from the source types other than 21 and 31 as well as the emissions from vehicles in source types 21 and 31 using fuels other than gasoline.

The steps laid out above are being repeated over the range of temperatures modeled during the 2008 baseline episodes. The OpMode distribution adjustments are being calculated at 10°F intervals from -50°F to 0°F to cover the full range of possible conditions and provide reasonable plugin benefits over the two SIP attainment modeling episodes.

Based on the information in Table 1 and using the steps laid out above OpMode distribution adjustments were iteratively calculated for -50°F and 0°F, the two endpoints of the temperature range used in the SIP modeling. The target reduction in starting exhaust directly emitted $PM_{2.5}$ would be 16.4% at -50°F. Two deviations were made from the methodology used for the -20°F. First the baseline starting emissions were calculated using a uniform daily temperature input of -50°F. And second the starting OpMode distribution adjustment multiplier was set based on the final step in the -20°F scenario. Table 4 summarizes the three iterative adjustments made to capture the final targeted direct $PM_{2.5}$ starting exhaust reduction of 16.4%.

Table 4
Iterative Approach to OpMode Distribution Adjustments and Start Emission Reductions for Gasoline LDVs at -50°F[75]

OpMode ID	Soak Time Intervals (minutes)	Default Distribution	Iterations		
			1	2	3
101	Soak Time < 6	0.185	0.225	0.214	0.234
102	6 ≤ Soak Time < 30	0.205	0.247	0.236	0.256
103	30 ≤ Soak Time < 60	0.096	0.116	0.111	0.121
104	60 ≤ Soak Time < 90	0.058	0.069	0.066	0.071
105	90 ≤ Soak Time < 120	0.042	0.050	0.048	0.051
106	120 ≤ Soak Time < 360	0.162	0.108	0.122	0.097
107	360 ≤ Soak Time < 720	0.114	0.082	0.091	0.075
108	720 ≤ Soak Time	0.139	0.103	0.113	0.094
OpMode Distribution Adjustment Multiplier			51.4%	43.5%	45.3%
Resulting Start Exh. Direct $PM_{2.5}$ Reduction			14.1%	17.1%	**16.4%**

The 0°F scenario again followed the approach from the -20°F with the exceptions of the meteorology profile inputs reflecting 0°F hourly temperatures and the first iteration adjustment. The first iteration adjustment at 0°F was determined based on interpolating the -20°F results

[75] See Table 1 for the measurement-based daily-composite $PM_{2.5}$ reduction target for -50°F along with the range of $PM_{2.5}$ reduction targets spanning temperatures -50°F to 0°F.

between the 80% adjustment and 5.1% direct $PM_{2.5}$ reduction and 51.4% adjustment with 14.1% direct $PM_{2.5}$ reduction. Interpolation yields an estimated adjustment of 63.2% for the first iteration step. Table 5 summaries the OpMode Distribution adjustments and resulting direct $PM_{2.5}$ starting exhaust reductions for each of the three iterations.

Table 5
Iterative Approach to OpMode Distribution Adjustments and Start Emission Reductions for Gasoline LDVs at 0°F[76]

OpMode ID	Soak Time Intervals (minutes)	Default Distribution	Iterations		
			1	2	3
101	Soak Time < 6	0.185	0.213	0.215	0.214
102	6 ≤ Soak Time < 30	0.205	0.235	0.236	0.236
103	30 ≤ Soak Time < 60	0.096	0.110	0.111	0.111
104	60 ≤ Soak Time < 90	0.058	0.066	0.066	0.066
105	90 ≤ Soak Time < 120	0.042	0.047	0.048	0.048
106	120 ≤ Soak Time < 360	0.162	0.124	0.122	0.122
107	360 ≤ Soak Time < 720	0.114	0.092	0.091	0.091
108	720 ≤ Soak Time	0.139	0.113	0.112	0.113
OpMode Distribution Adjustment Multiplier			63.2%	62.1%	62.3%
Resulting Start Exh. Direct $PM_{2.5}$ Reduction			10.1%	10.5%	**10.4%**

Finally it is noted that this approach, complex as it already is, implicitly assumes that the MOVES starting emission rates by operating mode are constant in calculation the weighted composite plug-in reduction percentages (across all operating modes), which they are not. Sensitivity analysis was conducted and found that if the starting exhaust emission factor variations were also accounted for, it would result in larger composite relative benefits that shown earlier in Table 1. Since these plug-in adjustments are not being used within the SIP to calculate control measure benefits, but rather and adjustments to baseline inventories, it was determined to keep this approach simpler by not additionally extracting starting rates by operating mode from separate MOVES runs and accounting for their impact.

[76] See Table 1 for the measurement-based daily-composite $PM_{2.5}$ reduction target for -50°F along with the range of $PM_{2.5}$ reduction targets spanning temperatures -50°F to 0°F.