Alaska Department of Environmental Conservation

Public Comment Draft

Residential Fuel Expenditure Assessment of a Transition to Ultra-Low Sulfur and High Sulfur No. 1 Heating Oil for the Fairbanks PM-2.5 Serious Nonattainment Area

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Prepared by

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Abbreviations

ADEC	Alaska Department of Environmental Conservation
BACM	Best Available Control Measure
BTU	British Thermal Unit
EIA	US Energy Information Agency
EPA	US Environmental Protection Agency
FNSB	Fairbanks North Star Borough
HS	High Sulfur
NPV	Net Present Value
OPIS	Oil Price Information Service
PM	Particulate Matter
PSI	Petro Star, Inc.
SIP	State Implementation Plan
ULS	Ultra-Low Sulfur

Executive Summary

In September 2017, the Alaska Department of Environmental Conservation (ADEC) Division of Air Quality requested the ADEC Economist to facilitate a research project regarding the evaluation of possible economic impacts of a potential PM-2.5 pollution control policy mandating a transition to ultra-low sulfur (ULS) heating oil in the Fairbanks PM-2.5 Serious Nonattainment Area. The ADEC Economist worked on this research together with the University of Alaska, Fairbanks Master of Science Resource and Applied Economics Program Director and graduate students. The initial report was released in March 2018 and evaluated the possible changes in home heating fuel expenditures for Fairbanks residents given a hypothetical requirement imposing a transition to ULS heating fuel.

Upon receiving feedback on the March 2018 draft, this report has been updated to address the comments received from the public and the United States Environmental Protection Agency (EPA). In July 2018, the ADEC purchased new data to update the fuel prices used in the analysis. In the fall of 2018, additional policy analysis of a potential high sulfur (HS) No. 1 heating oil mandate was completed. This content has been added to provide information on the expenditure effects of a HS No. 1 use requirement for a typical Fairbanks household. A summary of the energy content of each fuel type, and a discussion regarding sulfur reduction and its effect on energy (BTU) content is included in *Section II.* This updated final report is the outcome of the research conducted by ADEC and the University of Alaska Fairbanks.

Below is a summary of key findings from each section of the analysis.

Section I: Fuel Costs

Important findings from the review of the incremental ULS price differentials[1], the additional cost to purchase ULS over HS, for both Anchorage and Fairbanks wholesale markets, as well as purchasing Fairbanks HS No. 1 over HS No. 2 include:

- Since 2008-2010, the ULS price differential in Alaska has decreased significantly.
- From April 2017 to July 2018[2] the ULS No. 1 to HS No. 1 monthly price differentials for Anchorage range from 3 to 42 cents/gallon.
- The average ULS No. 1 to HS No. 1 price differential for Anchorage is 23 cents/gallon, representing an 11% price increase.
- Fairbanks ULS is more expensive than Anchorage, reflecting additional transport costs.
- The ULS No. 1 to HS No. 1 monthly price differentials for Fairbanks range from 16 to 54 cents/gallon over the 16 months evaluated.
- The average ULS No. 1 to HS No. 1 price differential for Fairbanks is 34 cents/gallon, representing a 15% increase.
- In Fairbanks, there is a larger ULS price differential between ULS No. 1 to HS No. 2 than ULS No. 1 to HS No. 1, as HS No. 2 tends to be cheaper relative HS No. 1.

[1] All price differentials are listed in the summary have rounded to the nearest cent.
[2] This is the 16-month time frame evaluated. All 16-month average figures listed are calculated using OPIS price data from April 2017 through July 2018.

- The average Fairbanks HS No. 1 to HS No. 2 price differential ranges from 5 to 10 cents/gallon using a 16-month time-period.
- The ULS No. 1 to HS No. 2 monthly price differentials for Fairbanks range from 21 to 59 cents/gallon over the 16 months evaluated.
- The average ULS No. 1 to HS No. 2 price differential for Fairbanks is 41 cents/gallon, representing a 19% increase.

Section II: Household Expenditure Cost Scenarios Analysis

Important findings from the analysis of how a hypothetical shift to more expensive ULS or HS No. 1 fuel would affect household heating expenditures for Fairbanks residential households include:

- Based on the survey data collected from 2011-2015, approximately 80% of respondent households reported having a central oil heating appliance in the household.[3]
- 40% of surveyed households reported using a central oil heating appliance with no other reported appliances. Households using a central oil boiler with no other appliances reported using an average of 1,230 gallons of fuel oil.[4]
- This analysis is on the short run effects of HS to ULS, and the HS No. 2 to HS No. 1 fuel transition, highlighting the price insensitivity of household heating for FNSB residents compared to long run effects.
- Price differentials of 34 and 41 cents/gallon were used to represent the difference between HS and ULS fuel prices.
- A price differential of 7 cents/gallon is used to represent the difference between Fairbanks HS No. 1 and HS No. 2 fuel prices.
- Average household expenditures on heating energy is $2,274 annually.[5]
- Using price differentials of 34 and 41 cents/gallon, an average annual fuel usage of 1,230[6] - 50% of FNSB households would see an expected expenditure increase of $311.96 or $374.86, respectively for the first year of a shift to ULS fuel.[7]
- Estimates represent a 14% to 17% increase in household heating expenditures in the first year.
- Using a price differential of 7 cents/gallon, - 50% of households would see an expected expenditure increase of $68.31 for the first year of a switch to HS No. 1.
- This estimate represents a 3% increase in household heating expenditures in the first year.
- ULS Monte Carlo Analysis results, using a constant fuel price of $2.10, estimate that the average annual increase in household heating expenditure is $329.73.

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[3] (Sierra Research Inc., 2015)
[4] (Sierra Research Inc., 2015)
[5] Section 2.2 Heating Oil Cost Models
[6] Fuel usage for central oil only homes is 1,230 gallons annually
[7] Assumed own-price elasticity of -0.2 is used for all modeled scenarios. The assumed rate of -0.2% is drawn from a study of home heating fuel demand conducted by Hirst, Goeltz, & Carney (1982) and implies that a 1% increase in the price of home heating oil will decrease the quantity demanded by 0.2%.

- This ULS Monte Carlo estimate represents a 15% increase in household expenditures in the first year.
- Based on the distribution of the Monte Carlo estimates, 90% of households are predicted to incur additional expenditures of $650 or less in the first year given a switch to ULS.
- HS No. 1 Monte Carlo Analysis results, using a constant fuel price of $2.10, estimate the average annual increase in household heating expenditure is $84.32.
- This HS No. 1 Monte Carlo estimate represents a 4% increase in household heating expenditures in the first year.
- Based on the distribution of the Monte Carlo estimates, 90% of households are predicted to incur additional expenditures of $160 or less in the first year given a switch to HS No. 1.
- ULS Monte Carlo results verify the estimates of an expected expenditure increase of $311.96 or $374.86, respectively, for the first year as the mean estimations fall within this range.
- HS No. 1 Monte Carlo results fall slightly outside the expenditure increase estimate with a mean calculated expected expenditure increase of $84.32, the median estimates are closer to the original estimate of $68.31 with an expected annual expenditure increase of $76.12.

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 PM-2.5 in the United States. The largest contributors to PM-2.5 in the FNSB are wood stoves and hydronic heaters.[8] Currently, two of the measures implemented to mitigate PM-2.5 emissions are requiring a removal of inefficient wood heating devices when a property is sold or leased[9] and requiring commercial wood sellers to register with the state and report the moisture content of wood they are selling to residential wood-burners.[10]

When EPA reclassified the Fairbanks PM-2.5 Nonattainment Area from a Moderate to Serious designation, it prompted the requirement for ADEC to conduct a Best Available Control Measure (BACM) analysis. The BACM analysis looks at control measures implemented throughout the United States in State Implementation Plans to control PM-2.5. This analysis was conducted as a part of the BACM process. This report provides information on potential changes in residential home heating expenditures in the Fairbanks PM-2.5 Nonattainment Area given hypothetical requirements to switch to different types of heating oil. *Section I* evaluates the fuel cost difference between ultra-low sulfur (ULS) and current heating fuels – high sulfur (HS) No. 1 or No. 2 – and the cost difference between HS No. 1 and HS No. 2. *Section II* assesses how price differences found between fuels would affect household heating expenditures for the typical FNSB household.

This report presents two evaluations of possible changes to household expenditures, the first which may arise from a conversion to ULS heating oil, and the second from HS No. 2 to HS No. 1. The analysis does not address any potential changes in household preferences and behaviors regarding home heating, nor does the assessment address other economic impacts which may arise from possible transition.[11] The modeled scenarios developed for *Section II* to determine potential changes to fuel price expenditures may be adapted to address other questions regarding direct fuel cost expenditure impacts to FNSB households. This model is an additional tool outside of this report and can be adapted to evaluate alternative price differentials, fuel usage quantities, and price elasticities.

[8] (U.S. Environmental Protection Agency, n.d.)
[9] Alaska State regulation. 18 AAC 50.077 and 18 AAC 50.079
[10] Alaska State regulation. 18 AAC 50.076(d)
[11] See Section 2.4 the Potential Benefits of a Switch to ULS for a further discussion of the potential benefits not captured in this expenditure analysis.

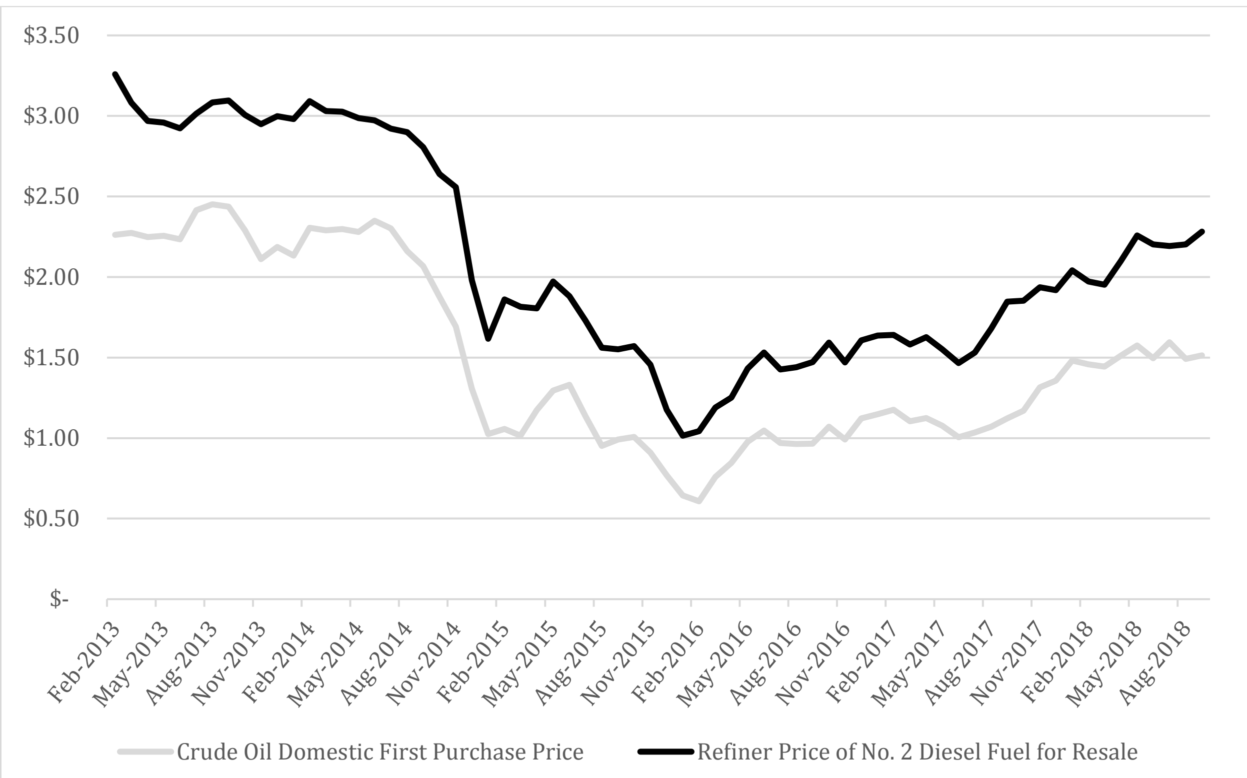
Section I: Fuel Costs

The purpose of this section is to estimate the cost effect of switching to ultra-low sulfur (ULS) heating oil, or to high sulfur (HS) No. 1 in the Fairbanks PM-2.5 Nonattainment Area. Estimates of the incremental price differences between the proposed ULS No. 1 and heating fuel products currently used, HS No. 1 and HS No. 2 are provided. These estimates were calculated by analyzing the Oil Price Information Service (OPIS) data to determine fuel cost differentials.

1.1 Fuel Cost Overview

Prior to the examination of ULS and Fairbanks HS No. 1 fuel prices, it is beneficial to review current distillate fuel price structures. The price of refined distillate fuels generally follows the price of crude oil, which is driven by the global market, weather, transportation, geopolitical, and economic factors. *Figure 1* provides a comparison of Crude Oil and Retail Diesel No. 2. This comparison depicts the price relationship between crude and refined fuels.

Figure 1: Crude Oil and Refined Diesel Prices, Dollars per Gallon



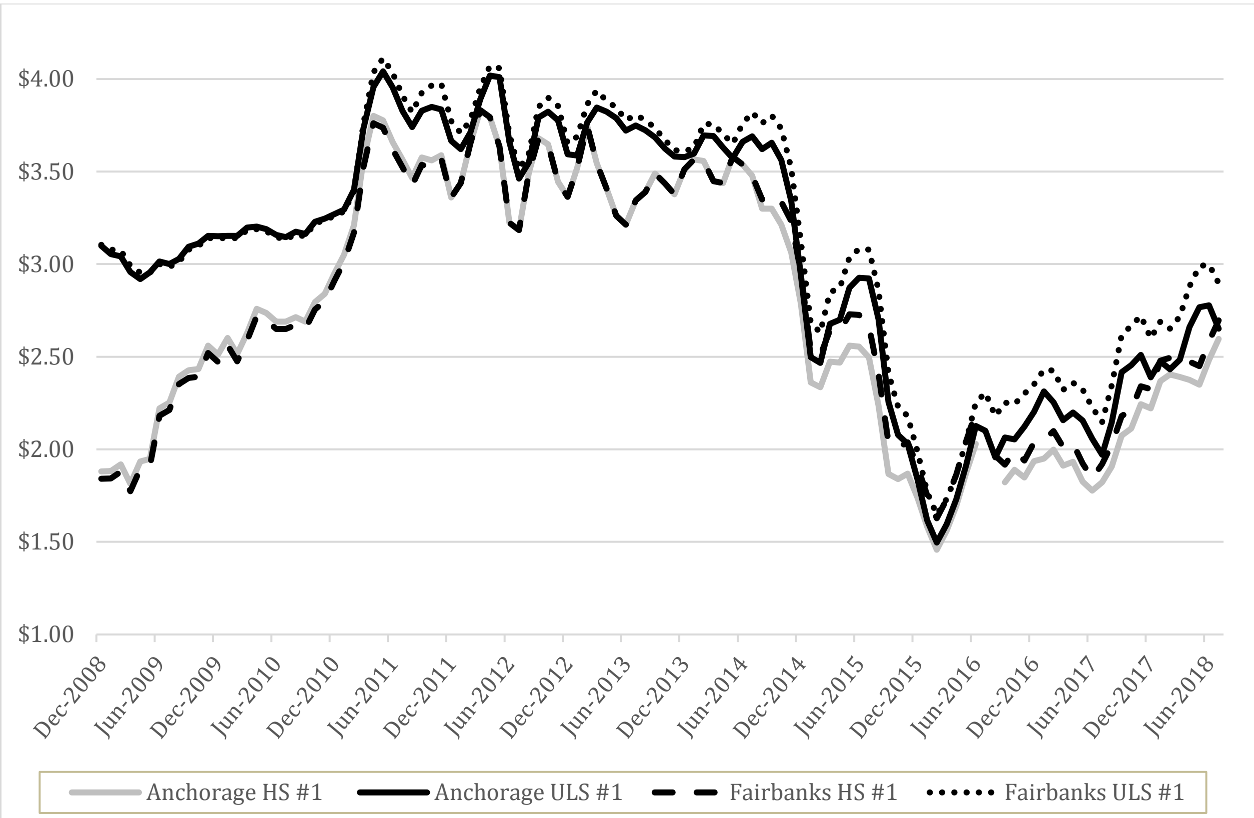
Source: Energy Information Administration (EIA), Energy Prices, September 2018[12]

[12] (EIA,2018) Crude Oil Prices "Crude Oil Domestic First Purchase Price" and (EIA,2018) "Refiner Price of No. 2 Diesel Fuel for Resale"

In recent years, there has been a significant drop in crude oil prices. This can be viewed holistically as a change in the global market influenced by a large-scale increase of US shale production (Institute for Energy Research, 2016).

Alaska is an isolated market with only five local refineries (two of which are in Prudhoe Bay and supply fuel for crude oil drilling operations). Even as prices for refined distillate fuels and heating fuels have fallen, in Alaska these prices are consistently above the national average. In addition, fuel prices are higher in Fairbanks than in Anchorage as fuel needs additional shipping to get to its destination (Northern Economics, 2007. p.15).

Figure 2: Alaska Fuel Price Comparison, Dollars per Gallon



Source: Alaska Department of Environmental Conservation, OPIS

Figure 2 presents the price of HS No. 1 in Anchorage, ULS No. 1 in Anchorage, HS No. 1 in Fairbanks, and ULS No. 1 in Fairbanks. These prices follow national market trends and reflect the price of crude oil. As a result, fuel prices in recent years are significantly lower than the 2011-2014 period.

One notable exception in Alaska is that the ULS Price Differential, the additional premium to purchase ULS over HS, has decreased significantly since 2008-2010. This can likely be attributed to increased ULS capacity, as new ULS capacity came online from Alaskan refineries. Beginning in 2008, Petro Star Inc. (PSI) invested $200 million to produce ULS at their Valdez refinery. In 2007, Andeavor (formerly known as Tesoro) invested $63 million and from 2010-2014 an additional $189 million to manufacture ULS fuel (Econ One Research, Inc., 2015. p.3). In Fairbanks, ULS tends to be more expensive than Anchorage, which may be explained by additional transportation costs. Section 1.2 and 1.3 will explore the actual observed price differences in Fairbanks rack fuel prices over time and product type.

1.1.1 OPIS Fuel Price Data

The data reviewed consists of monthly non-weighted calendar day averages gathered by the Oil Price Information Service (OPIS). OPIS is the only provider of spot, rack, and retail prices for the United States. OPIS is known for having a defined methodology for the collection of fuel price data. Rack price data used represents market wholesale terminal prices (OPIS, 2018).

This analysis focuses on Fairbanks rack fuel prices unless otherwise noted. The data are evaluated in a static manner. Historical market prices are reviewed to estimate the incremental cost difference between fuel types.

All prices are listed in nominal terms and have not been adjusted for inflation. This price data does not include costs associated with taxes or final transportation from the wholesale terminal to the final user. A benefit of using OPIS data is that it represents the market price. The market price in economics is the price at which an asset is bought or sold. Utilization of this type of price data helps reflect the actual market price, which adds to the credibility of the price differential estimates presented.

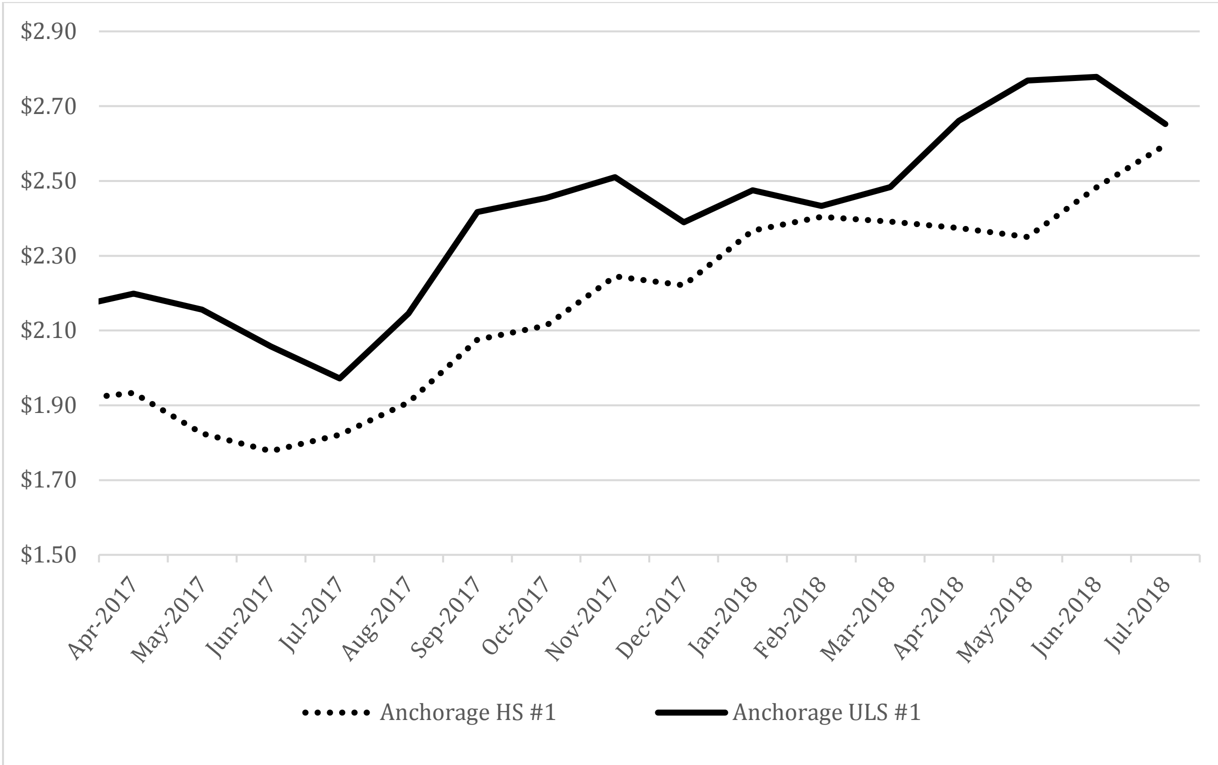
1.2 Fuel Cost Trends and Differentials

To develop estimates of the price difference between fuel types, a review of current pricing was conducted. The focus is a comparison of HS to ULS fuel prices and also a comparison of HS No. 2 to HS No. 1, as the hypothetical policy changes evaluated would require a transition to a fuel type that would fulfill EPA's sulfur content requirements for a PM-2.5 control measure. The purpose of this is to understand the cost difference between fuel types to gauge the potential fiscal impact on Fairbanks' households. A review of Anchorage prices is provided as background information should the purchase of Anchorage fuel and rail transport to Fairbanks be necessary.

Price data was evaluated by taking the non-weighted monthly average prices for Anchorage and Fairbanks, then calculating the price differentials between ULS and HS for each location. First, the fuel price differential between ULS No. 1 and HS No. 1 for Anchorage (*Table 1*) is detailed followed by the Fairbanks differentials. For Fairbanks, the price differential between both ULS No. 1 and HS No. 1 (*Table 2*), ULS No. 1 and HS No. 2 (*Table 3*), and HS No. 1 and HS No. 2 (*Table 4)* have been computed.[13]

[13] For the purpose of this analysis the fuel price differentials evaluated are individual fuel type price comparisons. There are uncertainties in the actual amount of mixed HS and ULS fuel in the heating oil products that are

Figure 3: Anchorage Distillate Cost Comparison, Dollars per Gallon



Source: Alaska Department of Environmental Conservation, OPIS

Figure 3 provides a visual representation of wholesale rack fuel prices in Anchorage over the past 16 months. As expected, there is a premium for ULS fuel. ULS production in Alaska is limited and requires additional resources to produce (Econ One Research, Inc., 2015).

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distributed and sold in the Fairbanks area due to fuel blending. The strategy used here focuses on a low (HS No. 1) and a high (HS No. 2) fuel price differential estimate for Fairbanks. Situations where fuel type blending occurs would fall into a differential between the two estimated ULS Fairbanks differentials calculated here.

***Table 1: Anchorage Rack Pricing Differential per Gallon HS No. 1*[14]**

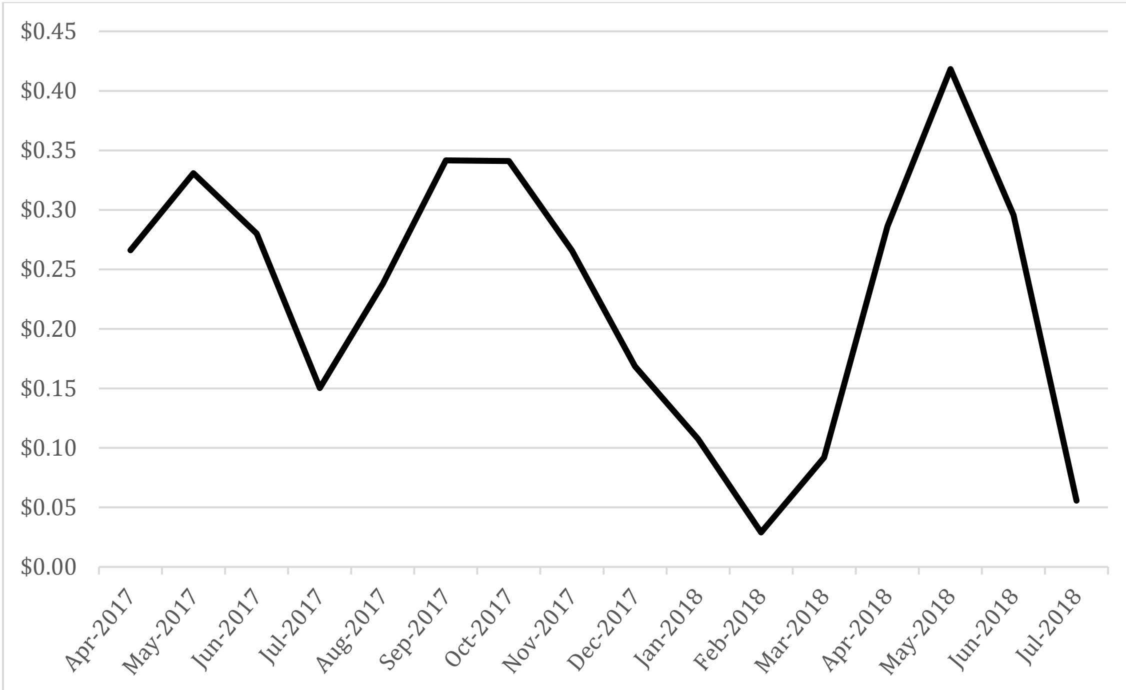
Month	ULS No. 1	HS No. 1	Price Spread ($)	Price Increase (%)
Apr-2017	2.20	1.93	0.27	13.99
May-2017	2.16	1.83	0.33	18.03
Jun-2017	2.06	1.78	0.28	15.73
Jul-2017	1.97	1.82	0.15	8.24
Aug-2017	2.15	1.91	0.24	12.57
Sep-2017	2.42	2.08	0.34	16.35
Oct-2017	2.45	2.11	0.34	16.11
Nov-2017	2.51	2.25	0.26	11.56
Dec-2017	2.39	2.22	0.17	7.66
Jan-2018	2.48	2.37	0.11	4.64
Feb-2018	2.43	2.40	0.03	1.25
Mar-2018	2.48	2.39	0.09	3.77
Apr-2018	2.66	2.37	0.29	12.24
May-2018	2.77	2.35	0.42	17.87
Jun-2018	2.78	2.48	0.30	12.10
Jul-2018	2.65	2.60	0.05	1.92
16 Month Average	**2.41**	**2.18**	**0.23**	**10.55**

Source: Alaska Department of Environmental Conservation, OPIS

Table 1 provides Anchorage price differentials by month for ULS No. 1 in comparison to HS No. 1. From April 2017 to July 2018, the 16-month average fuel price differential is 23 cents/gallon. This represents an average price differential of 10.55%. The average monthly ULS No. 1 price differential for during this time frame ranges from 3 – 42 cents/gallon.

[14] For presentation purposes all figures in each Differential Table have been rounded to two decimal points. This rounding will account for slight differences from of averages computed directly from raw OPIS data.

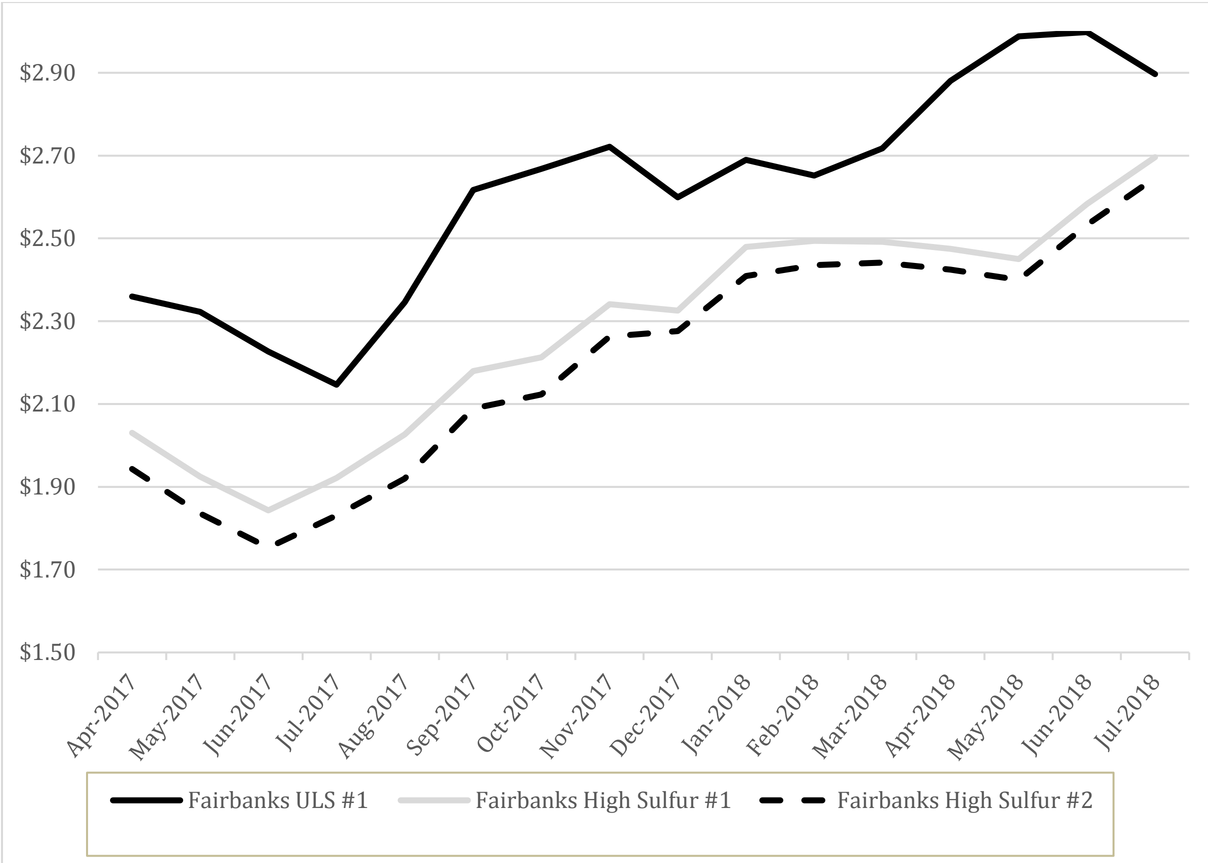
Figure 4: Anchorage Price Differential ULS No. 1 and HS No. 1, Dollars per Gallon



Source: Alaska Department of Environmental Conservation, OPIS

Figure 4 depicts the fuel price differential (detailed in *Table 1*) for the Anchorage wholesale market. Price differences range from a low of 3 cents/gallon to a high of 42 cents/gallon with a 16-month average differential of 23 cents/gallon. In 2018 the price spread increases significantly prior to dropping dramatically in July the most recent month of price data. The following set of figures and tables will explore the fuel price differential for the Fairbanks wholesale market.

Figure 5: Fairbanks Distillate Cost Comparison, Dollars per Gallon



Source: Alaska Department of Environmental Conservation, OPIS

Figure 5 presents wholesale rack fuel prices in Fairbanks over the past 16 months. As expected, there is a premium for ULS fuel. It is notable that the total price of ULS No. 1 has risen sharply since the summer of 2016. As the price difference between HS No. 1 and HS No. 2 is significant, this is taken into consideration through further analysis of each fuel type to develop specific scenarios for HS No. 1 and HS No. 2 fuel usage. The price differential between HS No. 1 and HS No. 2 is also analyzed separately.

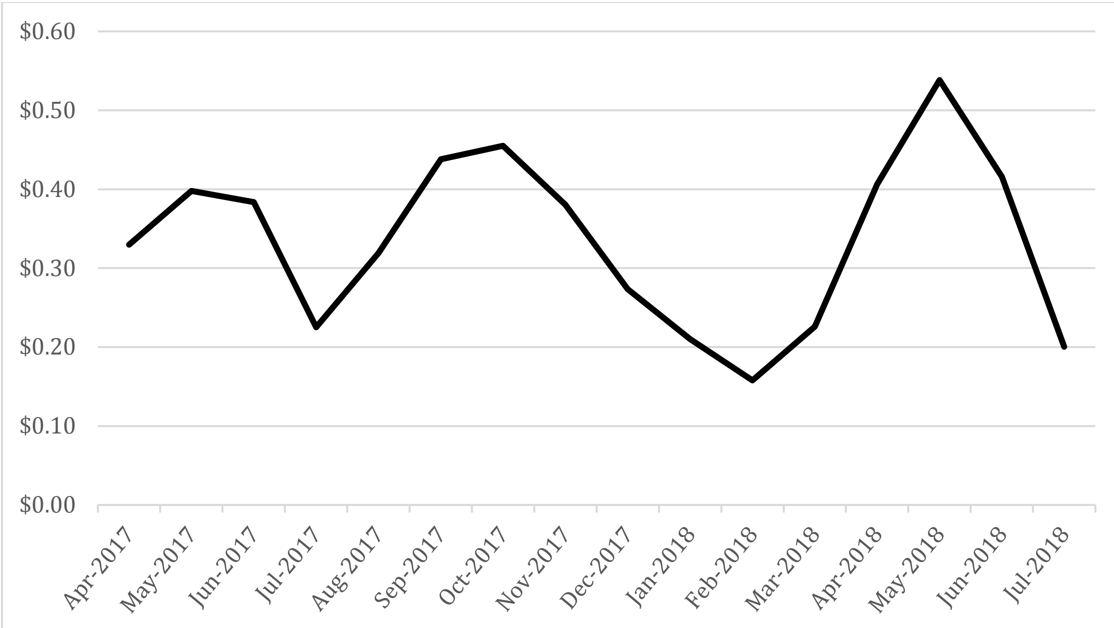
Table 2: Fairbanks Rack Pricing Differential per Gallon HS No. 1

Month	ULS No. 1	HS No. 1	Price Spread ($)	Price Increase (%)
Apr-2017	2.36	2.03	0.33	16.26
May-2017	2.32	1.93	0.39	20.21
Jun-2017	2.23	1.84	0.39	21.20
Jul-2017	2.15	1.92	0.23	11.98
Aug-2017	2.35	2.03	0.32	15.76
Sep-2017	2.62	2.18	0.44	20.18
Oct-2017	2.67	2.21	0.46	20.81
Nov-2017	2.72	2.34	0.38	16.24
Dec-2017	2.60	2.33	0.27	11.59
Jan-2018	2.69	2.48	0.21	8.47
Feb-2018	2.65	2.49	0.16	6.43
Mar-2018	2.72	2.49	0.23	9.24
Apr-2018	2.91	2.47	0.44	17.81
May-2018	2.99	2.45	0.54	22.04
Jun-2018	3.00	2.58	0.42	16.28
Jul-2018	2.90	2.70	0.20	7.41
16 Month Average	**2.62**	**2.28**	**0.34**	**15.12**

Source: Alaska Department of Environmental Conservation, OPIS

Table 2 presents Fairbanks price differentials month-by-month for ULS No. 1 in comparison to HS No. 1. From April 2017 to July 2018, the 16-month average fuel price differential is 34 cents/gallon, which represents an average premium of 15.12% for ULS No. 1 over HS No. 1. The average monthly ULS No. 1 price differential during this time frame ranges between 16 – 54 cents/gallon.

Figure 6: Fairbanks Price Differential ULS No. 1 and HS No. 1, Dollars per Gallon



Source: Alaska Department of Environmental Conservation, OPIS

Figure 6 presents the price differential of ULS No. 1 to HS No. 1 (detailed in *Table 2*) for the Fairbanks wholesale market. Price differences over the last 16-months range from a low of 16 cents/gallon to a high of 54 cents/gallon with an average difference of 34 cents/gallon.

Table 3: Fairbanks Rack Pricing Differential per Gallon HS No. 2

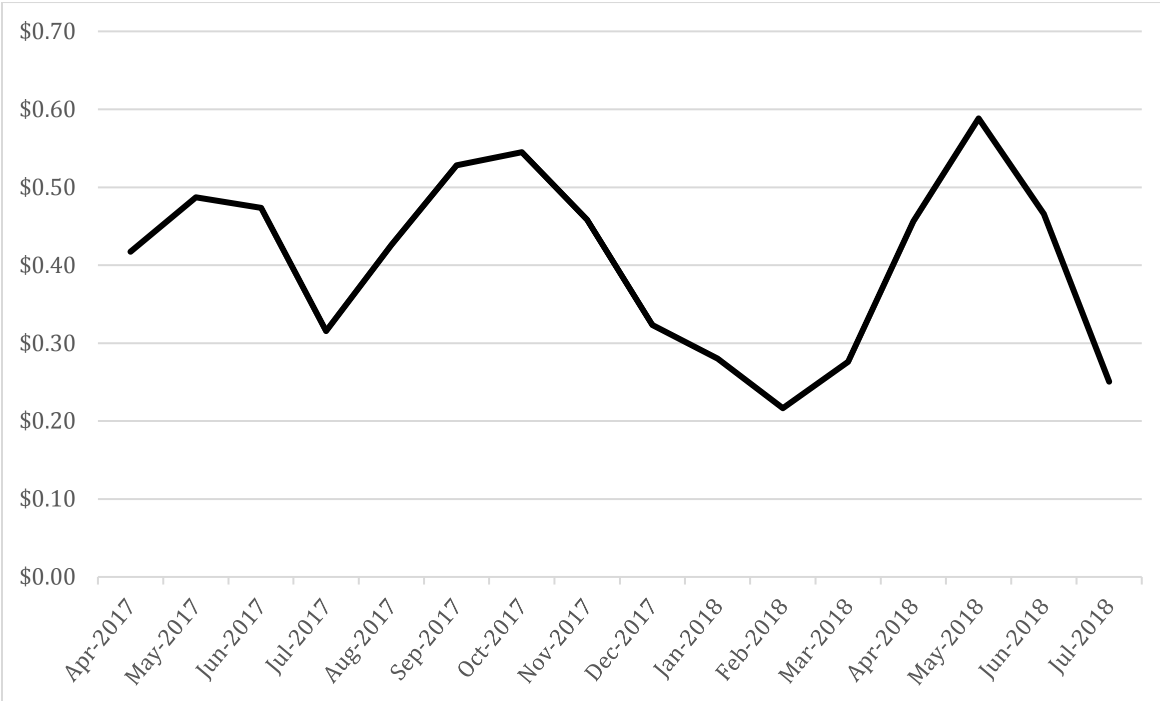
Month	ULS No.1	HS No. 2	Price Spread ($)	Price Increase (%)
Apr-2017	2.36	1.94	0.42	21.65
May-2017	2.32	1.84	0.48	26.09
Jun-2017	2.23	1.75	0.48	27.43
Jul-2017	2.15	1.83	0.32	17.49
Aug-2017	2.35	1.92	0.43	22.40
Sep-2017	2.62	2.09	0.53	25.36
Oct-2017	2.67	2.12	0.55	25.94
Nov-2017	2.72	2.26	0.46	20.35
Dec-2017	2.60	2.28	0.32	14.04
Jan-2018	2.69	2.41	0.28	11.62
Feb-2018	2.65	2.44	0.21	8.61
Mar-2018	2.72	2.44	0.28	11.48
Apr-2018	2.91	2.42	0.49	20.25
May-2018	2.99	2.40	0.59	24.58
Jun-2018	3.00	2.53	0.47	18.58
Jul-2018	2.90	2.65	0.25	9.43
16 Month Average	**2.62**	**2.21**	**0.41**	**18.55**

Source: Alaska Department of Environmental Conservation, OPIS

Table 3 provides Fairbanks price differentials by month for ULS No. 1 in comparison to HS No. 2. HS No. 2 is also used for residential heating oil in Fairbanks, and due to its lower price has the largest differentials.

The fuel price differentials, from April 2017 through July 2018 range from 21 to 59 cents/gallon. This results in a 16-month average price differential for ULS No. 1 in comparison to HS No. 2 in Fairbanks of 41 cents/gallon which represents an average premium of 18.55%.

Figure 7: Fairbanks Price Differential ULS No. 1 and HS No. 2, Dollars per Gallon



Source: Alaska Department of Environmental Conservation, OPIS

Figure 7 depicts ULS No. 1 over HS No. 2 fuel price differential (from *Table 3*) for the Fairbanks wholesale market. It is important to note that of all the fuel price differentials examined in this analysis, that ULS No. 1 over HS No. 2 for Fairbanks has the least amount of variance. While there still are month-to-month fluctuations the price premium has consistently been 22 cents/gallon or higher with 12 months being 30 cents/gallon or higher.

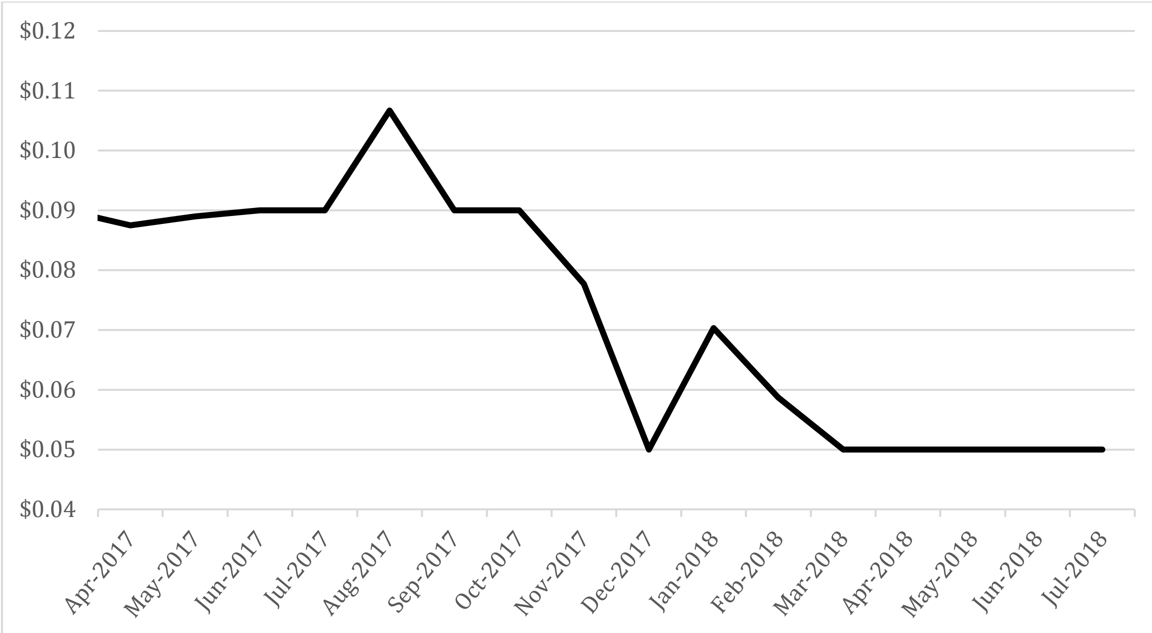
Table 4: Fairbanks Rack Pricing Differential per Gallon HS No. 1 and HS No. 2

Month	HS No. 1	HS No. 2	Price Spread ($)	Price Increase (%)
Apr-2017	2.03	1.94	0.09	4.64
May-2017	1.93	1.84	0.09	4.89
Jun-2017	1.84	1.75	0.09	5.14
Jul-2017	1.92	1.83	0.09	4.92
Aug-2017	2.03	1.92	0.11	5.73
Sep-2017	2.18	2.09	0.09	4.31
Oct-2017	2.21	2.12	0.09	4.25
Nov-2017	2.34	2.26	0.08	3.54
Dec-2017	2.33	2.28	0.05	2.19
Jan-2018	2.48	2.41	0.07	2.90
Feb-2018	2.49	2.44	0.05	2.05
Mar-2018	2.49	2.44	0.05	2.05
Apr-2018	2.47	2.42	0.05	2.07
May-2018	2.45	2.40	0.05	2.08
Jun-2018	2.58	2.53	0.05	1.98
Jul-2018	2.70	2.65	0.05	1.89
16-Month Average	**2.28**	**2.21**	**0.07**	**3.17**

Source: Alaska Department of Environmental Conservation, OPIS

Table 4 provides Fairbanks price differentials by month for HS No. 2 in comparison to HS No. 1. The fuel price differentials, from April 2017 through July 2018 range from 5 to 11 cents/gallon. This results in a 16-month average price differential for HS No. 2 in comparison to HS No. 1 in Fairbanks of 7 cents/gallon which represents an average premium of 3.17%.

Figure 8: Fairbanks Price Differential HS No. 2 and HS No. 1



Source: Alaska Department of Environmental Conservation, OPIS

Figure 8 depicts the fuel price differential (detailed in *Table 3*) for Fairbanks HS No. 2 and HS No. 1 wholesale market. Price differences range from a low of 5 cents/gallon to a high of 10 cents/gallon with a 16-month average differential of 7 cents/gallon. From August 2017 to March 2018 the price differential decreases significantly.

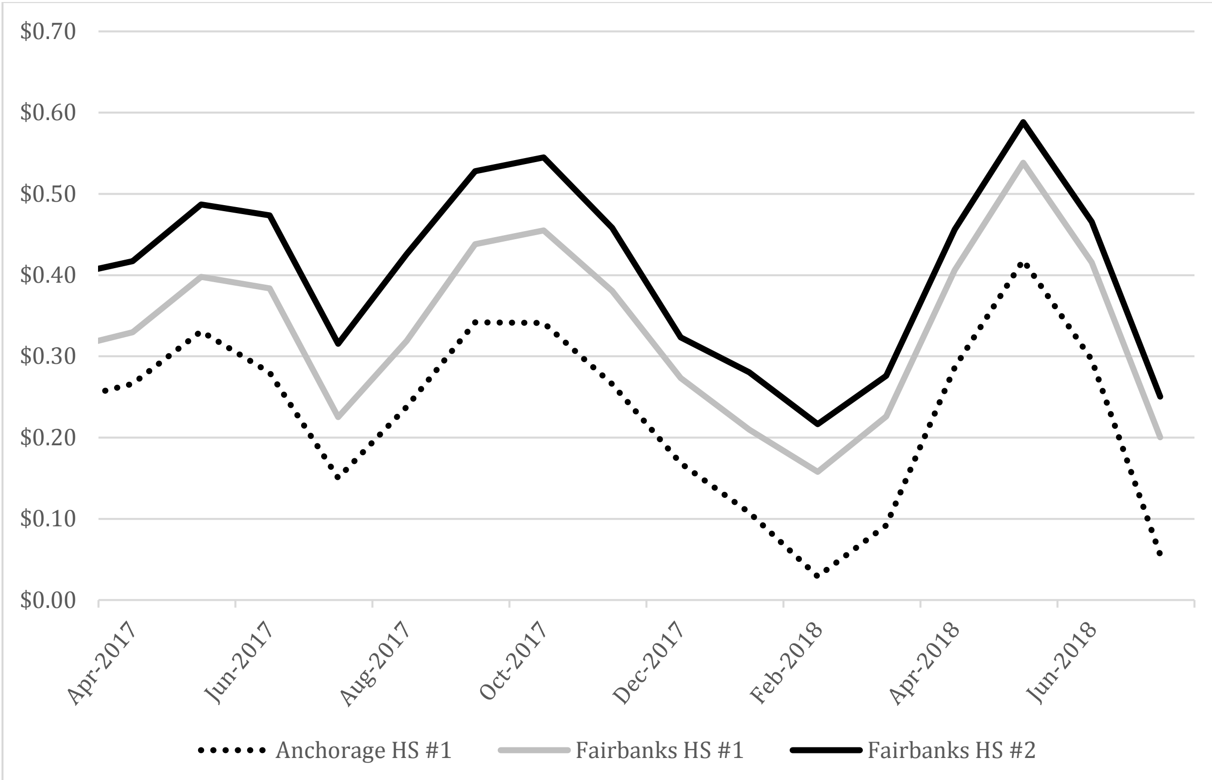
1.3 Fuel Differentials Summary

The incremental cost difference between HS and ULS, and between Fairbanks HS No. 1 and HS No. 2 heating fuel is important to review. A hypothetical change in fuel demand may induce further economic impacts and additional costs to households. The previous section reviewed the price differential of a potential shift from HS products to ULS No. 1, and Fairbanks HS No. 1 to HS No. 2 for individual rack fuels. In this section, a comprehensive examination of these differentials is provided.

These differentials indicate one of the cost impacts that hypothetical heating fuel requirements could have on Fairbanks. *Figure 8* includes ULS No. 1 fuel price differentials between Anchorage HS No. 1, Fairbanks HS No. 1 and Fairbanks HS No. 2.[15] *Figure 9* below includes the price differential between Fairbanks HS No. 1 and HS No. 2.

[15] Anacortes fuel prices were provided in the OPIS data, but are not evaluated, as there is no data to compute a ULS/HS differential (our current OPIS dataset indicates that Anacortes does not supply HS fuel). Northern Economics, found in previous work that reviewed 2006 and 2007 OPIS data from indicated that the Northwest area had a very small ULS price differential of about 1.5%. (Northern, 2007. p.57)

Figure 9: Alaska ULS No. 1 Price Differentials, Dollars per Gallon



Source: Alaska Department of Environmental Conservation, OPIS

The data in *Figure 9* indicates that the price differential between HS and ULS No. 1 ranges from 3 cents/gallon in Anchorage during February 2018, to 59 cents/gallon in Fairbanks during May 2018. The price differential between HS and ULS No. 1 fuel is significantly higher for Fairbanks than Anchorage. An explanation for this trend was provided by Northern Economics in their 2007 report: Cost Assessment for Diesel Fuel Transition in Western and Northern Alaska Communities, which states a key driver as, *"all ULS products are shipped by rail from Anchorage to Fairbanks, while the HS product is obtained from local refiners. The result is an average pricing premium…"*[16]

Additional fuel transportation logistics result in higher price premiums in the Fairbanks wholesale market. Anchorage fuel can be stored at Ship Creek where it then goes up the Alaska Railroad to Fairbanks. The latest publicly available information on the cost to ship fuel to Anchorage, from the Andeavor refinery in Kenai, is approximately 2 cents/gallon while the rail costs between Anchorage and Fairbanks is approximately 16 cents/gallon (Econ One Research, Inc., 2015, p.10). This study also estimated the cost of transport for ULS fuel from PSI's Valdez refinery to Fairbanks at approximately 20 cents/gallon (Econ One Research, Inc., 2015, p.25).

The fuel price differentials are reviewed here with the goal of developing an estimate of the direct expenditure impact to Fairbanks households. Information limitations result in an absence

[16] (Northern, 2007. p.56)

in evaluation of any potential added supplier capital costs to ship additional quantities of ULS and or HS No. 1 to Fairbanks. It is likely that, if these costs were to occur, they would be passed to the consumer. This analysis does not evaluate the effect of economies of scale with increased product demand or the potential for third party fuel distributors to enter the market to ship imported heating oil to Fairbanks and undercut competitors' prices. If these effects occurred, it is likely that this would result in no price increase or a potential for a price decrease for consumers. It is hard to predict which of these phenomena would occur and whether they would occur simultaneously. Though these factors are not analyzed in this review and beyond the scope of this study, ADEC recognizes that these factors are still important when analyzing the economic impacts of shifting to ULS heating fuel.

1.4 Fuel Cost Conclusions

Findings show through review of Fairbanks price data from April 2017 to July 2018, an average 34 cents/gallon for ULS over HS No. 1 and an average 41 cents/gallon premium for ULS over HS No. 2. Respectively, a shift from HS No. 1 to ULS No. 1 would result in a price increase of approximately 15%. While a shift from HS No. 2 to ULS No. 1 would result in a price increase of approximately 19%. A shift from HS No. 2 to HS No. 1 results in an average price differential of 7 cents/gallon, which represents an increase of approximately 3%. These price increases would directly affect household heating expenditures for fuel oil and are used in *Section II* to support the cost analysis.

Section II: Household Expenditure Scenarios Analysis

This section provides information on a cost model to explain potential changes in residential home heating expenditures assuming a switch to ultra-low sulfur (ULS) or shift from HS No. 2 to HS No. 1 heating fuel in the Fairbanks PM-2.5 Nonattainment Area. This section further employs a Monte Carlo analysis of the change in household heating oil expenditures from a switch to ULS, and a switch to HS No. 1. The objective of the Monte Carlo analysis is to help predict the expected change in household heating expenditures given a range of price differentials, annual household fuel consumption, and elasticity of demand estimates.

This assessment does not address the economic impact of both hypothetical heating fuel policy mandates, nor does it address the relative costs and benefits associated with conversion. Additional costs may include changes in fuel storage and distribution, whereas additional benefits would include improvements in air quality and reduced boiler maintenance. There is no assumed efficiency difference or boiler maintenance costs between HS No. 1 and HS No. 2. A switch to ULS or HS No. 1 may also produce behavioral responses by households which impact heating fuel demand in both the short and long run. It is important to note that the models do not take these issues into account and therefore results are only estimates based on the best information available at the time of publication.

2.1 Household Heating Oil Expenditure Changes from ULS

A potential transition from high sulfur (HS) home heating oil to ULS fuel would result in changes to household expenditures on fuel oil. Contributing factors include: fuel price differentials, heating efficiency changes, boiler maintenance cost reduction, and changes in the quantity of fuel used due to consumer price sensitivity. To assess how a potential transition from HS to ULS fuel might change household expenditures, this analysis makes several assumptions about key contributing factors likely to influence spending. First, expenditure estimates draw on the 16-month price differentials of 34 and 41.[17] Second, the differential adjusted prices are multiplied by the quantity of fuel consumed by a typical household using only a central oil-fired boiler. Finally, existing estimates of household fuel usage were adjusted to account for an average price sensitivity factor of -0.2%.

Evidence in the literature suggests that reducing sulfur and heat content in boiler fuel have a zero net change effect on fuel consumption.[18] Additional detail about the fundamental components of the estimates as well as supporting documentation is presented in the following discussion. It should also be noted that while the expenditure calculations do not include potential changes in maintenance costs that may occur, information about the potential savings have been included.

2.1.2 Household Heating Oil Expenditure Changes from HS No. 1

A potential switch from Fairbanks HS No. 2 to HS No. 1 would result in similar changes to household expenditures on fuel oil. It should be noted that the analysis of the change in household heating oil consumption from a switch to HS No. 1 uses the same underlying assumptions as discussed in *Section 2.2.1.* Differential prices between HS No. 1 and HS No. 2 are multiplied by the quantity of fuel consumed by a typical household using only a central oil-fired boiler. Existing estimates of household fuel usage were adjusted to account for an average price sensitivity factor of -0.2%. There is no assumed efficiency or boiler maintenance costs differences between HS No. 1 and HS No. 2.

2.1.3 Household Heating Oil Consumption

The cost scenarios are based on an assumed level of annual household heating oil demand. The estimated home heating oil usage is based on the Fairbanks Home Heating Telephone Survey conducted by Sierra Research Inc. Estimates utilized data[19] from 2011-2015, of the 2,304 households surveyed, 1,910 reported fuel quantities for at least one oil burning appliance. Homes that are heated only by a central oil burner are the most common heating configuration,

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[17] 34 and 41 cents/gallon are the differentials presented in *Section I*. These differentials represent the change from ULS No. 1 to HS No. 1 and HS No. 1 to No. 2 respectively. All modeling in *Section 2* uses 33 and 40 cents/gallon as inputs. These values represent the non-rounded price differences and do not significantly alter results.
[18] See Section 2.1.5 Appliance Efficiency and Maintenance Cost with ULS.
[19] A description of the data set is included in *Appendix A*.

representing about 40% of homes in the data set. On average, central oil burner FNSB homes consumed 1,230 gallons of heating fuel oil per year as shown in *Table 5* below. Household expenditures on heating energy is on average $2,274 annually for homes in the data as shown in *Table 5*. Homes with a central oil burner and a wood stove are also common in the data set, representing about 20% of households. *Table 6* contains the oil and wood consumption quantities for homes with a central oil burner/wood stove appliance combination. This analysis does not account for cross price effects of oil on other energy sources, such as firewood. Respondents were asked to estimate their annual fuel consumption (in gallons and in cost) over the phone. Fuel consumption estimates are heavily influenced by home size, heating degree days[20], and regional climate factors. These dynamics contribute to variability in responses resulting in large standard deviations for the estimates.

Table 5: Summary of Typical Annual Central Oil Only Appliance Household Consumption

	Mean	Median	Observations
Oil Usage (gal)	1230 (719)	1100	787
Home Size (sq ft)	1895 (827)	1842	787
Household Expenditures	$2274 ($2352)	$1850	787

Source: Sierra Research Inc., Fairbanks Home Heating Telephone Survey, 2011-2015
Note: Standard Deviations in parentheses

[20] Heating degree days are a common metric used to compare space heating loads or demand across locations or by month/season within a specific area. Heating degree days represent the number of degrees that that day's average temperature is below a base or reference number, typically 65° F.

Table 6: Summary of Typical Annual Central Oil Wood Stove Appliance Household Consumption[21]

	Mean	Median	Observations
Oil Usage (gal)	906 (535)	800	403
Wood Usage (cord)	3.6 (2.3)	3	403
Home Size (sq ft)	1935 (709)	1855	403

Source: Sierra Research Inc., Fairbanks Home Heating Telephone Survey, 2011-2015
Note: Standard Deviations in parentheses

2.1.4 Gross Energy Content and Emissions from Heating Fuels

Table 7: Heating Source Energy Content[22]

Fuel Type	**Content (BTU)**	**Unit**
HS No. 1 and No. 2 Blend	135,000	/gal
Natural Gas	1,010,000	/mcf
Wood, Pellet	16,000,000	/ton
Wood, Cordwood Wtd. Avg.	20,372,980	/cord
Coal, Stoker	15,200,000	/ton
Ultra-Low Sulfur Heating Oil*	134,000	/gal

* Estimated from HS Blend energy content and EIA (https://www.eia.gov/todayinenergy/detail.php?id=20092)
Source: FNSB Community Research Quarterly-Based Heating Fuel Energy Content

Table 7 presents the energy content in BTU's by heating fuel source. These are the energy content assumptions used in this analysis. Wood energy content based is on a baseline moisture content of 20% and a weighted mixture of spruce, birch, and aspen cordwood. The fuel oil energy content used is a common HS No. 1 and HS No. 2 weighted mixture of 31.8% HS No. 1 and 68.2% HS No. 2 used in Fairbanks residential space heating

[21] We are unable to calculate estimates of the additional fuel cost expenditures to these homes at this time. Additional work is being conducted to understand cross-price elasticity for households in this category.
[22] EIA's calculation of the heat content of distillate fuel supply in the United States reflects these changes, going from about 138.6 thousand British thermal units (Btu) per gallon in 1994, to an estimated 137.5 thousand Btu per gallon in 2014.

Table 8: Comparison of Key Emission Factors and Sulfur Content for Fairbanks Heating Fuels

Fuel	Emission Factor (lb/mmBTU)		Sulfur Content (ppmv)
	$PM_{2.5}$	SO_2	
HS No. 1 & 2	0.00340	0.215	2,053
HS No. 1	0.00365	0.102	896
HS No. 2	0.00330	0.263	2,566
Natural Gas	0.00749	0.000591	<16
Coal	0.526	0.612	2,000
Wood Burning	0.18 – 2.0*	0.023	<500
ULS	~0.003-0.004	0.00171	15

ppmv = parts per million by volume

* Covering a range of uncertified and EPA-certified cordwood and pellet devices, assuming zero (oven dry) moisture content

Source: compiled by Sierra Research, Inc

Table 8 summarizes emission factors per unit of fuel energy (in lb/MMBTU) to enable equivalent comparisons across the range of solid, liquid and gaseous heating fuels used in Fairbanks. Emission factors are listed for both directly-emitted $PM_{2.5}$ and SO_2 (the most significant precursor in Fairbanks). Sulfur contents of each fuel (in parts per million) are also compared. As shown in Table 8, emission factors of $PM_{2.5}$ and SO_2 vary by several orders of magnitude across the range of common heating fuels. SO_2 emission factors are generally related to sulfur content. $PM_{2.5}$ emission factors are less dependent upon sulfur content, expect within the same class of fuel (e.g., heating oil).

2.1.5 Sulfur Content Reduction and Effects on Energy Content

A misconception surrounding the sulfur content of fuels is that a reduction in sulfur content decreases the energy content (BTU's) of the distillate fuel source. Sulfur being removed from distillate fuel during the refining process is known as catalytic hydrotreating; catalytic hydrotreating strips away sulfur as well as nitrogen, oxygen, and metals from hydrocarbon compounds. These reactions reduce the weight per gallon and a small portion of the thermal energy obtained from the combustion of a gallon of distillate fuel. The Energy Information Administration's (EIA) calculation of the heat content of distillate fuel supply in the United States reflects these changes in the weight per gallon, going from about 138.6 thousand BTU's per gallon to an estimated 137.5 thousand BTU per gallon. This represents less than a 1% loss in energy content per gallon during the refining process for the removal of sulfur

2.1.6 Price Elasticity of Demand

The price elasticity of demand measures how sensitive the quantity demanded of a good or service is to a change in price.[23] 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, heating appliance(s) age, home age, and overall energy efficiency of the home. Demand is said to be "inelastic" when the percentage change in quantity is less than the percentage change in price. Demand is said to be "elastic" when the percentage change in quantity is greater than the percentage change in price. Cost scenarios are evaluated using an assumed oil price elasticity of 0.2%. Using an elasticity of 0 would imply that home heating oil demand is perfectly inelastic and that any change in the price of heating oil will not alter the quantity of heating oil demanded by households. This analysis assumes a constant price elasticity of demand[24] for all levels of home heating oil demand. The assumed rate of -0.2% is drawn from a study of home heating fuel demand conducted by Hirst, Goeltz, & Carney (1982) and implies that a 1% increase in the price of home heating oil will decrease the quantity demanded by 0.2%. Demand in this case is highly inelastic.[25]

Given a price increase to heating fuel, households will be incentivized to pursue activities that decrease heating expenditures. Immediate improvements such as caulking and weather stripping can reduce home heating expenditures in the average United States household by 2.5% (Gardner, 2008). A more drastic action, such as improving insulation and eliminating drafts within a home attic space, can reduce home heating expenditures by up to 7% (Gardner, 2008) in the typical US household. More simply put, homeowners will turn down their thermostat. FNSB households will have higher expenditures on home heating than the typical households similar relative to size due to extreme weather conditions. Cost savings associated with home efficiency improvements have a larger effect on FNSB household's price sensitivity to heating fuel. Specifically, FNSB homes have a more significant decrease in their price sensitivity to heating fuel due to cost savings from efficiency improvements.[26]

2.1.7 ULS and High Sulfur Cost Differentials

Drawing on *Section I*, the cost scenarios incorporate heating fuel price differentials based on 16 months (April 2017 through July 2018) of OPIS data for Fairbanks. No assumptions are made as to whether these price differentials will increase or decrease over time, and so all modeled scenarios employ constant price differentials. As mentioned in *Section 1.5*, the average price differential for ULS and HS No. 1 and ULS and HS No. 2, are 34 and 41 cents/gallon

[23] Examples of how the price elasticity of demand is calculated are explained in *Appendix B.*
[24] See *Appendix C*
[25] This estimate is for the short run effects of the transition to ULS fuel. Long run effects are not taken into consideration in this analysis, but would have lower costs compared to the short run.
[26] A decrease in the price sensitivity to heating fuel would indicate the households demand for will become more elastic.

respectively.[27] Both ULS price differentials are presented in different scenarios, referred to as Scenario 1 for the lower price differential of 34 cents/gallon, and Scenario 2 for the higher price differential of 41 cents/gallon. The ULS price differential of 34 cents/gallon represents the change between ULS and HS No. 1. The price differential of 41 cents/gallon represents the change between ULS and HS No. 2.

2.1.8 High Sulfur No. 1 and High Sulfur No. 2 Cost Differentials

In *Section 1.5* the Fairbanks HS price differential of 7 cents/gallon is based on the 16-month (April 2017-July 2018) averages of HS No. 1 and HS No. 2. Price differentials based on historical pricing data and calculations can be found in *Table 4.* This analysis does not make assumptions regarding current fuel usage mix consumed by the typical FNSB household.

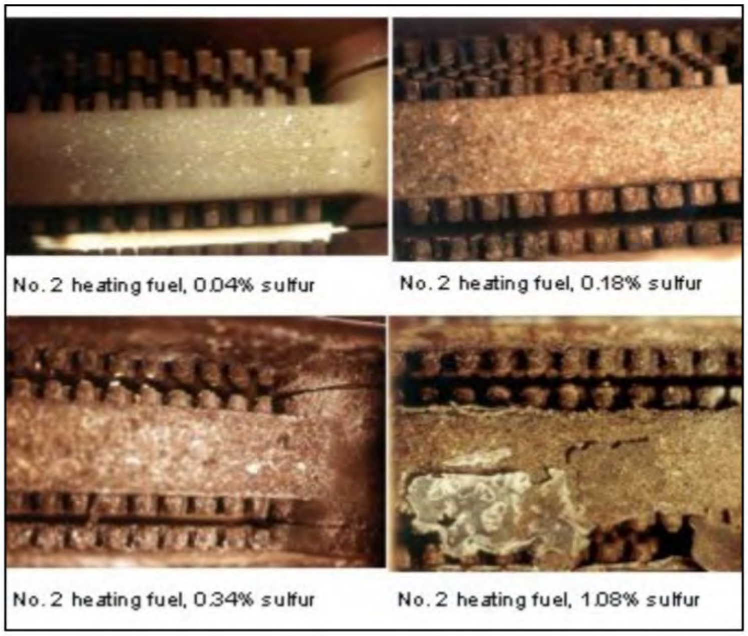
2.1.9 Appliance Efficiency and Maintenance Cost with ULS

Heat content differences in HS fuel and ULS fuel mean that more ULS fuel will need to be burned to maintain the same indoor temperatures.[28] As noted *in Section II,* there is no assumed fuel efficiency or boiler maintenance cost difference between HS No. 1 and HS No. 2; therefore, this section will focus solely on the appliance efficiency and maintenance costs associated with a hypothetical switch to ULS. Approximately 1% more ULS fuel by volume would be required to compensate for the loss in heat content over HS fuel oil (EIA, 2018). However, boilers burning ULS fuels operate at a higher level of efficiency. It is assumed that the balance of these effects results in no change to fuel quantity consumption. This analysis accounts only for changes in fuel consumption, but a brief discussion of potential maintenance and repair costs is included. An explanation of assumptions in this analysis and a relevant synopsis of two Brookhaven National Laboratory Reports (Batey & McDonald, 2007 and Batey & McDonald, 2015) are included here.

A switch from HS fuel to ULS fuel has a significant effect on boiler efficiency. Batey and McDonald, 2015 compared the rates of ‘boiler fouling’ in systems using conventional heating oil and ULS fuel. Decreases in boiler efficiency are caused by buildup of soot on heat exchange surfaces. As shown in *Figure 10*, soot buildup is directly related to the sulfur content of the burned fuel.

[27] Due to rounding error, all modeled scenarios are calculated using values of 33 and 40 cents/gallon for ULS to HS No. 1 and ULS to HS No. 2 price differentials respectively.
[28] Refer to *Table 7* and *Table 8* for energy content and sulfur content be fuel type

Figure 10: Buildup of Soot and Particulates on Heat Exchange Plates for Identical Boilers using Different Fuels



Source: Batey and McDonald, 2015, p. 14

The amount of buildup also increases with time and causes the boiler to consume more fuel to compensate for lost energy during heat transfer. Batey and McDonald, 2007 conducted a cost-benefit analysis of a potential transition from conventional fuel oil (2,000-2,500 ppm) to low sulfur fuel (0.05% sulfur by weight) in New York State. This earlier report estimates that boilers burning conventional fuel oil experience a decrease in efficiency of 2% per year due to fouling. This analysis assumes a zero-net change in fuel quantity, which is conservative given the availability of information. Estimates of household heating expenditures can easily be adjusted to account for different efficiency levels. A procedure for adjustments is presented in *Section 2.2*.

The rate of boiler fouling may also impact household expenditures on maintenance calls and routine boiler cleaning. Batey and McDonald, 2015 used a Boiler Fouling Scale to compare the relative rate of buildup for residential fuel oil compared to ULS fuels. After approximately one year of operation, the conventional fuel oil group scored 2.15 and the ULS group scored 0.47. The ratio of boiler fouling is then 2.15/0.47 = 4.6. This means that boiler fouling occurs in conventional fuel oil boilers at a rate that is 4.6 times greater than ULS boilers. As boilers are typically cleaned every 1.5 to 2 years, a boiler using ULS fuel would only need to be cleaned approximately every 6.9 years. The Batey and McDonald, 2007 analysis assumed an average boiler cleaning service call would require 1.1 hours of labor. They also assumed service call costs ranging from $44 - $104 per hour. Based on the reduction in maintenance from the fuel switch, they estimated average annual household savings of $16 - $40. These savings are presented in 2007 dollars for New York State residents. Potential maintenance savings to FNSB residents are most likely larger than the Batey and McDonald, 2007 estimates due to a higher cost of living. These maintenance considerations are not included in the cost scenarios.

Batey and McDonald, 2015 found that a switch from conventional fuel oil to ULS could pose some risk to boiler systems with certain types of lip seals present in some oil burner pumps. 85% of existing residential oil burning systems use black nitrile seals, which were unaffected by the change in sulfur content. However, a smaller proportion of brown 'Viton' type seals are highly susceptible to degradation from ULS fuels. These seals were used for a brief period in the early 2000's but were observed to have a much higher rate of failure than their nitrile substitutes. This may indicate a further increase in boiler repair costs for some households. With the proportion of the vulnerable seals so low, this effect is not included in the cost scenarios.

2.2 Heating Oil Cost Models

A cost model was developed using Fairbanks Home Heating Telephone Survey data from 2011-2015 collected by Sierra Research for DEC to estimate the impact on household fuel expenditures in the FNSB area. Scenarios were developed using five key assumptions, and are listed below:

Scenario 1: Annual household heating oil use of 1,230 gallons, an own-price elasticity of demand of -0.2, no net change in efficiency and energy loss, 5% rate of discount, and a price differential of 34 cents/gallon for ULS.

Scenario 2: Annual household heating oil use of 1,230 gallons, an own-price elasticity of demand of -0.2, no net change in efficiency and energy loss, a 5% rate of discount, and a price differential of 41 cents/gallon for ULS.

Scenario 3: Annual household heating use of 1,230 gallons, an own-price elasticity of demand of -0.2, no net change in efficiency and energy loss, 5% rate of discount, and a price differential of 7 cents/gallon between HS No. 1 and HS No. 2.

Table 9: Summary of Heating Oil Cost Model Scenarios

Scenario	Gallons of Prior Fuel Usage	Price Differential Cents/Gallon	Own-Price Elasticity
1. HS No. 1 to ULS	1230	34	-0.2
2. HS No. 2 to ULS	1230	41	-0.2
3. HS No. 2 to HS No. 1	1230	7	-0.2

Source: Alaska Department of Environmental Conservation, UAF Cost Model

2.2.1 Monte Carlo Simulation

One objective of this study is to utilize a Monte Carlo analysis as a tool to help predict the expected change in household heating expenditure given a range of ULS differential, annual household fuel consumption, and elasticity of demand estimates. The Monte Carlo analysis can also be used to verify the estimates from *Section 2.2.* In a Monte Carlo simulation, a random value is computed for each of the variables based on a range of the estimates provided. This makes the Monte Carlo a valuable tool for predicting the probability of a given outcome with either limited data or many variables. The Monte Carlo Analysis uses the minimum, maximum, and mean value of those distributions to generate five-thousand random trials based on the range of estimates to predict the outcome of each. Based on the results from the generation of values, the expected change in household heating expenditure is computed. For this analysis, the inputs: ULS differentials, HS No. 1 differential, annual household fuel consumption, and elasticity of demand estimates were varied using triangular distribution.

Table 10: Summary of ULS Monte Carlo Inputs

Inputs			
Variable	**Min**	**Max**	**Mean**
ULS Differential	0.2	0.4	0.34
Gallons of Fuel	45	5000	1230
Own-Price Elasticity of Demand	0.2	0.7	0.4
Current Fuel Price			
$2.10			

Source*:* Alaska Department of Environmental Conservation, UAF Monte Carlo Model

Table 11: Summary of HS No. 1 Monte Carlo Inputs

Inputs			
Variable	**Min**	**Max**	**Mean**
ULS Differential	0.05	0.10	0.07
Gallons of Fuel	45	5000	1230
Own-Price Elasticity of Demand	0.2	0.7	0.4
Current Fuel Price			
$2.10			

Source*:* Alaska Department of Environmental Conservation, UAF Monte Carlo Model

Table 11 and Table 12 present a summary of the inputs used to conduct the ULS Monte Carlo Simulation, and the HS No. 1 Monte Carlo Simulation. Both models used a constant fuel price per gallon of $2.10 to calculate the expected change in household heating expenditure below.[29]

2.2.2 Results of Monte Carlo Simulation

Table 12: Results of ULS Household Heating Expenditure

Annual Change in Household Heating Expenditures			
Min	**Max**	**Mean**	**Median**
$10.64	$1,185.35	$329.73	$294.86

Source*:* Alaska Department of Environmental Conservation Monte Carlo Model

Based on the results of the ULS Monte Carlo, the average change in annual household expenditure is approximately $329.73. The minimum change in expenditure is $10.64, and the maximum is $1,185.35. The results of the Monte Carlo further verify the estimates presented in *Section 2.2*, as the mean estimate of changes in household heating expenditures fall within the expected range of $311.96 and $374.86, with the median change in household heating estimates falling slightly outside the expected range.

Table 13: Results of HS No. 1 Household Heating Expenditures

Annual Change in Household Heating Expenditures			
Min	**Max**	**Mean**	**Median**
$3.00	$303.61	$84.32	$76.12

Source*:* Alaska Department of Environmental Conservation Monte Carlo Model

Based on the results of the HS No. 1 Monte Carlo, the average change in annual household expenditure is approximately $84.32. The minimum change in expenditure is $3.00, and the

[29] Alaska Energy Data Gateway, 2006

maximum is $303.61. The results from the HS No. 1 Monte Carlo Simulation is slightly outside the estimates calculated in *Section 2.2* at an average increase of $84.32 from a switch to HS No. 1, the median estimate was slightly closer to *Section 2.2* estimates at a predicted household expenditure increase of $76.12.

Table 13 and 14 present the estimated change in expenditure based on the Monte Carlo inputs. The change in expenditure based on the Monte Carlo simulations is calculated for both ULS and HS No. 1 as so:

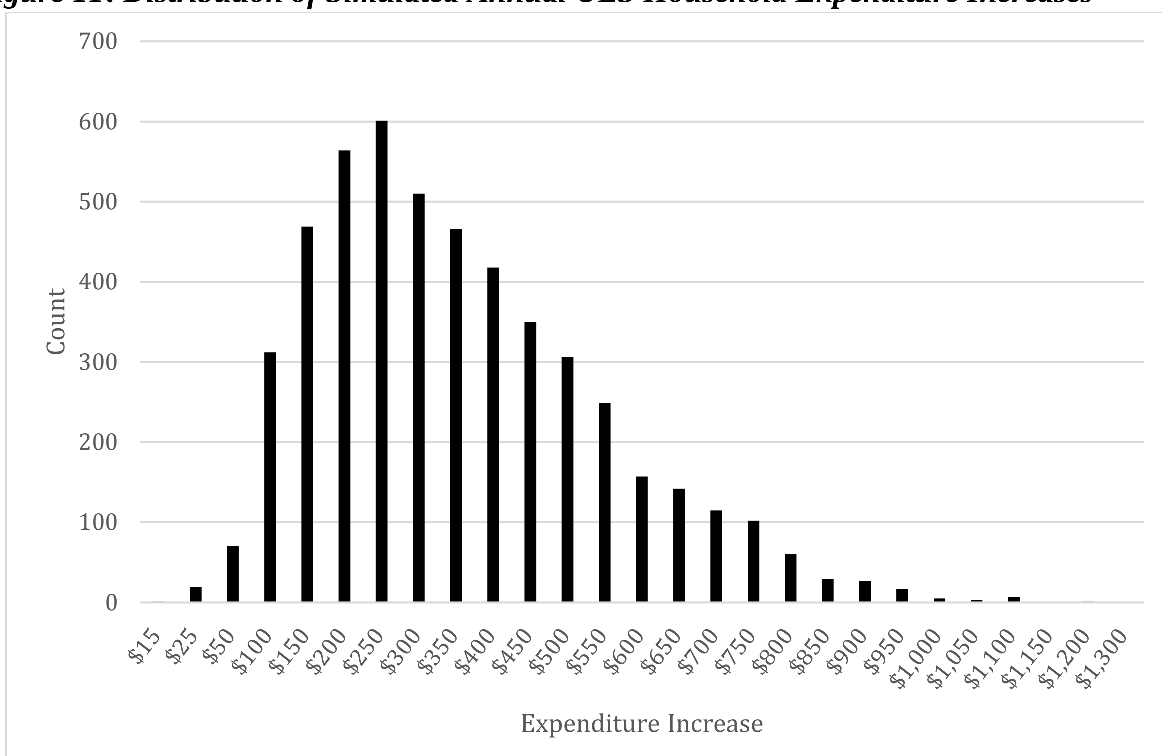
$$\left(\Delta Expenditure = \left(-Ed * \frac{Fuel}{Price}\right) * ULS\ Diff + Fuel\right) * (Price + ULS\ Diff) - (Fuel * Price)$$

Where *Fuel* is in gallons of heating oil per year used by the household, *Price* is the price of heating oil per gallon *ULS Diff* is the differential between HS No. 1 and ULS in the price per gallon. For example, using ULS Trial 1 calculations

$$\left(\Delta Expenditure = \left(-0.387 * \frac{603.19}{\$2.10}\right) * 0.28 + 603.19\right) * (\$2.10 + 0.28) - (603.19 * \$2.10) = \$96.16.$$

Using the above example, there is a predicted increase in annual household heating expenditure of $96.16.

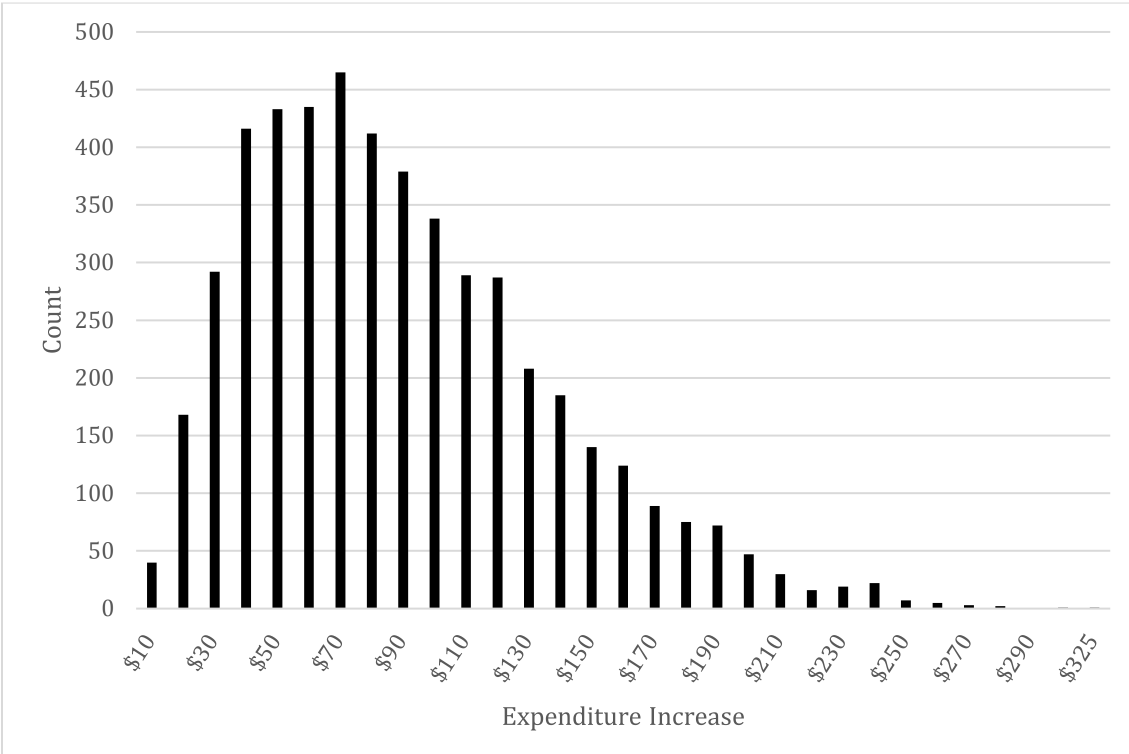
Figure 11*: *Distribution of Simulated Annual ULS Household Expenditure Increases



Source*:* Alaska Department of Environmental Conservation Monte Carlo Model

Figure 11 presents the triangular distribution of simulated expenditure increases based on the ULS differential. Based on the ULS price differentials: 20, 34, and 41 cents/gallon, the average change in annual household expenditure is approximately $329.73. The minimum change in expenditure is $10.64, with a maximum change of $1,185.35. The distribution of the data is skewed right, approximately 90% of households are predicted to incur additional expenditures of $650 or less in the first year given a switch to ULS.

Figure 12: Distribution of Simulated Annual HS No. 1 Household Expenditure Increases



Source: Alaska Department of Environmental Conservation Monte Carlo Model

Figure 12 presents the triangular distribution of simulated expenditure increases based on the HS No. 1 differential. Applying the HS No. 1 price differentials: 5, 7, and 10 cents/gallon, the average change in annual household expenditure is approximately $84.32. The minimum change in expenditure is $3.00 and the maximum is $303.61. Again, the distribution of the data is skewed right, 90% of households are predicted to incur additional expenditures of $160 or less in the first year given a switch to HS No. 1.

2.3 Summary of Household Impact

These estimates vary depending on the assumed household sensitivity to price changes and the price differential used. These estimates do not include the change in maintenance costs associated with changing to ULS, the potential switch to alternate fuels (for example wood or natural gas), or behavioral responses which reflect a change in home heating practices. It should be noted that these estimates do not account for the potential switch to wood consumption, as this is a concern for the FNSB area connected to the sensitivity of consumers to fuel price increases and the substitutability of the type fuel used in the home.

2.3.1 Household Impact from Switch to ULS

The estimated cost of a potential ULS transition to an average FNSB household would be between $311.96 and $374.86 in the first year, with models accounting for consumer sensitivity to prices and the lower price differential of 34 cents/gallon resulting in the lower estimates. This represents a percent increase in household heating expenditures of 13.5% - 16.5% in the first year given average annual household heating expenditures of $2,274. The ULS estimate is further verified by the results of the Monte Carlo simulation. Results estimate a mean increase in household heating expenditures of $329.73 or 14.5% increase in household heating expenditures which land within the immediate estimates. The discounted NPV of the increased cost from implementation to 25 years varies between $4,396.76 and $5,283.22, with the higher estimate being associated with the 41 cents/gallon price differential assumption and relatively inelastic demand.

2.3.2 Household Impact from Switch to HS No. 1

The estimated cost of a potential HS No. 1 transition (from HS No. 2) to an average FNSB household is $68.31 in the first year given a price differential estimate of 7 cents/gallon. The results from the HS No. 1 Monte Carlo Simulation is slightly outside the estimates calculated in *Section 2.2* at a calculated average increase of $84.32 or 3.7% in annual household heating costs.

2.4 Potential Benefits of Switch to ULS

Thus far, this analysis has provided estimates of the additional heating costs incurred by households from a potential switch from HS to ULS. The potential benefits associated with a switch to ULS discussed in this section are strictly qualitative. Benefits of a switch to ULS include reduced PM-2.5 emissions, which could result in potential health benefits for FNSB residents. Improved air quality from a reduction in sulfur oxide, particulate matter, and nitrous oxide, could reduce asthma and cardiovascular induced hospitalizations from PM-2.5 episodes during winter months (State of Alaska Department of Epidemiology, 2010). Environmental benefits include reducing ground level smog, which would increase visibility for drivers and pedestrians. Other benefits from a hypothetical switch could include increased heating equipment efficiency, and lower maintenance costs from reduced boiler fouling as discussed in *Section 2.1.5*.

2.5 Limitations

The data used in this analysis lacked some socio-demographic, housing characteristics, and price data. Data such as household income, number of individuals living in the household, and other household spending preferences was not collected from the initial household level surveys. Housing characteristics such as number of bedrooms/bathrooms, garage space, and household energy efficiency were not included in the data set.

There are current data limitations regarding the prices Fairbanks households pay for their firewood. If this analysis tried to incorporate firewood prices at this time data limitations would result in a lack of price variability in the modeled scenarios. Many households in Fairbanks report collecting their own firewood instead purchasing. It would be of great value to gather data on the length of time spent collecting wood.

Conclusion

A prospective switch to ultra-low sulfur (ULS) heating oil is predicted to increase residential heating expenditures for the typical Fairbanks North Star Borough (FNSB) household. This does not take into consideration any potential benefits of the change, such as savings in boiler maintenance, decreased costs associated with improved air quality, and other factors. The cost analysis provided in *Section II* (using the price differentials from *Section I*) represents the likely range of estimates for an increase in residential heating expenditures given the available information and scope of the analysis is between $311.96 and $374.86 in the first year. This represents a predicted increase in household expenditures of 13.5%-16.5% in the first year given annual household heating expenditures of $2,274.

A prospective switch to HS No. 1 from HS No. 2 heating oil is predicted to slightly increase residential heating expenditures for the typical FNSB household. The cost analysis provided in *Section II* of a hypothetical switch to HS No. 1 represents a predicted increase in household heating expenditures of $68.31 in the first year. This represents a predicted increase in household expenditures of 3% in the first year.

This analysis does not account for cross-price effects on alternative energy sources like firewood, even though many FNSB homes contain more than one heating appliance. Future research should examine household expenditures and determine whether the reduction in particulates and improvement in air quality are acceptable given the cost to consumers in the FNSB.

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Sierra Research Inc. Fairbanks Home Heating Telephone Survey Data 2006-2015 - Unified Format, provided July 2, 2018

Appendix A

This analysis estimates the typical FNSB household fuel oil usage to be 1,230 gallons per year. This assumption is based on the Fairbanks Home Heating Telephone Survey Data 2006-2015, collected and prepared by Sierra Research Inc. Analysis data on fuel usage was limited to the continuous time period from 2011-2015. The survey collected information on household characteristics, appliance types, and fuel consumption for home heating. The survey focused on heating oil, firewood, natural gas, and coal as the primary heating fuels, and asked respondents to estimate their fuel consumption in terms of annual quantity and expenditures. ADEC's estimate of household oil consumption isolated households that burned only oil in a central boiler. For households with a central oil burner and reported oil consumption > 0, the average FNSB home uses 1,230 gallons of conventional heating oil per year. All calculations were performed using the statistical analysis software, STATA.

Appendix B

Price elasticity of demand measures the responsiveness of the quantity demanded of a good to a change in its price. It is calculated by the percentage change in quantity demanded divided by the percentage change in price. Price elasticity of demand figures are presented in absolute terms, as they typically consist of negative values, due to the inverse relationship between price and the quantity demanded of a good or service.

$$E_d = \frac{\%\Delta Q}{\%\Delta P} \tag{3}$$

$$E_d = \frac{(Q_1 - Q)/Q}{(P_1 - p)/P} \tag{4}$$

These equations are all different ways to calculate the price elasticity of demand, with *equation 4* a more explicitly written version of *equation 3*. To find this value with calculus *equation 5* could be used. This uses the partial derivative of the quantity demanded with respect to the price of the good multiplied by the specific price of the good divided by the specific quantity demanded associated with that price.

$$E_d = \frac{\partial Q}{\partial P} \times \frac{P_0}{Q_0} \tag{5}$$

Appendix C

Figure 13: Price-Quantity Function Elasticity Example

Source: Farris & Pfeifer 2010

Constant elasticity demand function means the elasticity of demand is the same at every point along the demand curve, but the slope is different at every point. This is represented in *equation 6* where ε is the price elasticity of demand and k is a constant.

$$Q = kP^{\varepsilon} \tag{6}$$

Instead of a linear demand function, a constant elasticity demand function is assumed for this analysis because of the numerous assumptions made about heating fuel demand in the Fairbanks area. The post-transition level of heating oil demand is not known, so we assume fixed elasticity demand values across a range of fuel quantities.

Appendix D

Monte Carlo Analysis

The Monte Carlo Analysis, or Monte Carlo Simulation is a method of analysis developed in the 1940's which uses statistical sampling to obtain a probabilistic approximation to the solution of a model or an equation. Monte Carlo analysis uses the process of approximating the output of a model through the repetitive and random application of the model's framework. Through this process, the Monte Carlo simulation tells us based on a range of estimates how probable the resulting outcomes are. A Monte Carlo analysis can include a mix of point estimates and distributions for the input parameters.