APPENDIX W. EMISSIONS FACTORS FOR FUEL COMBUSTION FROM NATURAL GAS, LPG, AND OIL-FIRED RESIDENTIAL FURNACES AND BOILERS

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W.1 OVERVIEW

The modified version of the National Energy Modeling System (NEMS) used for the furnace and boiler energy-efficiency standards analysis, called NEMS-BT, comprehensively considers a wide range of aspects of energy use. However, this model does not consider household emissions of NO_x and SO_2 from the combustion of natural gas, residential heating fuel oil #2 (i.e., high-sulfur distillate fuel oil), and LPG. Because an efficiency standard could result in changes in these emissions, the Department has performed some elementary research to determine appropriate emissions factors for CO_2, NO_x, and SO_2 from household appliances. Specifically, this work focuses on emissions rates from the use of furnace and boilers and is used to calculate emissions savings from proposed efficiency standards. Because a majority of the savings from this standard are from furnaces, emissions factors for furnaces are presented over small-scale boilers whenever both are available.

This analysis attempts to verify that the emissions factors from the U.S. Environmental Protection Agency (EPA) for CO_2, NO_x, and SO_2 from natural gas, fuel oil #2, and LPG combustion are representative of the U.S.[1] The EPA cautions against the use of these emissions factors as representative of actual emissions. Rather, they are to be used, and are used here, as general approximations of national average emissions factors in order to calculate emissions savings that result from proposed furnace and boiler energy-efficiency standards. This analysis compares the EPA's emissions factors with those from other sources and with regional regulations.

Table W.1.1 summarizes the emissions factor estimates for the three fuels of interest. The values presented here are based on the EPA's assessment of combustion emissions (with the exception of SO_2 from LPG, see discussion below). These emissions estimates represent an approximate emissions factor for the U.S. as a whole. They are used, together with estimated energy savings, to calculate end-use site emissions savings. The emissions factors discussed in this analysis are represented as mass (g or kg) of the specific emission of interest per gigajoule (GJ) of energy input to the furnace and boiler.[*]

[*] 0.454 kg = 1 lb; 1.055 GJ = 1 MBtu

Table W.1.1 Estimated National Average Emissions Factors for Household Fuel Combustion of Natural Gas, Fuel Oil #2, and LPG

	CO_2 (kg/GJ)	NO_x (g/GJ)	SO_2 (g/GJ)
Natural Gas	50.6	40	0
Fuel Oil #2	68.6	55	218
LPG	58.7	66	7

There are significant differences in state regulations, making it difficult to generalize about localized emissions. For residential fuel oil combustion, stricter state standards exist in the northeastern United States and southern California than elsewhere. State and local agencies like southern California's South Coast Air Quality Management District (SCAQMD)[2], the New Jersey Department of Environmental Protection, and the New York Department of Environmental Conservation have established regulations for residential fuel combustion emissions. These regulations, however, are local to individual counties and do not apply to all regions in the Northeast or even all of California.

W.2 EMISSIONS FACTORS BY FUEL TYPE

W.2.1 All Fuels: Carbon Dioxide

NEMS-BT tracks CO_2 well, but factors are included here for completeness. The CO_2 estimates in Table W.1.1 are based on EPA's assessment of CO_2 combustion from natural gas, fuel oil #2, and LPG use. Other sources of information include the U.S. DOE's Energy Information Administration (EIA), Oregon State EPA, and the Gas Research Institute (GRI). All agree to within ± 2.0 percent of EPA's assessed estimate of CO_2 emissions. EPA's CO_2 emissions factors for natural gas, fuel oil #2, and LPG combustion are therefore a reasonable evaluation of nationally averaged CO_2 emissions rates.

Carbon monoxide (CO) can be formed by incomplete carbon oxidization, causing a severe health hazard. Carbon monoxide emissions only result from poorly functioning appliances, and since NEMS-BT assumes that all furnaces and boilers are functioning properly, it is unlikely that these emissions will change.

W.2.2 Natural Gas

W.2.1.1 Oxides of Nitrogen

Emissions of NO_x that result from the combustion of natural gas from appliances are also covered by regulations in some jurisdictions. The EPA's estimated NO_x emissions factor of 40 g/GJ from gas-fired furnaces is roughly equivalent to the regulation set by the state of New York. The SCAQMD limits NO_x emissions to 40 g/GW from gas-fired residential furnaces, equivalent to EPA's AP-42 estimate. The San Luis Obispo Air Pollution Control District also mandates the same NO_x limit from furnaces. The SCAQMD also provided performance test results from numerous commercially available residential gas furnaces. In general, the emissions rates ranged from 35-40 g/GJ NO_x with some higher efficiency units emitting between 26-35 g/GJ NO_x. New Jersey's state regulation mandates no more than 43 g/GJ NO_x emissions from natural gas combustion in small boilers and furnaces. The absence of regulations in other states suggests that most have emissions rates comparable to the EPA's estimated value.

W.2.1.2 Sulfur Dioxide

SO_2 emissions from natural gas combustion are assumed to be zero.

W.2.3 Fuel Oil #2

W.2.3.1 Oxides of Nitrogen

NO_x formation in combustion processes is significantly more complex than the formation of SO_2 or CO_2. NO_x can result from oxidization of N_2 in the fuel, but the larger source is N_2 in the combustion intake. This process is sensitive to combustion chemistry, and therefore, quite variable. It also implies that appliance design can lower NO_x emissions. An added difficulty is that the potential hazard of residential NO_x emissions is hard to quantify. NO_x is both an acid precipitation and ozone (O_3) precursor, but because residential appliances are a relatively small and dispersed (i.e., hard to monitor) source, these emissions tend to play a small role in NO_x control strategies. The O_3 hazards of NO_x emissions are highly variable both spatially and over time, as weather conditions favor or disfavor O_3 formation. One would, therefore, expect NO_x emissions rules to vary significantly across jurisdictions.

The value estimated by EPA of 55 g of NO_x/GJ is for residential oil-fired furnaces. Additional research into specific state regulations reveals good matches with EPA's emissions factor: New Hampshire limits NO_x emissions to 60 g/GJ for non-utility boilers and New York and New Jersey regulations cap emissions at 52 g of NO_x/GJ. These state limits confirm that EPA's estimate can serve as a reasonable national average.

W.2.3.2 Sulfur Dioxide

Emissions of SO_2 are a direct function of the sulfur content of the fuel. Assuming complete combustion of sulfur to SO_2 makes it easy to assess and compare emissions across data sources. Individual state and county regulations limiting the amount of sulfur in residential fuel oil, however, reveal substantial variability in SO_2 emissions factors from EPA's estimate of 218g of SO_2/GJ of fuel energy content for both residential furnaces and boilers. This is roughly equivalent to 0.5 percent sulfur content by weight using an emissions factor for fuel oil #2 of 43,950 g/GJ weight per unit energy content. A straight multiplication of the fuel energy content and the percentage of sulfur content in the fuel provide the emissions factor.

In the state of New York, SO_2 emissions limits range from 88-659 g/GJ depending on the county. In New Hampshire, the emissions rate of SO_2 from high-sulfur distillate fuel oil combustion cannot exceed 176 g/GJ. In Maine and Michigan, the regulations are higher than EPA's assessment, limiting SO_2 emissions from fuel oil to 500 g of SO_2/GJ of heat input. Such broad ranges and varying limits in certain regions are a strong argument for using EPA's averaged national value over a regionally weighted average incorporating the various state and county regulations.

Comparing the sulfur content of fuel oil from different refineries also demonstrates regional variability. Most sources were obtained through online websites detailing product specifications. Mobil Corporation's residential heating fuel oil (#2 high-sulfur) for most states contains a maximum 0.5% sulfur by mass (219 g of SO_2/GJ of heat input), which is very close to EPA's emissions factor. Mobil also markets fuel with lower sulfur content to some regions in the Northeast. For example, Mobil's lowest sulfur content residential heating fuel oil contains 0.2 percent sulfur by weight (88 g/GJ), as required in New York City, Philadelphia, parts of Delaware, and most of New Jersey. Other regional regulations adhered to by Mobil are 132 g/GJ for most of Pennsylvania and parts of New Jersey, a limit of 127 g of SO_2/GJ of heat input for the state of Illinois, and an SO_2 emissions factor of 145 g/GJ in Massachusetts. The sulfur contents of distillate fuel oil from Chevron, Phillips 66, and the American Society for Testing and Materials (ASTM) exactly match EPA's estimate, substantiating the use of the latter for the analysis. Considerable variation does exist among counties and states, especially in the Northeast. Nonetheless, EPA provides a reasonable estimate of emissions from residential oil-fired furnaces and boilers that are representative of the national average.

W.2.4 LPG

W.2.4.1 Oxides of Nitrogen

Although NES results are presented for LPG, EPA estimates emissions for only propane and butane, fuels within the LPG family of gases. In the United States, the composition of LPG is typically 90 percent propane (C_3H_8) by liquid volume, 5 percent propylene (C_3H_6), and 2.5 percent butane (C_4H_{10}).[3,4] This analysis uses EPA's propane emissions estimate to verify its comparability with LPG combustion or determines a more suitable estimate from other sources that best represents LPG emissions rates.

EPA estimates an emissions factor of 66 g of NO_x/GJ of energy input from propane-fired furnaces and boilers, which is slightly higher than the natural gas estimate. The University of New Hampshire's Energy Office estimates an emissions factor of 43 g/GJ from LPG combustion for the state of New Hampshire. In contrast, the state of New Jersey's EPA establishes an 86 g/GJ emissions factor. Both sources, therefore, support EPA's national assessment of NO_x emissions from residential propane combustion.

W.2.4.2 Sulfur Dioxide

The sulfur content of LPG is very low[5], although a few regulations exist in certain parts of the country. EPA's SO_2 emissions estimate is derived from the sulfur content of the propane fuel. With 90% of LPG comprised of propane, the EPA's propane emissions factor is a reasonable value for LPG emissions rates. Under the New Hampshire Department of Environmental Services (DES) regulation, the maximum sulfur content allowable is 13.3 g/GJ of SO_2 from LPG combustion. The San Diego County Air Pollution Control District enforces a stricter limit of only 8.8 g of SO_2/GJ of energy input using EPA's recommended value. Both the ASTM and Santa Barbara County Air Pollution Control District specify a sulfur standard of 0.0185 percent sulfur by weight, which approximates an emissions factor of 4.0 g of SO_2/GJ of energy input. This calculation is based on an LPG weight per unit energy of 21,756 g/GJ. Even lower, Nett Technologies Inc. estimates a 0.012 percent sulfur content by mass LPG average for the United States as well as Canada, which is approximately 2.6 g of SO_2/GJ of heat input.

The wide range of emissions factors for SO_2 makes it difficult to determine a representative estimate for the emissions factor and the very small net effect of any energy-efficiency standard argue against making a significant research effort. The obtained estimates range in magnitude from approximately 4 to 13 g/GJ of energy input. The statistical average or arithmetic mean of these four estimates is 7.2 g/GJ, the value provided in Table W.1.1. The averaged emissions factor estimate of 7.2 g/GJ energy input is reasonable to explain three of the five sources presented and suitably accounts for the average among the two extreme estimates. Table W.1.1 therefore adequately represents national SO_2 emissions from residential LPG combustion.

W.3 SUMMARY

This investigation of emissions factors from natural gas-, fuel oil-, and LPG-fired residential furnaces and boilers indicates that using the values estimated by EPA's AP-42 is a robust and credible basis for analysis with NES output. This analysis indicates that regulations at the state and county level, especially in the northeastern region of the United States, are generally not good estimators of the national average set forth by the EPA AP-42 report. This is especially true for SO_2

emissions factors from fuel oil combustion where individual state and county regulations are highly variable. Thus, although it is worthwhile examining regional legislation to support the national average, this analysis demonstrates the complexity that would be required to establish a weighted regional calculation for each emission. The EPA's own lack of data on the sulfur content of LPG made it difficult to derive a nationally representative emissions factor for the country as a whole. External sources were therefore incorporated in the Table W.1.1 estimate for SO_2 emissions from LPG combustion.

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