

AP-42 emissions data for fuels when utilized in equipment commonly found in Vermont. September, 2005.**No. 2 Fuel Oil****AP-42, Sec. 1.3**

"To convert to an energy basis (lb/MMBtu), divide by a heating value of ... 140 MMBtu/10³gal for No. 2 and distillate fuel oil."

To convert MMBtu to BBtu, multiply by 1,000

"S indicates ... if the fuel is 1% sulfur, then S = 1." In Vt., consider 0.5% fuel oil.

		Residential Furnace								
Table		1.3-12	1.3-1	1.3-1	1.3-1	1.3-3	1.3-3	1.3-1	1.3-2	sum
		CO2	CO	NOx	SO2	VOC ["NMTOC"]	TOC	Filterable PM	Condensable PM	Total PM
	lb/10 ³ gal	22,300	5	18	142	0.713	2,493	0.4	1.3	1.7
x	0.5	sulfur % in fuel			71					
/	140	= lb/MMBtu	159.2857	0.036	0.129	0.5071	0.005	0.018		0.012
x	1,000	= lb/BBtu	159,285.7	35.7	128.6	507.1	5.1	17.8		12.1

		Boilers <100 Million Btu/hr								
Table		1.3-12	1.3-1	1.3-1	1.3-1	1.3-3	1.3-3	1.3-1	1.3-2	sum
		CO2	CO	NOx	SO2	VOC ["NMTOC"]	TOC	Filterable PM	Condensable PM	Total PM
	lb/10 ³ gal	22,300	5	20	142	0.34	0.556	2	1.3	3.3
x	0.5	sulfur % in fuel			71					
/	140	= lb/MMBtu	159.2857	0.036	0.143	0.5071	0.002	0.004		0.024
x	1,000	= lb/BBtu	159,285.7	35.7	142.9	507.1	2.4	4.0		23.6

Natural Gas**AP-42, Sec. 1.4**

"To convert to an energy basis (lb/MMBtu), divide by a heating value of 1,020 MMBtu/10⁶ scf."

To convert MMBtu to BBtu, multiply by 1,000 scf = standard cubic foot.

		Residential Furnaces, uncontrolled								
Table		1.4-2	1.4-1	1.4-1	1.4-2	1.4-2	1.4-2	Filterable PM	Condensable PM	1.4-2 Total PM
		CO2	CO	NOx	SO2	VOC	TOC			
	lb/10 ⁶ scf	120,000	40	94	0.6	5.5	11			7.6
/	1,020	= lb/MMBtu	117.647	0.039	0.092	0.001	0.005	0.011		0.007
x	1,000	= lb/BBtu	117,647.1	39.2	92.2	0.6	5.4	10.8		7.5

Small Boilers, Uncontrolled

Table		1.4-2	1.4-1	1.4-1	1.4-2	1.4-2	1.4-2	Filterable PM	Condensible PM	1.4-2 Total PM
		CO2	CO	NOx	SO2	VOC	TOC			
	lb/10 ⁶ scf	120,000	84	100	0.6	5.5	11			7.6
/	1,020 =	lb/MMBtu	117.647	0.082	0.098	0.001	0.005	0.011		0.007
x	1,000 =	lb/BBtu	117,647.1	82.4	98.0	0.6	5.4	10.8		7.5

Residential Wood Stoves

AP-42, Sec. 1.10

Emissions factors for a Phase II Noncatalytic Residential Wood Stove, as reported to be typical in Vermont homes by the Vt. Agency of Natural Resources.

"To convert to an energy basis (lb/MMBtu), divide by a heating value of 17.3 MMBtu/ton."

"CO2 emitted from this source may not increase total atmospheric CO2 because the emissions may be offset by the uptake of CO2 by regrowing biomass."

Table		1.6-3	1.10-1	1.10-1	1.10-1	1.10-1	1.10-1	Filterable PM	Condensible PM	1.10-1 Total PM
		CO2	CO	NOx	SO2	VOC ["TNMOC"]	TOC			
	lb/ton		140.8	2	0.4	12	28			14.6
/	17.3 =	lb/MMBtu	195	8.139	0.116	0.694	1.618			0.844
x	1,000 =	lb/BBtu	195,000.0	8,138.7	115.6	693.6	1,618.5			843.9

Wood Residue Combustion in Boilers

Factors in tables presented as lb/MMBtu.

To convert MMBtu to BBtu, multiply by 1,000

"V" indicates information from actual emissions testing of typical gasifier in Vermont as supplied by equipment manufacturer to Vt. ANR.

Table		1.6-3	V	V	1.6-2	1.6-3	1.6-3	Filterable PM	Condensible PM	V Total PM
		CO2	CO	NOx	SO2	VOC	TOC			
	lb/MMBtu	195	0.300	0.300	0.025	0.017	0.039			0.300
x	1,000 =	lb/BBtu	195,000.0	300.0	25.0	17.0	39.0			300.0

Table 1.4-1. EMISSION FACTORS FOR NITROGEN OXIDES (NO_x) AND CARBON MONOXIDE (CO) FROM NATURAL GAS COMBUSTION^a

Combustor Type (MMBtu/hr Heat Input) [SCC]	NO _x ^b		CO	
	Emission Factor (lb/10 ⁶ scf)	Emission Factor Rating	Emission Factor (lb/10 ⁶ scf)	Emission Factor Rating
Large Wall-Fired Boilers (>100) [1-01-006-01, 1-02-006-01, 1-03-006-01]				
Uncontrolled (Pre-NSPS) ^c	280	A	84	B
Uncontrolled (Post-NSPS) ^c	190	A	84	B
Controlled - Low NO _x burners	140	A	84	B
Controlled - Flue gas recirculation	100	D	84	B
Small Boilers (<100) [1-01-006-02, 1-02-006-02, 1-03-006-02, 1-03-006-03]				
Uncontrolled	100	B	84	B
Controlled - Low NO _x burners	50	D	84	B
Controlled - Low NO _x burners/Flue gas recirculation	32	C	84	B
Tangential-Fired Boilers (All Sizes) [1-01-006-04]				
Uncontrolled	170	A	24	C
Controlled - Flue gas recirculation	76	D	98	D
Residential Furnaces (<0.3) [No SCC]				
Uncontrolled	94	B	40	B

^a Reference 11. Units are in pounds of pollutant per million standard cubic feet of natural gas fired. To convert from lb/10⁶ scf to kg/10⁶ m³, multiply by 16. Emission factors are based on an average natural gas higher heating value of 1,020 Btu/scf. To convert from lb/10⁶ scf to lb/MMBtu, divide by 1,020. The emission factors in this table may be converted to other natural gas heating values by multiplying the given emission factor by the ratio of the specified heating value to this average heating value. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Expressed as NO_x. For large and small wall fired boilers with SNCR control, apply a 24 percent reduction to the appropriate NO_x emission factor. For tangential-fired boilers with SNCR control, apply a 13 percent reduction to the appropriate NO_x emission factor.

^c NSPS=New Source Performance Standard as defined in 40 CFR 60 Subparts D and Db. Post-NSPS units are boilers with greater than 250 MMBtu/hr of heat input that commenced construction modification, or reconstruction after August 17, 1971, and units with heat input capacities between 100 and 250 MMBtu/hr that commenced construction modification, or reconstruction after June 19, 1984.

TABLE 1.4-2. EMISSION FACTORS FOR CRITERIA POLLUTANTS AND GREENHOUSE GASES FROM NATURAL GAS COMBUSTION^a

Pollutant	Emission Factor (lb/10 ⁶ scf)	Emission Factor Rating
CO ₂ ^b	120,000	A
Lead	0.0005	D
N ₂ O (Uncontrolled)	2.2	E
N ₂ O (Controlled-low-NO _x burner)	0.64	E
PM (Total) ^c	7.6	D
PM (Condensable) ^c	5.7	D
PM (Filterable) ^c	1.9	B
SO ₂ ^d	0.6	A
TOC	11	B
Methane	2.3	B
VOC	5.5	C

^a Reference 11. Units are in pounds of pollutant per million standard cubic feet of natural gas fired. Data are for all natural gas combustion sources. To convert from lb/10⁶ scf to kg/10⁶ m³, multiply by 16. To convert from lb/10⁶ scf to lb/MMBtu, divide by 1,020. The emission factors in this table may be converted to other natural gas heating values by multiplying the given emission factor by the ratio of the specified heating value to this average heating value. TOC = Total Organic Compounds. VOC = Volatile Organic Compounds.

^b Based on approximately 100% conversion of fuel carbon to CO₂. $CO_2[\text{lb}/10^6 \text{ scf}] = (3.67) (\text{CON}) (\text{C})(\text{D})$, where CON = fractional conversion of fuel carbon to CO₂, C = carbon content of fuel by weight (0.76), and D = density of fuel, 4.2x10⁴ lb/10⁶ scf.

^c All PM (total, condensable, and filterable) is assumed to be less than 1.0 micrometer in diameter. Therefore, the PM emission factors presented here may be used to estimate PM₁₀, PM_{2.5} or PM₁ emissions. Total PM is the sum of the filterable PM and condensable PM. Condensable PM is the particulate matter collected using EPA Method 202 (or equivalent). Filterable PM is the particulate matter collected on, or prior to, the filter of an EPA Method 5 (or equivalent) sampling train.

^d Based on 100% conversion of fuel sulfur to SO₂. Assumes sulfur content is natural gas of 2,000 grains/10⁶ scf. The SO₂ emission factor in this table can be converted to other natural gas sulfur contents by multiplying the SO₂ emission factor by the ratio of the site-specific sulfur content (grains/10⁶ scf) to 2,000 grains/10⁶ scf.

Table 1.3-12. DEFAULT CO₂ EMISSION FACTORS FOR LIQUID FUELS^a

EMISSION FACTOR RATING: B

Fuel Type	%C ^b	Density ^c (lb/gal)	Emission Factor (lb/10 ³ gal)
No. 1 (kerosene)	86.25	6.88	21,500
No. 2	87.25	7.05	22,300
Low Sulfur No. 6	87.26	7.88	25,000
High Sulfur No. 6	85.14	7.88	24,400

^a Based on 99% conversion of fuel carbon content to CO₂. To convert from lb/gal to gram/cm³, multiply by 0.12. To convert from lb/10³ gal to kg/m³, multiply by 0.12.

^b Based on an average of fuel carbon contents given in references 73-74.

^c References 73, 75.

Table 1.3-1. (cont.)

Firing Configuration (SCC) ^a	SO ₂ ^b		SO ₃ ^c		NO _x ^d		CO ^e		Filterable PM ^f	
	Emission Factor (lb/10 ³ gal)	EMISSION FACTOR RATING	Emission Factor (lb/10 ³ gal)	EMISSION FACTOR RATING	Emission Factor (lb/10 ³ gal)	EMISSION FACTOR RATING	Emission Factor (lb/10 ³ gal)	EMISSION FACTOR RATING	Emission Factor (lb/10 ³ gal)	EMISSION FACTOR RATING
Boilers < 100 Million Btu/hr										
No. 6 oil fired (1-02-004-02/03) (1-03-004-02/03)	157S	A	2S	A	55	A	5	A	9.19(S)+3.22 ⁱ	B
No. 5 oil fired (1-03-004-04)	157S	A	2S	A	55	A	5	A	10 ⁱ	A
No. 4 oil fired (1-03-005-04)	150S	A	2S	A	20	A	5	A	7	B
Distillate oil fired (1-02-005-02/03) (1-03-005-02/03)	142S	A	2S	A	20	A	5	A	2	A
Residential furnace (A2104004/A2104011)	142S	A	2S	A	18	A	5	A	0.4 ^g	B

- a To convert from lb/103 gal to kg/103 L, multiply by 0.120. SCC = Source Classification Code.
- b References 1-2,6-9,14,56-60. S indicates that the weight % of sulfur in the oil should be multiplied by the value given. For example, if the fuel is 1% sulfur, then S = 1.
- c References 1-2,6-8,16,57-60. S indicates that the weight % of sulfur in the oil should be multiplied by the value given. For example, if the fuel is 1% sulfur, then S = 1.
- d References 6-7,15,19,22,56-62. Expressed as NO₂. Test results indicate that at least 95% by weight of NO_x is NO for all boiler types except residential furnaces, where about 75% is NO. For utility vertical fired boilers use 105 lb/103 gal at full load and normal (>15%) excess air. Nitrogen oxides emissions from residual oil combustion in industrial and commercial boilers are related to fuel nitrogen content, estimated by the following empirical relationship: lb NO₂ /103 gal = 20.54 + 104.39(N), where N is the weight % of nitrogen in the oil. For example, if the fuel is 1% nitrogen, then N = 1.
- e References 6-8,14,17-19,56-61. CO emissions may increase by factors of 10 to 100 if the unit is improperly operated or not well maintained.
- f References 6-8,10,13-15,56-60,62-63. Filterable PM is that particulate collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. Particulate emission factors for residual oil combustion are, on average, a function of fuel oil sulfur content where S is the weight % of sulfur in oil. For example, if fuel oil is 1% sulfur, then S = 1.
- g Based on data from new burner designs. Pre-1970's burner designs may emit filterable PM as high as 3.0 lb/103 gal.
- h The SO₂ emission factor for both no. 2 oil fired and for no. 2 oil fired with LNB/FGR, is 142S, not 157S. Errata dated April 28, 2000. Section corrected May 2010.
- i The PM factors for No.6 and No. 5 fuel were reversed. Errata dated April 28, 2000. Section corrected May 2010.

Table 1.3-3. EMISSION FACTORS FOR TOTAL ORGANIC COMPOUNDS (TOC), METHANE, AND NONMETHANE TOC (NMTOC) FROM UNCONTROLLED FUEL OIL COMBUSTION^a

EMISSION FACTOR RATING: A

Firing Configuration (SCC)	TOC ^b Emission Factor (lb/10 ³ gal)	Methane ^b Emission Factor (lb/10 ³ gal)	NMTOC ^b Emission Factor (lb/10 ³ gal)
Utility boilers			
No. 6 oil fired, normal firing (1-01-004-01)	1.04	0.28	0.76
No. 6 oil fired, tangential firing (1-01-004-04)	1.04	0.28	0.76
No. 5 oil fired, normal firing (1-01-004-05)	1.04	0.28	0.76
No. 5 oil fired, tangential firing (1-01-004-06)	1.04	0.28	0.76
No. 4 oil fired, normal firing (1-01-005-04)	1.04	0.28	0.76
No. 4 oil fired, tangential firing (1-01-005-05)	1.04	0.28	0.76
Industrial boilers			
No. 6 oil fired (1-02-004-01/02/03)	1.28	1.00	0.28
No. 5 oil fired (1-02-004-04)	1.28	1.00	0.28
Distillate oil fired (1-02-005-01/02/03)	0.252	0.052	0.2
No. 4 oil fired (1-02-005-04)	0.252	0.052	0.2
Commercial/institutional/residential combustors			
No. 6 oil fired (1-03-004-01/02/03)	1.605	0.475	1.13
No. 5 oil fired (1-03-004-04)	1.605	0.475	1.13
Distillate oil fired (1-03-005-01/02/03)	0.556	0.216	0.34
No. 4 oil fired (1-03-005-04)	0.556	0.216	0.34
Residential furnace (A2104004/A2104011)	2.493	1.78	0.713

a To convert from lb/103 gal to kg/103 L, multiply by 0.12. SCC = Source Classification Code.

b References 29-32. Volatile organic compound emissions can increase by several orders of magnitude if the boiler is improperly operated or is not well maintained.

Table 1.5-1. EMISSION FACTORS FOR LPG COMBUSTION^a

EMISSION FACTOR RATING: E

Pollutant	Butane Emission Factor (lb/10 ³ gal)		Propane Emission Factor (lb/10 ³ gal)	
	Industrial Boilers ^b (SCC 1-02-010-01)	Commercial Boilers ^c (SCC 1-03-010-01)	Industrial Boilers ^b (SCC 1-02-010-02)	Commercial Boilers ^c (SCC 1-03-010-02)
PM, Filterable ^d	0.2	0.2	0.2	0.2
PM, Condensable	0.6	0.6	0.5	0.5
PM, Total	0.8	0.8	0.7	0.7
SO ₂ ^e	0.09S	0.09S	0.10S	0.10S
NO _x ^f	15	15	13	13
N ₂ O ^g	0.9	0.9	0.9	0.9
CO ₂ ^{h,j}	14,300	14,300	12,500	12,500
CO	8.4	8.4	7.5	7.5
TOC	1.1	1.1	1.0	1.0
CH ₄ ^k	0.2	0.2	0.2	0.2

^a Assumes PM, CO, and TOC emissions are the same, on a heat input basis, as for natural gas combustion. Use heat contents of 91.5 x 10⁶ Btu/10³ gallon for propane, 102 x 10⁶ Btu/10³ gallon for butane, 1020 x 10⁶ Btu/10⁶ scf for methane when calculating an equivalent heat input basis. For example, the equation for converting from methane's emissions factors to propane's emissions factors is as follows: lb pollutant/10³ gallons of propane = (lb pollutant /10⁶ ft³ methane) * (91.5 x 10⁶ Btu/10³ gallons of propane) / (1020 x 10⁶ Btu/10⁶ scf of methane). The NO_x emission factors have been multiplied by a correction factor of 1.5, which is the approximate ratio of propane/butane NO_x emissions to natural gas NO_x emissions. To convert from lb/10³ gal to kg/10³ L, multiply by 0.12. SCC = Source Classification Code.

^b Heat input capacities generally between 10 and 100 million Btu/hour.

^c Heat input capacities generally between 0.3 and 10 million Btu/hour.

^d Filterable particulate matter (PM) is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. For natural gas, a fuel with similar combustion characteristics, all PM is less than 10 μm in aerodynamic equivalent diameter (PM-10).

^e S equals the sulfur content expressed in gr/100 ft³ gas vapor. For example, if the butane sulfur content is 0.18 gr/100 ft³, the emission factor would be (0.09 x 0.18) = 0.016 lb of SO₂/10³ gal butane burned.

^f Expressed as NO₂.

^g Reference 12.

^h Assuming 99.5% conversion of fuel carbon to CO₂.

^j EMISSION FACTOR RATING = C.

^k Reference 13.

1.5 Liquefied Petroleum Gas Combustion

1.5.1 General¹

Liquefied petroleum gas (LPG or LP-gas) consists of propane, propylene, butane, and butylenes; the product used for domestic heating is composed primarily of propane. This gas, obtained mostly from gas wells (but also, to a lesser extent, as a refinery by-product) is stored as a liquid under moderate pressures. There are three grades of LPG available as heating fuels: commercial-grade propane, engine fuel-grade propane (also known as HD-5 propane), and commercial-grade butane. In addition, there are high-purity grades of LPG available for laboratory work and for use as aerosol propellants. Specifications for the various LPG grades are available from the American Society for Testing and Materials and the Gas Processors Association. A typical heating value for commercial-grade propane and HD-5 propane is 90,500 British thermal units per gallon (Btu/gal), after vaporization; for commercial-grade butane, the value is 97,400 Btu/gal.

The largest market for LPG is the domestic/commercial market, followed by the chemical industry (where it is used as a petrochemical feedstock) and the agriculture industry. Propane is also used as an engine fuel as an alternative to gasoline and as a standby fuel for facilities that have interruptible natural gas service contracts.

1.5.2 Firing Practices²

The combustion processes that use LPG are very similar to those that use natural gas. Use of LPG in commercial and industrial applications may require a vaporizer to provide the burner with the proper mix of air and fuel. The burner itself will usually have different fuel injector tips as well as different fuel-to-air ratio controller settings than a natural gas burner since the LPG stoichiometric requirements are different than natural gas requirements. LPG is fired as a primary and backup fuel in small commercial and industrial boilers and space heating equipment and can be used to generate heat and process steam for industrial facilities and in most domestic appliances that typically use natural gas.

1.5.3 Emissions^{1,3,5}

1.5.3.1 Criteria Pollutants -

LPG is considered a "clean" fuel because it does not produce visible emissions. However, gaseous pollutants such as nitrogen oxides (NO_x), carbon monoxide (CO), and organic compounds are produced as are small amounts of sulfur dioxide (SO₂) and particulate matter (PM). The most significant factors affecting NO_x, CO, and organic emissions are burner design, burner adjustment, boiler operating parameters, and flue gas venting. Improper design, blocking and clogging of the flue vent, and insufficient combustion air result in improper combustion and the emission of aldehydes, CO, hydrocarbons, and other organics. NO_x emissions are a function of a number of variables, including temperature, excess air, fuel and air mixing, and residence time in the combustion zone. The amount of SO₂ emitted is directly proportional to the amount of sulfur in the fuel. PM emissions are very low and result from soot, aerosols formed by condensable emitted species, or boiler scale dislodged during combustion. Emission factors for LPG combustion are presented in Table 1.5-1.

Table 1.5-1 presents emission factors on a volume basis (lb/10³gal). To convert to an energy basis (lb/MMBtu), divide by a heating value of 91.5 MMBtu/10³gal for propane and 102 MMBtu/10³gal for butane.

1.5.3.2 Greenhouse Gases⁶⁻¹¹ -

Carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) emissions are all produced during LPG combustion. Nearly all of the fuel carbon (99.5 percent) in LPG is converted to CO₂ during the combustion process. This conversion is relatively independent of firing configuration. Although the formation of CO acts to reduce CO₂ emissions, the amount of CO produced is insignificant compared to the amount of CO₂ produced. The majority of the 0.5 percent of fuel carbon not converted to CO₂ is due to incomplete combustion in the fuel stream.