Institute *for* Policy Integrity
New York University School of Law

Residual Risks

The Unseen Costs of Using Dirty Oil In New York City Boilers

Kevin R. Cromar
Jason A Schwartz

Report No. 5
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Executive Summary

New Yorkers breathe in a lot of pollution. Most people know smog from cars and buses is a major culprit, but a significant amount of dangerous air pollution may be coming from the buildings we live and work in. In some cases, the fumes can contribute to pollution-related deaths.

In the basements of many big residential, commercial, and institutional buildings—several thousand apartment complexes, schools, shopping centers, and the like in Manhattan, Brooklyn, Queens, and the Bronx—boilers are burning a dirty fuel to heat their units. This type of oil, referred to as "residual" because it is essentially the leftovers from the petroleum distillation process, releases soot and toxic chemicals into the air which, over time, can lead to cardiovascular disease, asthma, and even premature death.

This Report analyses the health, environmental, and economic benefits of switching away from this dirty fuel to cleaner alternatives, such as natural gas. Citywide, residential, commercial, and institutional boilers that burn residual oil contribute as much as 29% of all locally-generated, wintertime soot. Converting those sites to natural gas could decrease their contribution to soot concentrations by a minimum of 60%—decreasing how much soot New Yorkers breathe in.

The results of conversion would be hundreds of avoided mortalities, billions of dollars worth of measurable health benefits, and substantial additional health, environmental, and welfare effects. Residual oil exposes New Yorkers to a dangerous level of risk; this Report hopes to encourage and inform attempts to eliminate the unseen costs of using dirty oil in New York City boilers.

Lives Saved and Measurable Health Benefits

Because the small particles in soot can travel deep into lungs and even slip directly into the bloodstream, soot is at least partially responsible for many negative health outcomes. The increased health risks experienced by individuals exposed to elevated soot concentrations are comparable to those expected for a non-smoker who lives with a smoker.

This analysis estimates that full conversion from residual oil to natural gas could help New York City avoid a minimum of 73 to 188 mortalities each year. In addition, a switchover would prevent thousands of lost work days, significantly reduce the incidence of chronic bronchitis and non-fatal heart attacks, and lower the rate of childhood acute bronchitis by about 115 cases per year.

The faster these pollutants are reduced, the more lives are saved. For example, over a twenty-year period, if full conversion takes all twenty years, a minimum of nearly 600 mortalities will be avoided. For each year earlier that full conversion is implemented, a minimum of 10 additional mortalities will be avoided over that same twenty-year period. However, actual avoided mortalities could reach as high as 1,540 over twenty years, with 28 additional avoided mortalities for every year quicker that full conversion is achieved.

By way of comparison, total homicides in New York City have averaged about 540 per year over the last several years.[1] New York City had about 300 motor vehicle-related deaths in 2007,[2] and an average of 105 U.S. soldiers have died in Afghanistan each year since the conflict began in 2001.[3]

For the purposes of comparing the benefits of phasing out residual oil to potential costs, the health benefits can be given a monetary value, applying $6.9 million as a widely-accepted value for a statistical life. Using that and other conservative estimates, phasing residual oil out over a twenty-year period will generate about $5.3 billion worth of health benefits. For every year earlier that full conversion occurs, about $111 million in additional cumulative health benefits can be expected.

Particle Composition and Additional Health Benefits

Every source of soot emits a slightly different mix of chemicals and particles. Residual oil has notably high concentrations of nickel, a toxic heavy metal. Scientists believe high nickel levels may be even more linked to premature mortality than other types of soot pollution.

All the health benefits measured above stem from what amounts to a 1.5% reduction in New York City's total soot concentrations, ignoring any effects of nickel. By contrast, phasing out residual oil could reduce New York City's nickel concentrations by roughly 27%. Unfortunately, the precise health benefits of reducing nickel exposure cannot be quantified. But based on current scientific understanding, reducing nickel should result in extremely significant health benefits on top of those already calculated purely from reducing soot concentrations.

Additionally, residual oil emits more coarse particles, more sulfur dioxide, and more nitric oxides than other fuel alternatives. Reductions in these pollutants may also lead to improvements in public health, even though these potential effects are not quantified here.

Greenhouse Gases and Environmental Benefits

Residual oil also emits more carbon dioxide and elemental carbon than other fuel alternatives, both of which are potent greenhouse gases. Cutting greenhouse gas emissions will mitigate the speed and severity of global warming. Though no precise benefit can be quantified, switching a single large apartment building from residual oil to natural gas could cut nearly 300 metric tons of carbon dioxide each year. Citywide, the climate benefits of switching to cleaner fuels could easily total into the hundreds of millions dollars annually.

Switching boilers over to cleaner fuel types will also help increase national energy security, protect the natural and built environments from soot, and achieve cost-savings for energy consumers.

Methodology and Conservative Estimates

This analysis uses an innovative approach to calculate how much soot in New York City's ambient air can be traced back to the burning of residual oil in certain buildings. This methodology is made possible by two special characteristics of residual oil: (1) its emissions are high in nickel, and (2) its use varies widely from winter to summer. By comparing heating season and non-heating season nickel concentrations, in conjunction with other factors, we can determine what the air would be like if residual oil were phased out.

By relying directly on monitoring data available for nickel, this methodology entails much less uncertainty than a model-based approach. Furthermore, the generally conservative assumptions and methodologies employed will likely result in an overall underestimation of the actual impacts of residual oil use. In other words, all results reported here are conservative.

Cost Comparison and Conclusion

While this Report does not quantify the costs of phasing out residual oil, a qualitative comparison of costs and benefits is instructive. Likely capital costs of switching boilers will be one-time expenses that may at least partially overlap with inevitable replacement and maintenance costs for boilers. The annual operating costs are speculative, but most predictions suggest switching from residual oil to natural gas could be a cheaper option for consumers. Moreover, consumers may enjoy some additional efficiency gains and cost-savings from conversion.

By contrast, the quantitative and qualitative benefits of phasing out residual oil are annual, real, and significant, including potentially hundreds of avoided mortalities and billions of dollars in better health outcomes for New Yorkers. And while the speed of conversion might increase costs, policymakers should consider whether those costs are justified by the increased benefits of quicker conversion: as many as 28 additional mortalities avoided and $111 million in additional benefits for every year earlier that full conversion is achieved. Hopefully, both New York's citizens and its politicians will keep these findings in mind when making decisions about phasing out residual oil, whether those decisions are voluntary or regulatory in nature.

Introduction

New York City's Battle Against Soot

Of the many air pollutants that plague urban environments like New York City, fine particulate matter is among the most common and most visible: indeed, its more popular label—"soot"—is practically synonymous with pollution itself, and the title quickly conjures up images of smokestacks spewing filth and blackening the skies. Unfortunately, the specific sources, health effects, and costs imposed on New York City by particulate matter remain much more hidden.

This Report uncovers the portion of ambient particulate matter pollution that can be traced back to the residential and commercial boilers in New York City that burn the dirtiest type of heating fuel, called "residual oil." Next, the Report identifies the myriad health effects and other negative consequences owing to the combustion of residual oil. Finally, this Report calculates the monetary benefits of phasing out residual oil and converting to cleaner fuel types.

The continued use of residual oil exposes New Yorkers to a dangerous and costly level of risk. Through its analysis, this Report hopes to encourage and inform attempts to eliminate the unseen costs of using dirty oil in New York City boilers.

What Is Particulate Matter?

The air we breathe is filled with fine particles, called particulate matter or "PM." PM is a complex and diverse mixture of extremely tiny particles and liquids suspended in the air.[4] The smallest of these particles, those with diameters of less than 2.5 micrometers (about 1/30 the diameter of a human hair), are called fine particulate matter, or $PM_{2.5}$.[5] The heterogeneous nature of fine particulate matter is explained by the variety of independent sources, both local and non-local, that contribute to ambient air pollution: smokestacks, fires, and vehicle tailpipes all emit the various acids and chemicals that make up $PM_{2.5}$.[6]

These fine particles are small enough that they can travel deep into human lungs, reaching the bronchial and alveolar regions; they can even slip directly into the bloodstream.[7] The small size of the particles allows them to hang in the air and be transported to areas far from where they were generated.[8] In fact, most models estimate that the majority of $PM_{2.5}$ in New York City's atmosphere at any given time was emitted by out-of-state sources, such as Midwestern power plants.[9]

The health risks from the long-term inhalation and deposition of $PM_{2.5}$ are severe: impaired respiratory function, altered cardiovascular function, and premature death.[10] The increased health risks experienced by individuals exposed to elevated $PM_{2.5}$ concentrations are comparable to those expected for a non-smoker who lives with a smoker.[11]

Currently, over 60 million people, or approximately one in five Americans, live in areas with elevated levels of fine particulate matter—including New York City.[12] The federal government sets limits for maximum allowable daily and annual concentrations for $PM_{2.5}$,[13] but New York City lags behind much of the country in controlling soot, and the City has never attained the federal limits.[14]

Starting in 2007 with an effort called *PlaNYC*, New York City began work on a new approach to combat fine particulate matter and other persistent environmental threats. The City is painfully aware that many principal sources of particulate matter are non-local and so beyond its reach.[15] The largest local sources of $PM_{2.5}$ include heating fuel, transportation, power plants, and industrial processes.[16] The City developed a four-pronged strategy for $PM_{2.5}$: cut emissions from cars, trucks, and buses; cut emissions from off-road vehicles; set new standards for buildings; and enhance local green spaces.[17] While the City has already achieved some success with some of its initiatives, many other key proposals have been delayed or faltered. Most publicly, Mayor Bloomberg's plans for an all-hybrid, lower-polluting taxi fleet have been tied up in litigation,[18] and his effort to reduce transportation emissions and traffic through congestion pricing were stymied by the state legislature.[19] That leaves heating oil as one of the largest sources of particulate matter that the City can still try to control.

What Is Residual Oil?

A wide range of buildings, from single-family homes to large industrial facilities, use boilers to generate heat and set water temperature. Boilers typically burn either natural gas or petroleum-based heating oils as fuel.[20] Heating oil is classified into six types—numbered one through six—based on composition, boiling point, and viscosity: at higher numbers, the fuel is more viscous and emits more pollutants, but also tends to be cheaper. In fact, the heaviest oils are so viscous that they are near solid at room temperature and resemble tar or asphalt.[21]

When large buildings are densely located—as they are in New York City—the economics for delivery and use of the heaviest heating oil (#6) can encourage and perpetuate its selection as a fuel for combustion in boilers. As a result, while a great majority of residential, commercial, and institutional buildings both nationwide and in New York City have opted to use natural gas or the cleaner, lighter #2 "distillate" oil, a good number of buildings in the City continue to burn #6 "residual" oil.[22] As the name implies, #6 residual oil is often thought of as the "leftover" oil from the process of refining and distilling petroleum.[23]

Some older boilers may lack the necessary equipment to effectively process and burn anything but #6 residual oil or the slightly lighter blend of #6 residual and #2 distillate, known as #4. Buildings' fuel choices may also be restricted by the availability of natural gas. Unlike heating oil, which can be delivered by truck, natural gas is typically delivered by a local utility to a building via pipeline; if the necessary infrastructure is not yet in place, buildings do not use natural gas. On the other hand, natural gas infrastructure is expanding, and many newer boilers have "dual fuel" capability, meaning they can burn residual oil, distillate oil, or natural gas.[24]

New York does have some regulations in place controlling the use of heating oils. In particular, a New York City law dating from 1971, which was subsequently incorporated into state regulations, restricts the sulfur content of heating oil.[25] The City also issues permits for residential, commercial, and institutional boilers of certain sizes.[26] Nevertheless, there is no comprehensive database collecting information on how much residual oil is burned every year in the City. That lack of data potentially complicates any calculation of the health impacts of residual oil. This Report uses a unique methodology to overcome that difficulty.

What Is Our Methodology?

Residual oil emits more than just generic particulate matter—indeed, there is no such thing, since every independent source of particulate matter has its own composition and its own signature for $PM_{2.5}$ emissions. Besides emitting several other harmful pollutants, residual oil has a unique elemental composition for its $PM_{2.5}$ emissions: it emits a high level of nickel and vanadium particles. Also, though residual oil is used to heat water year-round, significantly more is used during the winter months, when space heating is necessary. Given seasonal fluctuations and the unique profile for nickel emissions, this Report can approximate the proportion of particulate matter attributable to the use of residual oil in commercial, institutional, and residential heating boilers. This Report will focus on commercial, institutional, and residential boilers, or CIR boilers, since the use of residual oil in industrial sources is much less seasonal, and since industrial sources are less likely to be the subject of potential regulation. Throughout the Report, calculations for #6 residual oil will include the portion of #6 mixed in to #4 blends. Based on those estimates, the quantitative health benefits of phasing out residual oil can also be determined.

Every year, some buildings will voluntarily switch from residual oil to cleaner fuels, for economic or other reasons. If New York City were to pass a regulation restricting the use of residual oil, the process of conversion could be sped up considerably. This Report does not attempt to estimate a baseline rate of voluntary conversion away from residual oil or to predict precise conversion rates under any particular hypothetical regulation. However, this analysis does explore four different time-conversion scenarios and demonstrates that the speed and manner of conversion significantly impacts the magnitude of annual health benefits. Hopefully, both New York's citizens and its politicians will keep the findings of this Report in mind when making decisions about phasing out residual oil, whether those decisions are voluntary or regulatory in nature.

Chapter One

Residual Oil is a Key Local Source of Fine Particulate Matter

This analysis uses an innovative approach to calculate how much fine particulate matter in New York City's ambient air can be traced back to the burning of residual oil at commercial, institutional, and residential (CIR) sites. This methodology is made possible by two special characteristics of residual oil: (1) its $PM_{2.5}$ emissions are high in nickel, and (2) its use has a strong seasonal variation. By comparing heating season and non-heating season nickel concentrations, in conjunction with elemental source profiles and EPA emission factors, this Chapter determines the $PM_{2.5}$ reductions possible if residual oil were phased out. Specifically, CIR residual oil use contributes on average about 3% of all measured fine particulate matter citywide—or roughly 29% of locally-generated wintertime concentrations.[27] Converting CIR sources from residual oil entirely to #2 distillate oil would reduce their $PM_{2.5}$ contributions by at least 18%; full conversion to natural gas would reduce their contributions by 60%.

A. Source Apportionment

Fine particulate matter ($PM_{2.5}$) is a complex and heterogeneous mixture of water droplets, acids such as sulfates and nitrates, elemental carbon, organic chemicals, metals, and other microscopic solids. Each independent source of $PM_{2.5}$—from interstate power plant emissions to local vehicle emissions—makes a unique contribution to the concentration of various elements in the ambient particulate matter in New York City. For example, emissions from residual oil are uniquely identified by their high nickel (Ni) and vanadium (V) content.[28] By identifying such source emissions profiles, it is possible to determine the mass of $PM_{2.5}$ attributable to each separate source, a practice known as source apportionment.

A recent source apportionment study used a standard Positive Matrix Factorization technique (PMF-2; see Appendix A for more detail) to determine the elemental source profiles for each of the sources that contributes to $PM_{2.5}$ in New York City.[29] The New York City-specific source profile (elemental fraction of source mass) for residual oil is a ratio of 0.0065 for Ni.[30] By applying such elemental source profiles to measurements of ambient Ni concentrations, the $PM_{2.5}$ mass due to burning residual oil can be determined. In other words, ambient Ni concentrations divided by the source profile value for residual oil equals the $PM_{2.5}$ mass attributable to residual oil burning.

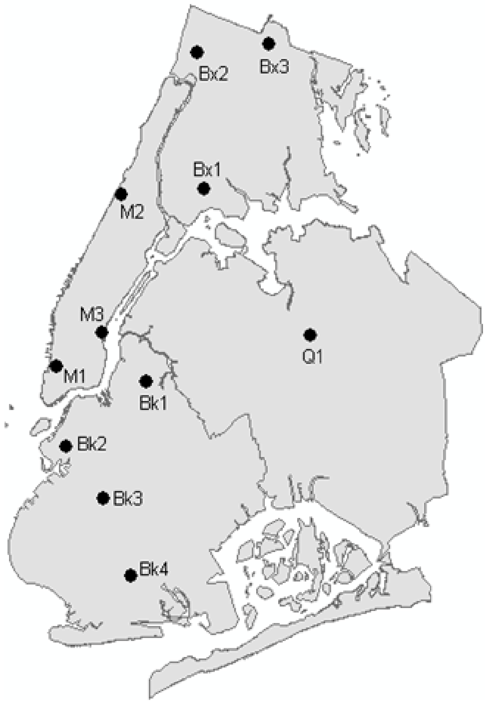
B. Ambient Nickel Concentrations

A number of different sources contribute to the average annual ambient nickel concentrations in New York City: regional long-range transport; emissions from nearby ports and marine vessels; burning of residual oil for electrical generation or industrial processes; and the use of residual oil for heating purposes in commercial, institutional, and residential (CIR) buildings.[31] Of these sources, the use of residual oil for CIR heating is subject to the greatest seasonal variations, with peaks during the winter heating season and lower emissions during the non-heating summer months.[32] Nickel emissions due to marine sources, utilities, industries, and background sources vary slightly throughout the year but do not exhibit the same level of seasonal variation.[33] Therefore, it is possible to closely estimate the fraction of annual nickel concentrations attributable to CIR heating by considering the difference in winter and summer nickel concentrations.

In 2000, the U.S. EPA established the Speciation Trends Network (STN) to monitor and determine the composition of $PM_{2.5}$ in urban areas. New York City currently has three STN sites that provide detailed data on the chemical composition of ambient $PM_{2.5}$, including ambient nickel concentrations. Additionally, a recent pilot study measured summer- and winter-time nickel concentrations at eight sites across the four largest boroughs in New York City from 2007-2008.[34] The locations of the three EPA STN sites and the eight additional monitoring locations are shown in Figure 1.[35] Currently, there is a lack of air monitoring data on $PM_{2.5}$ composition in the borough of Staten Island.

While the STN sites provide year-round data, the pilot study only took measurements during specific months: January through March and May through July.[36] Those periods do not encompass the full heating and non-heating seasons in New York City. Therefore, some additional analysis is necessary to convert the pilot study's measurements into data representative of the full heating and non-heating seasons. Examining several years of data from STN sites, a standard regression analysis indicates that the high nickel concentrations observed during the heating season last for approximately 3.85 months of the year (not just the three winter months the pilot study measured).[37] These results can be translated into time-weighted values, which were tested on data from the three STN sites and then were applied to the other eight sampling sites to determine annual averages for all 11 locations.

Figure 1. Map of Monitor Locations.



For each air monitoring site, the portion of annual nickel concentrations attributable to the combustion of residual oil by CIR buildings is determined by first taking the difference between nickel concentrations during the pilot study-defined heating and non-heating seasons, and then multiplying that difference by the time-weighted value for the full heating season (3.85/12). Table 1 shows the pilot study-defined heating and non-heating average nickel concentrations, the calculated annual average nickel concentrations, and the portion of the annual nickel concentrations attributable to CIR use of residual oil.

Table 1. Nickel Concentrations by Monitoring Location.

	Ni Concentrations (ng/m^3)				
Site	Heating Season	Non-Heating Season	Calculated Annual Average	Heating Minus Non-Heating Season	Annual Ni Attributable to CIR Residual Oil Use
Bx1	19.8	7.7	11.6	12.1	3.9
Bx2	17.7	5.2	9.2	12.5	4.0
Bx3	24.6	15.1	18.1	9.5	3.1
M1	13.0	4.5	7.2	8.5	2.7
M2	11.6	7.3	8.7	4.3	1.4
M3	19.9	12.5	14.9	7.4	2.4
Bk1	7.4	4.3	5.3	3.1	1.0
Bk2	13.5	3.0	6.4	10.5	3.4
Bk3	7.4	6.1	6.5	1.3	0.4
Bk4	6.3	6.3	6.3	0.0	0.0
Q1	16.2	3.9	7.8	12.3	4.0

Calculating the portion of annual nickel concentrations attributable to CIR residual oil combustion by comparing the heating and non-heating nickel concentrations has several important biases to consider. First, this approach fails to account for the use of residual oil by CIR sources to heat water during the non-heating season, which results in excluding the non-heating season emissions from these sources and *underestimating* their heating season contributions.

Secondly, some power plants near New York City are "load-following" or "peak-operating" plants, meaning they only operate during summer months when energy demand is the highest.[38] While most of these high demand-only power plants are gas powered, some do use residual oil as a secondary fuel—especially when natural gas demand is particularly high.[39] The increased residual oil use from these sources during the summer months also results in *underestimating* the heating season contributions to ambient nickel concentrations due to CIR use of residual oil.

Lastly, there is also a bias that results in *overestimating* the nickel concentrations that are due to CIR residual oil use. Atmospheric temperatures are much lower during the heating season (winter), and therefore atmospheric mixing heights are lower than during the non-heating season.[40] A lower atmospheric mixing height means less space in which emissions can concentrate. As a result, the same level of emissions will result in higher ambient concentrations during cooler months as compared to warmer months. Since part of the elevated nickel concentrations observed in the winter could result from mixing height changes rather than from the seasonal use of residual oil, the methodology used here could overestimate the portion of ambient nickel due to CIR residual oil use.

Ultimately, these potential biases point in opposite directions, and so there is no reason to believe that their net effect is significant; as a result, no additional quantitative adjustment is necessary to provide reasonable estimates of the annual nickel concentrations due to CIR use of residual oil. If any cumulative bias does exist, the generally conservative assumptions and methodologies employed here will likely result in an overall underestimation of the actual impacts of CIR residual oil use.

C. Annual $PM_{2.5}$ from CIR Residual Oil Use

Annual ambient $PM_{2.5}$ concentrations from CIR residual oil sources are determined using the annual nickel concentrations from these sources (calculated above) in conjunction with the elemental source profile for nickel. Across the eleven monitoring locations, the range of annual $PM_{2.5}$ concentrations attributable to these residual oil sources is 0.00-0.62 μg/m^3, with an average of 0.37 μg/m^3—that means citywide, residual oil contributes on average about 3% of all measured fine particulate matter.[41] A list of the regressed values for the annual $PM_{2.5}$ concentrations attributable to CIR residual oil use at each of the eleven monitoring locations is found in Table 2.

Table 2. Regressed $PM_{2.5}$ Concentrations by County.

County	Site	Annual Ni (ng/m^3)	Annual $PM_{2.5}$ (μg/m^3)	County-Aggregated Annual $PM_{2.5}$ Concentration Averages (μg/m^3)
Bronx	Bx1	3.9	0.60	0.56
	Bx2	4.0	0.62	
	Bx3	3.1	0.47	
New York	M1	2.7	0.42	0.36
	M2	1.4	0.21	
	M3	2.4	0.37	
Kings	Bk1	1.0	0.15	0.18
	Bk2	3.4	0.52	
	Bk3	0.4	0.06	
	Bk4	0.0	0.00	
Queens	Q1	4.0	0.61	0.39

Average $PM_{2.5}$ concentrations due to CIR residual oil combustion are calculated for each county in order to more readily use health statistics that are commonly aggregated at the county level. $PM_{2.5}$ values between monitor sites are determined by a standard statistical technique called Kriging interpolation using ArcView 9.3 and Spatial Analyst software.[42] County-average $PM_{2.5}$ levels are calculated, as weighted by neighborhood populations, by overlaying the interpolated values on population neighborhood maps.[43] The county-aggregated $PM_{2.5}$ values due to CIR residual oil combustion, presented in Table 2, are population-weighted in this manner in order to represent the average $PM_{2.5}$ concentration that each person in the county is likely exposed to due to these sources. These values are used in all health benefit calculations.

D. Emission Ratios for Conversion to #2 Distillate Oil and Natural Gas

As shown above in Table 2, average ambient $PM_{2.5}$ concentrations due to the CIR combustion of #6 residual oil—including the #6 residual oil component of blended #4 oil—ranges from a low of 0.18 μg/m^3 in Kings County to a high of 0.56 μg/m^3 in Bronx County. Restrictions on the use of residual oil will not completely eliminate those $PM_{2.5}$ concentrations, since the energy generated by residual oil combustion will need to be replaced by use of other fuel types, which also emit some quantity of particulate matter. The reduction of ambient $PM_{2.5}$ concentrations by conversion to other fuel types is calculated in Table 3 from emission factors and fuel efficiency values for #6 residual oil, #2 distillate oil, and natural gas.

Table 3. Primary $PM_{2.5}$ Emissions per Energy Unit by Fuel Type.

Fuel	BTUs	Emissions (lbs $PM_{2.5}$)	lbs $PM_{2.5}$/BTU	ratio to #6	1-ratio
#6	153600 (per gallon)	2.86 (per 1000 gal)	1.88E-08	1.00	0.00
#2	139400 (per gallon)	2.13 (per 1000 gal)	1.55E-08	0.82	0.18
NG	1020 (per cubic foot)	7.60 (per million cubic feet)	7.45E-09	0.40	0.60

Estimating $PM_{2.5}$ emissions and predicting ambient air quality impacts require the use of primary emission factors, which define a particular source's average emission rate for a pollutant relative to the intensity of a particular activity: for example, grams of pollution emitted per gallon of fuel burned. Primary $PM_{2.5}$ emission factors consist of both filterable and condensable fractions.[44] Filterable particulate matter can be either a solid or a liquid at stack temperature (i.e., the temperature at the emissions point, often a smokestack), while condensable particulate matter is a vapor or gas at stack temperature and condenses to a solid or a liquid after exiting the stack. Both fractions are stable in the atmosphere and are collected on ambient filters.[45] The inclusion of the condensable fraction in assessing the ambient impacts of heating oil conversion is especially important since a majority of emissions from #2 distillate oil and natural gas combustion are vapors that condense to form ambient $PM_{2.5}$.[46]

The U.S. EPA provides primary $PM_{2.5}$ emission factors for residual oil, distillate oil, and natural gas.[47] The emission factor for residual oil is defined by equation and is dependant on the sulfur content of the fuel.[48] The emission factor for residual oil used in this study is calculated assuming a sulfur content for #6 residual fuel of 0.3% (3000 parts per million), which is the maximum sulfur content allowed by current New York State Law.[49]

Fuel efficiency values and emission factors for #6 residual, #2 distillate, and natural gas are calculated from the U.S. EPA's *Compilation of Air Pollutant Emission Factors* (called the AP-42 document) and from efficiency statistics specific for New York State. Primary $PM_{2.5}$ emissions from #2 distillate oil are 82%, by energy unit, of #6 residual oil emissions. Natural gas emissions are 40% of #6 residual oil emissions.

Table 4. Decrease in Exposure upon Conversion.

	County-Aggregated Average Annual Ambient $PM_{2.5}$ Concentrations (μg/m^3)		
County	Current Concentrations Due To Residual Oil Use at CIR Buildings	Concentrations Due To Those Sources Assuming Full Conversion to #2 Distillate	Concentrations Due To Those Sources Assuming Full Conversion to Natural Gas
Bronx	0.56	0.46 (a decrease of 0.10)	0.22 (a decrease of 0.34)
New York	0.36	0.30 (a decrease of 0.06)	0.15 (a decrease of 0.21)
Kings	0.18	0.15 (a decrease of 0.03)	0.07 (a decrease of 0.11)
Queens	0.39	0.32 (a decrease of 0.07)	0.16 (a decrease of 0.23)

Converting from residual oil entirely to #2 distillate oil will result in a minimum 18% reduction in annual $PM_{2.5}$ ambient concentrations due to the burning of residual oil at CIR sites.[50] Full conversion to natural gas will result in a 60% reduction in annual $PM_{2.5}$ ambient concentrations from those same sources. Table 4 shows how such conversions would decrease the estimated average $PM_{2.5}$ concentration that each person in each county is likely exposed to due to use of heating fuels at CIR sources.

Chapter Two

Restricting Residual Oil's Use Will Save Lives

Ambient $PM_{2.5}$ pollution can travel deep into the lungs and even slip directly into the bloodstream. Consequently, $PM_{2.5}$ is at least partially responsible for many negative health outcomes, including mortality, cardiovascular and respiratory disease, and lost work days. Epidemiology studies have determined the relationship between $PM_{2.5}$ concentrations and such health results. Using these concentration-response functions, along with background health rates and population data for New York City, this Chapter estimates the annual reductions in mortality and morbidity due to restricting residual oil use. Full conversion at CIR sites from residual oil to natural gas, for example, could help New York City avoid about 73 to 188 mortalities each year, as well as prevent thousands of lost work days, significantly reduce the incidence of chronic bronchitis and non-fatal heart attacks, and lower the rate of childhood acute bronchitis by about 115 cases per year.

The magnitude of health benefits anticipated from restricting residual oil use depends on the rate of conversion to other fuel types; not all customers can or will convert to natural gas. Four conversion scenarios are used in this study to account for this variable. Over a 20-year period, if full conversion takes all twenty years, at least 597 mortalities will be avoided. For every five years earlier that full conversion is implemented, a minimum 54 additional mortalities will be avoided.

All the benefits calculated in this Chapter ignore the possible effect of particle composition on increased mortality, which could be significant and which is discussed further in Chapter Four.

A. Determining Improvements in Health Endpoints due to Pollution Reduction

A log-linear relationship describes how the relative risk for mortality and morbidity changes in response to ambient air pollution.[51] The general form for estimating reductions in health endpoints as a function of reduced ambient pollution concentrations is defined as:

$$\mathit{Reduction\ in\ Health\ Endpoint} = \left(1 - \frac{1}{\mathrm{EXP}(\beta \times \Delta\mathrm{Q})}\right) \times \mathit{Incidence} \times \mathit{Population}$$

Where, β is determined by specific epidemiological concentration-response functions;

ΔQ is the change in pollutant concentration;

Incidence is the age-adjusted incidence of the health endpoint; and,

Population is the number of people in the age groups defined by the epidemiological study that provided the beta value.

Table 5. Total Populations by County for the Age Ranges Used to Calculate Health Endpoints.

Health Endpoint	Start Age	End Age	2008 Population (millions)				
			Bronx	NY	Kings	Queens	Total
Hospital Admissions (HA), Asthma	0	64	1.25	1.39	2.21	1.98	6.82
Acute Myocardial Infarction (MI), Nonfatal	18	99	0.99	1.30	1.86	1.76	5.91
Mortality, All Cause; Mortality, Cardiovascular (Laden et al., 2006)	25	99	0.85	1.17	1.63	1.57	5.22
HA, All Cardiovascular (less MI); HA, Chronic Lung Disease (less Asthma); Work Loss Days	18	64	0.85	1.10	1.57	1.47	4.99
Chronic Bronchitis	27	99	0.81	1.13	1.55	1.51	4.99
Mortality, All Cause; Mortality, Cardiovascular (Pope et al., 2002)	30	99	0.74	1.07	1.44	1.41	4.66
HA, Pneumonia; HA, All Cardiovascular (less MI); HA, Congestive Heart Failure; HA, Dysrhythmia; HA, Ischemic Heart Disease (less MI)	65	99	0.14	0.20	0.29	0.29	0.92
Acute Bronchitis	8	12	0.11	0.07	0.18	0.14	0.50

The background incidences and populations used in these calculations are not inclusive of all age ranges. Instead, they include only the age ranges defined by the epidemiology studies that provide the concentration-response functions (note that two studies are used for all-cause and cardiovascular mortality calculations). In cases where the age-adjusted rate is not available for a given age range, it can be calculated if the overall age-adjusted rate, total population, and crude incidence by age group are known. This process was used in order to determine the age-adjusted rate for cardiovascular mortality for individuals 30-99 years old when only the overall (ages 0-99) adjusted rate was available by county from the New York State Department of Health.[52]

All health endpoints, except for cardiovascular mortalities, are calculated using EPA's BenMAP 3.0.14 software, which is available for download at the U.S. EPA website.[53] County-specific age-adjusted mortality rates, age-adjusted morbidity rates, and population data are all available in the BenMAP program.[54] Some of the morbidity incidence and prevalence data are grouped by region and therefore may slightly vary from New York City background rates.[55]

For this analysis, 2005 incidence rates are used for the all-cause mortality estimations, while all morbidity endpoints are calculated based upon 2000 incidence and prevalence data. Estimates of reductions in cardiovascular mortality are made using the 2004-2006 age-adjusted rates obtained from the New York State Department of Health.[56] All health endpoints are calculated using 2008 estimated populations. The exposed populations by county used for calculating each health endpoint are found in Table 5. A complete list of health endpoints used in this study along with the relevant epidemiology studies are listed in Appendix B.

B. Avoided Mortalities and Morbidities from Restricting Residual Oil

Central estimates by county of the avoided health endpoints as a result of converting CIR locations from residual oil to either #2 distillate oil or natural gas are found in Tables 6 and 7, respectively. The health endpoints listed in these tables are separated into two categories: chronic and acute exposure effects. Chronic, or long-term, exposure health effects include all-cause mortality, cardiovascular mortality, and chronic bronchitis. All other health effects are estimates based on acute pollution exposures.

Two estimates for all-cause mortality are calculated using concentration-response functions from two separate epidemiological studies: Pope and colleagues (2002), and Laden and colleagues (2006).[57] Both studies are extended analyses of long-term, prospective cohort studies whose initial publications have undergone extensive reanalysis by independent scientific experts.[58] A recent regulatory impact analysis performed by the U.S. EPA used these analyses to estimate reductions in premature, all-cause mortality caused by fine particulate matter; however, the estimates were not pooled due to differences in study design and study populations.[59] Similarly, the two estimates of avoided all-cause mortality calculated in this study are not pooled but presented as a range of central estimates.[60]

Assuming full conversion to #2 distillate oil, it is estimated that there will be 22 to 56 avoided all-cause mortalities annually, including 17 to 48 cardiovascular mortalities. Assuming full conversion to natural gas, it is estimated that there will be 73 to 188 avoided all-cause mortalities annually, including 58 to 127 cardiovascular mortalities.

The tables also detail a range of avoided morbidities, from avoiding thousands of lost work days to significant reductions in the incidence of chronic bronchitis, nonfatal myocardial infarction, and other heart and lung diseases. Of particular note are the total estimates for childhood acute bronchitis: just for ages 8 to 12, assuming full conversion to #2 distillate oil, it is estimated there will be about 34 avoided cases annually; assuming full conversion to natural gas, the central estimate rises to above 115 avoided cases annually.

Again, none of these estimates accounts for the potential effect of particle composition on mortality, which could be significant and which is discussed in Chapter Four.

Table 6. Central Estimates of Annual Health Endpoint Reductions Assuming Full Conversion to #2 Distillate Fuel.

			Annual Avoided Mortalities and Morbidities				
Chronic Pollutant Exposure	Start Age	End Age	Bronx	NY	Kings	Queens	Total
Mortality, All Cause (Laden et al., 2006)	25	99	16.3	11.5	10.0	18.1	55.9
Mortality, All Cause (Pope et al., 2002)	30	99	6.3	4.5	3.9	7.0	21.6
Mortality, Cardiovascular (Laden et al. 2006)	25	99	12.4	6.5	7.0	11.9	37.8
Mortality, Cardiovascular (Pope et al. 2006)	30	99	5.7	3.0	3.2	5.5	17.3
Chronic Bronchitis	27	99	3.8	3.4	2.4	5.0	14.6
Acute Pollutant Exposure							
Work Days Lost	18	64	840	700	505	1007	3052
Acute Myocardial Infarction (MI), Nonfatal	18	99	9.8	8.8	6.7	13.9	39.2
Acute Bronchitis	8	12	12.1	5.2	6.5	10.8	34.4
Hospital Admissions (HA), All Cardiovascular (less MI)	65	99	1.8	1.7	1.3	2.7	7.4
HA, Congestive Heart Failure	65	99	1.0	0.9	0.7	1.5	4.1
HA, Ischemic Heart Disease (less MI)	65	99	0.5	0.5	0.4	0.8	2.1
HA, Dysrhythmia	65	99	0.3	0.3	0.2	0.5	1.3
HA, All Cardiovascular (less MI)	18	64	1.1	1.0	0.7	1.5	4.4
HA, Pneumonia	65	99	1.2	1.1	0.9	1.9	5.1
HA, Asthma	0	64	1.1	0.7	0.6	1.1	3.4
HA, Chronic Lung Disease (less Asthma)	18	64	0.3	0.2	0.2	0.4	1.1

Table 7. Central Estimates of Annual Health Endpoint Reductions Assuming Full Conversion to Natural Gas.

			Annual Avoided Mortalities and Morbidities				
Chronic Pollutant Exposure	Start Age	End Age	Bronx	NY	Kings	Queens	Total
Mortality, All Cause (Laden et al., 2006)	25	99	54.6	38.7	33.6	60.8	187.8
Mortality, All Cause (Pope et al., 2002)	30	99	21.0	15.1	13.0	23.7	72.8
Mortality, Cardiovascular (Laden et al. 2006)	25	99	41.9	21.9	23.4	40.2	127.4
Mortality, Cardiovascular (Pope et al. 2006)	30	99	19.2	10.0	10.8	18.4	58.4
Chronic Bronchitis	27	99	12.8	11.5	8.1	16.7	49.0
Acute Pollutant Exposure							
Work Days Lost	18	64	2826	2354	1699	3388	10266
Acute Myocardial Infarction (MI), Nonfatal	18	99	33.0	29.6	22.4	46.7	131.7
Acute Bronchitis	8	12	40.4	17.4	21.7	36.1	115.7
Hospital Admissions (HA), All Cardiovascular (less MI)	65	99	6.1	5.6	4.3	9.0	24.9
HA, Congestive Heart Failure	65	99	3.3	3.1	2.3	4.9	13.6
HA, Ischemic Heart Disease (less MI)	65	99	1.7	1.6	1.2	2.5	7.0
HA, Dysrhythmia	65	99	1.0	0.9	0.7	1.5	4.2
HA, All Cardiovascular (less MI)	18	64	3.8	3.3	2.5	5.1	14.7
HA, Pneumonia	65	99	4.1	3.9	3.0	6.2	17.2
HA, Asthma	0	64	3.5	2.3	2.0	3.7	11.6
HA, Chronic Lung Disease (less Asthma)	18	64	0.9	0.8	0.6	1.2	3.6

C. Magnitude of Health Benefits Depends on Time and Rate of Fuel Conversion

The magnitude of the annual public health benefits that will result from restricting residual oil use depends on whether current residual oil users convert to natural gas or to #2 distillate oil, as well as how quickly they convert. Some residual oil users might convert voluntarily over time, for economic or other reasons; other users may only convert if required by regulation.

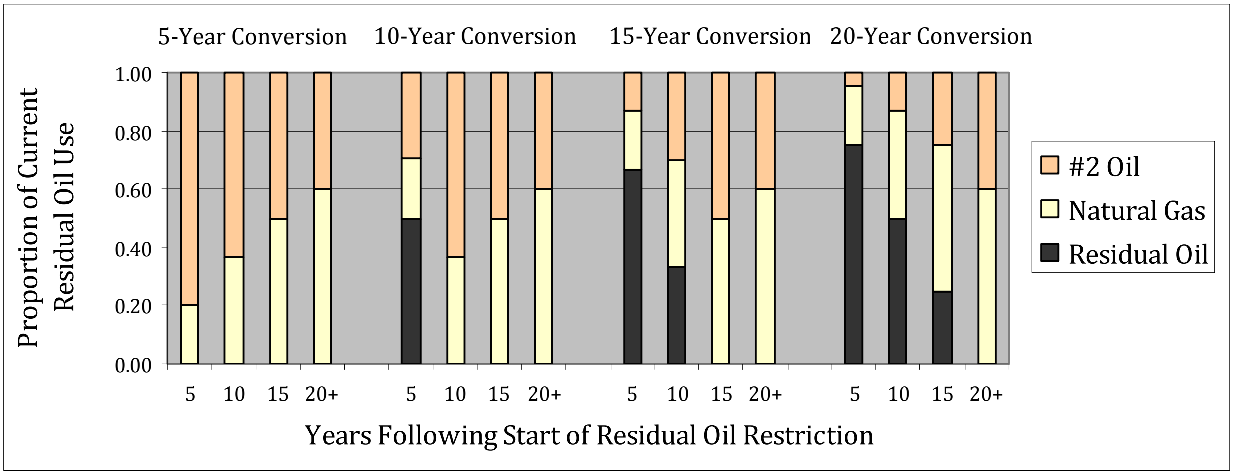
This analysis does not attempt to estimate a baseline rate of voluntary conversion or to predict precise conversion rates under any particular hypothetical regulation. Instead, this analysis explores four different time-conversion scenarios: 5, 10, 15, and 20-year time periods for full conversion from residual oil. Each scenario assumes that conversion from residual oil occurs regularly through time until full conversion. Each scenario also assumes that the conversion away from residual oil occurs at the same rate for both #6 and #4 residual oil.

Importantly, this analysis assumes a constant portion of conversion to natural gas versus #2 distillate oil, using Con Edison's expected conversion rates, during a 20-year phase out of residual oil.[61] Based on various factors, Con Edison—a natural gas provider for Manhattan, the Bronx, and parts of Queens—estimates that every year, four to five percent of residual oil heating customers will convert to natural gas, resulting in approximately 60% of the residual oil heating population converting to natural gas over 20 years.[62] If regulation requires full conversion by the end of 20 years, any remaining residual oil customers will have to switch to #2 distillate by that time.

However, that estimate of natural gas customers does not fully reflect how natural gas availability and use might change if a regulation were to mandate a full conversion timeline of less than 20 years. Such regulation could increase demand for natural gas and accelerate the expansion of natural gas infrastructure. Due to the difficulty of making such adjusted estimates, this analysis employs a conservative assumption and uses Con Edison's 20-year estimates for natural gas conversion in all four time-conversion scenarios explored. Nevertheless, actual conversion to natural gas could occur at a greater rate due to various regulatory or economic pressures, and a quicker, broader conversion to natural gas would increase the benefits of phasing out residual oil.

The estimated proportions of residual oil, #2 distillate oil, and natural gas used over time at sites that currently burn residual oil is shown in Figure 2 for each of the four conversion scenarios.

Figure 2. Fuel Proportions by Year for Four Time-Conversion Scenarios.



The cumulative avoided mortality estimates for each time-conversion scenario are found in Table 8. The range of estimates provided for each conversion scenario reflects the average calculations for avoided all-cause mortalities derived from the two different studies: Pope and colleagues (2002), and Laden and colleagues (2006). The central estimates of annual avoided mortalities due to lower ambient $PM_{2.5}$ concentrations are arithmetically averaged from the full conversion scenarios and therefore vary slightly from estimates independently calculated using log-linear estimates of the reductions in health risks. Given the level of pollution reduction calculated in this study, the central estimates used in Table 8 are within two percent of central estimates calculated using the log-linear reductions in relative risk.

Table 8. Cumulative Avoided Mortalities for Four Time-Conversion Scenarios.

	Years for Full Conversion			
Time after Start of Conversion Process	**5-Year Scenario**	**10-Year Scenario**	**15-Year Scenario**	**20-Year Scenario**
1st Year	7 – 17	4 – 12	4 – 10	3 – 9
2nd Year	20 – 51	13 – 34	11 – 29	10 – 26
3rd Year	39 – 102	26 – 68	22 – 57	20 – 51
4th Year	65 – 169	44 – 113	36 – 94	33 – 85
5th Year	97 – 252	65 – 168	54 – 140	49 – 126
6th Year	131 – 339	90 – 233	75 – 194	68 – 174
7th Year	167 – 432	120 – 309	99 – 256	89 – 230
8th Year	204 – 528	153 – 394	127 – 327	114 – 293
9th Year	243 – 629	189 – 489	157 – 405	141 – 363
10th Year	284 – 733	230 – 594	190 – 491	170 – 440
11th Year	326 – 842	272 – 702	226 – 584	203 – 523
12th Year	369 – 954	315 – 814	265 – 685	237 – 613
13th Year	414 – 1069	360 – 929	307 – 793	274 – 708
14th Year	460 – 1187	406 – 1048	352 – 908	314 – 810
15th Year	507 – 1309	453 – 1169	399 – 1030	356 – 918
16th Year	555 – 1434	501 – 1294	447 – 1154	400 – 1031
17th Year	605 – 1561	551 – 1421	495 – 1282	446 – 1150
18th Year	655 – 1691	601 – 1552	547 – 1412	494 – 1275
19th Year	706 – 1824	652 – 1685	598 – 1545	544 – 1405
20th Year	**759 – 1960**	**705 – 1820**	**651 – 1680**	**597 – 1540**

Over a twenty-year period, if full conversion takes all twenty years, a minimum of nearly 600 mortalities will be avoided. For every year quicker that full conversion is implemented, a minimum of 10 additional mortalities will be avoided over that same twenty-year period. However, it is equally as likely that the actual number of avoided mortalities will be 1,540 over twenty years with 28 additional avoided mortalities for every year quicker that full conversion is achieved.

After the twentieth year, under any of the four conversion scenarios, residual oil will be completely phased out of CIR boilers, and approximately 52 to 135 additional mortalities will be avoided every year. Since plans for natural gas infrastructure expansion are less certain after twenty years, these estimates assume a constant proportion of 60% CIR customers using natural gas and the rest burning #2 distillate oil. Therefore, these estimates likely represent minimum predictions for health benefits after twenty years, since natural gas use could increase beyond 60%.

Indeed, natural gas use could increase beyond 60%, either over time or as a result of regulatory and economic pressures. For example, if more stringent regulation increased demand for and availability of natural gas, all the estimated mortality statistics reported above would increase. Recall that 100% conversion to natural gas would result in 73 to 188 avoided mortalities per year.

Figures 3 and 4 show the average avoided mortalities per year and the cumulative avoided mortalities respectively for each of the four time-conversion scenarios as estimated using Pope and colleagues (2002) concentration-response functions. These numbers show the minimum number of avoided mortalities expected from the four different time-conversion scenarios.

Figure 3. Estimated Annual Avoided Mortalities by Time-Conversion Scenario.

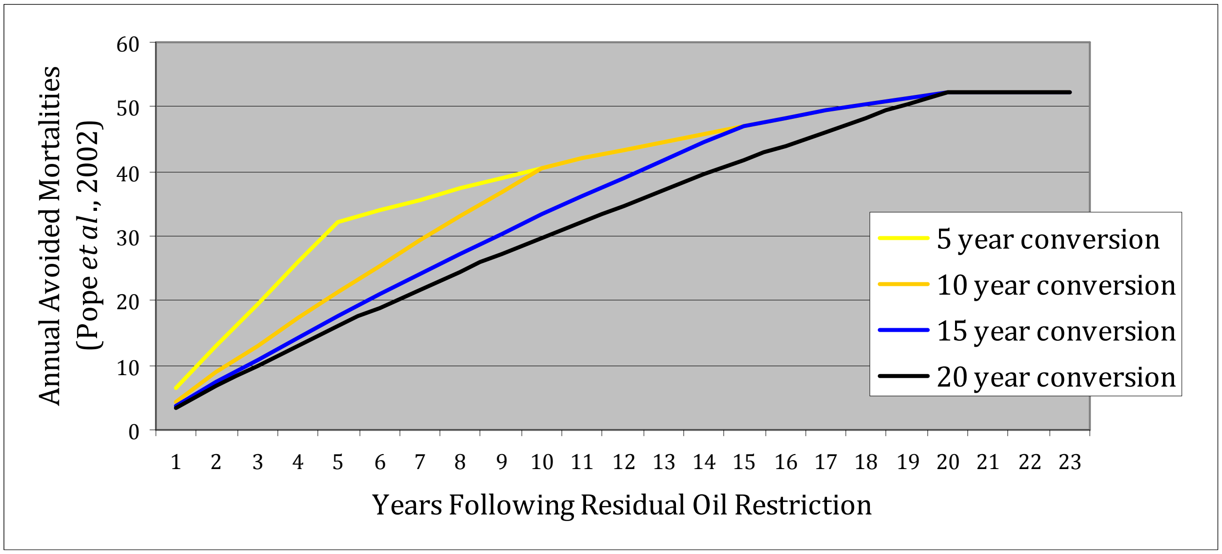
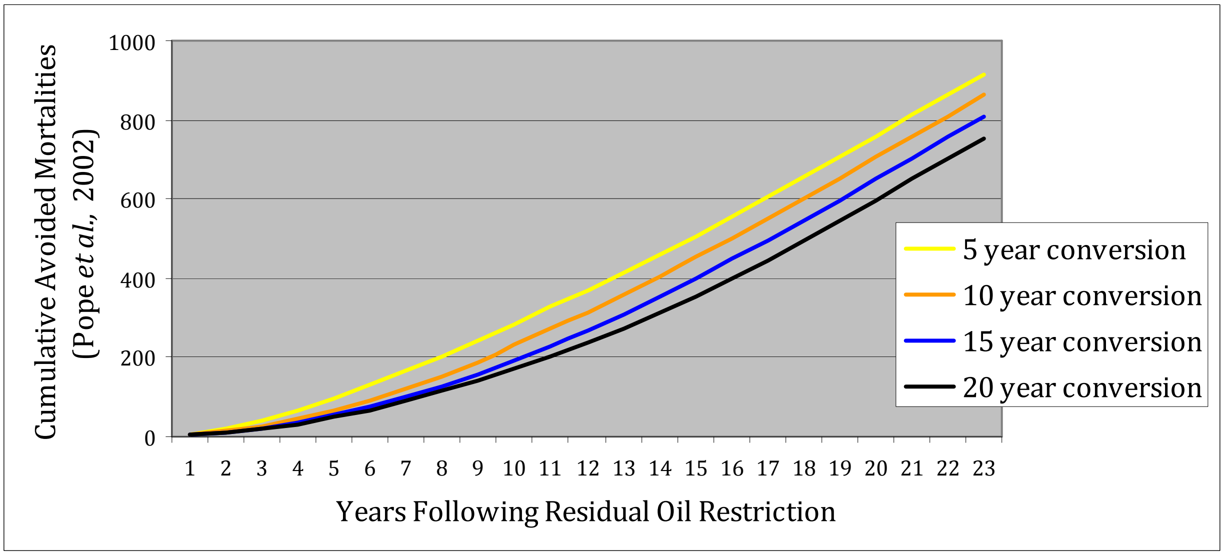


Figure 4. Estimated Cumulative Avoided Mortalities by Time-Conversion Scenario.



Chapter Three

Improving Community Health Delivers Significant Monetized Benefits

Saving lives, preventing illness, and generally improving public health delivers significant, quantifiable benefits that can be assigned a monetary value. Not only can the cost of illness be calculated—in terms of medical resources used, lost productivity (such as lost wages) during illness, and so forth—but individuals and society as a whole have a "willingness to pay" to avoid negative health outcomes. Government agencies routinely calculate and apply such monetary values when deciding whether to regulate a dangerous substance, to determine if the health benefits justify the economic costs of regulation.

Using conservative estimates for the monetized value of various health outcomes, phasing out use of residual oil at CIR sites over a twenty-year period will generate about $5.3 billion worth of health benefits. For every year earlier that full conversion occurs, an average of $111 million in additional cumulative health benefits can be expected. These estimates assume that no more than 60% of residual oil customers will convert to natural gas over a twenty-year period. However, if 100% converted to natural gas, monetized benefits could reach $558 million to $1.35 billion every year.

As with the previous section, all the benefits calculated in this Chapter ignore possible particle composition effects, which could be significant and which are discussed further in Chapter Four.

A. Monetizing the Value of Health Outcomes

Since the monetary value of avoiding mortalities typically constitutes the bulk of total monetized benefits for many environmental regulations, accurately determining the value of a statistical life is of great importance in generating health benefit estimations. The method for determining the value of a statistical life is complicated and not without dispute,[63] but the U.S. EPA has decades of experience with the practice of cost-benefit analysis.

Different values for a statistical life have been used by the EPA over the last several years in response to updated data, new economic theories, and changing economic conditions.[64] This analysis uses a recent and widely-accepted value calculated by the EPA, which is $6.9 million in 2008 dollars for each statistical life.[65]

The values of the avoided morbidities used in this study are based on the EPA's BenMAP 3.0.14 database.[66] The monetary values of avoided morbidities are calculated by concrete costs of the illness, individuals' willingness to pay to avoid the morbidity, or a combination of the two. The concrete costs of illness to society include the total value of the medical resources used as well as the value of lost productivity, such as wages lost.[67] The valuations have been inflation-adjusted and are presented in 2008 dollars.[68]

The annual monetized health benefits for full conversion of CIR sites to #2 distillate and natural gas are found in Tables 9 and 10, respectively. The ranges presented for total annual monetary benefits reflect the difference between using Pope and colleagues' figures for all-cause mortality and using those central estimates from Laden and colleagues instead.

Table 9. Annual Monetized Health Benefits Assuming Full Conversion to #2 Distillate Oil (Million 2008$).

Health Endpoint	Start Age	End Age	Annual Incidence Reduction	Monetized Benefits (Million 2008$)
Mortality, All Cause (Laden et al., 2006)	25	99	55.9	385.6
Mortality, All Cause (Pope et al. 2002)	30	99	21.6	149.4
Acute Myocardial Infarction (MI), Nonfatal	18	99	39.2	9.2
Chronic Bronchitis	27	99	14.6	6.2
Work Days Lost	18	64	3052	0.5
Hospital Admissions (HA), All Cardiovascular (less MI)	65	99	7.4	0.2
HA, All Cardiovascular (less MI)	18	64	4.4	0.1
HA, Pneumonia	65	99	5.1	0.1
HA, Asthma	0	64	3.4	0.03
HA, Chronic Lung Disease (less Asthma)	18	64	1.1	0.02
Acute Bronchitis	8	12	34.4	0.02
			Total	**165.8 – 402.0**

Table 10. Annual Monetized Health Benefits Assuming Full Conversion to Natural Gas Fuel (Million 2008$).

Health Endpoint	Start Age	End Age	Annual Incidence Reduction	Monetized Benefits (Million 2008$)
Mortality, All Cause (Laden et al., 2006)	25	99	187.8	1,295.8
Mortality, All Cause (Pope et al. 2002)	30	99	72.8	502.3
Acute Myocardial Infarction (MI), Nonfatal	18	99	131.7	31.1
Chronic Bronchitis	27	99	49.0	20.9
Work Days Lost	18	64	10266	1.8
Hospital Admissions (HA), All Cardiovascular (less MI)	65	99	24.9	0.7
HA, All Cardiovascular (less MI)	18	64	14.7	0.4
HA, Pneumonia	65	99	17.2	0.3
HA, Asthma	0	64	11.6	0.1
HA, Chronic Lung Disease (less Asthma)	18	64	3.6	0.06
Acute Bronchitis	8	12	115.7	0.05
			Total	**557.6 – 1,351.1**

B. Cumulative Monetary Benefits for Restricting Residual Oil

As demonstrated in Chapter Two, the magnitude of public health benefits will depend on whether current residual oil users convert to natural gas or to #2 distillate oil, as well as how quickly they convert. Using the same assumptions and the same four time-conversion scenarios employed above, the cumulative monetized benefits of restricting residual oil can be calculated. Recall that these assumptions are conservative. For example, the maximum proportion of natural gas consumers is estimated at 60%, a target only reached after twenty years time. If regulatory or economic pressures increase the demand for and availability of natural gas, the benefits of phasing out residual oil could be much greater than the conservative cumulative calculations made here.

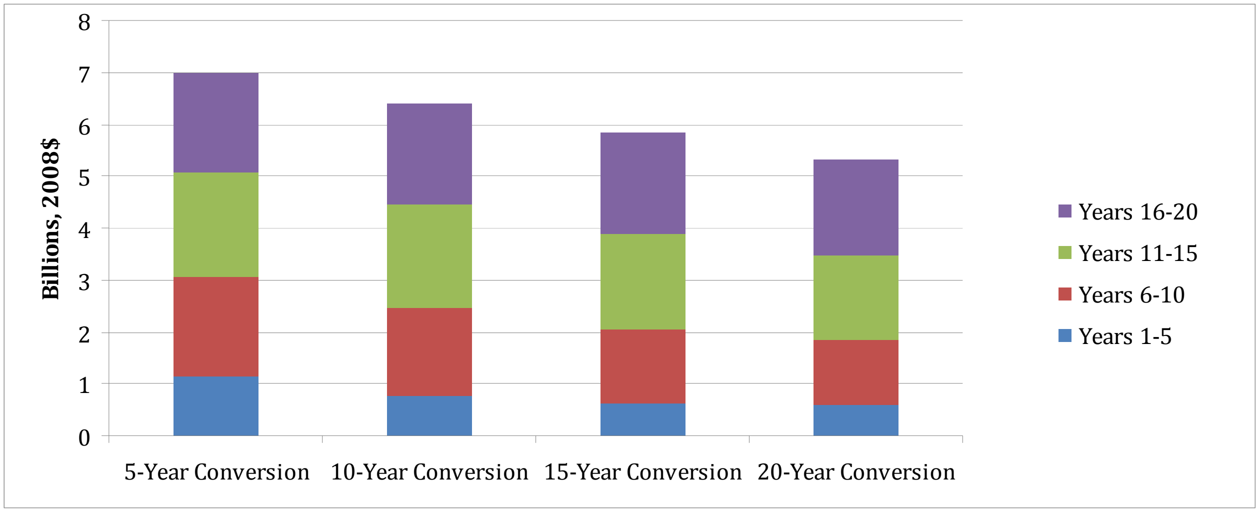
Table 11 and Figure 5 present these estimates, multiplying the monetary value of various health outcomes by the number of avoided mortalities and morbidities expected each year over a twenty-year period. The number of avoided mortalities anticipated in these calculations is based on an average of the Pope and colleagues (2002) estimates and the Laden and colleagues (2006) estimates, weighing each value equally. To be conservative, the monetary values of the various health outcomes have not been adjusted upward on an annual basis to keep pace with inflation or any other growth rate.

On the other hand, best economic practices require application of a discount rate to future streams of annual benefits, to determine the total net present value. Standard discount rates for this kind of context and timescale are 3% or 5%.[69] Table 11 and Figure 5 only present the values at the 3% discount rate, but calculations using the 5% rate are also given below.

Table 11. Cumulative Monetary Health Benefits (Million 2008$) for Four Time-Conversion Scenarios at a 3% Discount Rate.

	Years for Full Conversion			
Time after Start of Conversion Process	**5-Year Scenario**	**10-Year Scenario**	**15-Year Scenario**	**20-Year Scenario**
1st Year	$84.42	$56.85	$47.67	$43.07
2nd Year	$247.06	$165.97	$138.94	$125.43
3rd Year	$482.10	$323.07	$270.06	$243.56
4th Year	$784.09	$524.17	$437.53	$394.21
5th Year	$1,147.92	$765.55	$638.10	$574.36
6th Year	$1,521.22	$1,043.74	$868.73	$781.23
7th Year	$1,902.25	$1,355.53	$1,126.65	$1,012.22
8th Year	$2,289.44	$1,697.90	$1,409.26	$1,264.94
9th Year	$2,681.36	$2,068.05	$1,714.14	$1,537.18
10th Year	$3,076.69	$2,463.38	$2,039.05	$1,826.89
11th Year	$3,474.26	$2,860.95	$2,381.93	$2,132.17
12th Year	$3,873.00	$3,259.69	$2,740.85	$2,451.26
13th Year	$4,271.95	$3,658.64	$3,114.02	$2,782.55
14th Year	$4,670.24	$4,056.94	$3,499.80	$3,124.53
15th Year	$5,067.10	$4,453.79	$3,896.66	$3,475.84
16th Year	$5,461.82	$4,848.51	$4,291.38	$3,835.17
17th Year	$5,853.78	$5,240.48	$4,683.35	$4,201.37
18th Year	$6,242.43	$5,629.13	$5,071.99	$4,573.34
19th Year	$6,627.27	$6,013.97	$5,456.83	$4,950.09
20th Year	**$7,007.87**	**$6,394.56**	**$5,837.43**	**$5,330.68**

Figure 5. Cumulative Monetary Health Benefits for Four Time-Conversion Scenarios at a 3% Discount Rate.



Over a twenty-year period, if full conversion takes all twenty years, quantifiable health benefits will be worth approximately $5.3 billion (at a 3% discount rate; the value is $4.2 billion at a 5% rate). For every year quicker that full conversion is implemented, an average of $111 million in additional cumulative benefits (at a 3% discount rate, or $98 million at a 5% rate) will be generated over that same twenty-year period.

After the twentieth year, under any of the four conversion scenarios, residual oil will be completely phased out of CIR boilers, and approximately $370 million (at a 3% discount rate, or $247 million at a 5% rate) in annual benefits will be generated starting the twenty-first year.[70]

As already mentioned, none of these calculations takes into account the potential effects of particle composition on increased mortality. Such potential effects could greatly increase the benefits of phasing out residual oil. The significance of those effects is discussed in the next Chapter.

Additionally, these calculations assume that the proportion of natural gas consumers never exceeds 60%. Switching from residual oil to natural gas generates much greater benefits than switching to #2 distillate oil. If regulatory or economic pressures increased the demand for and availability of natural gas, the cumulative, monetized benefits calculated here could be much higher. For example, recall from Table 10 that the monetized benefits of a 100% conversion to natural gas could total $558 million to $1.35 billion every year.

Chapter Four

Actual Health Benefits Could Greatly Exceed Quantitative Estimates

All the significant health benefits calculated in the previous chapters were based on well-reviewed concentration-response functions for particulate matter. However, those functions ignore the role of particle composition on increased mortality and morbidity. Compared to other sources of $PM_{2.5}$, residual oil emissions have high nickel and vanadium concentrations. If nickel and vanadium particles have a larger impact on health than other components of New York City's soot, the actual avoided mortalities and morbidities from restricting residual oil would be greater than predicted by the reduction in fine particle mass alone. And while more data is necessary, many recent studies support the theory that $PM_{2.5}$ from residual oil, with its high concentrations of nickel and vanadium, may strengthen the relationship between particulate air pollution and premature mortality.

Ambient concentrations of other pollutants, like sulfur dioxide and nitric oxides, will also be altered if residual oil is phased out. Reductions in these pollutants may lead to additional improvements in public health; but, these potential health improvements are not quantified in this study.

Given the potential significance of these additional un-quantified benefits, the monetized benefits presented above in Chapter Three likely underestimate the full value of phasing out residual oil.

A. Particle Composition Modifies Health Effects Due to Air Pollution

In addition to particle size and mass concentration, particle composition is an important characteristic of particulate matter pollution. Particulate matter is heterogeneous in nature, composed of metals, secondary particles from acidic gases such as sulfates and nitrates, organic compounds, elemental carbon, and water vapor.

The composition of $PM_{2.5}$ is determined by the sources that contribute to the ambient air emissions. Sources of fine particles in New York City include but are not limited to: transported secondary aerosols with high concentrations of sulfur as well as selenium, black carbon, and vanadium; motor vehicle emissions with high concentrations of organic compounds, elemental carbon, zinc, and barium; soil and road dust represented by aluminum, calcium, silica, magnesium, iron, and potassium; sea salt with high concentration of chlorine and sodium; and oil combustion with high concentrations of nickel and vanadium.[71]

These components of $PM_{2.5}$ vary in their strength of association with seasons as well as size fractions. For example, components related to soil, road dust, and sea salts (fine crustal components) are more generally associated with larger, coarse particles. In regards to seasonal variations, secondary particle concentrations are higher in the warm summer months due to the increased photochemical activity and lower in the cooler winter months.[72]

The health effects of particulate air pollution, including premature mortality, have a proven association with fine particle composition. A study of six U.S. cities showed that increases in daily mortality are associated with combustion sources of $PM_{2.5}$ but not associated with fine crustal components such as soil, road dust, and sea salts.[73]

Another study looking at associations between particle composition and daily mortality in 25 U.S. cities found larger increases in all-cause daily mortality when $PM_{2.5}$ mass contained a higher portion of aluminum, silicon, sulfate, and nickel.[74] A study of long-term mortality in a cohort of male U.S. military veterans with hypertension showed that different components of $PM_{2.5}$ vary substantially in their association with survival: nickel, vanadium, nitrates, and elemental carbon were significantly associated with increased mortality in single pollutant models.[75] Each of these studies lends supporting evidence that $PM_{2.5}$ from residual oil combustion, with its high concentrations of nickel and vanadium, may positively modify the relationship between particulate air pollution and all-cause mortality.

Several studies have been carried out that specifically examine the associations of nickel and vanadium on mortality risk estimates. A recent study compared fine particle composition with the National Mortality and Morbidity Study's estimates for coarse particulate matter (PM_{10}) mortality risk in 60 U.S. metropolitan areas. It showed that, out of the 16 key components most closely related to major source categories, nickel and vanadium were the strongest predictors of variation in PM_{10} risk estimates across the metropolitan areas.[76] That analysis also showed that only nickel and vanadium were significantly associated with the much higher daily mortality in New York City than other U.S. cities.[77]

Re-analysis of the National Mortality and Morbidity Study comparing long-term average county-level nickel and vanadium $PM_{2.5}$ concentrations also found that nickel and vanadium concentrations modified the relationship between PM_{10} mass and all-cause mortality; however, when New York City counties were excluded during sensitivity analysis, the evidence of the effect was weaker and no longer statistically significant.[78]

This finding does not mean that nickel and vanadium do not increase the risk of particulate matter on human health, but it does show the sensitivity of findings to influential observations from counties in New York City.[79] Additional studies may be necessary to distinguish the possible metal toxicity from spatial confounding by other characteristics of New York City where the highest ambient levels of nickel and vanadium are found.[80]

B. Intervention Studies Provide Insights into Health Impacts of Fuel Conversion

Intervention studies, as opposed to observational epidemiological studies, provide a natural experiment to assess the impacts of air pollution on human health. Planned and unplanned environmental changes have provided invaluable information regarding the health benefits of reducing air pollutants.

Several relevant intervention studies are available that involved fuel conversions in metropolitan areas. One intervention study comparing mortality statistics six years before and after a 1990 ban on bituminous coal in Dublin, showed that non-traumatic deaths decreased 5.7% and cardiovascular mortality decreased by 10.3%.[81]

The concentration-response relationship for all-cause mortality in the Dublin intervention study is comparable to what was reported in another intervention study during a 13-month strike at a steel mill in Utah Valley from 1986-1987.[82] Interestingly, the decrease in the mortality rate for the Dublin intervention study was more than twice than what was predicted by time-series analysis of daily mortality for the same level of pollution reduction.[83] This illustrates that the actual health benefits of reducing air pollutants can be greater than what is estimated using time-series studies.[84]

Perhaps more relevant than the Dublin intervention study in assessing the health effects of restricting residual oil use in New York City is an intervention study of the health effects of a mandated conversion to low-sulfur fuel in Hong Kong. In a single weekend in 1990, Hong Kong implemented a full and permanent restriction that required all power plants and on-road vehicles to use fuel with a sulfur content of less than 0.5% by weight.[85] In the five years following the low-sulfur mandate, there was a 2.1% decrease in all-cause mortality and a 2.0% decrease in cardiovascular mortality, even though annual ambient particulate matter concentrations remained unchanged.[86]

The immediate and sustained decrease in mortality observed in Hong Kong was associated with reductions in ambient nickel and vanadium concentrations.[87] The decrease in ambient nickel and vanadium occurred because any desulfurization process also removes nickel and vanadium from the fuel oil. Similarly, conversion from residual oil to distillate oil or natural gas in New York City would also result in a large decrease in ambient nickel and vanadium concentrations, which may also lead to significant and additional reductions in all-cause and cardiovascular mortality.

C. Reduced Ambient Nickel Concentrations May Result in Additional Health Benefits

Restricting CIR residual oil use in New York City will result in lower ambient nickel and vanadium concentrations in addition to reducing ambient $PM_{2.5}$ concentrations. Nickel and vanadium emissions are much lower for #2 distillate oil and natural gas than #6 residual oil.[88] For example, compared to #6 residual oil, #2 distillate oil and natural gas only emit 0.5% and 0.4% of nickel respectively on a per-energy basis, as shown in Table 12. Nickel emissions per million BTUs for #6 residual oil and natural gas are calculated assuming 152,048 BTUs per gallon for #6 residual oil and 1020 BTUs per cubic feet of natural gas.

Table 12. Nickel Emissions by Fuel Type

Fuel	Ni Emissions (lbs)	Ni (lbs) per Million BTUs	Portion of #6 emissions
Residual Oil (#6)	0.0845 (per 1000 gallons)	5.56E-04	100.0%
Distillate Oil (#2)	0.000003 (per million BTUs)	3.00E-06	0.5%
Natural Gas	0.0021 (per million cubic feet)	2.06E-06	0.4%

Full conversion from residual oil (including both #6 residual oil and #4 blended oil) to #2 distillate oil and natural gas at CIR sources will result in a roughly 27% reduction in annual ambient nickel concentrations across New York City. This is in sharp contrast to the approximately 1.5% reduction in annual ambient $PM_{2.5}$ concentrations and the 4.5% reduction in annual ambient $PM_{2.5}$ from local sources.[89] Estimated reductions in nickel by county are shown in Table 13. The annual nickel concentration averages for Bronx, New York, and Queens Counties were obtained from the Speciation Trends Network operated by the U.S. EPA for the years 2005-2008.[90] The nickel annual average for Kings County was calculated from interpolation methods previously described and from data found in Table 1.

Table 13. Reductions in Ambient Nickel Concentrations by County

	2005-08 Ambient Nickel (ng/m^3)		
	Annual Average	Aggregate Reduction	Percent Reduced
Bronx	11.5	3.6	31.7%
New York	8.9	2.3	26.0%
Kings	6.1	1.2	19.4%
Queens	8.2	2.5	31.0%
		Average Reduction:	27%

Nickel, and to a lesser extent vanadium, has been shown in epidemiological studies to positively modify the effect between particulate pollution and mortality. Additionally, the results of the Hong Kong fuel oil intervention study have shown that decreases in all-cause and cardiovascular mortality are associated with lower concentrations of ambient nickel and vanadium, even in the absence of decreases in overall annual particulate matter concentrations. Given this supporting evidence, and the expected 27% reduction in ambient nickel concentrations, it is anticipated that the actual health benefits of restricting the use of residual oil at CIR sites will greatly exceed the estimates based solely upon the roughly 1.5% reduction in annual ambient fine particle concentrations.

D. Reductions in Airborne Pollutants Other Than $PM_{2.5}$

Emissions of air pollutants other than fine particles will also be reduced as a result of conversion away from residual heating oil. These pollutants include coarse particles ($PM_{10\text{-}2.5}$), sulfur dioxide

(SO_2), nitric oxides (NO_x), and carbon dioxide (CO_2). Carbon monoxide (CO) emissions will increase because they are related directly to the amount of fuel burned, and greater volumes of cleaner, lighter fuels are needed to generate the same energy as the denser residual oil can produce per unit of volume. Table 14 shows the percent change in the emission of these pollutants as a result of switching from #6 residual oil to #2 distillate oil or natural gas, according to EPA emission factors.[91]

Of particular note are the 88% and 100% reductions in coarse particulate matter emissions (particles with diameters from 2.5 to 10 microns) in #2 distillate oil and natural gas, respectively, as compared to #6 residual oil. Such reductions in the emission of coarse particulate matter would likely result in additional health benefits. In particular, coarse particulate matter irritates the eyes, nose, and throat, and epidemiologic evidence suggests a causal relationship between short-term exposure to $PM_{10-2.5}$ and cardiovascular effects, respiratory effects, and mortality, especially for sensitive populations, like children, the elderly, and those with pre-existing conditions.[92]

Table 14. Reductions in Pollutants by Fuel Conversion

	Percent Emissions Reduction per Unit Energy					
Fuel Conversion	$PM_{2.5}$	$PM_{10-2.5}$	NOx	SO_2	CO	CO_2
#6 residual to #2 distillate	17.6	88.0	59.9	33.4	-10.4	7.2
#6 residual to natural gas	60.3	100.0	72.9	99.8	-150.4	32.7

Estimating health effects due to reductions in air pollution requires information on ambient air concentrations. Ambient $PM_{2.5}$ concentrations due to CIR residual oil use were determined by applying a New York City-specific source profile to ambient nickel concentrations. Since similar source apportionment data is not available for the other pollutants, the same technique can not be used to determine ambient concentrations and make quantitative health impact estimates.

In the absence of data regarding the portion of ambient levels of these other pollutants attributable to CIR residual oil use, quantitative estimates of the health impacts due to restricting residual oil is outside the scope of this analysis. Additionally, qualitative estimates of change in citywide emissions of these pollutants due to restricting residual oil are not made in this analysis using EPA's National Emissions Inventory (NEI), since area source emissions estimates for industrial, commercial, and institutional boilers are uncertain and may not accurately represent emissions from New York City boilers.[93] Chapter Five of this study does include some additional qualitative discussion of the environmental benefits from reducing carbon dioxide emissions.

The above discussion focused on reductions in other pollutants due to burning cleaner fuels, like natural gas, instead of residual oil. The distribution mechanism for natural gas versus residual oil may also affect the emission of harmful air pollutants. In particular, residual oil is typically delivered by truck to individual buildings; natural gas is usually delivered by pipeline.[94]

The U.S. Department of Energy's Argonne National Laboratory has developed a model to study Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET). Since GREET focuses on transportation fuels and national averages, it does not perfectly model full lifecycle emissions from the delivery of residual oil and natural gas used for heating purposes in New York City. However, generally, GREET does suggest that the delivery of residual oil by ocean tanker, barge, and truck emits more sulfur dioxide and particulate matter than pipeline delivery of natural gas, though natural gas delivery does emit more methane.[95] Changing delivery patterns could also affect New York City traffic (including noise and congestion) and jobs.

E. Additional Un-Quantified Health Effects

$PM_{2.5}$ has proven cardiovascular and respiratory health effects beyond mortality or hospital admissions, but due to the predicted smaller magnitude of such effects and the lack of data, these additional health benefits are not quantified in this study. Similarly, though suggestive evidence links fine particulate matter to a range of other health endpoints, from low-birth weight to lung cancer, such effects are not analyzed here.[96] Also, this analysis also does not fully attempt to explore how all susceptible local subpopulations, such as those suffering from certain pre-existing diseases, might change the valuation of health impacts in New York City.[97]

Moreover, this study has only quantified health benefits for the four boroughs of New York City where sufficient air monitoring data exists. However, there is a chance that restricting residual oil use in New York City could also improve the air quality for Staten Island, Long Island, Connecticut, and other surrounding areas. More information about regional pollution patterns and better air monitoring data would be necessary to calculate these non-local health benefits.

Finally, this study assumes that, as it is phased out, residual oil will be replaced by the consumption of enough distillate oil or natural gas to generate an equivalent number of BTUs. Some CIR boilers may already be burning residual oil at near-optimal efficiency. However, other sites might upgrade to more efficient boilers or burners as they convert away from residual oil, meaning fewer BTUs will be necessary to meet the building's heating needs. Some boilers can burn either #6 residual oil or #2 distillate; but using #6 oil requires an extra energy input to keep the fuel sufficiently warm and viscous for use, and #6 residual oil tends to clog and foul the heating unit more quickly, which may reduce overall efficiency. If switching to cleaner fuels also increases efficiency, fewer BTUs of the cleaner fuels will be necessary compared to residual oil.[98] The result would be additional reductions across all pollutants, as less fuel is consumed. This study does not attempt to quantify such efficiency gains, but they could be significant.

Chapter Five

Restricting Residual Oil Also Benefits the Environment and Public Welfare

In addition to the significant health benefits discussed above, switching CIR boilers over to cleaner fuel types will also help mitigate the speed and severity of global warming, increase national energy security, protect the natural and built environments from particulate matter, and achieve cost-savings for energy consumers. For example, though no precise benefit can be quantified, citywide the total climate benefits of switching to cleaner fuels could easily total into the hundreds of millions of dollars annually.

A. Reductions in Greenhouse Gas Emissions

Relative to #6 residual oil, #2 distillate oil and natural gas both emit less carbon dioxide—the greenhouse gas pollutant most responsible for global climate change. The cleaner fuels also produce less elemental carbon (known as black carbon)—a major constituent of particulate matter that results from incomplete combustion; elemental carbon is now believed to be the most significant single agent of global warming after carbon dioxide. Natural gas's lifecycle emissions of nitrous oxide and methane—two other greenhouse gases—might exceed #6 residual oil's emissions of those two pollutants, but the total impact on the climate of such increases will be vastly outweighed by the carbon dioxide reductions achieved by the cleaner fuel.[99]

Cutting greenhouse gas emissions will mitigate the speed and severity of the myriad impacts of climate change on the environment, the economy, public health, and national security. Such benefits can be approximated by the "social cost of carbon" (SCC), which assigns a specific monetary value to the marginal impact over time of an additional ton of carbon dioxide-equivalent emissions. SCC estimates take into consideration such factors as net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services.

While all current SCC estimates involve a great deal of uncertainty and incompleteness that likely results in significant underestimation, federal agencies have recently settled on relatively consistent range of SCC figures.[100] Despite the high potential for underestimation, these figures provide a good starting point for analyzing the benefits of reducing greenhouse gas emissions.

Table 15 shows the carbon dioxide reductions of switching from #6 residual oil to either #2 distillate oil or natural gas. These emission factors are calculated from the Energy Information Administration's database.[101] Due to data availability, for the purposes of this rough estimation, emissions of black carbon, methane, and nitrous oxide will not be analyzed. The carbon dioxide reductions achieved by switching to cleaner fuels can then be monetized by multiplying the number of tons cut by an SCC estimate. Table 15 shows estimations using SCC values at both the low and high end of the range developed by federal agencies (for year 2010 emissions).

Table 15. Primary CO_2 Emissions per Energy Unit by Fuel Type.

Fuel	CO_2 (lbs) Per Million BTUs	% Reduction from #6 Emissions	CO_2 (tons) Reduced from #6 Emissions, Per Million BTUs	Benefits Per Million BTUs (SCC of $5.46)	Benefits Per Million BTUs (SCC of $61.19)
#6	173.72	0%	0	0	0
#2	161.27	7.2%	0.0056	$0.03	$0.34
NG	116.98	32.7%	0.0257	$0.14	$1.57

Though the benefits of reducing greenhouse gas emissions may seem small per BTU, New York City likely burns millions of gallons of residual oil to generate trillions of BTUs each year. For example, a single large New York City apartment building might burn approximately 72,000 gallons of residual oil to generate 10.8 billion BTUs per year.[102] If that one building switched to natural gas, the climate benefits could total nearly $17,000 each year. Unfortunately, no comprehensive database exists of all the buildings using residual oil or of how much fuel they burn. Some reports suggest that as many as 9,000 large CIR buildings in New York City might use residual oil.[103] Though no precise benefit can be quantified, citywide the climate benefits of switching to cleaner fuels could easily total into the hundreds of millions of dollars annually.

Moreover, the relative impacts of the various heating fuels on greenhouse gas emissions should be remembered when comparing fuel prices and costs. As further discussed in Chapter 6, under any national cap on greenhouse gas emissions (or under an expansion of the regional cap already in place), some of the climate costs of these fuels would be internalized into their unit prices, erasing some of #6 residual oil's price advantages over #2 distillate and making natural gas seem even more cost-effective. While a policy phasing out the use of #6 residual oil would not change the overall greenhouse gas emissions under a national or regional cap (since polluters will always emit up to the level of the cap), switching to cleaner fuels for boilers would remain a highly cost-benefit justified method of complying with the cap.

B. Increased Energy Security

Federal agencies, such as the U.S. EPA and the Department of Transportation, calculate that reducing U.S. reliance on petroleum sources for fuel will generate benefits for "energy security."[104]

Global petroleum supply faces greater geopolitical instability compared to natural gas. A sudden, unanticipated disruption to oil supply could trigger effects that ripple through the U.S. economy. As a result, reducing domestic oil consumption decreases the risk of lost economic output during such a supply shock. EPA and the Department of Transportation value this benefit at around $6.70 per every barrel of petroleum not imported.[105] This study does not attempt to translate that figure into the quantified energy security benefits from curbing the use of residual oil, nor does it estimate the energy security impact of increasing demand for #2 distillate oil or natural gas. Nevertheless, there could be important energy security benefits to restricting use of residual oil (which the United States mostly imports) and relying more heavily on natural gas (for which the United States has expanding domestic production capacity).[106]

C. Environmental and Welfare Benefits of $PM_{2.5}$ Reductions

The U.S. EPA's 2009 draft Integrated Science Assessment for particulate matter lists a host of environmental and welfare effects caused by fine particulate matter, such as visibility impairment; chemical effects and physical deposition on vegetation, soil, and aquatic ecosystems; and physical deposition on buildings and culturally important items, like statutes and artwork.

The specific ecological effects of particulate matter depend in large part on chemical composition. Notably, nickel—a signature element of residual fuel's emissions profile—is one of the few heavy metals in particulate matter documented to frequently cause direct toxicity to plant life in field conditions.[107]

D. Cost-Savings for Energy Consumers

As discussed in Chapter Four, a switch to cleaner fuel types could be accompanied by some efficiency gains, in part because the particulate matter from #6 residual oil clogs and fouls the heating equipment more quickly. Using residual oil entails greater maintenance costs for the consumer to preserve a basic level of operation and efficiency. For example, switching a dual-fuel boiler from #6 residual oil to #2 distillate oil could reduce the rate of fouling and permit longer time intervals between vacuum cleanings. This study does not attempt to quantify any maintenance cost savings, though they could be significant.[108]

Chapter Six

Speculative, Limited Costs versus Real, Significant Benefits

Due to a lack of data, this study does not quantify the costs of phasing out the use of residual oil in CIR boilers. Instead, costs are discussed qualitatively. The two main categories of costs are conversion costs and operating costs. The likely capital conversion costs are one-time expenses that may at least partially overlap with inevitable replacement and maintenance costs; the annual operating costs are speculative, but most predictions suggest switching from residual oil to natural gas could be a cheaper option for consumers; and consumers may enjoy some additional efficiency gains and cost-savings. By contrast, the quantitative and qualitative benefits of phasing out residual oil are annual, real, and significant.

A. Conversion Costs and Operating Costs

To convert to cleaner fuel types, some CIR buildings will only require minor changes to their boiler equipment; others will need more substantial equipment replacement and new fuel delivery infrastructure. A few studies have attempted to estimate an average range of conversion costs: for example, one recent report gives an estimated range of $2,000 to $50,000 per building.[109] Though conversion cost estimates remain uncertain, it is important to remember that these are largely one-time capital costs. Moreover, heating equipment has a finite lifespan and must be replaced from time-to-time no matter what type of fuel a building uses.

Operating costs include the cost of purchasing enough fuel to generate the desired BTU output and the cost of maintaining the boiler equipment. The U.S. Department of Energy projects that, over the next decade, the average price of #2 distillate oil in the New York area will be a few dollars more per million BTUs than for #6 residual oil, and the average price of natural gas will be slightly over a dollar less per million BTUs than for #6 residual oil.[110] These estimates do not take into account how any additional restrictions in New York on the sulfur content of residual oil could increase the price of #6 fuel, nor do they consider how local utilities' contracts for "interruptible" natural gas service could decrease the price of natural gas.[111]

These estimates also do not take into account the effects of future regulations. For example, a national or regional cap on greenhouse gas emissions could very well cover the emissions from heating fuel. Such a cap would raise the price of fuel according to its greenhouse gas emissions, as the price internalizes some of the climate costs. Under the national cap-and-trade system proposed by the U.S. House of Representatives, fuel importers would have to hold emission allowances worth about $12 per ton of carbon dioxide-equivalent emissions (for year 2015). That would raise the price of #6 residual oil by about 7 cents per million BTUs relative to the price of #2 distillate oil; and it would raise the price of #6 residual oil by about 31 cents per million BTUs relative to the price of natural gas.[112]

Future regulations could also affect prices by changing demand for various fuel types. A New York City ban on #6 residual oil's use in CIR boilers would at most only marginally increase demand for #2 distillate oil and natural gas.[113] A perhaps more significant effect on demand might result from new national and international emissions standards for marine vessels, a prime consumer of #6 residual oil.[114] Such regulations could at first increase demand for low-sulfur residual oils, but eventually would slightly increase demand—and, therefore, price—for distillate fuels.[115] Similarly, worldwide demand for distillate continues to rise.[116] On the other hand, refiners have in the past responded to increased demand for distillate by increasing distillate yields.[117]

Some analysts have speculated that future costs of natural gas will not remain lower than residual oil per BTU, because natural gas is subject to potential supply interruptions and price spikes.[118] However, such analysis ignores the recent price volatility of petroleum, the recent expansion of domestic natural gas production, and the local plans to expand natural gas delivery infrastructure.[119]

Finally, all potential cost increases from converting to cleaner heating fuels must be weighed against the potential efficiency gains and cost savings that could accompany use of cleaner heating fuels.

B. Comparison of Costs and Benefits

This study does not include a sufficiently detailed or quantitative analysis of costs to draw a final conclusion about the magnitude of any potential net benefits from phasing out the use of residual oil in CIR boilers. That said, the likely capital conversion costs are one-time expenses that may at least partially overlap with inevitable replacement and maintenance costs; the annual operating costs are speculative, but most predictions suggest switching from residual oil to natural gas could be a cheaper option for consumers; and consumers may enjoy some additional efficiency gains and cost-savings. By contrast, the quantitative and qualitative benefits of phasing out residual oil are annual, real, and significant, including potentially hundreds of avoided mortalities and billions of dollars in better health outcomes for New Yorkers.

Costs and benefits should also be compared when considering the appropriate rate of conversion away from residual oil. For example, in designing a potential regulation to restrict residual oil use in CIR boilers, policymakers should take note that, for every year quicker full conversion is achieved, an additional 10 avoided mortalities and $111 million in quantifiable health benefits would result cumulatively over a twenty-year period. These significant, quantifiable public health benefits—in conjunction with the myriad qualitative health, environmental, and welfare benefits—may well justify the costs of faster mandatory conversion.

Conclusion

More Information Could Reveal Even Greater Benefits

The sources and impacts of pollution are not always obvious. Most New Yorkers probably spend little time thinking about how the buildings they live and work in are heated, or how those heating options might affect their health, their environment, and their welfare.

This Report has revealed one unseen source of a dangerous level of risk to New Yorkers: commercial, institutional, and residential boilers that burn residual oil. Citywide, these sources contribute as much as 29% of all locally-generated, wintertime particulate matter. Converting these sites to cleaner fuels, such as natural gas, could substantially decrease their contribution to soot concentrations—decreasing how much soot New Yorkers breathe in, and generating tremendous benefits.

For example, assuming that 60% of residual oil customers convert to natural gas over a twenty-year time period, with the rest converting to #2 distillate oil, phasing out residual oil will generate a minimum of 600 avoided mortalities and $5.3 billion worth of better health outcomes for New Yorkers. If the timeline for conversion is quicker, or if a larger proportion of customers switch to natural gas, those numbers greatly increase.

Yet not even those numbers capture all the hidden costs of burning residual oil. This analysis employs a series of conservative assumptions, meaning the results reported likely underestimate the benefits of phasing out residual oil. With more information, even greater benefits might be revealed.

Conservative Assumptions and Underestimation

This analysis employs a series of conservative assumptions. To start, by relying directly on monitoring data available for nickel, the methodology applied here entails much less uncertainty than a model-based approach. Furthermore, the methodology attributes only 27% of New York City's annual ambient nickel concentrations to the burning of residual oil at CIR sites. Because this approach fails to account for summer-time use of residual oil to heat water at CIR sites, as well as the summer-time use of residual oil at certain power plants, the annual nickel contribution from CIR sites is likely underestimated. As a result, all calculations for $PM_{2.5}$ concentrations and associated health impacts—which are all based on that initial nickel estimate—are conservative estimates.

Additionally, the emission factors for #2 distillate oil, compared to #6 residual oil, are very conservatively estimated. The estimates were drawn from documents provided by the U.S. EPA, which suggest that converting from residual oil to #2 oil would achieve an 18% reduction in $PM_{2.5}$ contributions. However, those same EPA documents also give alternative estimates, which would indicate that converting to #2 oil could achieve as much as a 32% reduction. Had the less conservative number been used, estimated mortality rates and other health effects would have changed significantly.[120]

Next, this analysis used expected conversion rates to natural gas provided by Con Edison. But that estimate does not fully reflect how natural gas availability and use might change if a regulation were to mandate a full conversion timeline of less than 20 years. Such regulation could increase demand for natural gas and accelerate the expansion of natural gas infrastructure. Due to the difficulty of making such adjusted estimates, this analysis employs a conservative assumption and consistently uses Con Edison's 20-year estimates for natural gas conversion. Nevertheless, actual conversion to natural gas could occur at a greater rate due to various regulatory or economic pressures, and a quicker, broader conversion to natural gas would significantly increase the benefits of phasing out residual oil.

Finally, when monetizing the health benefits, this analysis uses widely-accepted numbers for the value of a statistical life and for social willingness to pay to avoid various health endpoints. While economists continue to debate the appropriate monetized values for all those endpoints, some evidence suggests that the values used here fall on the conservative end of the scale.

Overall, the estimates provided by this study represent the minimum anticipated health benefits that will result from restricting the use of residual oil at CIR sites. The actual health impacts of restricting residual oil is likely much greater than these estimates.

Need for More Information

This analysis unfortunately had to leave several substantial benefits un-quantified, due to a lack of information. Most especially, phasing out residual oil could reduce New York City's toxic nickel concentrations by roughly 27%, but the precise health benefits cannot be calculated. Similarly, residual oil emits more greenhouse gases, more sulfur dioxide, and more nitric oxides than cleaner fuel alternatives, but the potentially large benefits to the climate, environment, and human health cannot be estimated with currently available data.

Developing emission factors specific to New York City and to the sulfur content of its heating fuels would be an important first step in estimating some of these hard-to-quantify benefits. Given the likely strong relationship between nickel concentrations and mortality rates, more scientific study of the health impacts of nickel is warranted.

Finally, the collection and application of new information should be an ongoing process. If New York City does develop a regulation to phase out residual oil, its scope, timeline, and stringency should be regularly reevaluated over time as new information on both costs and benefits is gathered. Indeed, this Report already suggests that while the speed of conversion might increase estimated costs, those costs might be well justified by the increased benefits of quicker conversion.

Hopefully, both New York’s citizens and its politicians will keep these findings in mind when making decisions about phasing out residual oil, whether those decisions are voluntary or regulatory in nature.

Appendix A: Description of Positive Matrix Factorization

A brief description of the PMF-2 technique is provided here, with a more detailed description available in other documents.[121] PMF-2 assumes that measured trace element concentrations, x_{ij}, are from p independent pollution sources:

$$x_{ij} = \sum_{k=1}^{p} g_{ik} f_{kj} + e_{ij}$$

Where, x_{ij} is the jth species concentration measured in the ith sample;

g_{ik} is the mass contribution from the k^{th} source on the i^{th} sample (referred to as the G Matrix);

f_{kj} is the j^{th} species mass fraction from the k^{th} source (referred to as the F Matrix); and,

e_{ij} is the residual term or the unexplained part of x_{ij}.

The mass contributions for each source category can be estimated by a mass regression step once the G and F matrices are known. Daily $PM_{2.5}$ mass is regressed onto the PMF output G matrix, and the beta coefficients (β1…βp) are used to estimate daily mass contributions from p source categories:

Mass = β0 + β1*G1 + β2*G2 +… + βp*Gp

An intercept term (β0) is included in the model, given the possibility of certain sources not being fully represented by the model due to the set of elements chosen for the source apportionment model. The beta coefficients are then used to transform the F matrix to provide the fraction of mass associated with each element (i.e., source elemental “profiles”).[122]

Appendix B. Epidemiological Studies Used in Calculating Health Benefits of Decreased Ambient PM2.5 Concentrations

Health Endpoint	Authors	Year	Location	Study title	Age Start	Age End	Function	Beta	Background
All-Cause Mortality	Laden et al.	2006	6 cities	Reduction in Fine Particulate Air Pollution and Mortality: Extended Follow-up of the Harvard Six Cities Study.	25	99	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.014842	Incidence*POP
All-Cause Mortality	Pope et al.	2002	51 cities	Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particle air pollution	30	99	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0,00582689	Incidence*POP
Cardiovascular Mortality	Laden et al.	2006	6 cities	Reduction in Fine Particulate Air Pollution and Mortality: Extended Follow-up of the Harvard Six Cities Study.	25	99	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.024686	Incidence*POP
Cardiovascular Mortality	Pope et al.	2004	Nationwide	Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease.	30	99	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.011333	Incidence*POP
Acute Myocardial Infarction	Peters et al.	2001	Boston, MA	Increased particulate air pollution and the triggering of myocardial infarction.	18	99	(1-(1/((1-Incidence*A) *EXP(Beta*DeltaQ)+Incidence*A))) *Incidence*0.93*POP	0.0092849	Incidence*POP*A
Chronic Bronchitis	Abbey et al.	1995	SF, SD, South Coast Air Basin	Chronis Respiratory Symptoms Associated with Estimated Long-Term Ambient Concentrations of PM2.5 and Other Pollutants.	27	99	(1-(1/((1-Incidence) *EXP(Beta*(MAX(Q1,C)-MAX(Q0,C))) +Incidence*POP* (1-Prevalence)	0.01318504	Incidence*POP* (1-Prevalence)
Work Loss Days	Ostro	1987	Nationwide	Air Pollution and Morbidity Revisited: A Specification Test.	18	64	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.0046	Incidence*POP
HA, All Cardiovascular (less MI)	Moolgavkar	2003	Los Angeles, CA	Air Pollution and Daily Deaths and Hospital Admissions in Los Angeles and Cook Counties.	65	99	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.0003442	Incidence*POP
HA, All Cardiovascular (less MI)	Moolgavkar	2000	Los Angeles, CA	Air Pollution and hospital admissions for diseases of the circulatory system in three U.S. metropolitan areas.	18	64	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.0003415	Incidence*POP
HA, Pneumonia	Ito	2003	Detroit, MI	Associations of Particulate Matter Components with Daily Mortality and Morbidity in Detroit, Michigan.	65	99	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.0016595	Incidence*POP
HA, Asthma	Sheppard	2003	Seattle, WA	Ambient Air Pollution and Nonelderly Asthma Hospital Admissions in Seattle, Washington, 1987-1994.	0	64	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.0010446	Incidence*POP
Acute Bronchitis	Dockery et al	1996	24 communities	Health Effects of Acid Aerosols on North American Children - Respiratory Symptoms.	8	12	(1-(1/((1-Incidence) *EXP(Beta*DeltaQ)+Incidence))) *Incidence*POP	0.0170958	Incidence*POP
HA, Chronic Lung Disease (less asthma)	Moolgavkar	2000	Los Angeles, CA	Air Pollution and Hospital Admissions for Chronic Obstructive Pulmonary Disease in Three Metropolitan Areas in the United States.	18	64	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.0007333	Incidence*POP
HA, Congestive Heart Failure	Ito	2003	Detroit, MI	Associations of Particulate Matter Components with Daily Mortality and Morbidity in Detroit, Michigan.	65	99	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.001292	Incidence*POP
HA, Dysrhythmia	Ito	2003	Detroit, MI	Associations of Particulate Matter Components with Daily Mortality and Morbidity in Detroit, Michigan.	65	99	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.0020327	Incidence*POP
HA, Ischemic Heart Disease (less MI)	Ito	2003	Detroit, MI	Associations of Particulate Matter Components with Daily Mortality and Morbidity in Detroit, Michigan.	65	99	(1-(1/EXP(Beta*DeltaQ))) *Incidence*POP	0.0013001	Incidence*POP

Notes

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[1] *The New York Times*, New York City Homicides, http://projects.nytimes.com/crime/homicides/map (last visited Jan. 19, 2010) (showing New York City homicide statistics for the years 2003-2009).

[2] Bureau of Vital Statistics, New York City Dept. of Health & Mental Hygiene, Summary of Vital Statistics 2007, 11 (2008), *available at* http://www.nyc.gov/html/doh/downloads/pdf/vs/2007sum.pdf (showing 300 total deaths for motor vehicle accidents).

[3] *See* U.S. Dept. of Defense, Casualty Report, http://www.defense.govnews/casualty.pdf (last visited Jan. 19, 2010); iCasualties.org, Operating Enduring Freedom, http://icasualties.org/OEF/ (last visited Jan. 19, 2010) (showing annual coalition mortalities from 2001-present).

[4] U.S. Envtl. Prot. Agency, Particulate Matter, http://www.epa.gov/oar/particlepollution/ (last visited Jan. 19, 2010).

[5] U.S. Envtl. Prot. Agency, Particulate Matter: Basic Information, http://www.epa.gov/air/particlepollution/basic.html (last visited Jan. 19, 2010).

[6] *Id.*

[7] William C. Hinds, Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles (2d ed. 1999).

[8] Jay R. Turner & David T. Allen, *Transport of Atmospheric Fine Particulate Matter: Part 1-Findings from Recent Field Programs on the Extent of Regional Transport within North America*, 58 J. Air Waste Mgmt. Ass'n. 254 (2008).

[9] Y. Qin, E. Kim, & P. Hopke, *The Concentrations and Sources of PM2.5 in Metropolitan New York City*, 40 Atmospheric Environment S312-S332 (2006); *see also* City of New York, PlaNYC: A Greener, Greater New York, 120 (2007) ("Depending on the time of year, up to 70% of particulate matter measured in the city comes from somewhere else.").

[10] *See* C. Arden Pope III & Douglas W. Dockery, *Health Effects of Fine Particulate Air Pollution: Lines that Connect*, 56 J. Air Waste Mgmt. Ass'n. 709 (2006).

[11] Sarah E. Hill et al., *Mortality among Lifelong Nonsmokers Exposed to Secondhand Smoke at Home: Cohort Data and Sensitivity Analyses*, 165 Am. J. Epidemiology 530 (2007). Exposure to an additional 10 $\mu g/m^3$ of fine particles causes a 16-17% increase in the total risk of mortality and a 12–28% increase in the risk of cardiovascular-related mortality. Francine Laden et al., *Reduction in Fine Particulate Air Pollution and Mortality: Extended Follow-Up of the Harvard Six Cities Study*, 173 Am. J. of Respiratory & Critical Care Med. 667 (2006); C. Arden Pope, III et al., *Cardiovascular Mortality and Year-Round Exposure to Particulate Air Pollution: Epidemiological Evidence of General Pathophysiological Pathways of Disease*, 109 Circulation 71 (2004).

[12] *See* Am. Lung Ass'n, State of the Air: 2008 (2008), *available at* http://www.lungusa.org/sota08. The 60 million individuals who live in areas with unsafe annual $PM_{2.5}$ concentrations include around 50 million living in areas with annual concentrations above 15 $\mu g/m^3$ and over 11 million living in areas with annual concentrations above 14 $\mu g/m^3$. The U.S. EPA's Clean Air Scientific Advisory Committee recently recommended a maximum concentration standard of 13-

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14 μg/m³. More than half of these individuals are especially susceptible to the health effects of long-term exposure to fine particles. *Id.* These include over 15 million children, almost 7 million elderly, 1.5 million children with asthma, 3.5 million adults with asthma, almost 2 million people with chronic bronchitis, less than 1 million people with emphysema, almost 15 million people with cardiovascular disease, and over 3 million diabetics. *Id.* at 7.

[13] The U.S. EPA sets National Ambient Air Quality Standards (NAAQS) in accordance with Section 109 of the Clean Air Act. 42 U.S.C. § 7409. The Act's stated objective is to protect the health of sensitive populations as well as general public welfare. The EPA first set the NAAQS for particulate matter in 1971 as one of six regulated pollutants under the Act. In 1997, the EPA revised its PM standards to include separate standards for fine particles that had been linked to serious health problems ($PM_{2.5}$). The EPA revised these standards once more in 2006, nearly halving the 24-hour $PM_{2.5}$ standard, and revoking a standard for coarser particulate matter (PM_{10}) due to a lack of evidence linking long-term PM_{10} exposure to health problems. *See* U.S. Envtl. Prot. Agency, Particulate Matter: PM Standards, http://www.epa.gov/air/particlepollution/standards.html (last visited Jan. 19, 2010). In February 2009, the D.C. Circuit Court of Appeals held that the EPA's 2006 $PM_{2.5}$ NAAQS were unsupported by "adequately reasoned decisionmaking" and were contrary to the Clean Air Act's mandate. The court remanded the standards back to the EPA for further proceedings. Am. Farm Bureau Fed'n v. EPA, 559 F.3d 512, 521 (D.C. Cir. 2009). The 2006 standards remain in effect, but EPA is in the process of reviewing them in light of the court's ruling.

[14] PLANYC, *supra* note 9, at 119.

[15] *See id* at 120 (noting, optimistically, that "[s]ome of these [out-of-state] polluters can be held accountable [in court]").

[16] *Id*.

[17] *Id.* at 121.

[18] *See* Michael M. Grynbaum, *Judge Blocks City's Penalty for Nonhybrid Cab Owners*, N.Y. TIMES, June 22, 2009 ("A federal judge dealt another setback on Monday to the Bloomberg administration's two-year effort to convert the city's yellow taxi fleet to gas-and-electric hybrids.").

[19] Press Release, New York City Mayor's Office, Statement by Mayor Michael R. Bloomberg on the Failure of the State Legislature to Vote Congestion Pricing (Apr. 7, 2008) (available through http://www.nyc.gov).

[20] They can also use bio-diesel and other fuels. For more background on how boilers work, see ENVIRONMENTAL DEFENSE FUND, THE BOTTOM OF THE BARREL: HOW THE DIRTIEST HEATING OIL POLLUTES OUR AIR AND HARMS OUR HEALTH (2009).

[21] *Id.*

[22] *See id* at 29.

[23] U.S. Energy Info. Admin., Petroleum Refining and Processing Definitions, Sources, and Explanatory Notes, http://tonto.eia.doe.gov/dnav/pet/TblDefs/pet_pnp_pct_tbldef2.asp (last visited Jan. 19, 2010) ("A general classification for the heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations….No. 6 fuel oil includes Bunker C fuel oil and is used for the production of electric power, space heating, vessel bunkering, and various industrial purposes.").

[24] *See generally* BOTTOM OF THE BARREL, *supra* note 20.

[25] *See* N.Y. COMP. CODES R. & REGS. tit. 6 § 225-1.2 (d) (1985).

[26] *See* N.Y.C. ADMIN. CODE tit. 24 ch. 1.

[27] Using a wintertime average of 13 μg/m³ for $PM_{2.5}$ concentrations in New York City (a little higher than measured at the EPA sites but a little lower than the NYCCAS study, *compare* N.Y.C. DEPT. OF HEALTH & MENTAL HYGIENE ET AL., THE NEW YORK CITY COMMUNITY AIR SURVEY 21 (2009)), the 1.25 μg/m³ of wintertime $PM_{2.5}$ due to CIR residual oil use is 9.6% of wintertime concentrations. Using results from a source apportionment of fine particles in New York City, *see infra*, locally-generated $PM_{2.5}$ may only account for about one-third of the wintertime concentrations. Therefore, residual oil combustion from CIR sites may account for 29% of locally-generated $PM_{2.5}$ in the wintertime.

[28] Qin et al., *supra* note 9.

[29] R. Lall, A Source Apportionment and Time-Series Health Analysis of Fine Particle Air Pollution in New York City (2008) (Ph.D. thesis, N.Y.U. School of Medicine).

[30] *Id*. at tbl. 3.2.

[31] ICF CONSULTING & APPLIED STATISTICAL ASSOCIATES, PETROLEUM INFRASTRUCTURE STUDY: FINAL REPORT 107 (2006) (prepared for the New York State Energy and Research and Development Authority).

[32] R.E. Peltier et al., *Residual Oil Combustion: A Major Source of Airborne Nickel in New York City*, fig. 3, J EXPO. ANAL. ENVIRON. EPIDEMIOL. (2008).

[33] *Id*. at fig. 4.

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[34] R.E. Peltier RE & M. Lippmann. *Residual Oil Combustion: Distributions of Airborne Nickel and Vanadium within New York City*, J. EXPO. SCI. ENVIRON. EPIDEMIOL. (2009).

[35] The site identifications on the map are different than what appear in Peltier and Lippmann, *id.* The three EPA STN sites have been relabeled as Bx1, M1, and Q1. Affects of the potential proximity of monitoring sites to specific residual oil burning devices are avoided by the methodology employed in this study (i.e., using seasonal differences and applying Kriging interpolation).

[36] *Id*.

[37] The time-weighted values are equal to the fraction of the year represented by the pilot study heating and non-heating seasons. Therefore, the time-weighted values equal 0.321 (3.85months / 12 months) and 0.679 (8.15 months / 12 months) for the heating and non-heating seasons, respectively. The use of these time-weighted values results in estimates of the annual mean with an error of approximately five percent.

[38] NORTHEAST STATES FOR COORDINATED AIR USE MANAGEMENT, HIGH ELECTRIC DEMAND DAY AND AIR QUALITY IN THE NORTHEAST (2006), *available at* http://www.ct.gov/dep/lib/dep/air/energy/final_white_paper_hi-electric_demand_day_06052006%5B1%5D.pdf.

[39] *See* New York Independent System Operators, Power Trends 2008, http://www.nyiso.com.

[40] R. BARRY & R. CHORLEY R, ATMOSPHERE, WEATHER, AND CLIMATE (8th ed., 2003).

[41] *See* NEW YORK CITY COMMUNITY AIR SURVEY, *supra* note 27, at 21 ("Across all NYCCAS sampling sites, after adjusting for temporal differences, wintertime PM2.5 averaged 14.1 μg/m3, compared with 12.4 μg/m3 at DEC regulatory monitoring sites.").

[42] ESRI Inc., ArcView 9.3.1 (2008), http://www.esri.com. Kriging interpolation is a geostatistical technique allowing estimation of values across the areas of New York where there is no monitoring data, based on the eleven observational points in geographic space where data does exist. Kriging interpolation provides confidence intervals around those points. The average variance around these Kriging interpolated values is 20 percent.

[43] Maps available from New York City Department of City Planning, http://www.nyc.gov/planning.

[44] MINNESOTA POLLUTION CONTROL AGENCY, ESTIMATING PM2.5 EMISSIONS FOR AERA'S (2006), http://www.pca.state.mn.us/publications/aq9-12.pdf.

[45] U.S. EPA Measurement Policy Group, $PM_{2.5}$ Emissions Data, Testing, and Monitoring Issues, http://www.epa.gov/ttnnaaqs/pm/presents/condensable_pm_issues-ron_myers.ppt (last visited Aug. 31, 2009).

[46] U.S. EPA, NO. AP-42-ED-5, COMPILATION OF AIR POLLUTANT EMISSION FACTORS: VOLUME 1, STATIONARY POINT AND AREA SOURCES (1995).

[47] U.S. EPA, Factor Information Retrieval (FIRE) Data System, http://www.epa.gov/ttn/chief/efpac/index.html (last visited Apr. 30, 2009).

[48] *Id.* The emission equation used for residual oil is: E = 1.92*A + 1.5; where, A = 1.12*S + 0.37; and, S = sulfur content by percent.

[49] N.Y. COMP. CODES R. & REGS. tit. 6 § 225-1.2 (d) (1985). However, according to anecdotal evidence and informal discussions with city and state officials, the law is loosely enforced, and sulfur content of #6 residual oil is likely often much higher than the values used in this analysis.

[50] This analysis uses a very conservative estimate of the reduction in $PM_{2.5}$ emissions expected from converting from #6 residual oil to #2 distillate heating oil. The 18% reduction utilized includes both the filterable and condensable portions of primary $PM_{2.5}$ emissions. The filterable $PM_{2.5}$ emission factor for #2 distillate oil used here is 0.83 lbs/1000 gallons, as listed in Table 1.3-7 of the EPA's AP-42 document, which coincides with what is listed in the EPA's WebFIRE document. However, it is unclear that this is the appropriate emission factor, as the calculation listed in footnote c of the same table indicates that the emission factor for filterable $PM_{2.5}$ for #2 distillate oil could be 0.46 lbs/1000 gallons (or 1.92*A, where A=0.24 for #2 distillate oil). Using this emission factor would have estimated a 32% reduction in $PM_{2.5}$ emissions when converting to #2 distillate oil from #6 residual oil (as opposed to the 18% reduction calculated in this analysis).

[51] L. CHESTNUT & B. OSTRO, EMPIRE STATE ELECTRIC ENERGY RESEARCH CORP., THE NEW YORK ELECTRICITY EXTERNALITY STUDY, VOLUME I: INTRODUCTION AND METHODS, ch. 5 (1995).

[52] The overall age-adjusted rate for cardiovascular mortalities in New York County is 253.8 per 100,000 individuals, with a total population of 1,634,795. Since 99.5% of the crude cardiovascular mortality rate occurs in individuals 30-99 years old, the age-adjusted rate for individuals ages 30-99 multiplied by the population aged 30-99 is simply 99.5% of the overall age-adjusted rate. This value can either be divided by the population aged 30-99 to find the age-adjusted rate for that age group, or it can be used directly in the health benefits calculation since the product of the population and age-adjusted rate is needed in the calculation.

[53] U.S. EPA, Environmental Benefits Mapping and Analysis Program (BenMAP), http://www.epa.gov/air/benmap.

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[54] U.S. EPA, Environmental Benefits Mapping and Analysis Program (BenMAP) User's Manual (2008).

[55] U.S. EPA, Environmental Benefits Mapping and Analysis Program (BenMAP) User's Manual Appendices (2008).

[56] N.Y.S. Dept. of Health, Statistics, http://www.health.state.ny.us/statistics (last visited May 30, 2009).

[57] *Compare* F. Laden et al., *Reduction in Fine Particulate Air Pollution and Mortality*, 173 Am. J. of Respiratory & Critical Care Medicine 667-672 (2006), *with* C. Pope et al., *Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution*, 287 J. of the AMA, 1132-1141 (2002).

[58] D. Krewski et al., *Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality* (Special Report to the Health Effects Institute, Cambridge MA) (2000).

[59] U.S. EPA, 2006 National Ambient Air Quality Standards for Particle Pollution: Regulatory Impact Analysis (2006).

[60] The concentration-response functions provided by the two aforementioned epidemiology studies are assigned in this analysis an equal likelihood of representing the true relative risk of $PM_{2.5}$ concentrations in New York City. The true health benefits that will occur are expected to be between the two central estimates provided by these two studies. The 95% confidence intervals around the central estimates have not been reported since they are much smaller than the margin between the central estimates themselves and do not significantly alter the estimated health benefits of restricting residual oil.

[61] This analysis does not assume any significant growth in the use of biodiesel or other alternative options for heating.

[62] E-mail Correspondence with Christine Cummings, Con Edison Public Relations–NYC Government Relations (August 28, 2009). This estimate is based upon the following assumptions: there will be no significant changes in fuel costs; there will be no significant changes in the costs to the customer to convert their equipment; there will be no significant changes in the incentives customers may receive from Con Edison or NYSSERDA; oil heating customers have remained such due to positive economic benefits; and, no significant improvements made to #2 oil to reduce emissions will affect the number of conversions.

[63] *See* C. Dockins et al., U.S. EPA Nat'l Ctr for Envtl. Econ., Value of Statistical Life Analysis and Environmental Policy (2004). The general approach taken by the EPA is to perform meta-analyses of willingness-to-pay studies involving workers wages and survey responses from sampled populations. These analyses provide mean predicted values and confidence intervals. These confidence intervals can be very large. For example, for several years the EPA calculated that the mean value of one statistical life as $5.5 million (1999$) with a lower and upper confidence limit of $1 million (1999$) and $10 million (1999$) respectively.

[64] *Id*.

[65] *Id.* However, a recent draft of EPA's economic analysis guidelines suggests that, in the future, EPA will recommend a central VSL of $7.0 million (2006$). Nat'l Ctr. for Evntl. Econ., U.S. Envtl. Prot. Agency, Guidelines for Preparing Economic Analysis 7-6 (Sept. 12, 2008) (unpublished external review draft). Using that slightly higher value would result in slightly higher benefits estimates throughout this Report. Also, several biases and potentials for underestimation are built in to the EPA's methodology for calculating the VSL. For an example of such criticism, see Richard L. Revesz & Michael A. Livermore, Retaking Rationality: How Cost-Benefit Analysis Can Bettter Protect the Environment and Our Health (2008).

[66] BenMAP User's Manual Appendices, *supra* note 55.

[67] BenMAP User's Manual, *supra* note 54.

[68] *See* Bureau of Labor Statistics, U.S. Dept. of Labor, Consumer Price Index, http://www.bls.gov/cpi (last visited June 30, 2009).

[69] Though the White House Office of Management and Budget recommends using discount rates of 3% and 7%, in recent reviews of the costs and benefits of emissions controls under the Clean Air Act, the EPA's Scientific Advisory Board has recommended using an intermediate 5% rate instead. Because there are reasons to be skeptical about an estimated 7% real, pre-tax opportunity cost of capital, this Report has focused on 3% and 5% rates. *See* Guidelines for Preparing Economic Analysis, *supra* note 65, at 6-13 n.92 & generally ch.6.

[70] At the 3% discount rate depicted in Figure 5, the cumulative monetary health benefits after 20 years are $7 billion, $6.4 billion, $5.8 billion, and $5.3 billion (2008$), for 5-year conversion, 10-year conversion, 15-year conversion, and 20-year conversion, respectively. At 5% discount rate, $5.6 billion, $5.1 billion, $4.6 billion, and $4.2 billion.

[71] L. Zheng et al., *Sources of Fine Particle Composition in New York City,* 38 Atmospheric environment 221 (2004).

[72] Lall, *supra* note 29.

[73] F. Laden et al., *Association of Fine Particulate Matter from Different Sources with Daily Mortality in Six U.S. Cities*, 108 Envtl. Health Perspectives 10 (2000).

[74] M. Franklin, P. Koutrakis, & J. Schwartz, *The Role of Particle Composition on the Association Between $PM_{2.5}$ and Mortality*, 19 *Epidemiology* 5 (2008).

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[75] F. Lipfert et al., *$PM_{2.5}$ Constituents and Related Air Quality Variables as Predictors of Survival in a Cohort of U.S. Military Veterans*, 18 Inhalation Toxicology 645-657 (2006).

[76] M. Lippmann M et al. *Cardiovascular Effects of Nickel in Ambient Air*, 114 Envtl. Health Perspectives 1662–1669 (2006).

[77] R.E. Peltier & M. Lippmann, *supra* note 34.

[78] F. Dominici et al., *Does the Effect of PM_{10} on Mortality Depend on PM Nickel and Vanadium Content? A Reanalysis of the Nmmaps Data*, 115 Envtl. Health Perspectives 1701–1703 (2007).

[79] *Id.*

[80] F. Lipfert et al., *supra* note 75.

[81] L. Clancy et al., *Effects of Air-Pollution Control on Death Rates in Dublin, Ireland: an Intervention Study*, 360 Lancet 1210-1214 (2002).

[82] C. Pope et al., *Daily Mortality and PM_{10} Pollution in Utah Valley*, 47 Arch. Envtl. Health 211–17 (1992).

[83] R. Brook et al., *Air Pollution and Cardiovascular Disease: A Statement for Healthcare Professionals from the Expert Panel on Population and Prevention Science of the American Heart Association*, 109 *Circulation* 2655-2671 (2004).

[84] It is important to note that concentration functions using long-term or chronic pollution exposures results in higher estimates of health endpoints than the cumulative short-term or daily pollution time-series concentration response estimates. It is possible that the use of concentration-response functions from long-term pollution studies may have provided a better estimate of the reduced mortality in Dublin than the short-term time-series concentration functions.

[85] A. Hedley et al., *Cardiorespiratory and All-Cause Mortality after Restrictions on Sulfur Content of Fuel in Hong Kong: an Intervention Study*, 360 *Lancet* 1646-52 (2002).

[86] *Id.*

[87] R.E. Peltier & M. Lippmann, *supra* note 34.

[88] U.S. EPA, Factor Information Retrieval (FIRE) Data System, *supra* note 47. Unfortunately, there is a lack of adequate emission factors for #4 blended oil, which complicates calculations of nickel reductions by switching from #4 oil to an alternative heating fuel..

[89] Y. Qin et al., *supra* note 9. Qin et al. estimates that 69% to 82% of $PM_{2.5}$ mass in New York City is from non-local sources. This estimate is similar to the Lall and Thurston estimate that 90% of sulfate mass was identified as being transported into New York City. *See* R. Lall & G. Thurston, *Identifying and Quantifying Transported vs. Local Sources of New York City $PM_{2.5}$ Fine Particulate Matter Air Pollution*, 40 Atmospheric Envrt. 336-346 (2005).

[90] U.S. EPA, Air Quality System (AQS) Annual Summary Monitor Data Queries, http://www.epa.gov/aqspubl1/annual_summary.html (last visited June 30, 2009).

[91] Data for carbon dioxide emission factors comes from Energy Info. Admin., U.S. Dept. of Energy, Fuel Emission Factors, http://www.eia.doe.gov/oiaf/1605/excel/Fuel%20Emission%20Factors.xls (last visited Jan. 19, 2010).

[92] Nat'l Ctr. for Envtl. Assessment, U.S. EPA, EPA/600/R-08/139F, Integrated Science Assessment for Particulate Matter at 2-28 (2009); U.S. EPA, PM_{10} Fact Sheet, http://www.epa.gov/wtc/pm10/pm_fact_sheet.html (last visited Jan. 19, 2010).

[93] *Compare* Ozone Transport Commission, ICI Boilers: OTC SAS Committee Meeting (2009).

[94] *See generally* Bottom of the Barrel, *supra* note 20.

[95] For more information on the emissions of volatile organic compounds, carbon monoxide, nitrogen oxides, sulfur oxides, particulate matter, methane, nitrous oxide, and carbon dioxide, see Argonne Nat'l Lab., GREET Model 1.8 (2008), *available for download at* http://www.transportation.anl.gov/modeling_simulation/GREET/index.html.

[96] *See* Integrated Science Assessment for Particulate Matter, *supra* note 92.

[97] *See id.* for more details on various susceptible populations. This analysis does look at a few age-specific populations, in particular the effects of soot on childhood bronchitis. Long-term studies carried out in California demonstrate that children living in areas with higher annual concentrations of $PM_{2.5}$ experience less growth in lung function as compared to children in areas with cleaner air. W. James Gauderman et al., *The Effect of Air Pollution on Lung Development from 10 to 18 Years of Age*, 351 New Eng. J. Med. 1057 (2004). Research studies have also shown that the incidence and severity of lung disease in children is also increased as a result of chronic exposure to elevated concentrations of $PM_{2.5}$. Rob McConnell et al., *Prospective Study of Air Pollution and Bronchitic Symptoms in Children with Asthma*, 168 Am. J. of Respiratory & Critical Care Med. 790 (2003).

[98] *See generally* Bottom of the Barrel, *supra* note 20.

[99] *See* GREET Model, *supra* note 95. Though nitrous oxide and methane are more potent greenhouse gases than carbon dioxide per ton emitted, so many more tons of carbon dioxide are emitted that its effects often dominate a fuel's lifecycle emissions. Some elements of particulate matter are theorized to have a possible cooling effect on the climate, but that

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cooling potential might be outweighed by opposing warming potentials of other elements, and are certainly outweighed by the overall warming effects of carbon dioxide emissions and black carbon emissions. *See* Integrated Science Assessment for Particulate Matter, *supra* note 92.

[100] Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, 74 Fed. Reg. 49,454, 49,612 (proposed Sept. 28, 2009).

[101] EIA, Fuel Emission Factors, *supra* note 91 (factors given for "Heavy Fuel Oil (No. 5, 6 fuel oil), bunker fuel"; "Middle Distillate Fuels (No. 1, No. 2, No. 4 fuel oil, diesel, home heating oil)" and "Weighted National Average Pipeline Natural Gas"). It is unclear how the sulfur-content of New York City specific oils might affect these emission factors.

[102] Bottom of the Barrel, *supra* note 20, at 68.

[103] *Id.* at 3.

[104] The two other possible energy security benefits ("monospony benefits" and military cost reductions) are not discussed because (a) the quantities of fuel implicated by this rule are unlikely to produce significant benefits; and (b) "monspony benefits" are not actually efficiency gains and should be treated as distributional impacts. *See* Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, *supra* note 100.

[105] *Id.* at 49,622 (for year 2015, midpoint estimate).

[106] *See* Clifford Krauss, *Shale Fracturing Could Lead to Boom in World Supplies*, N.Y. Times, Oct. 10, 2009 ("The fracturing technique has led to an increase in U.S. gas supplies of 40 percent.").

[107] *See* Integrated Science Assessment for Particulate Matter, *supra* note 92.

[108] For example, a 2005 study by NESCAUM found that switching to lower-sulfur fuel, by virtue of reducing particulate matter emissions, could achieve maintenance cost savings of $29,000 a year per 1000 houses on a national basis. NESCAUM, Low Sulfur Heating Oil in the Northeast States: An Overview of Benefits, Costs, and Implementation Issues (2005). To some extent such a figure would not represent a standard benefit, but rather would constitute a wealth transfer from maintenance companies to fuel consumers. Nonetheless, such efficiency or distributional effects could be significant.

[109] Bottom of the Barrel, *supra* note 20.

[110] U.S. Energy Info. Admin., Supplemental Tables, Updated Annual Energy Outlook 2009 Reference Case with ARRA, http://eia.doe.gov/oiaf/aeo/supplement/stimulus/suparra.htm (last visited Jan. 19, 2010) (giving 2010-2020 averages for the Middle Atlantic region, in 2007$). The estimates for distillate, residual, and natural gas are only given for commercial/institutional customers, not for residential customers. It is unclear whether the price of residual oil fully accounts for New York's sulfur requirements, which could raise the price above this average estimate.

[111] *See* Bottom of the Barrel, *supra* note 20 (discussing how New York utilities give price breaks to buildings that accept contracts for "interruptible" gas supply).

[112] See analysis from Chapter 5, *supra*, on the relative climate impacts of various heating fuels.

[113] *See* U.S. EPA, EPA-420-R-09-019, Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines at 7-10 (2009) (noting that switching all marine vessels in U.S. waters from standard #6 residual to lower sulfur fuels will only result in a "small increase in the price of marine distillate fuels"); *cf.* Energy Policy Research Foundation, *Costs and Supply Risks to Prohibitions on the Use of No. 4 and No. 6 Oil in New York City* (preliminary report) (Feb. 12, 2009).

[114] On December 12, 2009, the EPA finalized emission standards under the Clean Air Act for Category 3 marine diesel engines (marine engines with per-cylinder displacement at or above 30 liters). 40 C.F.R. § 94 (2009). In this new regulation, the EPA forbids the production and sale of marine fuel oil above 1,000 ppm sulfur in U.S. waters unless the vessel achieves equivalent emission reductions through alternative measures. Only a select number of ships on the Great Lakes are allowed to buy residual fuel that does not meet the 1,000 ppm sulfur standard. These standards will go into effect January 2015. *See* U.S. Envtl. Prot. Agency, Ocean-going Vessels: EPA Regulations, http://www.epa.gov/otaq/oceanvessels.htm#regs (last visited January 19, 2010). The new regulation applies to U.S.-flagged vessels and is equivalent to the standards in the MARPOL treaty, which contains marine pollution standards set forth by the International Maritime Organization (IMO). The standards in Annex VI of MARPOL, representing marine air pollution, came into force in May 2005. U.S. Envtl. Prot. Agency, New Law Bolsters U.S. Efforts to Make Ocean-Going Ships Cleaner, http://yosemite.epa.gov/opa/admpress.nsf/6424ac1caa800aab85257359003f5337/f1e6594e8e04fdd88525748e0069fb1f!OpenDocument (last visited January 19, 2010). Annex VI also applies to the United States after President Bush signed the Act to Prevent Pollution from Ships (33 U.S.C. 1901, et. seq.).

[115] *See* U.S. EPA, EPA-420-R-09-019, Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines 7-10 (2009); Petroleum Infrastructure Study: Final Report, *supra* note 31, at ES-12 ("Likely

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changes will require the use of low sulfur bunkers and marine diesels by vessels along the East Coast, and in turn, may drive up the price of residual fuel shifting the relationship between fuels.").

[116] *See* PETROLEUM INFRASTRUCTURE STUDY: FINAL REPORT, *supra* note 31.

[117] *See* Energy Policy Research Foundation, *supra* note 113, at 8.

[118] *See id*.

[119] *See* Letter from Michael Livermore, Exec. Dir. of IPI, to Minerals Management Service, U.S. Dep't of Interior (Apr. 6, 2009) (discussing price volatility of petroleum); Krauss, *supra* note 106; E-mail Correspondence with Christine Cummings, Con Edison Public Relations–NYC Government Relations (August 28, 2009) (discussing plans for increased availability of natural gas in New York City).

[120] If the emissions from #2 distillate oil are actually 68% that of #6 residual oil in New York City (as opposed to the 82% figure used in this study), then there would be an additional 55-143 avoided mortalities expected over twenty years. Also, the emission factors used in this analysis assume the sulfur content of residual oil to be .3% (3000 ppm). However, the law that mandates sulfur content in heating oil is loosely enforced, and sulfur content of #6 residual oil is likely often much higher than the values used in this analysis.

[121] P. HOPKE, A GUIDE TO POSITIVE MATRIX FACTORIZATION, *available at* http://www.epa.gov/ttnamti1/files/ambient/pm25/workshop/laymen.pdf; *see also*, U.S. EPA, EPA/600/R-08/108, PMF 3.0 Fundamentals and User Guide.

[122] Lall, *supra* note 29.

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