Chapter 3 The fuel effect: *What is being burned matters*

There are three types of fuel used in residential and commercial boilers for heating:

- *Residual fuel oil*
- *Distillate fuel oil*
- *Natural gas*

In general, a heating system can burn any of these fuels, regardless of whether it produces hot water or steam. Heating systems designed for each fuel type will have different fuel supply systems and burners, but the other components of the system will be the same (heat exchanger and heating supply loop— see chapter 2).

Both residual and distillate fuel oils are liquid fuels derived from petroleum. In the United States there are six grades of fuel oil, numbered 1 through 6. The lower the number, the lighter the fuel is, with lower boiling point, viscosity and energy content per gallon. No. 1 through No. 4 fuel oil grades are considered to be distillate fuels, while No. 5 and No. 6 fuel oils are considered residual fuels. No. 5 residual fuel is not burned in heating systems in New York City. No. 4 oil is a mixture (50/50mix) of No. 2 heating oil and No. 6 residual fuel. Heavy residual oils are so viscous that they are solid at room temperature and must be kept in heated storage tanks.

The distillate grades typically used in boilers include No. 2 fuel oil and No. 4 fuel oil. The residual grades used for heating system boilers include both No. 5 and No. 6 fuel oil.

Compared with residual fuels, distillate fuels are more expensive per gallon but they are much cleaner, i.e., they produce significantly lower emissions of NO_x, PM and SO_2 when burned in a boiler.

Natural gas, which is primarily composed of methane (CH_4), is a lighter than air gas that is typically supplied to buildings via underground distribution pipelines owned by a utility company.

Natural gas is the cleanest of the fuels typically used for residential and commercial space heating—when burned in a boiler it produces much lower emissions than either residual or distillate fuels do.

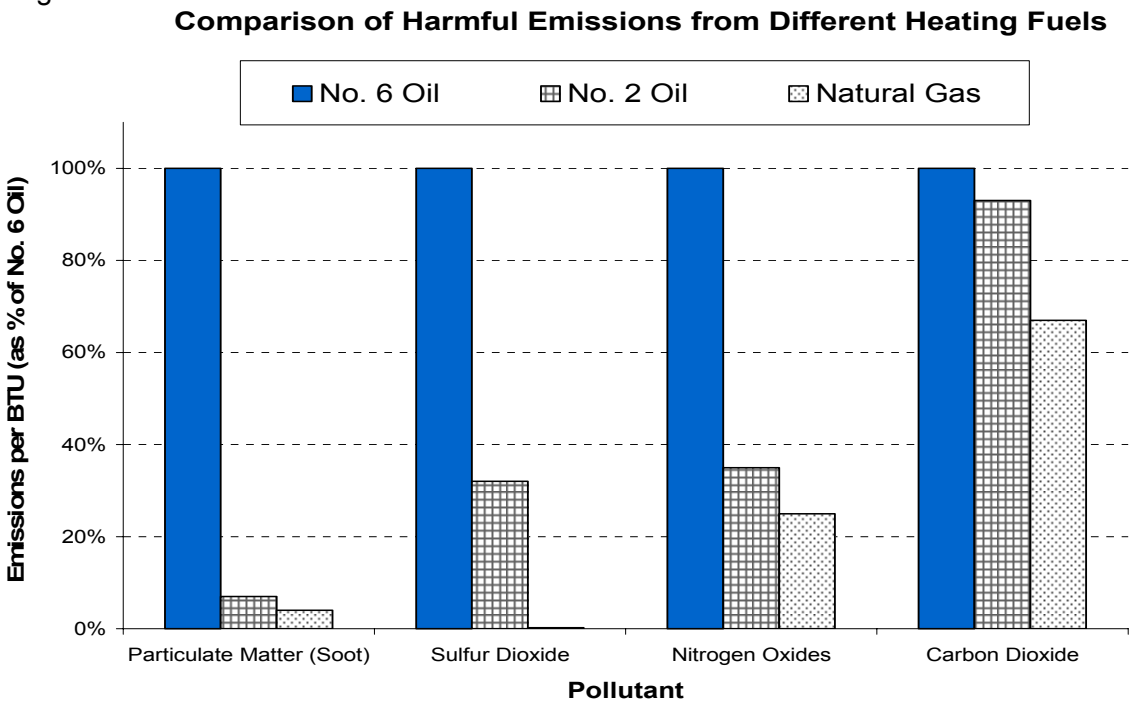
Comparison of petroleum fuel oils

Property	Distillate fuels			Residual fuels	
	No. 1	No. 2	No. 4	No. 5	No. 6
Energy content (Btu/gal)	135,000	140,000	146,000	144,500	150,000
Flash point (°F)	100	100	131	131	140
Specific gravity	0.82	0.86	0.91	0.94	0.96
Maximum Allowable Sulfur content (ppm)—NYC	2,000	2,000	3,000	3,000	3,000

Switching from No. 6 oil to No. 2 heating oil reduces $PM_{2.5}$ emissions by about 94%, SO_2 by about 68% and nitrogen oxides (NOx) by about 65%. Switching from No. 6 oil to natural gas reduces $PM_{2.5}$ emissions by about 96%, SO_2 by over 99% and NOx by about 75%. In terms of global warming pollution, switching from No. 6 oil to No. 2 heating oil reduces heat-trapping CO_2 emissions by about 7%, and natural gas reduces CO_2 emissions by about 30% compared to No. 6 oil.[1]

Figure 5 below depicts the dramatic difference in pollutants generated by No. 6 oil compared to No. 2 heating oil or natural gas. No. 4 oil is typically a 50/50 mix of No. 6 oil and No. 2 heating oil.

Figure 5:



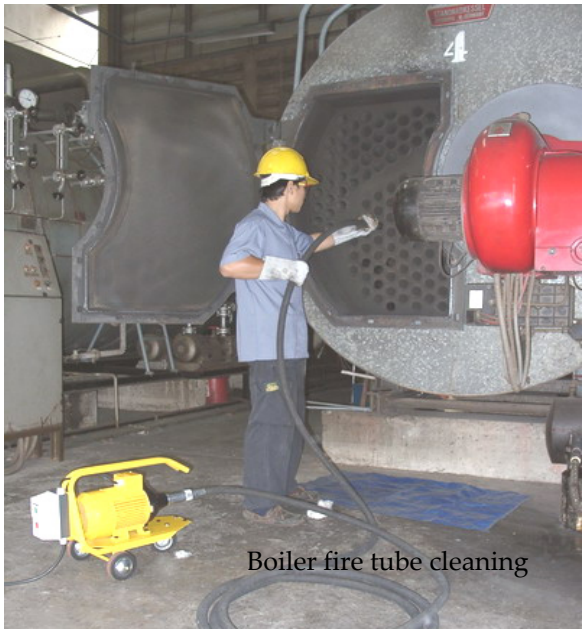
Residual fuels

Residual fuel, No. 6 oil, is the heaviest and thickest of all fuel oils—it literally comes from the "bottom of the barrel" of refined petroleum. It resembles tar or asphalt and must be stored in heated tank kept at approximately 100°F to keep it liquid so that it can be pumped into the burner of a boiler. When being pumped, the temperature must be increased to approximately 150°F to 200°F.

Residual fuels usually contain high concentrations of sulfur and other contaminants such as heavy metals. The sulfur content of residual fuel is limited to 3,000 parts per million (ppm) in New York City by local law that was later incorporated into state limits. However, in neighboring counties the sulfur limit is 10,000 ppm and in some parts of the country No. 6 oil can contain as much as 40,000 ppm sulfur.[2]

Residual fuels have higher energy content per gallon than distillate fuels—No. 6 oil contains approximately 150,000 Btu/gal.[3]

Residual fuels are less expensive per gallon and less expensive per Btu than distillate fuels. According to the Energy Information Administration, the average price of No. 6 fuel oil in 2010 for commercial customers will be $10.97 per million btu (mmBtu), which is $1.65 per gallon. Over the next ten years the average price of residual No. 6 oil is projected to increase slowly, reaching $16.68/mmBtu in 2020. Average prices for No. 6 fuel oil are projected to be approximately $15.14/mmBtu between 2010 and 2020.[4]


Boiler fire tube cleaning

Because residual fuels are very viscous and require heating for them to flow, they are generally only used in large boilers with heating capacity greater than 2.5 million Btu/hr (mmBtu/hr). The heating equipment, in addition to the energy required to keep the fuel liquid, is expensive; for smaller boilers these costs generally outweigh the fuel cost savings relative to distillate fuels.

Since No. 4 and No. 6 oil contain a high percentage of contaminants and produce greater particulate emissions when burned than No. 2 heating oil, boiler cleaning and maintenance is required frequently. During operation, soot accumulates on the surfaces of the heat exchanger and pipes, reducing the efficiency of heat transfer. This soot must be removed during the heating season by operating a soot blower.[5] If the collected soot is not removed regularly, the efficiency of the boiler will decrease and more fuel will be required to heat the building.

Distillate fuels

No. 1 through No. 4 fuel oils are considered distillate fuels. These fuels, which are liquid at room temperature, are less viscous and have lower energy content per gallon than residual fuels. They also have lower sulfur content and fewer contaminants.

No. 2 fuel oil is a medium distillate that is used in diesel engines and also as heating oil. No. 2 fuel oil usually has an energy content of 140,000 Btu/gal (7% less energy per gallon than No. 6 oil).

The sulfur content of distillate fuels used for heating is regulated at the state level and varies significantly by location. In New York City, the maximum sulfur allowed in No. 2 heating oil is 2,000 ppm.

Distillate fuels typically cost more than residual fuels. According to the Energy

Northeastern states' heating fuel sulfur limits

State	Sulfur Limit In percent	Sulfur Limit In parts per million
Connecticut	0.3	3000
Maine	0.3 to 0.5	3000 to 5000
Massachusetts	0.3	3000
New Hampshire	0.4	4000
New Jersey	0.2 to 0.3	2000 to 3000
New York Upstate	1.0 to 1.5	10,000 to 15,000
New York Downstate	0.2 to 0.37	2000 to 3700
Rhode Island	0.5	5000
Vermont	2.0	20,000

Source: NESCAUM, 2003

Information Administration, the average price of No. 2 fuel oil for commercial customers in 2010 will be $16.15/mmBtu, which is $2.26 per gallon. Over the next ten years the average price of No. 2 oil is projected to increase slowly, reaching $22.11/mmBtu in 2020. Average prices for No. 2 fuel oil are projected to be approximately $20.49/mmBtu between 2010 and 2020.[6]

When burning No. 2 heating oil there is significantly less boiler maintenance required than when burning residual fuel. Distillate fuels do not need to be heated, nor do they require soot blowers. This reduces the maintenance load to quarterly or biannual cleaning and inspection. The maintenance cost savings relative to residual fuels at least partially offsets the increased fuel cost of distillate fuels.

The heaviest of the distillate fuels is No. 4 oil. No. 4 oil is usually made by splash mixing residual No. 6 oil with No. 2 heating fuel in a 50/50 mix, and has a heating value of

Comparison of heating fuels price projections (Average 2010 - 2020)

Fuel	Energy content	Price	
		per gallon	per million Btu
No. 2 fuel oil	140,000 Btu/gal	$2.87	$20.49
No. 4 fuel oil	145,000 Btu/gal	$2.57	$17.82
No. 6 fuel oil	150,000 Btu/gal	$2.27	$15.14
Natural gas	1,028 Btu/scf	NA	$10.73
Interruptible natural gas	1,028 Btu/scf	NA	$8.26

No price projections exist for interruptible natural gas rates.
Interruptible natural gas rate provided by National Grid – New York City, September 2008

approximately 146,000 Btu/gal. No. 4 oil is normally used in industrial and commercial boilers, as well as in marine vessels.

Because No. 4 distillate is made using residual and distillate fuels, it possesses some qualities of both fuel types. Like No. 2 oil, No. 4 oil is a liquid at room temperature and does not have to be stored in a heated tank. In order to improve fuel atomization, however, it generally must be heated (using a heat exchanger in the supply line) prior to being pumped into the boiler's burner assembly.

No. 4 oil has higher energy content than No. 2 oil, and is typically priced mid-way between the cost of No. 2 oil and No. 6 oil. Based on Energy Information Administration projections, the average price of No. 4 oil between 2010 and 2020 is expected to be approximately $17.82/mmBtu ($2.57/gallon).[7]

It is worth mentioning that the Mid-Atlantic/Northeast Visibility Union (MANE-VU) has formed a regional coalition of state governments from Maine to Maryland and the oil industry to improve air quality and visibility in the region. MANE-VU's plan is to lower the sulfur content of heating oil to 500 ppm by 2012 and 15 ppm by 2016 for No. 2 oil

and also contain a biofuel component. Due to the dramatic reduction in sulfur levels, high efficiency boilers can be installed further reducing emissions.[8] Thus, this regional strategy does not improve upon the existing limits in New York City (3000 ppm) for No. 4 and 6 oil. Another major effort of MANE-VU is to improve heating system efficiency. Go to www.nescaum.org for more information.

Biodiesel fuel

Biodiesel fuel is a distillate-type liquid fuel typically produced through the reaction of a vegetable oil or animal fat with methanol, in the presence of a catalyst, to yield glycerin and methyl esters. These methyl esters are separated from the methanol and glycerin and sold as biodiesel fuel. The methanol is reused in the production process and the glycerin is sold for other uses. The energy content and physical properties of biodiesel are similar to those of No. 2 petroleum distillate fuel, though it has virtually no sulfur and contains more fuel-bound oxygen.

Therefore, biodiesel can be used in the place of No. 2 distillate, both in boilers and in diesel engines. For diesel vehicles and boilers, biodiesel is typically used as either a B5 blend of 5% biodiesel and 95% petroleum diesel, or a B20 blend of 20% biodiesel and 80% petroleum diesel.

Emissions testings have shown that the use of B20 biodiesel in a boiler can reduce PM emissions by 20%, as well as decrease NO_x emissions by up to 20%.[9] Blends with higher biodiesel content can provide greater PM reductions. For example, the Brookhaven National Laboratory (BNL) has studied the use of bioheat blends in oil-fired heating systems for several years. BNL is the national leader in the United States for testing of fuels and heating equipment for the oilheat industry.[10] One focus of the research at BNL has been to determine if bioheat blends could be substituted for conventional heating oil without modification or adjustment to existing oil-fired heating systems.[11]

The results have shown that nearly identical, and even somewhat improved, combustion performance can be achieved with bioheat blends of up to approximately 30 percent concentration without any changes. Another result that was seen often in laboratory tests was that the addition of biodiesel to heating oil led to a reduction in the emission of nitrogen oxides (NOx) from the heating systems. The $PM_{2.5}$ testing showed that particulate emissions were directly and primarily dependent on the sulfur content of the fuel. Initial laboratory testing data has indicated decreasing $PM_{2.5}$ emissions with increasing biodiesel concentrations in the bioheat blends. Because biodiesel contains little or no sulfur, increased use of bioheat blends should therefore be expected to contribute to reduced smog in major urban areas.[12]

Quality control is of critical importance during biodiesel production and distribution. The National Biodiesel Board has established the BQ-9000 quality control program for biodiesel manufacturers. Under the BQ-9000 quality control program, all production batches of biodiesel must be tested for compliance with the ASTM D 6751 standard. All

biodiesel deliveries to wholesale distributors must be tracked to enable tracing of downstream problems back through the supply chain to the original producer.[13]

The main benefits of using domestically produced biodiesel fuel in either a diesel engine or a boiler is reduced emissions, reduced use of imported petroleum fuel and domestic job creation if U.S. soybeans or waste vegetable oil are used as a feedstock. As a renewable fuel, the use of biodiesel also reduces net fuel cycle heat-trapping carbon dioxide emissions compared with the use of petroleum fuels. The magnitude of the reductions depends on the biodiesel feed stock. Carbon dioxide is the primary greenhouse gas produced by human activity; reducing carbon dioxide emissions through the use of biodiesel will help to slow or reduce global warming.

Natural gas

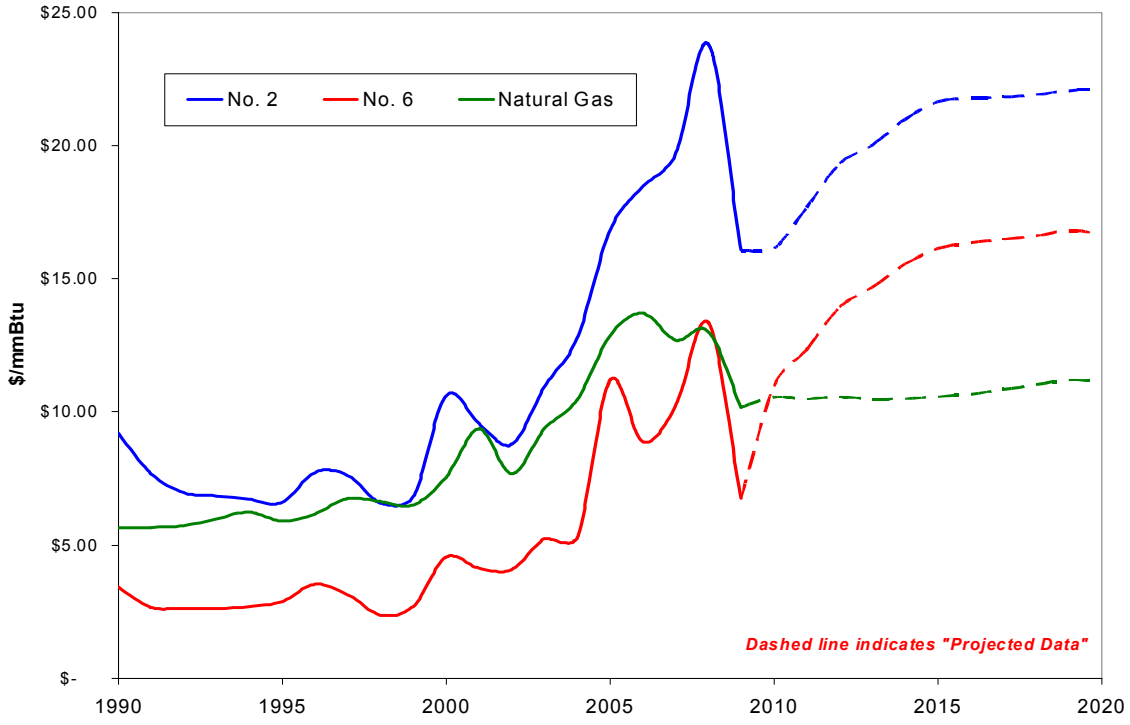
Natural gas is a gaseous fossil fuel primarily composed of methane, but it also includes small amounts of carbon dioxide, nitrogen, helium and hydrogen sulfide. In nature natural gas is odorless and colorless, but to aid in the detection of leaks a strong-smelling sulfur-based chemical called mercaptan is typically added to pipeline gas.[14]

In the United States, natural gas is measured in units of standard cubic feet (scf) or "therms."[15] One therm of natural gas is equal to 100 scf.

One scf of natural gas contains approximately 1,028 Btu of energy; 146 scf of natural gas would have the same amount of energy as one gallon of No. 6 fuel oil, while 136 scf of natural gas would have the same amount of energy as one gallon of No. 2 fuel oil.

According to the Energy Information Administration, the average price of natural gas for commercial customers in 2010 will be $10.55/mmBtu ($1.08/therm). Over the next ten years the average price of natural gas is projected to increase only slightly, reaching $11.13/mmBtu in 2020. Average prices for natural gas are projected to be approximately $10.73/mmBtu between 2010 and 2020.[16]

Historical/projected price comparison ($/mmBtu) for heating fuels: 1990–2020



Source: U.S. Energy Information Administration

Pollution Savings When Switching To Cleaner Fuels (Source: City of New York):

Pollutant and unit	All No. 4/6 heating fuel replaced by natural gas	All No. 4/6 heating fuel replaced by No. 2
PM (tons per year)	1,282	814
NOx (tons per year)	4,839	3,794
CO2 (MMT per year)	1.01	0.13

Equivalent Pollution Reductions (Source City of New York):

Equivalent PM Reductions	- 7.4-11.6 *billion* less VMT for cars (1994-2003 MY) - 1.9-3.0 *billion* less VMT for trucks (just considering PM10, for 1999-2002 MY)
Equivalent NOx Reductions	- 5.7-7.3 *billion* less VMT for cars (1994-2003 MY) - 186-237 *million* less VMT for trucks (1999-2002 MY)
CO_2 Reductions	- 6% of the PlaNYC greenhouse gas reduction wedge for efficient buildings (16.4 MMT) every year

Over the next ten years the price of natural gas is forecast to be significantly lower than the price of either No 2 oil or No. 6 oil. Using the forecasted prices, a quantity of natural gas with the same energy content as one gallon of No. 6 oil (146 scf) would cost on average $1.61 – $0.66 less than a gallon of No. 6 oil. A quantity of natural gas with the same energy content as one gallon of No. 2 oil (136 scf) would cost $1.50 – $1.36 less than a gallon of No. 2 fuel.

However, to ensure proper supply so that interruptible service customers are not forced to switch to oil regularly, the City should work with Con Edison and National Grid to project the increase in demand for natural gas if the city bans No. 4 and 6 oils. The City should work with ConEdison and National Grid to ensure sufficient distribution nodes and pipes; and, to ensure that delivery capacity is made available.

Boiler maintenance when burning natural gas is significantly reduced compared with burning fuel oils. For residential homes, a natural gas boiler requires virtually no cleaning because natural gas does not produce significant amounts of soot that can collect on the burner or heat exchanger. Other benefits of natural gas for heating (if only natural gas is burned) include:

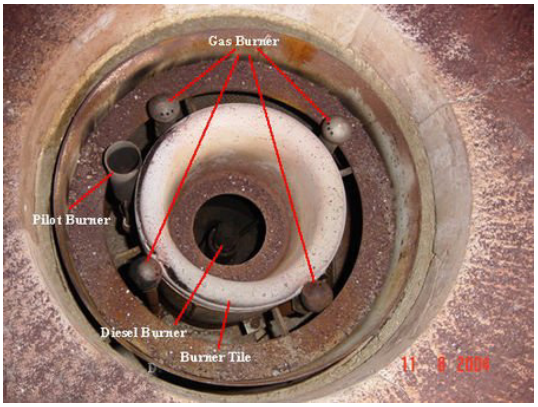
- A storage tank is not required
- Constant supply with no scheduled deliveries required
- High boiler efficiency
- Lower emissions

Dual fuel

As fuel prices increase, another option is becoming more popular: dual fuel. Using a dual fuel-capable burner system gives one the option of choosing either of two different fuels depending on which is currently less expensive. For small residential units, dual fuel burners are usually set up to burn either natural gas or No. 2 fuel oil.

For large commercial units, dual fuel burners may be set up to burn either natural gas or No. 4/No. 6 oil. Dual fueling allows a building owner to operate the boiler primarily on natural gas, but with the option to switch to the other fuel if that would be more cost effective. Not only does dual fuel capability give one the option of switching based on price, it may also allow a building owner to get a discount on the natural gas service.

Small dual fuel burner (natural gas/No. 2)



Source: Wikipedia

Most natural gas providers offer an interruptible service agreement that

discounts their natural gas rate, provided the customer agrees to certain terms of the contract. The terms usually require the customer to lock in a certain amount of natural gas use per year; penalties could result if less is used. Also, the utility company can require that the customer switches to oil for various reasons (e.g. when ambient temperatures are below 19 deg F.). We recommend checking the exact terms with the natural gas providers so that an informed decision can be made.

As part of the deal, the customer is often required to have on hand at least ten days of backup fuel supply at all times. As an example, in the winter of 2008/2009, ConEdison required its customers to switch to oil for just a few days. Penalties apply if the customer is required to switch to oil but fails to do so.

Heating system emissions

All of the heating fuels discussed here create pollutants when burned in a boiler, but some are much cleaner than others. Natural gas is the cleanest fuel, while residual No. 6 fuel oil is by far the dirtiest.

Burning No. 6 fuel oil creates 26 times more PM, 4 times more NO_x and 527 times more SO_2 than burning natural gas. Even No. 2 distillate fuel oil is significantly cleaner than No. 6 residual fuel. Burning No. 2 oil instead of No. 6 oil reduces PM, NO_x and SO_2 emissions by 93%, 65% and 68%, respectively.

Switching from a dirtier to a cleaner fuel can drastically reduce the emissions that the boiler releases to the atmosphere. Unlike power plants that can install stack controls to reduce emissions, buildings have no such controls and the emissions from dirty oil pollute the air we all breathe.

As shown below, annual heating-related PM, NO_x and SO_2 emissions from a typical two-

Combustion emissions from different heating fuels

Fuel	*grams/million Btu*				
	PM	NOx	SO2	VOC	CO
Natural Gas	0.86	41.82	0.27	2.45	17.78
#2 Oil [1]	1.32	58.33	45.99	1.81	16.19
#4 Oil [2]	12.47	62.55	140.75	0.77	15.65
#6 Oil [3]	18.05	166.33	142.43	3.86	15.10

Fuel	*g/gallon* [4]				
	PM	NOx	SO2	VOC	CO
Natural Gas	0.12	5.85	0.04	0.34	2.49
#2 Oil [1]	0.18	8.17	6.44	0.25	2.27
#4 Oil [2]	1.81	9.07	20.41	0.11	2.27
#6 Oil [3]	2.71	24.95	21.36	0.58	2.27

[1] *With 2,000 ppm sulfur*

[2] The PM emission factor is integrated based on EPA AP-42 emission factors for #2 fuel oil and #6 fuel oil (0.3% S).

[3] *With 3,000 ppm sulfur*

[4] *For natural gas, g/ #2 Fuel Oil Equivalent gallon*

Source: EPA AP-42 emission factors

family detached house could be reduced by 34%, 28% and 99%, respectively, by switching from No. 2 oil to natural gas. Annual heating-related PM, NO_x and SO_2 emissions from a typical 200-unit apartment building could be reduced by 199 pounds, 1,286 pounds and 1,148 pounds, respectively, by switching from No. 6 oil to No. 2 oil. They could be reduced by an additional 5 pounds (PM), 197 pounds (NO_x) and 544 pounds (SO_2) if switching from No. 6 oil to natural gas. Carbon dioxide (CO_2) emissions are reduced by about 30% when switching from oil to natural gas.

For example, the reduction in annual PM emissions from switching from No. 6 oil to natural gas in a 200-unit apartment building[17] would be equivalent to taking more than 33 delivery trucks off the road.[18]

Heating system emissions: 200-unit apartment building

Building Type	Fuel Burned	Typical Annual Energy Use		Annual Emissions (lbs)		
		mmBTU	Gallons (oil) Therms (NG)	PM	NOx	SO_2
200 Unit Apartment (with a 5 MMBtu/hr boiler)	#6 Heating Oil	5,400	36,000	214.9	1,980.2	1,695.6
	#2 Heating Oil	5,400	38,571	15.7	694.4	547.6
	Natural Gas	5,400	54,000	10.3	497.9	3.2
	% Reduction (No. 6 to No. 2)			*93%*	*65%*	*68%*
	% Reduction (No. 6 to Natural Gas)			*95%*	*75%*	*100%*
	% Reduction (No. 2 to Natural Gas)			*34%*	*28%*	*99%*

Sources: US Energy Information Association and US EPA

References

[1] According to the EIA web site. Online resource is available at http://www.eia.doe.gov/oiaf/1605/excel/Fuel%20Emission%20Factors.xls.
The following are CO2 emission rates for the different fuels:

Natural Gas:	117.6 lb/mmBtu
#2 Oil:	159.3 lb/mmBtu
#6 Oil;	166.7 lb/mmBtu

Compared to No. 2 heating oil, natural gas results in a 26% reduction in CO2. Compared to No. 6 oil, natural gas results in a 29% reduction in CO2. Efficiency gains also result in a one-for-one reduction in CO2 (i.e .,10% reduction in fuel use [mmBTU] results in a 10% reduction in CO2 emissions, all else being equal).

[2] For example, Nassau County and Westchester County can burn No. 6 fuel with sulfur contents of 3,700ppm and in Suffolk County the sulfur content can go up to 10,000ppm. Some Counties in New York State can burn fuel up to 15,000ppm in sulfur content.

[3] Btu stands for British thermal unit. Btu is a unit of power defined as the amount of energy required to raise the temperature of one pound of liquid water by one degree Fahrenheit.

[4] Energy Information Administration, *Annual Energy Outlook 2009, Table 3 Energy Prices by Sector and Source;* Report #:DOE/EIA-0383(2009), March 2009; *http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html;* All prices quoted are in 2007 dollars and are projected prices for commercial customers in the EIA reference case.

[5] A basic soot blower consists of a rotating nozzle attached to a steam, water or air line. The nozzle is rotated using a motor (automatic) or chain fall (manual). The rotating nozzle directs the steam, water or air at the pipes and heat exchanger, and dislodges ash and soot. The ash and soot are then carried out the exhaust stack.

[6] Energy Information Administration, *Annual Energy Outlook 2009, Table 3 Energy Prices by Sector and Source;* Report #:DOE/EIA-0383(2009), March 2009; *http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html;* All prices quoted are in 2007 dollars and are projected prices for commercial customers in the EIA reference case.

[7] Energy Information Administration, *Annual Energy Outlook 2009, Table 3 Energy Prices by Sector and Source;* Report #:DOE/EIA-0383(2009), March 2009; *http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html;* All prices quoted are in 2007 dollars and are projected prices for commercial customers in the EIA reference case.

[8] Information provided by Sprague Energy.

[9] Massachusetts Oilheat Council & National Oilheat Research Alliance, "Combustion Testing of a Biodiesel fuel oil blend in Residential Oil Burning Equipment," July 2003, http://www.biodiesel.org/resources/reportsdatabase/reports/hom/20030801_htg-002.pdf (accessed November 13, 2008) and Biodiesel for Heating of Buildings in the United States, NYSERDA. Online resource available at: http://www.bnl.gov/est/erd/biofuel/files/pdf/AlbrechtKrishnaPaper.pdf

[10] Biodiesel for Heating of Buildings in the United States, NYSERDA. Online resource available at: http://www.bnl.gov/est/erd/biofuel/files/pdf/AlbrechtKrishnaPaper.pdf

[11] Ibid.

[12] Ibid.

[13] The National Biodiesel Board (http://www.biodiesel.org/) has a section (http://biodiesel.org/askben/) for questions on heating applications. Interested persons can submit via e-mail questions about biodiesel and receive responses within 24 hours or less.
[14] Pacific Gas and Electric Company, "What is Natural Gas?," http://www.pge.com/microsite/safety_esw_ngsw/ngsw/basics/whatis.html (accessed August 20, 2008).
[15] A standard cubic foot of natural gas is measured at 60°F at a pressure of 14.73psia.
[16] Energy Information Administration, *Annual Energy Outlook 2009, Table 3 Energy Prices by Sector and Source;* Report #:DOE/EIA-0383(2009), March 2009; *http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html;* All prices quoted are in 2007 dollars and are projected prices for commercial customers in the EIA reference case.
[17] By switching from No. 6 oil to natural gas annual heating-related PM, NO_x and SO_2 emissions from a 200-unit apartment building could be reduced by 258 pounds, 1,483 pounds and 1,692 pounds, respectively.
[18] Based on the average U.S. Class 6 truck, which travels 12,800 miles per year (USDOE) and emits 0.22 g/mi PM (USEPA, calendar year 2007 fleet average).