Granite Bridge: Environmental Benefits of System Expansion

Analysis of the Potential Emission Benefits of Natural Gas Conversions
from Liberty Utilities' Granite Bridge Project
September 2018[1]

The Granite Bridge project helps ensure that the current and future needs of natural gas customers in Southern New Hampshire can be reliably met. The project strengthens gas system operations, eliminates older and less efficient energy alternatives for the state's residents and businesses, and will help Liberty Utilities meet the state's natural gas needs at the lowest possible cost, with minimal impact. Moreover, it will allow many residential and business customers currently heating with more expensive heating sources to opt for natural gas.

In providing an alternative heating source option, Granite Bridge comes with a significant upside: it opens the door to achieving reductions in emissions of pollutants by displacing higher-emitting heating sources. And reducing local sources of pollution means reducing premature deaths, respiratory and other health impacts, and the risks associated with global warming.

How will these benefits be captured?

The construction of Granite Bridge will increase access to natural gas for thousands of residents and businesses across southern New Hampshire, including residents that currently meet their heating and hot water needs through older equipment and higher-emitting fossil fuel resources.

Finally, Granite Bridge will significantly reduce heavy-duty truck traffic that currently delivers liquid fuel to satellite fuel centers and customers across the state, reducing the pollutants associated with delivery operations.

What are the potential benefits?

- The combustion of fuel to meet home and business heating and hot water needs is a major source of local pollutants - including nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter (PM), mercury (Hg), carbon dioxide (CO_2) and methane (CH_4), the latter two of which are associated with climate change.

- These pollutants lead to or exacerbate premature deaths, asthma, and other major health problems for the state's residents, and increase the economic and environmental risks of climate change. For example, the New Hampshire Department of Environmental Services estimates that one premature death due to air pollution results in $9.35 million in costs, one asthma-related emergency room visit costs $440, and one lost work day averages $150.[2] Moreover, they estimate that fine particulate matter and ozone accounted for approximately $3.8 billion in health impacts in New Hampshire from 2013 through 2015.[3]

[1] This Report was authored by Jonathan Baker, Paul Hibbard, Grace Howland, and Andrea Okie of Analysis Group.
[2] "Considerable variability in valuation exists. Valuations presented here are interpolated median 2011 valuations." New Hampshire Department of Environmental Services, State of new Hampshire Air Quality – 2017: Air Pollution Trends, Effects and Regulation, March 2018, available at https://www.des.nh.gov/organization/commissioner/pip/publications/documents/r-ard-17-01.pdf, Table 4.2, p. 64-65.
[3] Figure reported in 2010 dollars. Economic impacts of air pollution consider ozone and particulate matter pollution. New Hampshire Department of Environmental Services, State of new Hampshire Air Quality – 2017: Air Pollution Trends, Effects and Regulation, March 2018, available at https://www.des.nh.gov/organization/commissioner/pip/publications/documents/r-ard-17-01.pdf, Table 4.3, p. 66.

- Opening up access to natural gas will displace the use of energy sources for heating and hot water needs that are less clean and less efficient. The corresponding reduction in emissions is therefore driven by the lower emission rates of natural gas and by the ability to use more efficient equipment for heating and hot water.

- When Granite Bridge comes into service, Liberty Utilities expects to be adding approximately 1,500 residential customers and 90 commercial and industrial ("C&I") customers each year - customers that will be choosing natural gas for heating and hot water over oil, propane, or some other heating source.[4] Over the 17 year period analyzed, Liberty Utilities expects to add 24,962 residential customers and 1,520 C&I customers.[5] These are customers that would not have access to natural gas for these services without the Granite Bridge project.[6] Thus, over time, as these customers switch to natural gas (or select it for heating), the state will achieve reductions in emissions of NO_x, SO_2, PM, Hg, CO_2, and CH_4, and realize corresponding health benefits, compared to using more polluting sources.

- Health benefits derive from reducing emission of pollutants associated with negative health impacts:
    - Nitrogen oxides are implicated in a wide variety health and environmental impacts. Health impacts include respiratory infection and disease, such as asthma. Environmental effects include acid rain, haze, and nutrient pollution in coastal waters.[7]

    - Sulfur dioxide is implicated in a wide variety of health and environmental impacts. Like NO_x, health impacts include respiratory infection and disease, such as asthma. Environmental effects include acid rain and haze.[8]

    - Particulate matter is implicated in a wide variety of health and environmental impacts. Health impacts include negative effects on the heart and lungs, such as respiratory disease and non-fatal heart attacks. Environmental effects include acid rain, depletion of nutrients in soil and water, and negative effects on the diversity of ecosystems.[9]

    - Mercury is implicated in a wide variety health and environmental impacts. Some of the health impacts include headaches, changes in nerve response, and poor performance on test of mental function. Prolonged high exposure can cause kidney effects, respiratory

[4] This value starts at 1,925 additional residential customers in 2021/2022 (approximately when Granite Bridge is expected to be operational), declining to 1,230 additional residential customers in 2037/2038 for a total of 24,962 total additional residential customers over this time period. In addition, approximately 1,520 C&I customers will be added over the same timeframe. Estimates are based on resource plan forecasts by Liberty Utilities.

[5] Liberty Utilities' customer growth and fuel consumption projections are reported in gas years, November to October. This analysis includes 17 years of gas years from Nov 2021/Oct 2022 to Nov 2037/Oct 2038.

[6] Expected customer growth stems from new service and conversions within the company's existing service territory and new access to natural gas along the route of the Granite Bridge project in towns that currently do not have access to natural gas. Liberty Utilities has noted that without Granite Bridge, it may need to impose a moratorium on new natural gas services. See New Hampshire Public Utilities Commission, Docket No. DG 17-198, Liberty Utilities (EnergyNorth Natural Gas) Corp. d/b/a Liberty Utilities, Approval of Natural Gas Supply Strategy, Pre-Filed Testimony of Susan L. Fleck and Francisco C. Dafonte, December 21, 2017, p. 19, available at http://www.puc.state.nh.us/Regulatory/Docketbk/2017/17-198/INITIAL%20FILING%20-%20PETITION/17-198_2017-12-22_ENGI_PDTESTIMONY_FLECK_DAFONTE.PDF.

[7] "Nitrogen Dioxide (NO_2) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NOx) […] NO_2 is used as the indicator for the larger group of nitrogen oxides." EPA, Basic Information about NO_2, accessed September 5, 2018, available at https://www.epa.gov/no2-pollution/basic-information-about-no2#Effects.

[8] EPA, Sulfur Dioxide Basics, accessed September 5, 2018, available at https://www.epa.gov/so2-pollution/sulfur-dioxide-basics.

[9] EPA, Health and Environmental Effects of Particulate Matter (PM), accessed September 5, 2018, available at https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm.

failure, and death. Environmental effects are concentrated in animals that eat fish. Due to mercury exposure, these animals are subject to reduced reproduction, slower growth and development, and abnormal behavior, and even death.[10]

- Emissions of greenhouse gases contribute to the social, economic and environmental risks associated with climate change.

By how much will emissions decrease?

Table 1 – Aggregate lifetime emission reductions

Emissions reductions from using natural gas-fired heating/hot water systems compared to using a standard efficiency oil-fired heating/hot water system and a high efficiency oil-fired heating/hot water system.

	Residential Reductions		**C&I Reductions**		**Total Reductions**	
	(Standard Eff. Oil) less (NG)	*(High Eff. Oil) less (NG)*	*(Standard Eff. Oil) less (NG)*	*(High Eff. Oil) less (NG)*	*(Standard Eff. Oil) less (NG)*	*(High Eff. Oil) less (NG)*
Nitrogen Oxide (pounds)	2,914,268	2,360,867	1,204,337	975,641	4,118,605	3,336,507
Sulfur Dioxide (pounds)	531,995	407,855	219,850	168,548	751,845	576,403
Particulate Matter (pounds)	145,856	112,686	60,276	46,568	206,131	159,254
Mercury (pounds)	51	43.61	21	18.02	71	62
CO_2 + CO_2e Methane (tons)	724,758	490,648	299,510	202,763	1,024,269	693,411

For the purpose of this analysis, we compare the use of natural gas-fired space and water heating technology to the continued use of oil-fired space and water heating technology. For comparison, we provide estimates of what these reductions mean in terms of an equivalent number of cars taken off the road for one year.[11] Referring to Table 1, over the 17 year period analyzed, conversions from standard-efficiency oil to natural gas of residential and C&I customers will result in the following total emission reductions:

- Impact on NO_x emissions:
  - 4.1 million pounds total (171 thousand equivalent cars off the road for one year)
- Impact on SO_2 emissions:
  - 752 thousand pounds total
- Impact on PM emissions: [12]
  - 206 thousand pounds total (1.9 million equivalent cars off the road for one year)
- Impact on Hg emissions:
  - 71 pounds total
- Impact on CO_2-equivalent emissions:
  - 1 million tons total (200 thousand equivalent cars off the road for one year)

[10] EPA, Basic Information about Mercury, accessed September 5, 2018, available at https://www.epa.gov/mercury/basic-information-about-mercury; Health impacts listed are from inhaling elemental mercury, EPA, Health Effect of Exposures to Mercury, accessed September 5, 2018, available at https://www.epa.gov/mercury/health-effects-exposures-mercury.

[11] EPA, Greenhouse Gas Emissions from a Typical Passenger Vehicle, Office of Transportation and Air Quality, EPA-420-F-18-008, March 2018. EPA, Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks, Office of Transportation and Air Quality, EPA-420-F-08-024, October 2008.

[12] These estimates assume all PM emissions are $PM_{2.5}$.

Table 2 – Per-customer average annual emission reductions

Emissions reductions from using natural gas-fired heating/hot water systems compared to using a standard efficiency oil-fired heating/hot water system and a high efficiency oil-fired heating/hot water system.

	Residential Reductions		C&I Reductions	
	(Standard Eff. Oil) less (NG)	*(High Eff. Oil) less (NG)*	*(Standard Eff. Oil) less (NG)*	*(High Eff. Oil) less (NG)*
Nitrogen Oxide (pounds)	11.97	9.70	56.70	45.94
Sulfur Dioxide (pounds)	2.19	1.68	10.35	7.94
Particulate Matter (pounds)	0.60	0.46	2.84	2.19
Mercury (ounces)	0.0033	0.0029	0.0157	0.0136
CO_2 + CO_2e Methane (tons)	2.98	2.02	14.10	9.55

Referring to Table 2, each additional residential customer and each additional C&I customers would result in the following average annual decreases in emissions in New Hampshire relative to using standard efficiency oil.[13] We also provide an estimate of the number of cars that would annually emit these emission decreases.[14]

- Impact on NO_x emissions:
  - 12 pounds from an individual residential conversion (0.5 car-equivalents).
  - 57 pounds from an individual C&I conversion (2.4 car-equivalents).

- Impact on SO_2 emissions:
  - 2 pounds from an individual residential conversion.
  - 10 pounds from an individual C&I conversion.

- Impact on PM emissions:
  - 0.6 pounds from an individual residential conversion (5.8 car-equivalents).
  - 2.8 pounds from an individual C&I conversion (27 car-equivalents).[15]

- Impact on Hg emissions:
  - 0.003 ounces from an individual residential conversion.
  - 0.016 ounces from an individual C&I conversion.

- Impact on CO_2-equivalent emissions:
  - 2.9 tons from an individual residential conversion (0.6 car-equivalents).
  - 14 tons from an individual C&I conversion (2.8 car-equivalents).

[13] The annual average is a simple average over 17 years of emission reductions per customer. As average consumption per customer changes each year, actual annual values differ slightly over time.
[14] EPA, sourced above.
[15] These estimates assume all PM emissions are PM2.5.

Table 3 – Per-customer lifetime emission reductions

Emissions reductions from using natural gas-fired heating/hot water systems compared to using a standard efficiency oil-fired heating/hot water system and a high efficiency oil-fired heating/hot water system.

	Residential Reductions		**C&I Reductions**	
	(Standard Eff. Oil) less (NG)	*(High Eff. Oil) less (NG)*	*(Standard Eff. Oil) less (NG)*	*(High Eff. Oil) less (NG)*
Nitrogen Oxide (pounds)	204	165	964	781
Sulfur Dioxide (pounds)	37	28	176	135
Particulate Matter (pounds)	10	8	48	37
Mercury (ounces)	0.0565	0.0487	0.2677	0.2308
CO_2 + CO_2e Methane (tons)	51	34	240	162

Referring to Table 3, over the 17 year period analyzed, the conversions from each individual additional residential and C&I customer will result in the following emission reductions and equivalent cars taken off the road:[16]

- Impact on NO_x emissions:
    - 204 pounds from an individual residential conversion. (8.5 equivalent cars off the road for one year)
    - 964 pounds from an individual C&I conversion. (40 equivalent cars off the road for one year)

- Impact on SO_2 emissions:
    - 37 pounds from an individual residential conversion.
    - 176 pounds from an individual C&I conversion.

- Impact on PM emissions:
    - 10 pounds from an individual residential conversion. (98 equivalent cars off the road for one year)
    - 48 pounds from an individual C&I conversion. (464 equivalent cars off the road for one year)

- Impact on Hg emissions:
    - 0.06 ounces from an individual residential conversion.
    - 0.27 ounces from an individual C&I conversion.

- Impact on CO_2-equivalent emissions:
    - 51 tons from an individual residential conversion. (9.9 equivalent cars off the road for one year)
    - 240 tons from an individual C&I conversion. (46 equivalent cars off the road for one year)

Figure 1 through Figure 5 illustrate the per-customer lifetime emissions for the three technology options we analyze (standard efficiency oil, high efficiency oil, and natural gas). Overall, the following figures demonstrate that households that meet their heating and hot water needs with natural gas produce significantly lower emissions than households using oil-fueled heating technology.

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[16] EPA, sourced above.

Figure 1a – Residential Customers

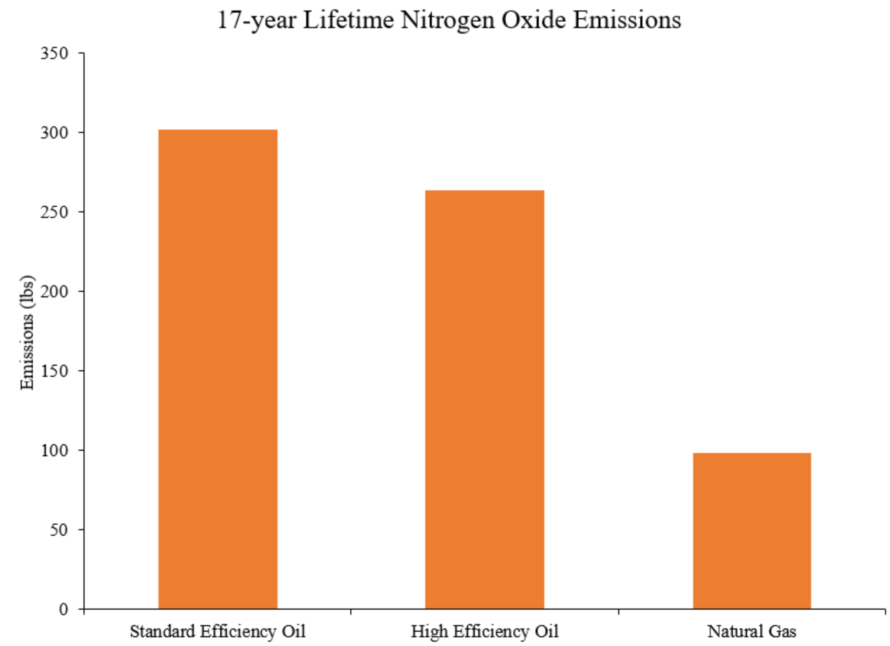


Figure 1b – C&I Customers

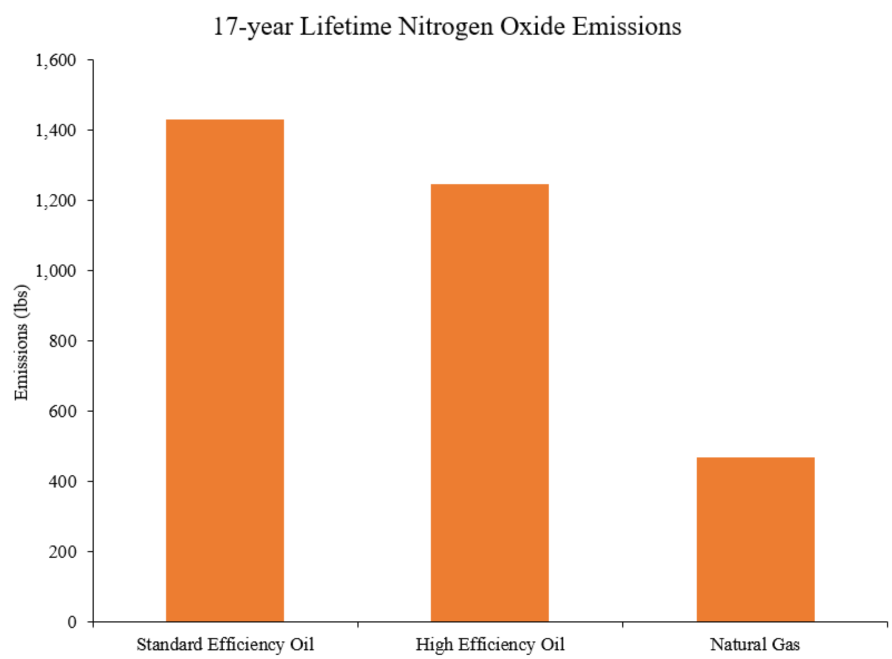


Figure 2a – Residential Customers

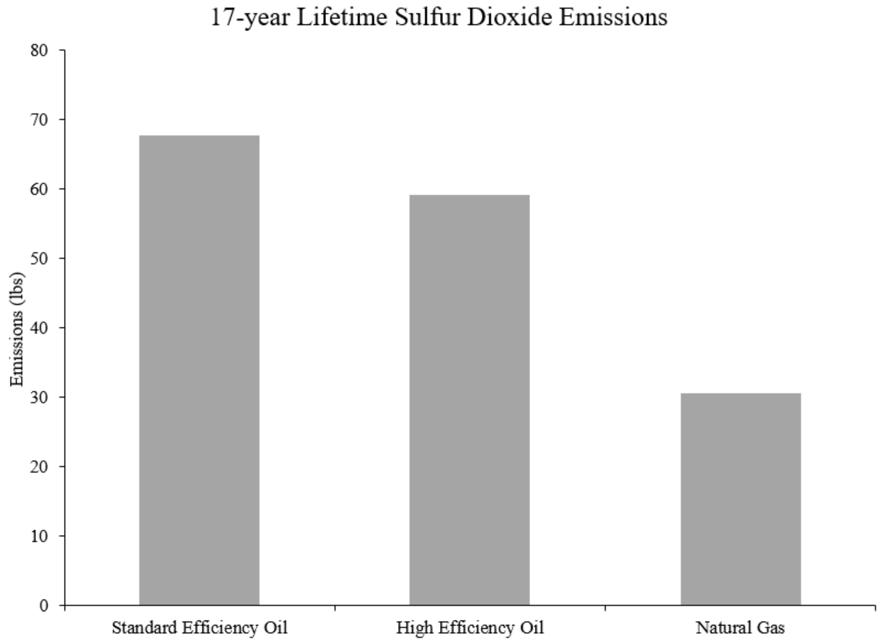


Figure 2b – C&I Customers

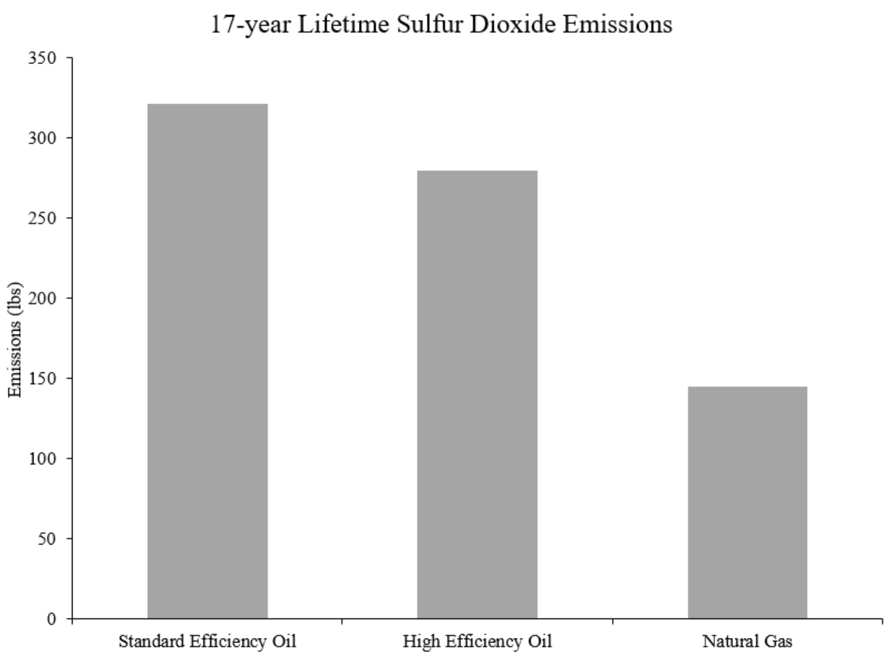


Figure 3a – Residential Customers

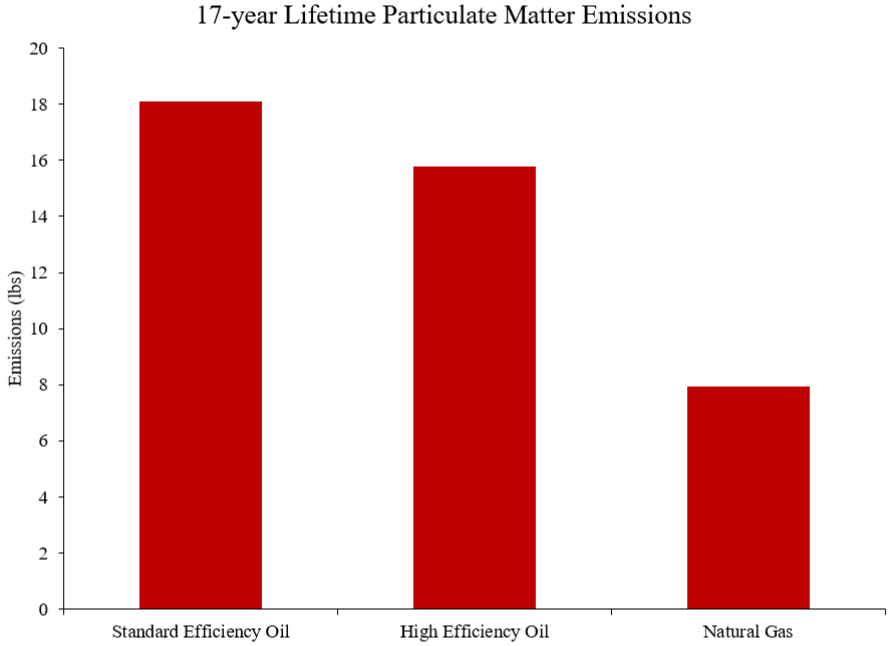


Figure 3b – C&I Customers

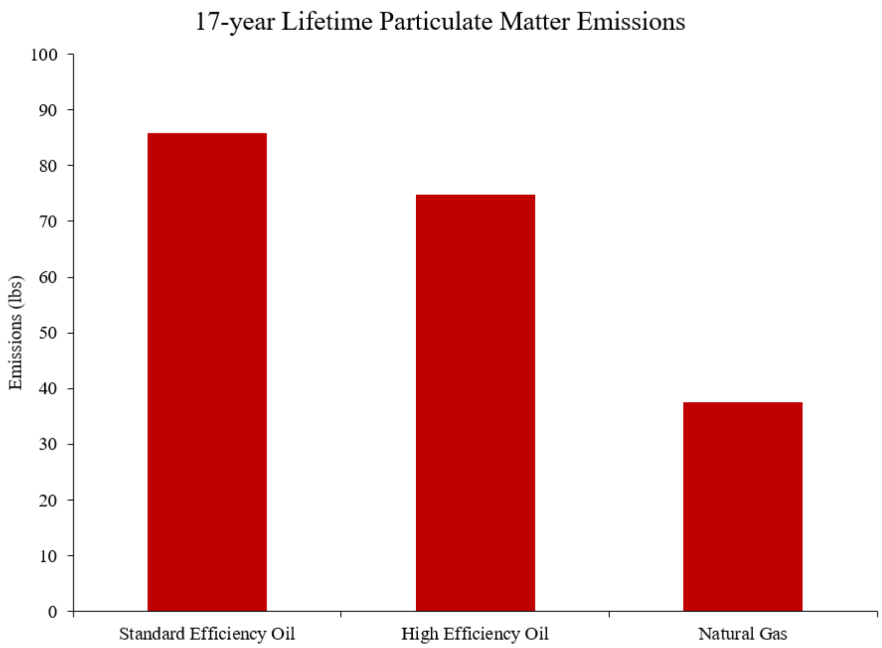


Figure 4a –Residential Customers

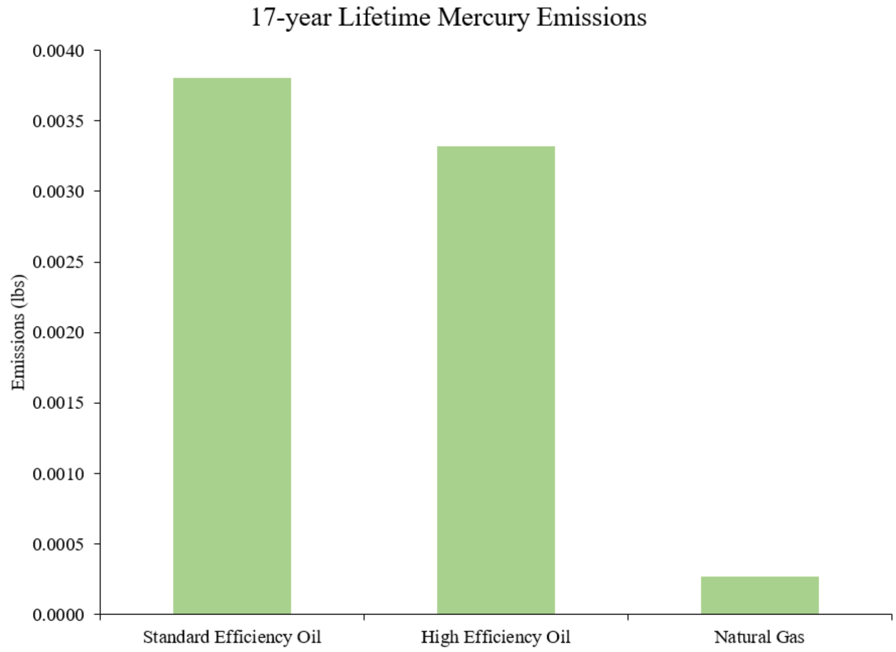


Figure 4b – C&I Customers

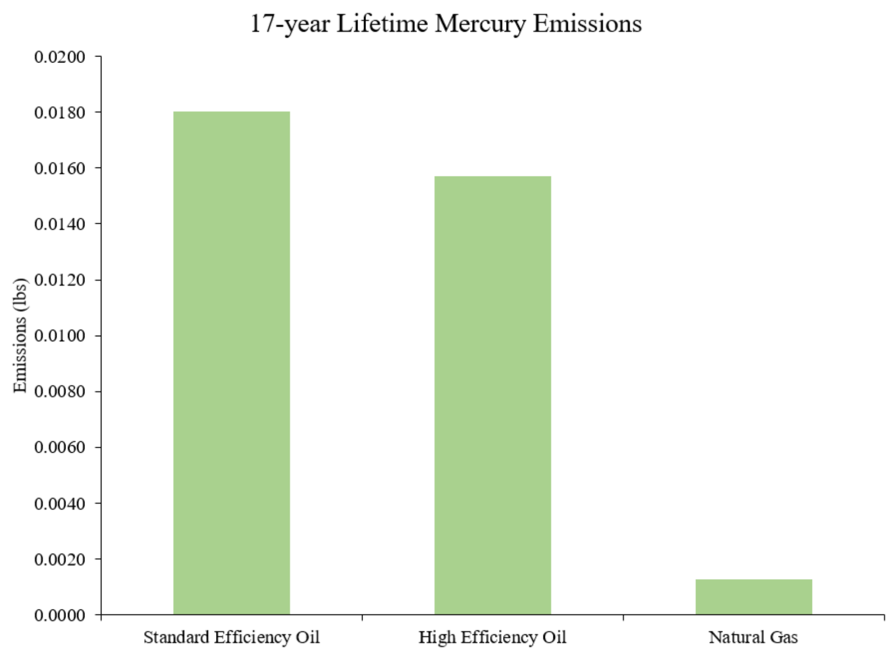


Figure 5a – Residential Customers

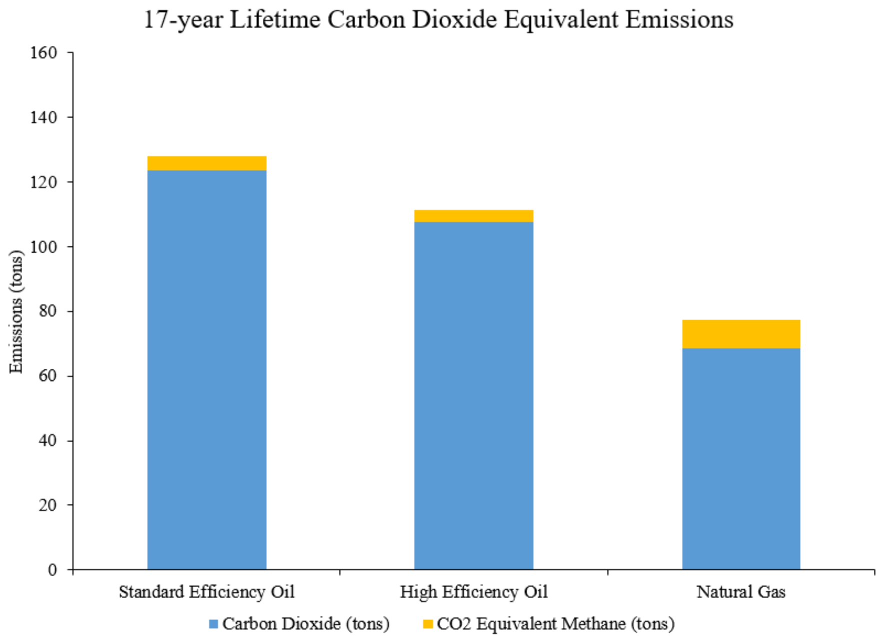
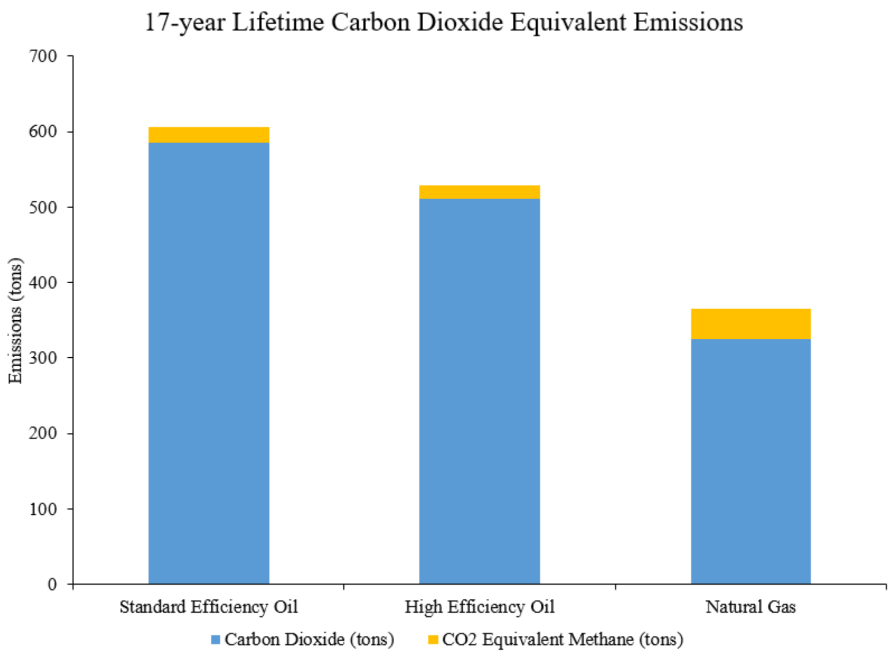


Figure 5b – C&I Customers



What are the potential health benefits?

AG modeled the potential health benefits of customers switching from standard oil heating to efficient natural gas heating in four New Hampshire counties[17] using the EPA Co-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool.[18] At a high level, the COBRA model estimates annual health impacts based on user-specified emissions changes. The model includes baseline emission levels for 2017 and projected baseline emission levels for 2025. The results below are based on the 2025 baseline data, and monetary benefits are discounted at a 3 percent[19] discount rate to 2017 dollars.

Residential health benefits: On average from 2021-2038, Liberty Utilities projects it will acquire 1,468 new residential natural gas customers per year.[20]

- In aggregate over 17 years, the residential health benefits from 1,468 customers using natural gas instead of oil for heating and hot water are:
  - $1.4 million to $3.1 million in total health benefits
  - $1.2 thousand in all respiratory hospital admits
  - 14 avoided lost work days
- The average *annual* health benefits are:
  - $80 thousand to $181 thousand in total health benefits
  - $70 in all respiratory hospital admits
  - 0.85 avoided lost work days

Commercial & Industrial health benefits: On average from 2021-2038, Liberty Utilities projects it will acquire approximately 90 new commercial & industrial natural gas customers per year.[21]

- In aggregate over 17 years, the health benefits from these customers using natural gas instead of oil for heating and hot water are:
  - $363 thousand to $819 thousand in total health benefits
  - $311 in all respiratory hospital admits
  - 3.9 avoided lost work days

[17] Belknap, Hillsborough, Merrimack, and Rockingham counties. These counties cover the path of the Granite Bridge project and Liberty Utilities' current natural gas service territory.

[18] The COBRA model is available for download here: https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-health-impacts-screening-and-mapping-tool. COBRA is a screening tool used to approximate air quality impacts and associated costs. EPA notes that COBRA requires the use of air quality, health impact, and economic variables that are uncertain, and these uncertainties should be considered when interpreting results. See EPA, User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA) Version: 3.2, available at https://www.epa.gov/statelocalenergy/users-manual-co-benefits-risk-assessment-cobra-screening-model, p. 15.

[19] If a 7% discount rate is used, the monetary health benefits vary as follows: Residential Aggregate, $1.2 million to $2.7 million in total health benefits and $1.2 thousand in all respiratory hospital admits. Residential Annual Average, $71 thousand to $161 thousand in total health benefits and $70 in all respiratory hospital admits. C&I Aggregate, $324 thousand to $731 thousand in total health benefits $311 in all respiratory hospital admits. C&I Annual Average, $19 thousand to $43 thousand in total health benefits and $18 in all respiratory hospital admits.

[20] In order to capture the impacts of customers using natural gas for heating and hot water, we assume that the alternative is to use heating oil (or a more polluting source). We model these impacts by adjusting the emissions in the oil and natural gas combustion emission tiers of COBRA. That is, annual baseline oil heating emissions for the given number of converting customers are subtracted from the residential distillate oil combustion emission tier in COBRA. Conversely, annual natural gas emissions for the same number of converting customers are added to the residential natural gas combustion emission tier in COBRA. The oil and gas emissions used are calculated as the annual average per-customer emissions over the 17 year period 2021-2038; this is multiplied by the 1,468 new residential gas customers. The calculations assume all PM emissions are $PM_{2.5}$.

[21] The COBRA model measures fuel combustion emissions for the commercial and industrial sectors separately. These results allocate 75% of Commercial & Industrial emission changes to the Commercial/Institutional emission tier in COBRA, and 25% to the Industrial emission tier in COBRA based on the division of electricity sales by sector in the 2016 EIA 861 data for New Hampshire. The COBRA commercial results are then added to the industrial results for one commercial & industrial health impact. The same methodology for capturing the conversion effect described in footnote 20 for the residential health benefits is also used for the commercial and industrial health benefits. The calculations assume all PM emissions are $PM_{2.5}$.

- The average *annual* health benefits are:
    - $21 thousand to $48 thousand in total health benefits
    - $18 in all respiratory hospital admits
    - 0.23 avoided lost work days

Technical Appendix

Analytic Method & Findings

We estimate annual emissions from using natural gas or oil for heating and hot water over a 17-year period for residential and commercial and industrial customers in the Liberty Utilities' New Hampshire service area.[22] Potential emission, health, and economic impacts stem from the lower level of emissions from using natural gas.

Our method for estimating annual emissions for each fuel involves two primary estimates. First, we estimate annual energy demand required for heating customers based on customer average consumption estimates from Liberty Utilities. Second, we estimate annual emissions of various pollutants associated with our estimated demand using emissions factors. After estimating annual emissions, we calculate total emissions as the sum across all years. We describe each step outlined above more fully below.

Annual Energy Demand: For each year and each technology option (described in the next section), we estimate energy demand in MMBtu using Eq. (1) below:

$$\text{(Energy Demand)} = \text{(Annual Load)} / \text{(Boiler Efficiency)} \qquad (1)$$

where 'Annual Load' refers to the projected annual energy required (in MMBtu) to heat either a residential or commercial and industrial space in Liberty Utilities' New Hampshire service area. AG received per customer demand projections for 2017/2018 through 2037/2038 from Liberty Utilities. AG has considered demand projections beginning in the 2021/2022 heating year, since this is approximately the proposed in service time for the Granite Bridge project. To translate these demand projections at point of end-use to Annual Load estimates, we assume the annual demand projections reflect the demand of a customer using the standard heating technology option (see Table 1 below). Based on our assumed technology efficiencies for the standard heating option, we then back out an estimate for 'Annual Load.'[23]

Air Pollutant Emissions: To estimate emissions, we apply emission factors for each considered pollutant to each technology. Discussed more fully below, we source emissions factors from the Gas Technology Institute's Source Energy and Emissions Analysis Tool (SEEAT)[24] and EPA. With the exception of particulate matter (PM) and mercury (Hg), our emission factors consider both emissions due to fuel combustion as well as emissions from upstream processing (such as extracting, processing, and transportation).

We estimate emissions in pounds using Eq. (2) below:

$$\text{(Emissions)} = \text{(Energy Demanded)} \times \text{(Emission Factor)} \qquad (2)$$

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[22] Customers that may select or switch to natural gas for heating and hot water would otherwise use an alternative fuel for this purpose - such as oil, propane, coal, wood, or electric heat pumps. In our calculations we use oil as a proxy for the heating technology that would be used other than natural gas. Oil is by far the dominant *non-gas* technology for heating in the New Hampshire counties representing the current service territory of Liberty Utilities and/or the counties crossed by the Granite Bridge project. See New Hampshire Employment Security, Economic and Labor Market Information Bureau, *New Hampshire Economic Conditions: It's Cold outside: Winter Heating in New Hampshire*, January 2013.

[23] For example, consider a hypothetical demand projection in 2018 of 100 MMBtu. If the heating technology option equals 75 percent, then the annual heating load must be 100 × 0.75 = 75 MMBtu (See Eq. (1)). Note that we implicitly assume that average annual load per customer declines over time.

[24] http://seeatcalc.gastechnology.org/.

where 'Energy Demanded' is described above in Eq. (1) and 'Emission Factor' describes the pounds of emissions per MMBtu of energy demanded at the point of end-use.

We assume that emission factors remain fixed for the 17-year analysis period.[25]

In the sections below, we describe in more detail the heating technology options and the emission factors we use to estimate emissions.

Technology Options

We consider the following three heating technologies.

1. **Standard Efficiency Oil:** heating provided by a standard oil-burning boiler.
2. **High Efficiency Oil:** heating provided by a newer, more efficient oil-burning boiler.
3. **Natural Gas:** heating provided by a higher efficiency natural gas-burning boiler.

Table 1 presents our assumptions regarding the technological efficiency associated with each heating option. We derive these efficiencies from the Massachusetts Technical Reference Manual.[26] We assume the same heating technology efficiencies for residential as well as commercial and industrial customers.

Table 1
Summary of Heating Technology Combinations and Efficiency Assumptions

Heating Option	Boiler Efficiency
Standard Efficiency Oil	0.75
High Efficiency Oil	0.86
Natural Gas	0.894

Emission Factors

The combustion of oil and natural gas for heating emits various air pollutants. Methane leaks from natural gas lines and the extraction, processing, and transportation of natural gas and oil also emit air pollutants. We consider both sources of emissions in our analysis.

For upstream emissions, we utilize the SEEAT tool's New Hampshire emission factors for NO_x, SO_2, CH_4, and CO_2. For downstream emissions, we use EPA emissions factors for NO_x, SO_2, PM, Hg, CH_4, and CO_2 (we do not consider any upstream emissions of particulate matter or mercury). Table 2 below illustrates the upstream and combustion emission factors that we consider.

[25] This implies little degradation in boiler efficiency and a relatively unchanged pollutant content of distillate oil and natural gas.
[26] Mass Save, "Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures; 2016-2018 Program Years – Plan Revision," October 2015, 436 pages).

Table 2[27]
Emission Factors for Nitrogen Oxide, Sulfur Dioxide, Particulate Matter, Mercury, Methane, and Carbon Dioxide (lb/MMBtu)

upstream	NO_x	SO_2	PM	Hg	CH_4	CO_2	Source
Oil	0.500	0.272	--	--	1.387	166.6	SEEAT
Natural Gas	0.594	0.302	--	--	6.947	127.8	SEEAT
combustion							
Oil	0.143	0.0015	0.0143	3.0E-06	0.0066	163.1	EPA
Natural Gas	0.037	0.0006	0.0075	2.5E-07	0.0022	117.0	EPA

Because of losses in the production and distribution process, every one MMBtu of natural gas combusted in a home boiler requires more than one MMBtu to have been extracted (the same idea applies to oil). A complete assessment of air pollutant emissions requires assessing the emissions due to these "upstream" losses. We assume losses in each upstream process (extraction, processing, transportation, and distribution) based on SEEAT's assessment of losses for New Hampshire. Table 3 illustrates these losses. To fix ideas, Table 3 implies that 5.1 percent (1 - 0.949) of energy is lost in the extraction of fuel oil, and that 1 percent of natural gas is lost in the distribution phase.

Table 3
Upstream Losses Assumed by SEEAT and Adopted by AG

	Extraction	Processing	Transportation	Distribution	Total
Oil	0.949	0.891	0.997	0.996	0.840
Natural Gas	0.962	0.97	0.99	0.99	0.915

Note: 'Total' is derived by taking the product across the extraction, processing, transportation, and distribution loss estimates. Note that the SEEAT tool considers residual fuel oil, while our analysis considers distillate fuel oil.

To combine the upstream and combustion emissions factors, we follow the same method as SEEAT, adding a weighted average upstream emission factor with the combustion emission factor for each pollutant.[28] We summarize this method below in Eq. (3):

[27] We consider distillate fuel oil No. 2. For NO_x, SO_2, PM and Hg, we use the EPA AP 42, Fifth Edition (Volume I, Chapter 1: External Combustion Sources), available at https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors. For distillate fuel oil, Table 1.3-1 reports a NO_x emission factor of 20 lb/10^3 gallons. Table 1.3-1 also reports an SO_2 distillate fuel oil emission factor of 142S lb/10^3 gallons, where S refers to the percent of sulfur content by weight (see Table 1.3-1 note b). We assume S = 0.0015, noting that the EIA states that "[s]ince 2006, most distillate fuel has had less than 15 parts per million (ppm) of sulfur" (see EIA, "Large reduction in distillate fuel sulfur content has only minor effect on energy content," February 24, 2015, available at: https://www.eia.gov/todayinenergy/detail.php?id=20092; see also Vermont Dept. of Environmental Conservation, "Sulfur Content in Heating Oil – Fact Sheet," which indicates that 15ppm equals 0.0015 percent by weight). Table 1.3-1 finally reports a filterable PM emission factor for distillate fuel oil of 2 lb/10^3 gallons. To convert to lb/MMBtu, we divide by 140 MMBtu/10^3 gallons (see AP 42, at p. 1.3-8). Finally, Table 1.3-10 reports an Hg emission factor for distillate oil of 3 lb/10^{12} Btu. To convert to lb/MMBtu, we divide by 10^6. For natural gas, Table 1.4-1 reports a NOx emission factor of 50 lb/10^6 scf. Table 1.4-2 reports a SO_2 emission factor for natural gas of 0.6 lb/10^6 scf. Table 1.4-2 also reports a total PM emission factor for natural gas of 7.6 lb/10^6 scf. Finally, Table 1.4-4 reports total PM emission factor for natural gas of 2.6e-4 lb/10^6 scf. To convert to lb/MMbtu, we divide by 1020 Btu/scf (see AP 42, at section 1.4.1). For methane and carbon dioxide, we use EPA's Emission Factors for Greenhouse Gas Inventories, March 9, 2018 update (available at: https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf). EPA reports No. 2 oil's CH_4's emission factor as 3.0 g / MMBtu and CO_2's emission factor as 73.96 kg / MMBtu. EPA reports natural gas's CH_4's emission factor as 1.0 g / MMBtu and CO_2's emission factor as 53.06 kg / MMBtu. To convert to lb / MMBtu, we multiply by 0.002205 (for CH_4) and 2.205 (for CO_2), since 2.205 pounds equals 1 kilogram.

[28] See Gas Technology Institute, Full-Fuel-Cycle Energy and Emission Factors for Building Energy Consumption – 2013 Update, at p. A-6 - A-7.

$$\text{(Composite Emission Factor)} = \text{(Weighted Upstream Emission Factor)} + \text{(Combustion Emission Factor)} \qquad (3a)$$

$$\text{(Weighted Upstream Emission Factor)} = \text{(Upstream Emission Factor)} \times (1 - \text{'Total'}) / (\text{'Total'}) \qquad (3b)$$

where ‘Total’ refers to the product of the loss estimates for extraction, processing, transportation, and distribution shown in Table 3.

Table 4 below presents our resulting composite emission factors for NO_x, SO_2, PM, Hg, CH_4, and CO_2.

Table 4
Composite Emission Factors (lb/MMBtu)

	NO_x	SO_2	PM	Hg	CH_4	CO_2
Oil	0.238	0.053	0.0143	3.0E-06	0.271	194.87
Natural Gas	0.093	0.029	0.0075	2.5E-07	0.651	128.91

Note: The emission factor for PM and Hg reflects combustion only. Furthermore, for oil, the combustion factor for PM reflects filterable PM only.