Assessment of Clean Gasoline in the Northeast and Mid-Atlantic States

White Paper

NESCAUM

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ASSESSMENT OF CLEAN GASOLINE IN THE NORTHEAST AND MID-ATLANTIC STATES

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About NESCAUM

NESCAUM is a 501(c)(3) nonprofit association of air quality agencies in the Northeast. NESCAUM's Board of Directors consists of the air directors of the six New England states (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont), New Jersey, and New York. Its purpose is to provide scientific, technical, analytical, and policy support to the air quality and climate programs of the eight Northeast states. A fundamental component of NESCAUM's efforts is to assist its member states in implementing national environmental programs required under the Clean Air Act and other federal legislation.

Acknowledgments

NESCAUM gratefully acknowledges the funding support provided for this study by the Energy Foundation, the International Council on Clean Transportation (ICCT), and the Mid-Atlantic/Northeast Visibility Union (MANE-VU).

NESCAUM thanks staff from the state air quality agencies in the Northeast for providing helpful comments and input for this report.

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ES-1. Overview

This White Paper summarizes the results of an assessment by the Northeast States for Coordinated Air Use Management (NESCAUM) of the need for, and the costs and benefits associated with, lowering gasoline sulfur content to an average of 10 parts per million (ppm) as part of the U.S. Environmental Protection Agency's (USEPA's) Tier 3 rulemaking for cars and light-duty trucks. This rule is expected to be proposed in late 2011 or early 2012 and finalized in 2012. This report is intended to inform state environmental officials in the Northeast and Mid-Atlantic about the public health and environmental benefits of lower sulfur gasoline in the region and cost of achieving them.

Lowering the sulfur content of gasoline allows pollution control equipment on cars and trucks to operate more effectively and can significantly reduce oxides of nitrogen (NOx) and other emissions from gasoline-powered vehicles. The emission reductions from the in-use fleet would be achieved concurrent with the introduction of the cleaner fuel, without the need for fleet turnover. The combined reductions from the Tier 3 vehicle emission standards and fuel sulfur requirements could be a significant component in achieving the needed reduction of ambient levels of air pollutants known to have adverse public health and environmental impacts. Similar gasoline sulfur requirements are currently in place in California, Europe, and Japan.

ES-2. Public Health and Environmental Need for Reducing NOx Emissions from Light-duty Vehicles

NOx emissions contribute to a number of adverse public health and environmental outcomes within the Ozone Transport Region (OTR), which extends from northern Virginia to Maine along the Eastern Seaboard. NOx is the most important contributor to elevated regional ozone concentrations and an important precursor to fine particulate matter (PM2.5) formation. These two pollutants are responsible for tens of thousands of premature deaths, hospital admissions, and lost work and school days in the U.S. annually. NOx is also a key factor in a number of environmental problems that affect the Northeast and Mid-Atlantic region, including acid rain, coastal marine eutrophication, and regional haze.

During severe ozone and fine particulate matter events, the geographic scale of the problem can extend beyond the OTR's borders and include over 200,000 square miles across the eastern United States. Local and regional sources as well as air pollution transported hundreds of miles from distant sources outside the OTR contribute to elevated ozone and fine particle concentrations in the region.

National and regional NOx controls, including those for motor vehicles, have proven to be extremely effective in lowering ambient levels of ozone in the eastern U.S. NOx emissions and ambient ozone concentrations in the OTR have dropped significantly since 1997, along with the frequency and magnitude of exceedances of the health-based national ambient air quality standard (NAAQS) for ozone. However, even with the projected benefits associated with the USEPA's Cross-State Air Pollution Rule, many of the most populous areas of the OTR are predicted to be nonattainment for the current 0.075 ppm ozone NAAQS in 2015. Attaining the standard in these areas will require significant additional NOx reductions within the OTR and in upwind areas that contribute to the pollution burden in the region. The Clean Air Scientific Advisory Committee (CASAC) has recommended that the ozone NAAQS be lowered to within a range of 0.060 to 0.070 ppm, which would create a further need for NOx reductions to better protect public health. Reductions not achieved through the Tier 3 program and other federal measures would have to come from additional controls on local sources.

Atmospheric sources of nitrogen can be key contributors to acidification of forest soils and fresh water ecosystems in the eastern United States. Atmospheric deposition of nitrogen also plays an important role in degraded water quality in economically important marine estuaries of the Eastern Seaboard due to excess nutrient loads. In addition, NOx emissions are transformed in the atmosphere to form nitrates that contribute to hazy views of urban skylines as well as scenic vistas in protected national parks and wilderness areas, especially during winter months.

ES-3. Contribution of Cars and Light Trucks to NOx Emissions in Mid-Atlantic/Northeast States

Gasoline-powered cars and light-duty trucks emitted about 29 percent of all NOx in the Mid-Atlantic/Northeast region in 2007 (Table ES-1). Air quality modeling suggests motor vehicles (gasoline and diesel) operating within and outside the OTR are the most significant contributors to ozone concentrations on days that exceed the NAAQS in the largest nonattainment areas in the region, which speaks to the importance of further lowering NOx emissions from motor vehicles in the OTR and in adjacent regions.

Table ES-1. Relative Source Contributions of NOx Emissions in the OTR, 2007.

Source	NOx Emissions (%)
HIGHWAY VEHICLES	52
ON-ROAD GASOLINE LIGHT-DUTY VEHICLES	*29*
ON-ROAD DIESEL VEHICLES	*22*
OFF-HIGHWAY	13
FUEL COMB. ELEC. UTIL.	13
FUEL COMB. RESIDENTIAL	5
OTHER INDUSTRIAL PROCESSES	4
FUEL COMB. INDUSTRIAL	2
OTHER MISCELLANEOUS (sum of source sectors contributing <1.7% each to total NOx)	11

Source: MANE-VU 2007 Inventory provided by the Mid-Atlantic Regional Air Management Association (November 2011). Note that this table covers all jurisdictions of the OTR except Virginia.

ES-4. Emission Reductions from 10 ppm Gasoline Sulfur Standard

A 10 ppm sulfur gasoline standard would reduce NOx emissions by approximately 25 percent from the existing fleet of gasoline-powered vehicles. The estimated per state and aggregate regional reduction benefits for gasoline-powered on-road vehicles are presented in Table ES-2. Based on the preliminary regional mobile source inventory for 2017, as calculated by NESCAUM with the USEPA's MOVES model, a 10 ppm average gasoline sulfur requirement could reduce NOx emissions in the OTR by over 51,000 tons per year, or 141 tons per day.

As shown in Table ES-2, the low sulfur gasoline component of the Tier 3 program would reduce NOx emissions by more than 60,000 tons per year in eight Midwest states and almost 65,000 tons per year in 10 southeastern states that abut the OTR. These reductions will benefit air quality in the OTR by: (1) lowering the "ozone reservoir" that forms in the eastern U.S., (2) reducing the amount of low-level NOx emissions and pollutants derived from NOx (e.g., nitrates) that are transported into the OTR, and (3) ensuring that vehicles registered in other states but operating in the OTR emit less NOx.

As indicated in Table ES-2, light-duty vehicles in the three regions are predicted to emit over 1,100,000 tons of NOx in 2017 absent the low sulfur gasoline standard. A 10 ppm average sulfur gasoline requirement could reduce NOx emission from this sector by nearly 180,000 tons per year, or almost 500 tons per day in the eastern U.S.

Table ES-2. On-road Gasoline Vehicle Emissions and Estimated Reductions Based on MOVES Estimates for 2017.

State/DC/Region	2017 Gasoline On-road Base NOx (tpy)	Est. NOx Reductions from 10 ppm S	
		(tpy)	(tpd)
Connecticut	20,700	-3,100	-8
Delaware	5,400	-800	-2
District of Columbia	2,000	-300	-1
Maine	10,000	-1,500	-4
Maryland	32,600	-5,000	-14
Massachusetts	35,100	-5,300	-15
New Hampshire	8,400	-1,300	-4
New Jersey	44,300	-6,700	-18
New York	88,600	-13,500	-37
Pennsylvania	70,500	-10,700	-29
Rhode Island	5,600	-900	-2
Vermont	5,000	-800	-2
Virginia OTR Counties	11,300	-1,700	-5
OTR Total	**339,500**	**-51,600**	**-141**
Midwest States Total[1]	**402,300**	**-61,000**	**-167**
Southeast States Total[2]	**427,800**	**-64,900**	**-178**
3 Region Total	**1,169,600**	**-177,500**	**-486**

[1] IL, IN, IA, MI, MN, MO, OH, WI.

[2] AL, FL, GA, KY, MS, NC, SC, TN, VA (not including counties in OTR), WV.

NESCAUM used the USEPA's Environmental Benefits Modeling and Analysis Program (BenMAP)[3] to estimate the annual number of avoided adverse health events (e.g., emergency room visits) and their monetized value within the OTR that would be associated with the implementation of a federal low sulfur gasoline program. Table ES-3 shows BenMAP estimates of avoided health impacts in the OTR in 2018 in the range of $234 million to $1.2 billion (in 2006$). The central value of this range is approximately $710 million. The health benefits valuation is dominated by avoided premature mortality, which ranges between 29 and 158 incidents in the OTR. Most of the mortalities avoided are due to lower ozone levels resulting from reduced NOx emissions by on-road gasoline vehicles. Modeled health benefits from PM2.5 reductions associated with lower sulfur gasoline are more modest due to the small relative contribution of gasoline combustion to total emissions of sulfur dioxide, which leads to secondary PM2.5 formation. The values presented in this paper are derived from a conservative approach and demonstrate that there will be immediate and significant health benefits in the OTR from lowering sulfur in gasoline for the on-road vehicle fleet in 2018. This assessment does not account for the monetary benefits associated with environmental improvements that would accrue from reduced nitrogen emissions related to the low sulfur gasoline program.

Table ES-3. Estimated Annual Monetized Health Benefits Due to Low Sulfur Gasoline in OTR.

	Value [Millions of 2006$]		
	Ozone	PM2.5	Total
Morbidity	$19.5	$3.9	$23.4
Mortality	$196 - $877	$15 - $285	$210 - $1,162
Total Avoided Health Incidence	**$215 - $896**	**$19 - $289**	**$234 - $1,186**

Note: Monetized benefits include all of Virginia.

ES-5. Cost-effectiveness of 10 ppm Gasoline Sulfur Standard

Cost estimates for 10 ppm sulfur gasoline derived from two studies and emission reduction estimates from MOVES runs conducted by NESCAUM were used to assess the costs-effectiveness of NOx reductions from the Tier 3 low sulfur gasoline program. To capture the range of potential cost-effectiveness values, cost estimates from the USEPA's Mobile Source Air Toxics (MSAT) notice of proposed rulemaking and a recent study sponsored by the International Council on Clean Transportation (ICCT) were used to calculate the potential cost per ton of NOx reduced.

[3] USEPA. 2010. *Environmental Benefits Mapping and Analysis Program (BenMAP)*, BenMAP 4.0.35, US Version (September 2010). Available at http://www.epa.gov/air/benmap/download.html.

Table ES-4. Estimated Cost-Effectiveness of Tier 3 Low Sulfur Gasoline Requirements

Cost	Cost-Effectiveness ($/ton NOx)
0.5 cents/gal *(USEPA MSAT)*	$2,500
0.8 cents/gal *(ICCT)*	$4,000
1.4 cents/gal *(ICCT)*	$7,000

As shown in Table ES-4, the cost-effectiveness of lower sulfur gasoline is estimated at $2,500 per ton NOx reduced, based on the USEPA MSAT cost estimate of 0.5 cents per gallon. The ICCT-sponsored study provides a conservative cost estimate of 1.4 cents per gallon, which translates to a cost-effectiveness of around $7,000 per ton in the OTR. The ICCT also provides a sensitivity case cost estimate of 0.8 cents per gallon that accounts for refineries capable of producing 10 ppm sulfur gasoline at lower capital expenditure and assumes a lower target return on investment (7 percent instead of 10 percent). Using the sensitivity case cost of 0.8 cents per gallon, the estimated cost-effectiveness of the overall program is $4,000 per ton of NOx reduced. The cost-effectiveness of low sulfur gasoline compares favorably to a number of other emission reduction strategies that are already in place or are being considered in the OTR, as well as previous federal fuel sulfur rules. Many of the most cost-effective NOx reduction measures have already been implemented.

Based on the total NOx reductions estimated for the OTR and all of Virginia resulting from 10 ppm low sulfur gasoline, the total program cost in 2017 for this region would be in the range of $143 – $400 million (Table ES-5) using the USEPA MSAT and ICCT gasoline cost range of 0.5 – 1.4 cents per gallon. This compares favorably to the total monetized program health benefits in 2018 derived from BenMAP, which are in the range of $234 – $1,186 million. The estimated monetized benefits are based on public health benefits from lowering exposure to ozone and sulfate PM2.5, and do not include health benefits from lowering other pollutants or benefits to the environment, such as decreases in acid rain and eutrophication.

Table ES-5. Comparison of Estimated Low Sulfur Gasoline Program Costs and Monetized Health Benefits for the Mid-Atlantic and Northeast Region.

Total Low Sulfur Program Costs	Monetized Health Benefits
$143 – $400 million	$234 – $1,186 million

Note: Total costs and benefits estimates are for the OTR plus all of Virginia.

ES-6. Economic Impact of a 10 ppm Gasoline Sulfur Standard

The expected 10 ppm sulfur gasoline proposal would represent the latest in a series of regulatory initiatives to remove sulfur from transportation fuels. The USEPA previously established a 30 ppm sulfur standard for gasoline as part of the Tier 2 motor vehicle rulemaking (2000), a 15 ppm sulfur limit for highway diesel (2001), and a 15 ppm sulfur limit for non-road diesel (2004). Additionally, many states in the OTR have already or are in the process of establishing low sulfur standards for distillate oil used for heating. To comply with these rules, U.S. refiners have invested significant capital to add and enhance desulfurization capacity.

During past low sulfur fuel rulemakings, refiners raised a set of consistent concerns: (1) the requirements went too far, too fast; (2) they would result in fewer operating refineries; (3) they would lead to fuel shortages; and (4) the refining costs would be excessively high. The final rules provided for regulatory flexibility, which along with industrial innovation to meet the new requirements, resulted in manageable implementation of the rules. In retrospect, both USEPA and industry estimates of the predicted costs for complying with federal fuel sulfur standards were found to be typically higher than actual costs as refiners found innovative and less costly ways to achieve these standards. Original estimates of the cost of lowering sulfur in transportation fuels were principally based on the assumption that refiners would continue to deploy traditional conventional technology to achieve compliance. In actual practice, refiners opted for a combination of technology and facility efficiency improvements to cost-effectively remove sulfur.

The USEPA built considerable regulatory flexibilities into the fuels standards to ease the regulatory burden on refiners, including: (1) providing several years of lead time for all refiners to add or enhance desulfurization capabilities; (2) averaging, banking, and trading programs to encourage early compliance where possible and provide means for extending compliance dates where needed; (3) provisions for smaller and geographically isolated refiners to further extend compliance deadlines and credit generation opportunities; (4) opportunities for refiners to integrate their desulfurization infrastructure planning processes across all three fuels programs; (5) interim sulfur limits to allow refiners to phase their operations into compliance with the final standards; and (6) various hardship waiver provisions to provide a means to address unexpected circumstances.

ES-7. Conclusion

The results of this analysis indicate that lowering the sulfur content of gasoline to an average of 10 ppm would cost-effectively reduce NOx emissions from cars and light trucks. Low sulfur gasoline could be one of the most significant strategies available to address ground-level ozone pollution in the OTR. The projected NOx reductions associated with the Tier 3 / low sulfur gasoline proposal would also help mitigate fine particle concentrations, acid rain, waterbody eutrophication, and regional haze – all significant challenges in the Northeast and Mid-Atlantic region.

A key advantage to lowering sulfur in gasoline is that the emission reductions will occur immediately and come from all gasoline vehicles equipped with catalytic converters, regardless of the vehicle's model year. As a federal requirement, the low sulfur gasoline rule would result in very significant NOx reductions across the entire domain in the eastern U.S., thus diminishing the adverse public health and environmental outcomes in the OTR related to NOx emissions.

Given the stringency of existing state controls in the OTR, federal constraints on state regulation of motor vehicle fuels, and the fact that the OTR is significantly affected by pollution transport from sources outside the region, national emission control measures for light-duty vehicles are critical to achieving further improvements in air quality. Without the mobile source and other federal measures, emission reductions will have to be accomplished by further controlling local sources in the OTR in order to compensate for the foregone national measures. While local controls remain necessary, some of the additional measures will be above and beyond what otherwise would be needed, and at greater cost.

1. INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) is scheduled to propose new emission standards for model year 2014 and later light-duty motor vehicles in early 2012 (Tier 3 standards). The Tier 3 proposal is expected to include a 10 parts per million (ppm) limit on the average fuel sulfur content of gasoline. Similar sulfur requirements are currently in place in California, Europe and Japan. Lowering gasoline sulfur content allows pollution control equipment on cars and trucks to operate more effectively and can significantly reduce nitrogen oxides (NOx) and other emissions from all gasoline-powered vehicles. Unlike vehicle emission standards that require the fleet to "turnover" before the full emission benefits are realized, fuel quality programs provide reductions concurrent with the introduction of the cleaner fuel. NOx emissions are important contributors to ozone and fine particle pollution, which pose a significant public health threat in the Northeast and Mid-Atlantic region. These emissions also contribute to regional environmental problems including acid rain, eutrophication of waterbodies, and regional haze.

This White Paper summarizes the results of an assessment by the Northeast States for Coordinated Air Use Management (NESCAUM) of the need for, and the costs and benefits associated with, lowering gasoline sulfur content to 10 ppm as part of the USEPA's Tier 3 rulemaking. It is intended to inform state environmental officials in the Northeast and Mid-Atlantic region about the public health and environmental benefits of lower sulfur gasoline. This analysis focuses on the Ozone Transport Region (OTR) that extends from northern Virginia to Maine,[4] but evaluates the potential benefits that might be realized in the region as a result of Tier 3 NOx reductions in adjacent regions that affect air quality in the OTR. This paper provides information on: (1) the public health and environmental need for reducing light-duty vehicle NOx emissions in the OTR; (2) the impact that lower sulfur gasoline would have on emission inventories, air quality, and public health; (3) the estimated cost-effectiveness of this strategy; (4) the relative benefits and cost of this measure compared to other possible NOx control strategies; and (5) insight about the potential economic impacts of this program based on previous environmental fuel quality regulations.

[4] The OTR includes Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and the northern Virginia counties in the DC metropolitan area.

2. BACKGROUND CONTEXT

The USEPA committed to proposing Tier 3 standards in 2008 to help states meet the National Ambient Air Quality Standard (NAAQS) for ozone and is late in delivering the much needed reductions from the light-duty vehicle sector, which is the largest source of ozone-forming pollutants in the OTR. The Tier 3 program would: (1) ensure less polluting cars to help the states meet the 0.075 ppm ozone health standard; and (2) mitigate any adverse impacts on air quality from the implementation of the "Renewable Fuel Standard 2" (RFS-2).[5]

The California Air Resources Board (CARB) is also preparing a proposal for new light-duty motor vehicle standards (LEV III), with the goal of harmonizing with the Tier 3 federal standards. Both CARB and the USEPA are considering stringent fleet average tailpipe standards for NOx, volatile organic compounds (VOCs), and particulate matter (PM), as well as near-zero evaporative emissions. As part of the proposed Tier 3 rulemaking, the USEPA is also expected to set an average sulfur content requirement of 10 ppm for gasoline. Federal standards currently require gasoline suppliers to meet an average sulfur standard of 30 ppm and cap the maximum sulfur content at 80 ppm. California already caps sulfur at 30 ppm, and the average sulfur content of gasoline in that state is about 9 ppm. The European Union and Japan allow a maximum of 10 ppm sulfur in gasoline.[6]

2.1. Overview of Benefits

The low sulfur gasoline standard is expected to reduce NOx emissions by approximately 25 percent from the existing fleet of light-duty vehicles by enabling catalytic converters to operate more effectively.[7] The emission reductions from the in-use fleet would be achieved upon introduction of the cleaner fuel, without the need for fleet turnover. The combined reductions from the new vehicle emission standards and fuel sulfur requirements could be a significant component in the reduction of ambient levels of air pollutants known to have adverse public health and environmental impacts. Reductions not achieved through this and other federal measures would have to come from additional controls on local sources in the region.

2.2. State Authority under the Clean Air Act

The Clean Air Act (CAA) limits state authority to regulate emissions from motor vehicles and fuels. The CAA preempts state and local governments from adopting or enforcing emission standards for new motor vehicles. However, California can receive a

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[5] The Energy Independence and Security Act of 2007 (EISA) requires the USEPA to revise the Renewable Fuel Standard program to incorporate greater amounts of renewable fuels into transportation fuels. The USEPA expects that the increased renewable fuel content of RFS-2 will result in higher emissions of NOx, hydrocarbons, ethanol, and acetaldehyde. [USEPA. 2009. *Fuels and Fuel Additives: EPA Proposes New Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond*, USEPA, EPA-420-F-09-023 (May 2009). Available at http://www.epa.gov/oms/renewablefuels/420f09023.htm (accessed September 2, 2011).]

[6] Ober, J.A. 2003. "Sulfur," in *U.S. Geological Survey Minerals Yearbook – 2003*, United States Geological Survey. Available at http://minerals.usgs.gov/minerals/pubs/commodity/sulfur/sulfumyb03.pdf.

[7] See discussion in Section 4.3.

waiver of preemption from the USEPA for its emission standards and enforcement procedures. Section 177 of the CAA allows other states to adopt the California vehicle standards in lieu of the federal standards. Ten Northeast and Mid-Atlantic states and the District of Columbia have adopted California's low emission vehicle standards. Section 211(c) of the CAA limits states, except for California, from further regulating constituents of gasoline, including sulfur, that are already regulated by the federal government. Therefore, states in the OTR must rely on federal action on gasoline sulfur content to further reduce NOx from the existing fleet of cars and light trucks.

2.3. Current State Efforts

Individually, the states in the OTR are implementing some of the most health protective air pollution control programs in the nation. Collectively, they have implemented a host of regional NOx, VOC, and sulfur dioxide (SO_2) control measures, including the first regional cap and trade program for NOx, adoption of the California low emission vehicle standards, and consumer products and architectural coatings standards to reduce VOCs. These initiatives, combined with federal measures, including the Federal Motor Vehicle Emission Control program, have led to important air quality and public health improvements in the OTR. Given the stringency of existing state controls, federal constraints on state regulation of motor vehicle fuels, and the fact that the OTR is significantly affected by pollution transport from sources outside the region, national control measures for light-duty vehicles are critical to achieving further improvements in air quality.

3. PUBLIC HEALTH AND ENVIRONMENTAL NEED

The OTR, home to over 62 million people, is subject to episodes of poor air quality resulting from ground-level ozone and fine particle pollution. During severe events, the scale of the problem can extend beyond the OTR's borders and include over 200,000 square miles across the eastern United States. Local and regional sources as well as air pollution transported hundreds of miles from distant sources outside the OTR contribute to elevated ozone and fine particle concentrations in the region.

This section summarizes the air quality challenge facing the OTR, with a focus on ozone. It describes the contribution of light-duty vehicles to the NOx emission inventories in the Northeast and Mid-Atlantic states.

3.1. Adverse Impacts of NOx Emissions

As indicated in Table 3-1, NOx emissions contribute to a number of adverse public health and environmental outcomes. NOx is the most important contributor to regional ozone concentrations and an important precursor to fine particulate matter formation. These two pollutants are responsible for tens of thousands of premature deaths, hospital admissions, and lost work and school days in the U.S. annually. NOx is also a key factor in a number of environmental problems that affect the Northeast and Mid-Atlantic region.

Table 3-1. Adverse Public Health and Environmental Impacts of NOx in the OTR.

Ozone and PM2.5
• Reduces lung function, aggravates asthma and other chronic lung diseases
• Can cause permanent lung damage from repeated exposures
• Contributes to premature death
Acid Deposition
• Damages forests
• Damages aquatic ecosystems, e.g., Adirondacks and Great Northern Woods
• Erodes manmade structures
Coastal Marine Eutrophication
• Depletes oxygen in the water, which suffocates fish and other aquatic life in bays and estuaries, e.g., Chesapeake Bay and Long Island Sound
Visibility Impairment
• Contributes to regional haze that mars vistas and views in urban and wilderness areas

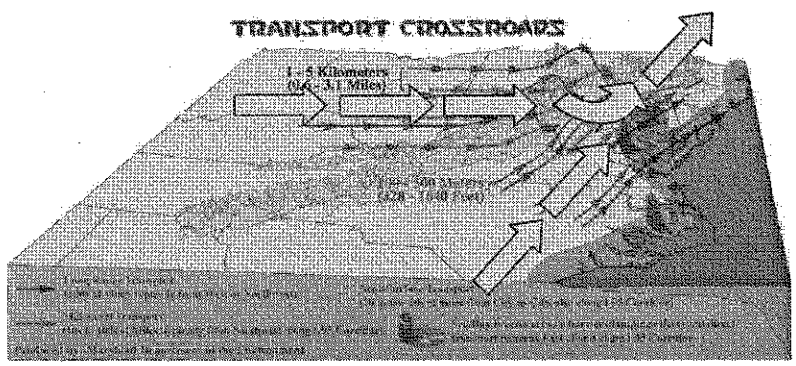
3.1.1. Ozone

Ozone remains a persistent regional pollution problem in parts of the OTR during warm weather months. The evolution of severe ozone episodes in the OTR often begins with the passage of a large high pressure area from the Midwest to the middle or southern Atlantic states. As depicted in Figure 3-1, there are three primary pollution transport mechanisms that affect air quality in the OTR: long-range, mid-level, and near-surface.

One transport mechanism that can play a key role in moving pollution long distances along the Eastern Seaboard is the "nocturnal low level jet" (NLLJ). The NLLJ is a regional-scale phenomenon of higher wind speeds a few hundred meters above the surface, just above the stable night-time (nocturnal) boundary layer. The jet has been observed just before or during ozone events and can convey air pollution several hundred miles overnight from the southwest to the northeast, directly in line with the major population centers of the Northeast Corridor.[8]

During severe ozone episodes associated with high pressure systems, multiple transport features are embedded within a large ozone reservoir arriving from source regions to the south and west of the OTR. A severe ozone episode can contain elements of long-range air pollution transport from outside the OTR, regional scale transport within the OTR, and local transport along coastal shores due to bay, lake, and sea breezes.

3 Types of Transport Contribute to Ozone Problem



- Westerly, local and southerly/night-time low level jet (NLLJ) transport converge on the Mid-Atlantic area.
- Sea and bay breezes act as a barrier or wall and funnel ozone and other air pollutants up the Northeast Corridor.
- On bad air days, 60-100 ppb of ozone comes into the OTR as a result of transport
- Need comprehensive, strong federal measures to meet attainment

Figure 3-1. Modes of Air Pollution Transport into and within the OTR.

Collectively, NOx emissions and ambient ozone concentrations in the OTR have dropped significantly since 1997, along with the frequency and magnitude of ozone exceedances of the health-based ozone national ambient air quality standard (NAAQS).[9] Despite this demonstrated progress, Figure 3-2 shows that even with the projected benefits associated with the USEPA's Cross-State Air Pollution Rule (CSAPR), many of

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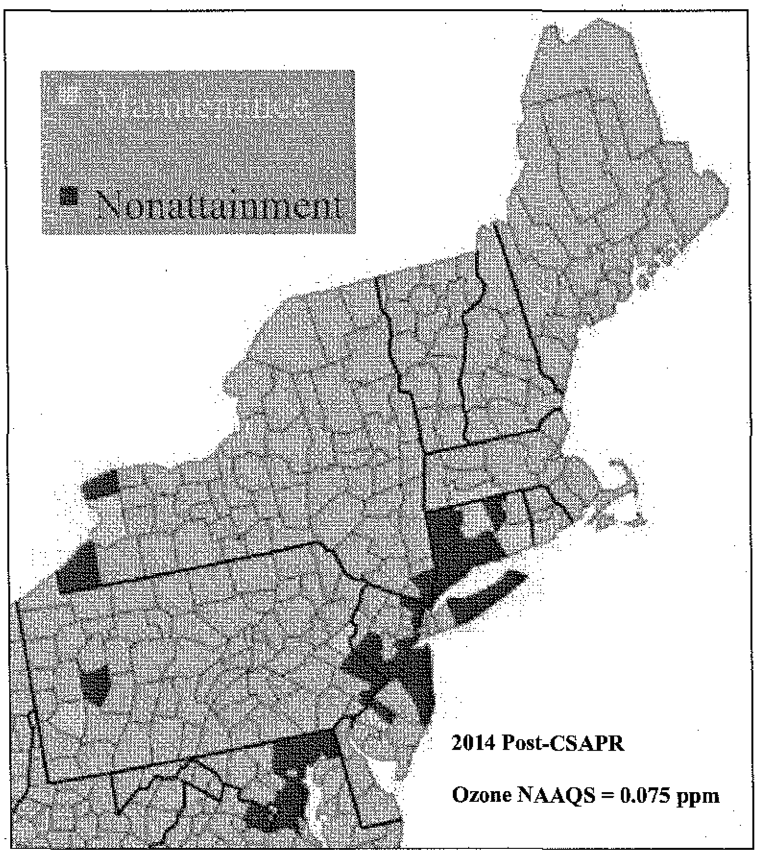
[8] Philbrick, C.S., W. Ryan, R. Clark, P. Hopke, and S. McDow. 2003. *Processes controlling urban air pollution in the Northeast: Summer 2002.* Final Report for the Pennsylvania Department of Environmental Protection (July 25, 2003).

[9] NESCAUM. 2010. *The Nature of the Ozone Air Quality Problem in the Ozone Transport Region: A Conceptual Description*, prepared for the Ozone Transport Commission by NESCAUM, Boston, MA (August 2010). Available at http://www.nescaum.org/documents/2010_o3_conceptual_model_final_revised_20100810.pdf/.

the most populous areas of the OTR will continue to violate the current 0.075 ppm ozone NAAQS (8-hour average).[10] Attaining the standard in these areas will require significant additional NOx reductions within the OTR and in upwind areas. Federal measures such as the Tier 3/low sulfur gasoline program will significantly reduce NOx emission and help states achieve the requisite reductions.



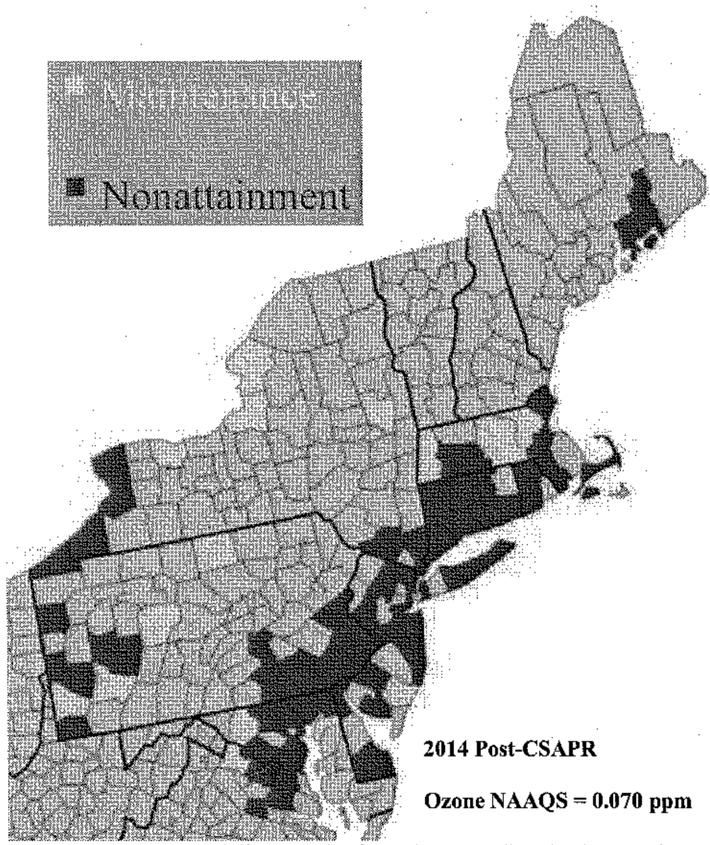
Based on CAMx modeling results for CSAPR [USEPA, *Air Quality Modeling Final Rule Technical Support Document*, June 2011, http://www.epa.gov/airtransport/pdfs/AQModeling.pdf].

Figure 3-2. Projected Nonattainment & Maintenance Counties for 0.075 ppm ozone NAAQS in 2014 after CSAPR Implementation.

Looking toward the future, additional NOx reductions will be critical to ozone attainment in a broader swath of the OTR if the USEPA were to adopt a more health protective ozone NAAQS in the range recommended by the USEPA's Clean Air Scientific Advisory Committee (CASAC). Figure 3-3 shows the predicted expansion of

[10] Note that the figure only highlights counties that have ozone monitors located within them that are projected to be nonattainment or maintenance areas for the ozone standard. Additional counties within the same metropolitan areas will also be affected by high ozone pollution.

nonattainment areas in the OTR based on a more stringent ozone NAAQS of 0.070 ppm (8-hour average), which is at the upper end of CASAC's previously recommended range of 0.060 – 0.070 ppm.



Based on CAMx modeling results for CSAPR [USEPA, *Air Quality Modeling Final Rule Technical Support Document*, June 2011, http://www.epa.gov/airtransport/pdfs/AQModeling.pdf].

Figure 3-3. Projected Nonattainment & Maintenance Counties for Hypothetical 0.070 ppm ozone NAAQS in 2014 after CSAPR Implementation.

3.1.2. Particulate Matter

Scientific evidence has established a solid link between cardiac and respiratory health risks and transient exposure to ambient fine particle pollution that is capable of penetrating deep into the lungs.[11] Exceedances of the fine particle NAAQS can occur at any time of the year, with some of the highest levels often reached in the winter. There are important differences in the chemical species responsible for high fine particle levels during summer and winter in the OTR. Regional fine particle formation in the eastern

[11] USEPA. 2005. *Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information*, USEPA OAQPS Staff Paper, EPA-452/R-05-005a, (December 2005).

United States is primarily due to SO_2, but NOx is also important because of its influence on the chemical equilibrium between sulfate and nitrate pollution during winter when nitrates can be a relatively greater contributor to urban PM2.5 levels.

3.2. Adverse Environmental Impacts of NOx Emissions

3.2.1. Acid Deposition

Atmospheric sources of nitrogen are a primary contributor to acidification of forest soils and fresh water ecosystems in the Northeast and Mid-Atlantic region. Nitrogen saturation results in a number of important changes in forest ecosystem functions, including: (1) increased acidification of soils and surface waters; (2) depletion of soil nutrients and the development of plant nutrient imbalances; and (3) forest decline and changes in species composition. More than 30 percent of the lakes in the Adirondacks and at least 10 percent of the lakes in New England are susceptible to the effects of acidic episodes that include long-term increases in mortality, emigration, and reproductive failure of fish, as well as short-term acute effects. Acidic episodes can occur at any time of the year but typically are most severe during spring snowmelt, when biological demand for nitrogen is low and saturated soils exhibit lower nitrogen retention.[12]

3.2.2. Coastal Marine Eutrophication

Airborne nitrogen is an important contributor to eutrophication, the process by which a body of water acquires a high concentration of nutrients that promote excessive growth of algae. As the algae die and decompose, high levels of organic matter and decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish. Atmospheric nitrogen is a major contributor to eutrophication of key coastal resources in portions of the OTR, including Chesapeake Bay, Delaware inland bays, Barnegat Bay in New Jersey, and Long Island Sound (Figure 3-4).[13]

The Chesapeake Bay watershed is the largest estuary in the U.S. and stretches across more than 64,000 square miles, encompassing parts of six states — Delaware, Maryland, New York, Pennsylvania, Virginia and West Virginia — and the entire District of Columbia. Since the 1950s, the Bay has experienced a decline in water quality due to over-enrichment of unwanted nutrients such as phosphorus and nitrogen. The major contributors to nutrient discharge in the Bay are wastewater effluent, urban and agricultural runoff, and air deposition.[14]

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[12] Driscoll, C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C. Eagar, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C. Weathers. 2001. *Acidic deposition in the northeastern United States: Sources and inputs, ecosystem effects, and management strategies*, BioScience 51, 180–198.

[13] Bricker, S.B., C.G. Clement, D.E. Pirhalla, S.P. Orlando, and D.R.G. Farrow. 1999. *National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries*, NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science. Silver Spring, MD: 71 pp.

[14] Maryland Department of the Environment, *Chesapeake Bay Restoration*, http://www.mde.state.md.us/programs/Water/Pages/water/bayrestoration.aspx (accessed September 1, 2011).

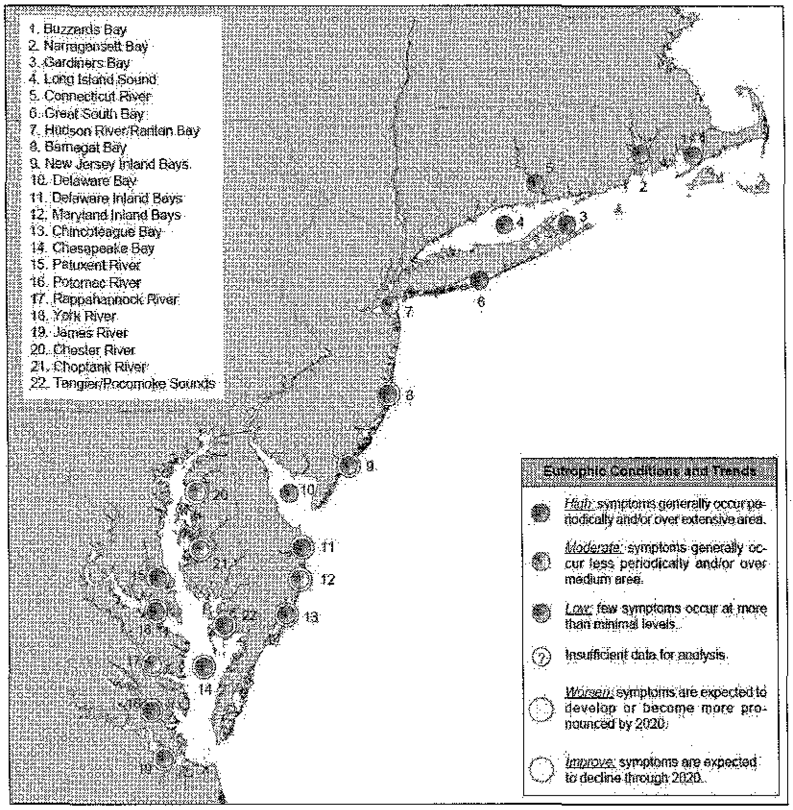

Figure from Bricker, et al. (*see* footnote 13).

Figure 3-4. Coastal Marine Eutrophication Conditions and Trends in Middle Atlantic Region.

3.2.3. Visibility Impairment

Regional haze is a form of air pollution that obscures the views of city skylines (Figure 3-5) as well as "pristine" scenic vistas (Figure 3-6). It is caused by fine particle air pollution and can cover hundreds of square miles in the East. Natural visibility conditions in the East are estimated at over 60 to 80 miles in most locations. Under current polluted conditions, average visibility ranges from 20 to 40 miles. On the worst days, regional haze can reduce visibility to just a few miles.

Outdoor recreation is a multi-billion dollar industry in the U.S. and is of particular economic importance to communities near protected federal lands. Surveys indicate visitors have rated "clean, clear air" as among the most important features of national parks and have overwhelmingly ranked scenic views and clean air as "extremely" or "very" important. Studies have yielded estimates in the billions of dollars for the visibility benefits associated with substantial national pollution reductions.[15] While

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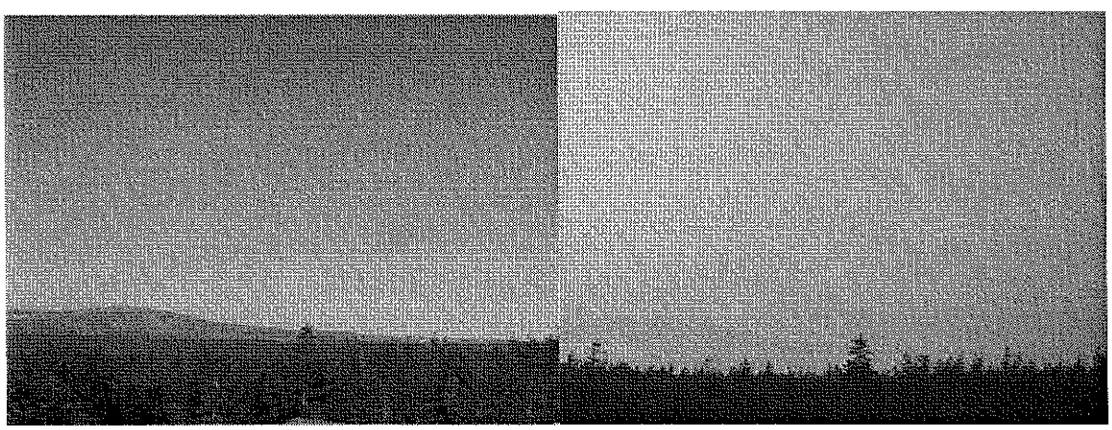
[15] NESCAUM. 2001. *Regional Haze and Visibility in the Northeast and Mid-Atlantic States*, NESCAUM, Boston, MA (January 31, 2001). Available at http://www.nescaum.org/documents/regional-haze-and-visibility-in-the-northeast-and-mid-atlantic-states/.

sulfate, formed from SO_2 emissions, is the most important particle constituent of regional haze, reductions in other local and distant pollutant emissions, including NOx, will be necessary to achieve the nation's long-term goal of restoring pristine visibility conditions year-round in national parks and wilderness areas.[16]

Photo from CAMNET: Realtime Air Pollution and Visibility Monitoring Network, www.hazecam.net.

Figure 3-5. Winter Pollution Haze Layer over Boston, MA on January 14, 2010.



Photos from CAMNET: Realtime Air Pollution and Visibility Monitoring Network, www.hazecam.net.

Figure 3-6. Comparison of a clear day on February 22, 2008 (left) and a hazy polluted day on August 17, 2009 (right) in Acadia National Park, ME.

[16] In 1999, the USEPA promulgated the Regional Haze Rule in pursuit of the national visibility goal created by Congress in the Clean Air Act to ultimately restore natural visibility conditions in 156 national parks and wilderness areas across the country (called "Class I" areas).

4. MOBILE SOURCE EMISSIONS IMPACTS

This section explains the continued importance of addressing emissions from the on-road vehicle fleet in the OTR, and quantifies the expected emission reductions from the existing fleet associated with the introduction of 10 ppm sulfur gasoline.

4.1. Contribution of Cars and Light Trucks to NOx Emissions in Mid-Atlantic/Northeast States

As shown in Table 4-1, on-road gasoline-powered cars and light-duty trucks emitted about 29 percent of all NOx in the Mid-Atlantic/Northeast region in 2007. This sector is the largest source of NOx emissions in the region in 2007.

Table 4-1. Relative Source Contributions of NOx Emissions in the OTR, 2007.

Source	NOx Emissions (%)
HIGHWAY VEHICLES	51.76
ON-ROAD GASOLINE LIGHT-DUTY VEHICLES	*29.28*
ON-ROAD DIESEL VEHICLES	*22.48*
OFF-HIGHWAY	13.39
FUEL COMB. ELEC. UTIL.	13.41
FUEL COMB. RESIDENTIAL	4.59
OTHER INDUSTRIAL PROCESSES	3.82
FUEL COMB. INDUSTRIAL	1.82
OTHER MISCELLANEOUS (sum of source sectors contributing <1.7% each to total NOx)	11.21

Source: MANE-VU 2007 Inventory provided by the Mid-Atlantic Regional Air Management Association (November 2011). Note that this table covers all jurisdictions of the OTR except Virginia.

4.2. Contribution of Source Sectors to Ozone Nonattainment

The following figures show the predicted relative contributions of various source sectors to 2015 exceedance-level ozone concentrations in three large metropolitan areas within the OTR – New York City (Figure 4-1), Philadelphia (Figure 4-2), and Baltimore (Figure 4-3).[17] These indicate the proportional contributions from various source sectors during periods of peak ozone concentrations. These charts assume super-regional controls on power plants based on the USEPA's court-remanded Clean Air Interstate Rule (CAIR). Although CSAPR has now replaced CAIR, these figures provide a reasonable approximation of source contributions to these nonattainment areas under peak ozone conditions. These predictions do not include Tier 3 vehicle standards. Motor vehicles (gasoline and diesel) are the most significant contributors to elevated ozone concentrations in all three of these nonattainment areas. Modeling suggests that emissions from motor vehicles operating within and outside these nonattainment areas

[17] USEPA. 2005. *Results of 2010/2015 Post-CAIR Ozone Source Apportionment Modeling* (August 2005). Available at http://www.epa.gov/ttnnaaqs/ozone/o3imp8hr/documents/materials/CAIR_2010_2015_SA_summary_final.ppt.

are responsible for approximately one-third of the ozone formed. This speaks to the importance of further lowering NOx emissions from the existing fleet of vehicles.

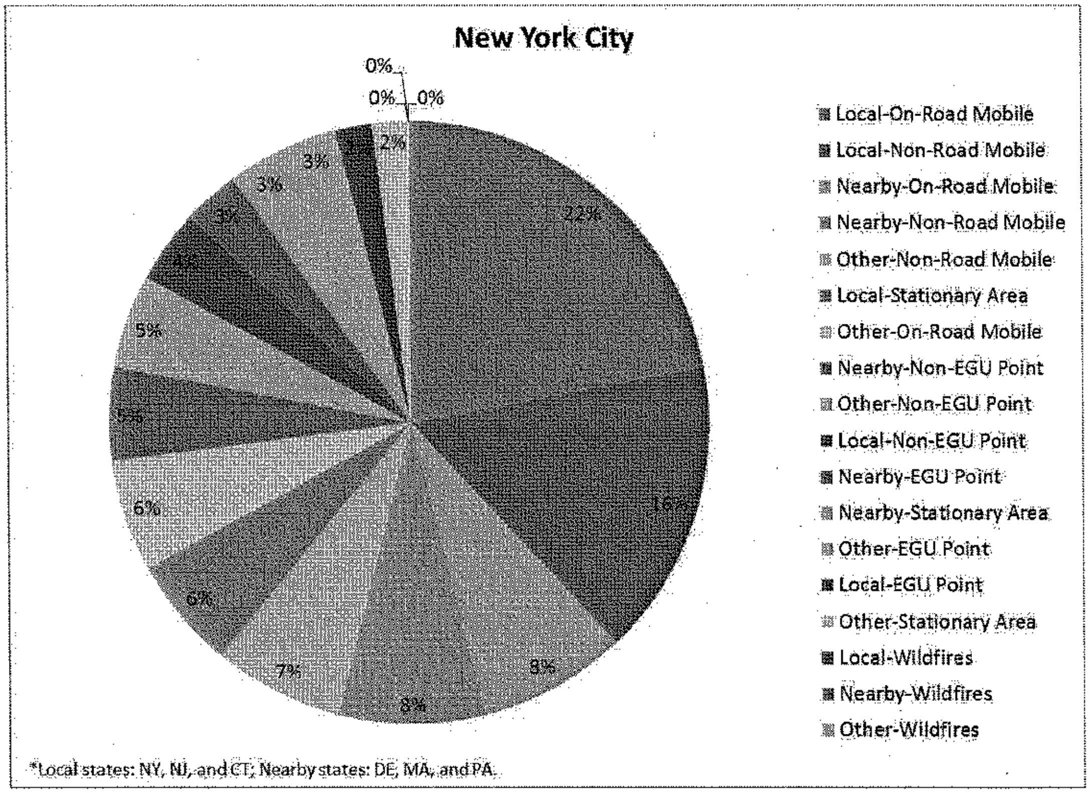


Figure 4-1. 2015 Average Contribution (%) by State/Sector to Exceedance-level Ozone in the New York City Nonattainment Area.

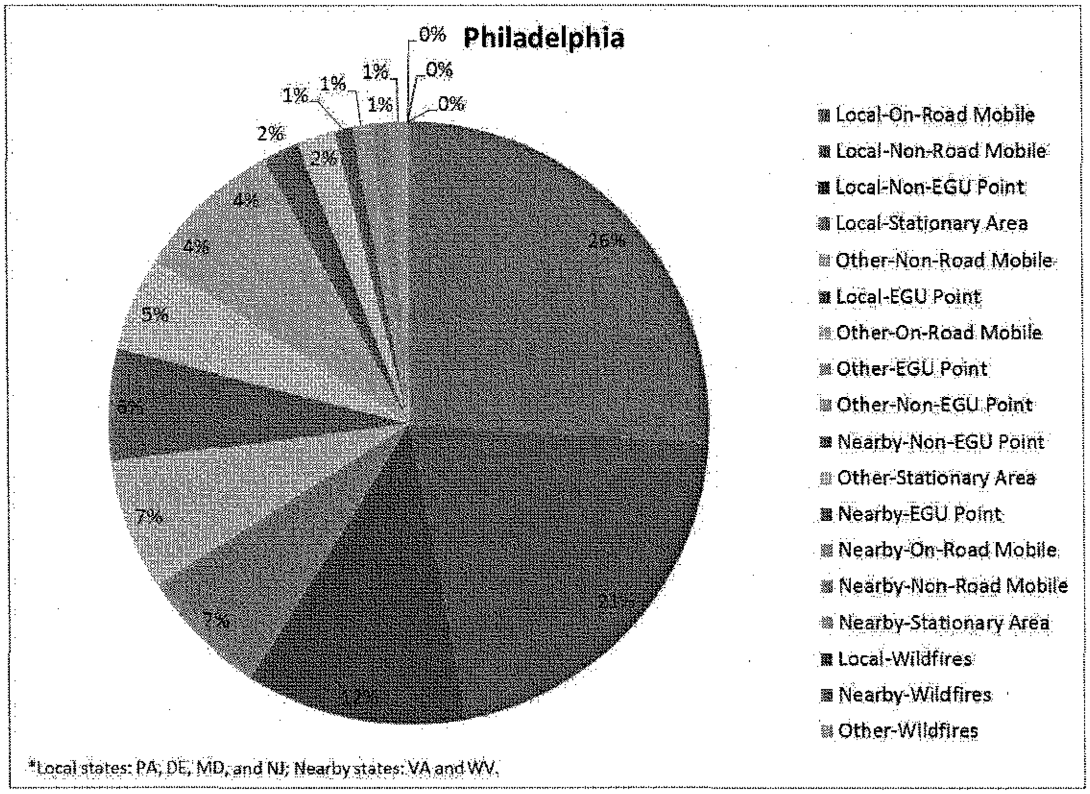


Figure 4-2. 2015 Average Contribution (%) by State/Sector to Exceedance-level Ozone in the Philadelphia Nonattainment Area.

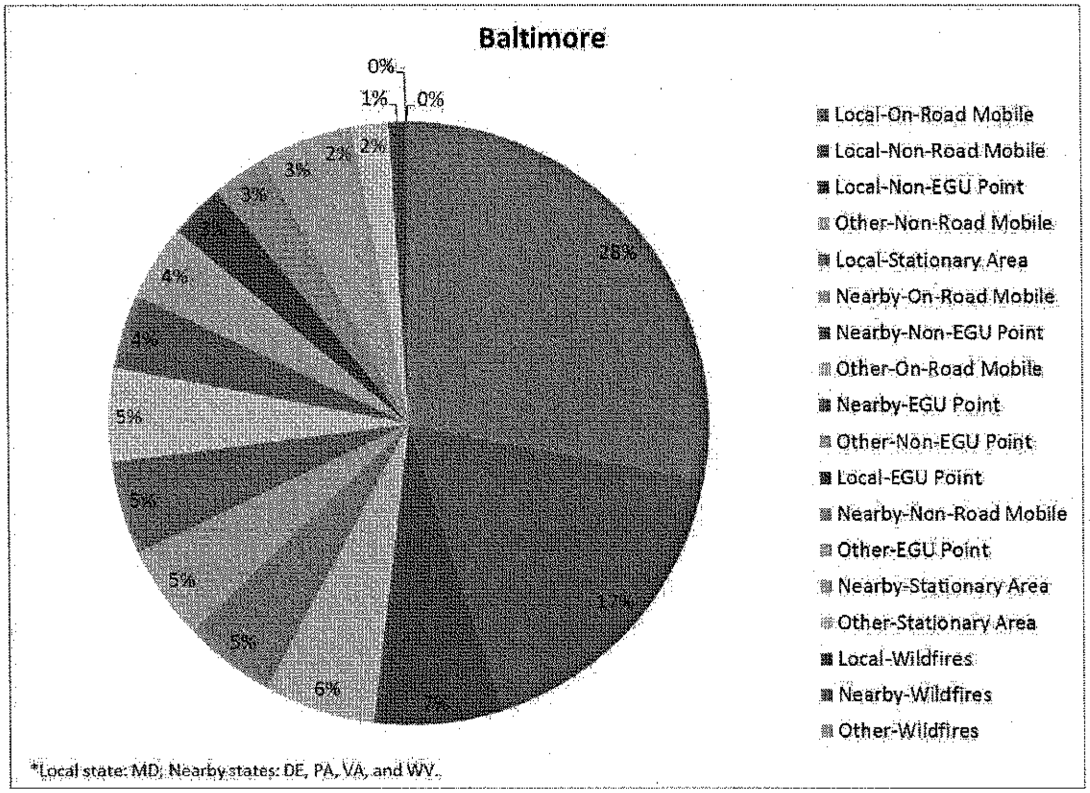


Figure 4-3. 2015 Average Contribution (%) by State/Sector to Exceedance-level Ozone in the Baltimore Nonattainment Area.

4.3. Emission Reductions from 10 ppm Gasoline Sulfur Standard

Reducing the average sulfur content of gasoline from the current average of 30 ppm to 10 ppm will provide significant and immediate emission reductions from the existing vehicle fleet. Sulfur in gasoline inhibits the effectiveness of the catalytic converters used to reduce NOx and other emissions from vehicles. When exposure to sulfur is minimized, the performance of these devices improves dramatically. Numerous studies have documented this effect. For example, Ball et al. (2011)[18] compared NOx emissions from a late-model vehicle operating on two types of gasoline, one with 30 ppm and one with 3 ppm sulfur. They found that tailpipe NOx emissions were around 40

[18] Ball, D., D. Clark, and D. Moser. 2011. *Effects of Fuel Sulfur on FTP NOx Emissions from a PZEV 4 Cylinder Application*, SAE Technical Paper 2011-01-0300, doi:10.4271/2011-01-0300.

percent lower with the 3 ppm sulfur fuel.[19] For additional analysis and discussion of the effect of fuel sulfur on catalyst performance, see MECA (2011).[20]

NESCAUM used the USEPA's MOVES model[21] to calculate baseline light-duty vehicle NOx emissions for the projection year 2017. NOx reduction estimates for the 10 ppm sulfur gasoline component of the expected federal Tier 3 proposal were taken from a recent report by the National Association of Clean Air Agencies (NACAA).[22]

The estimated per state and aggregate regional reduction benefits for gasoline-powered on-road vehicles are presented in Table 4-2. Based on this preliminary regional inventory for 2017 calculated with MOVES, a 10 ppm average gasoline sulfur requirement could reduce NOx emissions in the OTR by over 51,000 tons per year, or 141 tons per day.

As shown in Table 4-2, the low sulfur gasoline component of the Tier 3 program would also significantly reduce NOx emissions in eight Midwest states, with fleetwide reductions of over 60,000 tons per year. Similar reductions are also projected for ten southeast states, with NOx reductions of almost 65,000 tons in 2017. These reductions will benefit air quality in the OTR by: (1) lowering the transported "ozone reservoir" that forms in the eastern U.S., (2) reducing the amount of low-level NOx emissions and pollutants derived from NOx (e.g., nitrates) that are transported into the OTR, and (3) ensuring that vehicles registered in other states but operating in the OTR emit less NOx.

As indicated in Table 4-3, light-duty vehicles are predicted to emit over 1,100,000 tons of NOx in 2017 absent the low sulfur gasoline standard. A 10 ppm average sulfur gasoline requirement could reduce NOx emission by nearly 180,000 tons per year, or almost 500 tons per day in the eastern U.S.

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[19] Sensitivity to fuel sulfur will vary with catalyst design and placement, duty cycle, and other parameters. Less advanced catalyst formulations found on older cars and heavy-duty vehicles could exhibit lesser or greater NOx impacts compared to the advanced emission control system studied by Ball et al.

[20] Manufacturers of Emission Controls Association (MECA), 2011. *Clean Air Facts: Cleaner Fuels for Cleaner Motor Vehicles*. Available at http://meca.org/galleries/default-file/fuelsfact%200811%20FINAL.pdf.

[21] The MOtor Vehicle Emission Simulator (MOVES) model was developed by USEPA's Office of Transportation and Air Quality to estimate emissions for mobile sources, including cars, trucks, and motorcycles.

[22] National Association of Clean Air Agencies (NACAA). 2011. *Cleaner Cars, Cleaner Fuel, Cleaner Air: The Need for and Benefits of Tier 3 Vehicle and Fuel Regulations*, NACAA, Washington, DC (October 2011), p. 16 (citing M. Walsh). Available at http://www.4cleanair.org/documents/NACAATier3VehandFuelReport-EMBARGOED-Oct2011.pdf.

Table 4-2. On-road Gasoline Vehicle Emissions and Estimated Reductions Based on MOVES Estimates for 2017.

Ozone Transport Region			
State/DC	2017 Gasoline On-road Base NOx (tpy)	Est. NOx Reductions from 10 ppm S	
		(tpy)	(tpd)
Connecticut	20,700	-3,100	-8
Delaware	5,400	-800	-2
District of Columbia	2,000	-300	-1
Maine	10,000	-1,500	-4
Maryland	32,600	-5,000	-14
Massachusetts	35,100	-5,300	-15
New Hampshire	8,400	-1,300	-4
New Jersey	44,300	-6,700	-18
New York	88,600	-13,500	-37
Pennsylvania	70,500	-10,700	-29
Rhode Island	5,600	-900	-2
Vermont	5,000	-800	-2
Virginia OTR Counties	11,300	-1,700	-5
OTR Total	**339,500**	**-51,600**	**-141**

Midwest States			
State	2017 Gasoline On-road Base NOx (tpy)	Est. NOx Reductions from 10 ppm S	
		(tpy)	(tpd)
Illinois	70,300	-10,700	-29
Indiana	48,900	-7,400	-20
Iowa	20,500	-3,100	-8
Michigan	67,200	-10,200	-28
Minnesota	36,600	-5,600	-15
Missouri	45,000	-6,800	-19
Ohio	73,800	-11,200	-31
Wisconsin	40,000	-6,000	-16
Total	**402,300**	**-61,000**	**-167**

Southeast States			
State	2017 Gasoline On-road Base NOx (tpy)	Est. NOx Reductions from 10 ppm S	
		(tpy)	(tpd)
Alabama	34,800	-5,300	-15
Florida	95,600	-14,500	-40
Georgia	64,000	-9,700	-27
Kentucky	32,700	-5,000	-14
Mississippi	23,100	-3,500	-10
North Carolina	56,300	-8,500	-23
South Carolina	27,900	-4,200	-12
Tennessee	43,500	-6,600	-18
Virginia[23]	36,900	-5,600	-15
West Virginia	13,000	-2,000	-5
Total	**427,800**	**-64,900**	**-178**

Table 4-3. Regional Gasoline Vehicle Emissions and Estimated Reductions Based on MOVES Estimates for 2017.

Region	2017 Gasoline On-road Base NOx (tpy)	Est. NOx Reductions from 10 ppm S	
		(tpy)	(tpd)
Ozone Transport Region Total	339,500	-51,600	-141
Midwest States Total	402,300	-61,000	-167
Southeast States Total	427,800	-64,900	-178
3 Region Total	**1,169,600**	**-177,500**	**-486**

To provide additional context for the scale of NOx reductions possible from low sulfur gasoline, Table 4-4 shows that the reductions would be about three times greater than what will be achieved in the OTR in 2014 from the Cross-State Air Pollution Rule.

[23] The NOx emissions for Virginia in the table of southeast states do not include emissions from the VA counties in the OTR. That portion of VA's gasoline vehicle NOx emissions appear in the Ozone Transport Region table.

Table 4-4. Comparison of NOx Reductions from CSAPR and 10 ppm S Gasoline in OTR.

State/DC	CSAPR NOx Reductions (tpy)	Est. NOx Reductions from 10 ppm S (tpy)
Connecticut	6	-3,100
Delaware	15	-800
District of Columbia	0	-300
Maine	0	-1,500
Maryland	-375	-5,000
Massachusetts	41	-5,300
New Hampshire	-156	-1,300
New Jersey	-286	-6,700
New York	-1,160	-13,500
Pennsylvania	-15,110	-10,700
Rhode Island	0	-900
Vermont	0	-800
Virginia OTR Counties	-43	-1,700
OTR Total	**-17,068**	**-51,600**

Note: Negative values are projected NOx reductions. Positive values are projected NOx increases.

Source for CSAPR NOx reductions in 2014: USEPA. 2011. *Regulatory Impact Analysis for the Federal Implementation Plans to Reduce Interstate Transport of Fine Particulate Matter and Ozone in 27 States; Correction of SIP Approvals for 22 States*, Docket ID No. EPA-HQ-OAR-2009-0491, USEPA Office of Air and Radiation (June 2011), p. 57, Table 3-12,. Note that the CSAPR NOx reductions to do not include later technical revisions by the USEPA announced in October 2011.

5. IMPACT OF PREDICTED POLLUTION REDUCTIONS ON PUBLIC HEALTH

Using the results from the inventory analysis described in Section 4, NESCAUM evaluated the potential public health impacts in the OTR associated with the projected reduction in mobile source emissions from the proposed Tier 3/LEV III and low sulfur gasoline rules.

A federal 10 ppm sulfur standard would reduce emissions from cars and light trucks in the OTR and in upwind states whose emissions contribute to air quality problems in the region. Ground-level emissions help produce the ozone "reservoir" formed upwind and outside the region that is carried into the OTR. Motor vehicles are also a major component of emissions within the region contributing to local air pollution problems and transported overnight along the Northeast Corridor by the nocturnal low level jet.

5.1. Baseline for Estimating Health Benefits of Low Sulfur Gasoline

NESCAUM used the USEPA's Environmental Benefits Modeling and Analysis Program (BenMAP)[24] to estimate the number of avoided adverse health events (e.g., premature mortality) and their monetized value within the OTR that would be associated with the implementation of a federal low sulfur gasoline program. BenMAP applies health impact functions that relate changes in pollutant concentrations with changes in the incidence of specific health endpoints. The program allows users to estimate the health and economic benefits of an air quality program while adequately describing the uncertainty and variability in the estimates.

BenMAP uses a "damage-function" approach to estimate the benefits associated with air quality improvements. This method assigns values to changes in individual health endpoints (specific effects that can be associated with changes in air quality). Because NOx is a precursor to ozone and fine particle formation, BenMAP was run for both types of pollution. Lowering sulfur content in gasoline would also have an effect on sulfate fine particles, although highway vehicle emissions are a small contributor to total sulfate in the OTR (<1%).[25]

The air quality changes used as inputs to BenMAP in this exercise were extrapolated from a baseline using the results of previous air quality modeling done by NESCAUM of a future regional pollution control scenario in 2018.[26] The 2018 future scenario incorporated "On the Books/On the Way" (OTB/OTW) control strategies and additional "Beyond on the Way" (BOTW) control options that the Ozone Transport Commission (OTC) has considered for achieving regional ozone, particulate matter, and

[24] USEPA. 2010. *Environmental Benefits Mapping and Analysis Program (BenMAP)*, BenMAP 4.0.35, US Version (September 2010). Available at http://www.epa.gov/air/benmap/download.html.
[25] USEPA. 2008 National Emissions Inventory, http://www.epa.gov/ttn/chief/net/2008inventory.html.
[26] NESCAUM. 2008. *MANE-VU Modeling for Reasonable Progress Goals*, prepared for MANE-VU by NESCAUM, Boston, MA (February 7, 2008). Available at http://www.nescaum.org/documents/modeling-for-reasonable-progress-final-021208.pdf/.

visibility goals.[27] This modeled air quality baseline accounts for emission control measures already in place as well as potential future control requirements that, while not final at the time of the modeling, may achieve additional pollution reductions by 2018.

Some of the OTB/OTW measures assumed to be in place by 2018 within the OTR include:

- Federal Clean Air Interstate Rule (predecessor of the Cross-State Air Pollution Rule);
- Federal Tier 2 tailpipe standards (or CA LEV standards in OTR states that adopted the California motor vehicle program) and low sulfur gasoline (30 ppm);
- Federal highway heavy-duty diesel engine standards / ultra-low sulfur diesel requirements;
- Federal non-road diesel engine standards / ultra-low sulfur diesel rule;
- OTR state low sulfur heating oil requirements; and
- Various state laws, regulations, and enforcement measures in individual OTR states.

For the BOTW measures, the OTC identified a number of source categories to consider for additional emission reductions. Individual OTR states and DC selected which of these sectors could be candidates in their jurisdictions for further emission controls, and these were included in the 2018 air quality modeling.[28] The source categories identified by the OTC are:

- Consumer Products
- Portable Fuel Containers
- Adhesives and Sealants Application
- Diesel Engine Chip Reflash
- Cutback and Emulsified Asphalt Paving
- Asphalt Production Plants
- Cement Kilns
- Glass Furnaces
- Industrial, Commercial, and Institutional (ICI) Boilers

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[27] MARAMA. 2007. *Development of Emission Projections for 2009, 2012, and 2018 for NonEGU Point, Area, and Nonroad Source in the MANE-VU Region*, prepared for MANE-VU by MARAMA, Towson, MD (February 2007). Available at http://www.marama.org/visibility/Inventory%20Summary/MANEVU_Emission_Projections_TSD_022807.pdf.

[28] Ozone Transport Commission. 2007. *Identification and Evaluation of Candidate Control Measures*, Final Technical Support Document, prepared by MACTEC Federal Programs, Inc. (Herndon, VA), February 28, 2007. Available at http://otcair.org/upload/Documents/Reports/OTC%20Control%20Measures%20TSD%20070228%20Final%20SB.pdf.

- Regional Fuels (extending reformulated gasoline to OTR counties that do not currently have it)
- Electric Generating Units (beyond expected federal requirements)

By including these measures in the 2018 future control scenario, the BenMAP results for a 10 ppm low sulfur gasoline requirement provide a conservative estimate of the health benefits above and beyond those to be garnered from measures already expected to be in place or that are under consideration by individual OTR jurisdictions for implementation by 2018.

5.2. Methods for Estimating Air Quality Impacts of Low Sulfur Gasoline in the OTR

NESCAUM developed a first-order estimate of the air quality impacts of reduced sulfur in gasoline by applying linear reduction factors to the 2018 air quality model results for ozone and sulfate PM2.5.[29] These reduction factors were applied to model results at every grid cell and time-step.

The reduction factor for ozone was developed based on an estimated 8 percent reduction in NOx emissions from all gasoline and diesel on-road mobile sources resulting from the introduction of low sulfur gasoline.[30] The 2018 inventory year was used because it is the inventory year of the projected OTB/OTW and BOTW modeled reference case of ozone levels in the OTR.[31] For the purpose of this analysis, the original 2018 NOx emissions inventory was modified by replacing the mobile source NOx emissions estimated by the older MOBILE6 emissions inventory model with updated estimates from MOVES. Total on-road mobile source emissions (gasoline and diesel) are about 37 percent of all NOx emissions in the 2018 OTR inventory. On-road gasoline mobile source NOx emissions represent about 20 percent of the total inventory. While the NOx reduction is estimated to be about 8 percent relative to the total on-road mobile source sector, the NOx reductions accrue from only the gasoline portion of the total on-road fleet.

The NOx-ozone response was derived from a study by Butler et al. of observed decreasing ozone trends occurring contemporaneously with historical NOx reductions in the eastern United States from 1997 to 2008.[32] This study estimated about a 13 percent decrease in average maximum daily 8-hour ozone concentrations during the five month ozone season (May-September) resulting from a 32 percent decrease in annual total NOx

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[29] NESCAUM used the Community Multi-scale Air Quality (CMAQ) model, which provided hourly modeled air pollutant levels over an eastern U.S. domain at a 12 km grid resolution.

[30] National Association of Clean Air Agencies (NACAA). 2011. *Cleaner Cars, Cleaner Fuel, Cleaner Air: The Need for and Benefits of Tier 3 Vehicle and Fuel Regulations*, NACAA, Washington, DC (October 2011), p. 16 (citing M. Walsh). Available at http://www.4cleanair.org/documents/NACAATier3VehandFuelReport-EMBARGOED-Oct2011.pdf.

[31] MARAMA. 2007. MANE-VU Future Years Emissions Inventory. Available at http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory (accessed October 17, 2011).

[32] Butler, T.J., F.M. Vermeylen, M. Rury, G.E. Likens, B. Lee, G.E. Bowker, and L. McCluney. 2011. *Response of ozone and nitrate to stationary source NOx emission reductions in the eastern USA*, Atmospheric Environment, 45:1084-1094. doi:10.1016/j.atmosenv.2010.11.040.

emissions in the eastern United States. This corresponds to about a 0.4 percent reduction in average daily maximum 8-hour ozone per 1 percent reduction in total NOx emissions.

An estimated 8 percent reduction from an overall 37 percent on-road mobile source NOx share in the total NOx inventory, coupled with the 0.4 percent ozone reduction per 1 percent NOx reduction, results in an estimated overall 1.2 percent reduction in ozone associated with introducing 10 ppm sulfur gasoline. This 1.2 percent estimated ozone reduction in the 2018 modeled ozone concentrations is used as an input to BenMAP to generate the estimated health benefits. Ozone reductions are estimated only for the May through September ozone season and do not consider reductions below an assumed 30 ppb natural ozone background.[33]

NESCAUM applied a similar methodology in developing the PM2.5 reduction factor. NESCAUM multiplied the sulfur-content reduction (from 30 to 10 ppm in gasoline, or 67 percent) by the contribution of gasoline-powered vehicles to total sulfur dioxide emissions in OTC states, or 0.41 percent (EPA 2011), and then by the SO_2-PM2.5 response factor. The response factor is 8 percent in the winter (October through April) and 50 percent in the summer (Tsimpidi et al. 2007).[34] Therefore, the reduction factor for PM2.5 was 0.02 percent in the winter and 0.14 percent in the summer. We do not estimate nitrate PM2.5 reductions, which could be relatively important in winter when nitrate PM2.5 is more stable at lower ambient air temperatures. Competition with relatively abundant sulfate, however, makes estimates difficult in our approach. Additional air quality modeling could better quantify the potential impact.

5.3. Estimated Health Benefits of Low Sulfur Gasoline in OTR

By using the first-order estimate of air quality reductions in the OTR from 10 ppm low sulfur gasoline, BenMAP provided an estimate of avoided health impacts in the OTR in 2018 in the range of $234 million to $1.2 billion (in 2006$) annually. The central value of this range is approximately $710 million. Table 5-1 summarizes the BenMAP monetized health benefits for ozone and PM2.5 for morbidity and mortality health endpoints within the OTR. Appendix A provides a breakdown of these benefits for each jurisdiction in the OTR. The health benefits valuation is dominated by avoided premature mortality, which ranges between 29 and 158 incidents in the OTR. Most of the mortalities avoided are due to lower ozone levels resulting from reduced NOx emissions by on-road gasoline vehicles. Health impacts from PM2.5 reductions are more modest due to the small relative contribution of gasoline combustion to total emissions of SO_2, which limits secondary PM2.5 formation.

These values represent first-order estimates of the expected immediate health benefits of 10 ppm low sulfur gasoline in the OTR, and are based on a broad range of incidences from health impact studies. Therefore, the resulting health benefits are

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[33] USEPA. 2007. *Staff Paper. Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information*, OAQPS Staff Paper, USEPA Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, EPA-452/R-07-007 (July 2007).

[34] Tsimpidi A.P., V.A. Karydis, and S.N. Pandis. 2007. *Response of Inorganic Fine Particulate Matter to Emission Changes of Sulfur Dioxide and Ammonia: The Eastern United States as a Case Study*, Journal of the Air & Waste Management Association, 57:1489-1498. DOI:10.3155/1047-3289.57.12.1489. Table 1 (p. 1493).

presented as a broad range as well. Specifically modeling a Tier 3 / low sulfur gasoline program rather than using the first-order linear reduction method applied here would provide refined estimates of expected pollutant reductions, avoided morbidity and mortality incidences, and geographic distribution of benefits. Notwithstanding the potential for more refined modeling, the values presented in this paper suggest that there will be immediate and significant health benefits in the OTR from lowering sulfur in gasoline for the on-road vehicle fleet in 2018, and the value of those health benefits may be much greater than the program costs. This assessment does not account for the monetary benefits associated with environmental improvements that would accrue from reduced nitrogen emissions related to the low sulfur gasoline program.

Table 5-1. Estimated Annual Monetized Health Benefits in 2018 Due to Low Sulfur Gasoline in OTR.

	Value [Millions of 2006$]		
	Ozone	PM2.5	Total
Morbidity	$19.5	$3.9	$23.4
Mortality	$196 – $877	$15 – $285	$210 – $1,162
Total Monetized Health Benefits	**$215 – $896**	**$19 – $289**	**$234 – $1,186**

Note: Monetized benefits include all of Virginia.

6. COST AND BENEFITS OF TIER 3 / GASOLINE SULFUR PROGRAM

Cost estimates for 10 ppm sulfur gasoline derived from two different studies and emission reduction estimates from MOVES runs conducted by NESCAUM were used to assess the costs-effectiveness of NOx reductions from the Tier 3 low sulfur gasoline program. The cost estimates in cents per gallon come from the USEPA's Mobile Source Air Toxics (MSAT) proposed rule and a recent study sponsored by the International Council on Clean Transportation (ICCT).

To put this program in context, this section also compares the potential emission reduction and cost-effectiveness of 10 ppm sulfur gasoline to other emission control options that states might consider to achieve the NAAQS and to strategies that have already been employed.

6.1. USEPA Cost Estimates for Lower Sulfur Gasoline

National cost estimates for lowering sulfur in gasoline to an average of 30 ppm for the 2000 Tier 2/Gasoline Sulfur Rule[35] were:

- aggregate capital costs: $4.5 billion
- average annual operating costs (over 'lifetime'-2030): $1.8 billion
- average per gallon costs (over 'lifetime'-2030): 1.5 cents

The USEPA's MSAT rule proposal projected an average cost increase of 0.5 cents per gallon for 10 ppm sulfur gasoline.[36]

6.2. ICCT Cost Estimates

In 2011, the ICCT sponsored a study by MathPro to provide an estimate of the cost of lowering gasoline sulfur to an average of 10 ppm. The study concluded that complying with a national 10 ppm sulfur standard will cost 0.8 to 1.4 cents per gallon.[37]

6.3. Cost-Effectiveness

To bound the range of potential cost-effectiveness of a 10 ppm sulfur standard, the cost estimates from the USEPA's MSAT study and the ICCT-sponsored study were used to calculate the potential cost per ton of NOx reduced. To derive the dollar per ton of NOx reduced from the cents per gallon cost estimates, the volume of gasoline consumed in the OTR was derived from the MOVES 2017 results. Along with NOx emissions, the MOVES model can specify the energy consumed by vehicles as an output.

[35] USEPA. 1999. *Regulatory Impact Analysis-Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements*, Chapter V: Economic Impact, Table V-36.

[36] 71 Fed. Reg. 15804. March 29, 2006. *Control of Hazardous Air Pollutants From Mobile Sources; Proposed Rule,* at p. 15904. Available at http://edocket.access.gpo.gov/2006/pdf/06-2315.pdf.

[37] International Council for Clean Transportation (ICCT). 2011. *Refining Economics of a National Low Sulfur, Low RVP Gasoline Standard*, prepared by MathPro Inc., West Bethesda, MD (October 25, 2011). Available at http://www.theicct.org/pubs/ICCT04_Tier3_Report_Final_v4_All.pdf.

A fuel characteristics table in the MOVES database shows that a conversion factor of 115,000 Btu per gallon can be used to convert the energy consumption output into gallons of gasoline. Table 6-1 displays potential cost-effectiveness derived from the USEPA MSAT and ICCT studies.[38]

Table 6-1. Estimated Cost-Effectiveness of NOx Reductions from Low Sulfur Gasoline Requirements.

Cost	Cost-Effectiveness ($/ton NOx)
0.5 cents/gal *(USEPA MSAT)*	$2,500
0.8 cents/gal *(ICCT)*	$4,000
1.4 cents/gal *(ICCT)*	$7,000

As shown in Table 6-1, the cost-effectiveness of lower sulfur gasoline is estimated at $2,500 per ton NOx reduced, based on the USEPA MSAT cost estimate of 0.5 cents per gallon. The ICCT-sponsored study provides a conservative cost estimate of 1.4 cents per gallon from which NESCAUM estimates a cost-effectiveness of around $7,000 per ton in the OTR. The ICCT also provides a sensitivity case cost estimate of 0.8 cents per gallon that accounts for refineries capable of producing 10 ppm sulfur gasoline at lower capital expenditure and assumes a lower target return on investment (7 percent instead of 10 percent). From the sensitivity case cost of 0.8 cents per gallon, NESCAUM estimates the cost-effectiveness of the overall program to be $4,000 per ton of NOx reduced.

6.4. Relative Emission Reduction Potential and Cost-effectiveness of Low Sulfur Gasoline

Meeting federal air quality standards throughout the OTR and continuing the progress that has been achieved will require new emission reduction strategies. The 12 states and Washington, DC that constitute the OTR are considering a portfolio of potential new or enhanced emission control measures to reduce ozone, with a focus on NOx controls. Table 6-2 presents estimated emission reductions for a number of potential NOx control measures along with their cost-effectiveness. For comparative purposes, the table also shows the cost-effectiveness of the Tier 2 regulation for light-duty vehicles and the heavy-duty highway vehicle rule.

[38] The previously cited 2011 NACAA report *Cleaner Cars, Cleaner Fuel, Cleaner Air* estimates a cost-effectiveness of $3,300/ton using the ICCT 0.8 cents per gallon cost. NESCAUM's derived cost may be higher due to differences in geographic scope – the NACAA estimate is based on a national fleet mix (outside of California), while NESCAUM's is for the OTR only. In addition, there may be differences in the input assumptions used with MOVES to generate the total on-road NOx emissions given by NACAA and NESCAUM. This would lead to differences in projected NOx emissions reduced and gasoline volume consumed that would result in different cost-effectiveness estimates. The difference in cost-effectiveness estimates, however, does not affect overall conclusions from the comparison of the costs of low sulfur gasoline with other NOx measures in Table 6-2, nor the comparison of total program costs to monetized health benefits shown in Table 6-3.

The estimated 141 tons per day achievable from just the low sulfur gasoline provisions of the USEPA Tier 3 rulemaking suggests that this initiative has the potential to achieve greater reductions in the OTR than any of the possible regional strategies listed in the table. Further, even greater NOx reductions would occur in the neighboring regions from this federal measure, which will reduce the impacts of transported pollution into the OTR.

Table 6-2. Emission Reductions and Cost-effectiveness of Existing and Potential NOx Control Measures.

Source	OTR Summer NOx Emission Reductions (tons/day)[39]	Cost-Effectiveness ($/ton NOx)
ICI Boilers (area & point sources)[40]	107.2	$750 - $7,500 (Low NOx Burners) $1,300 - $3,700 (SNCR) $2,000 - $14,000 (SCR)
Combustion Turbines – SCR		$2,010 - $19,120[41]
Highway – Heavy-duty and Diesel-fueled Vehicles / Engine Standards and Fuel Sulfur Controls		$10,561[41]
Tier 2 Light-duty Vehicle Emissions and Gasoline Sulfur Controls		$6,297[41]
Phase II RFG (extended to all of OTR)	4.8	$3,700 - $5,200[39]
Glass/Fiberglass Furnaces	37.3	$2,150 - $5,300[39]
10 ppm Sulfur Gasoline	**141[42]**	**$2,500 - $7,000**

At an estimated $2,500 to $7,000 per ton NOx reduced, as suggested by the USEPA MSAT and ICCT studies, low sulfur gasoline compares favorably to a number of other emission reduction strategies, including the Tier 2 and heavy-duty diesel programs, in terms of cost-effectiveness. A large portion of the most cost-effective NOx reduction measures – those associated with power plants – have already been implemented or are expected to accrue with the implementation of CSAPR.

[39] Ozone Transport Commission. 2007. *Identification and Evaluation of Candidate Control Measures*, Final Technical Support Document, prepared by MACTEC Federal Programs, Inc., Herndon, VA (February 28, 2007). Available at http://otcair.org/upload/Documents/Reports/OTC%20Control%20Measures%20TSD%20070228%20Final%20SB.pdf.

[40] Cost numbers from literature values tabulated by A. Bodnarik, *ICI Boiler NOx & SO_2 Control Cost Estimates*, NH Dept. of Environmental Services, presented at OTC Committee Meeting, Modeling/Stationary & Area/Mobile Sources, Niagara Falls, NY (September 3, 2009). Available at http://otcair.org/upload/Documents/Meeting%20Materials/ICI%20Boiler%20Control%20Cost%20presentation%20090309%20long%20version.pdf.

[41] USEPA. 2006. *AirControlNET Version 4.1 Development Report*, prepared by E.H. Pechan & Associates (Springfield, MA), Pechan Report No. 06.05.002/9011.002, May 2006. Available at http://www.epa.gov/ttn/ecas/models/DevelopmentReport.pdf.

[42] From 2017 MOVES results presented in this white paper.

The dollar per ton of NOx reduced estimates can be used to estimate a total program cost for the OTR, which compares well to the estimated total monetized health benefits presented in Section 5. Table 6-3 presents the comparison of estimated total program costs with its projected monetized health benefits.

Table 6-3. Comparison of Estimated Low Sulfur Gasoline Program Costs and Monetized Health Benefits for the Mid-Atlantic and Northeast Region.

Total Low Sulfur Program Costs	Monetized Health Benefits
\$143 – \$400 million	\$234 – \$1,186 million

Note: Total costs and benefits estimates are for the OTR plus all of Virginia.

An estimated reduction in NOx emissions of 57,200 tons in 2017 from low sulfur gasoline would be achievable in the OTR and all of Virginia[43] at a total program cost in the range of \$143 – \$400 million using the USEPA MSAT and ICCT cost estimates (0.5 – 1.4 cents per gallon). Total monetized program health benefits in 2018 derived from BenMAP are in the range of \$234 – \$1,186 million, indicating that a program cost within the USEPA MATS – ICCT range is within or below the low end of the estimated health benefits range. The estimated monetized benefits are based on public health benefits solely from lowering exposure to ozone and sulfate PM2.5, and do not include health benefits from lowering other pollutants or benefits to the environment, such as decreases in acid rain and eutrophication.

This analysis shows that 10 ppm sulfur gasoline could be a very significant and cost-effective measure compared to other available NOx control options. The emission reductions will be realized immediately upon introduction of the clean gasoline. The benefits will accrue within the OTR and across the entire region of the eastern U. S. that contributes the pollution burden in the Northeast and Mid-Atlantic region.

[43] NOx reductions and gasoline consumption for all of Virginia are included in this comparison to have the same geographical coverage as the BenMAP monetized health benefits.

7. PROJECTING THE COST OF ENVIRONMENTAL REGULATIONS

This section highlights past efforts to estimate the economic impact of environmental fuel quality regulations and compares predictions to actual experience. The focus in this section is on previous USEPA regulatory initiatives that mandated reductions in the sulfur content of gasoline and diesel fuel. Three major initiatives are summarized in Section 7.1.

7.1. Previous National Fuel Sulfur Regulations

7.1.1. "Tier 2" Gasoline Sulfur Regulation (2000)

With the implementation of the Tier 2 program,[44] interim gasoline sulfur standards were phased in, beginning in 2004. The final gasoline sulfur standards were set at a refinery average of 30 ppm with a per gallon cap at 80 ppm. The initial compliance year for large refineries was 2006. Small refiners were given extensions of up to two additional years (2007-2008) in certain circumstances.

7.1.2. Highway Diesel Ultra-Low Sulfur Regulation (2001)

A refiner sulfur limit of 15 ppm for diesel began on June 1, 2006, with full implementation completed by June 1, 2010.[45] The regulation allowed for up to 20 percent of the highway diesel fuel produced to exceed the 15 ppm sulfur cap through 2009. An averaging, banking, and trading component made it possible for some refiners to continue exclusive production of 500 ppm sulfur diesel fuel throughout the interim compliance period.

7.1.3. Non-Road Diesel Ultra-Low Sulfur Regulation (2004)

Under the non-road diesel rule, fuel sulfur content was phased down in two steps.[46] Beginning June 2007, refiners were subject to a 500 ppm limit and by June 2010, a 15 ppm limit. For the locomotive and marine diesel fuel markets, refiners were given an additional two years, to June 2012, before the refinery 15 ppm limit took effect. For compliance flexibility, the small refiner deadline for compliance with the 500 pm sulfur limit was June 2010, three years after the compliance deadline for larger refiners. Similarly, the small refiner deadline for compliance with the 15 ppm sulfur limit was June 2014, four years after the compliance deadline for larger refiners.

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[44] 65 Fed. Reg. 6698 *ff.* February 10, 2000. *Tier 2 Motor Vehicle Emission Standards and Gasoline Sulfur Control Requirements; Final Rule.*

[45] 66 Fed. Reg. 5002 *ff.* January 18, 2001. *Control of Air Pollution from new Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements; Final Rule.*

[46] 69 Fed. Reg. 38958 *ff.* June 29, 2004. *Control of Emissions of Air Pollution From Non-Road Diesel Engines and Fuel; Final Rule.*

7.2. Regulatory Flexibilities Offered to Refiners

The USEPA built significant regulatory flexibilities into these fuel standards to ease the regulatory burden on refiners, including: (1) providing several years of lead time for all refiners to add or enhance desulfurization capabilities; (2) averaging, banking, and trading programs to encourage early compliance where possible and provide means for extending compliance dates where needed; (3) provisions for smaller and geographically isolated refiners to further extend compliance deadlines and credit generation opportunities; (4) opportunities for refiners to integrate their desulfurization infrastructure planning processes across all three fuels programs; (5) interim sulfur limits to allow refiners to phase their operations into compliance with the final standards; and (6) various hardship waiver provisions to provide a means to address unexpected circumstances.

7.3. Concerns Raised by Petroleum Refining/Marketing Industry during Rulemakings

Because of a common thread running through each of the rules (i.e., requirements for substantial desulfurization of major refined products), the petroleum refining and marketing industries raised several recurring concerns in their comments on each set of USEPA fuel sulfur rulemakings. The following inset paragraphs draw upon industry comments and testimony on the USEPA proposals to provide their perspective on the previous rulemakings.

> **Too Far** – The very low sulfur limits as proposed are unnecessarily stringent and/or place too much of the burden on the fuels side of the equation for achieving the engine standards. The National Petrochemical and Refiners Association (NPRA) stated in testimony to the USEPA that a 50 ppm cap on diesel sulfur would be sufficient to meet the emission reduction goals of the highway diesel program and, "unlike the…EPA proposal, this level of sulfur reduction is sustainable."[47] For the gasoline rulemaking, one commenter to the USEPA recommended a 150 ppm average with a 300 ppm maximum, stating that anything lower was not feasible for most refiners.[48]
>
> **Too Fast** – The lead time is insufficient for refiners to secure financing, engineering design expertise, permit approvals, and construction resources in order to procure and install the additional desulfurization units necessary to meet the stringent limits. As one industry representative stated to the USEPA, "Competition among U.S., Canadian and European refiners, all trying to reduce sulfur in the same time frame, will be too intense to allow everyone access to the new technology, which probably will result in everyone scrambling for basically within a one-year time frame to achieve the proper place in the feud [*sic*] to be in compliance

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[47] Testimony of Robert Slaughter, General Counsel, National Petrochemical and Refiners Association. *USEPA Public Hearing on Proposed Heavy-duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements*, New York City, NY (June 19, 2000). Hearing transcript available at http://www.epa.gov/otaq/regs/fuels/diesel/nyctrans.pdf.

[48] USEPA. 1999. *Tier 2 Motor Vehicle Emission Standards & Gasoline Sulfur Control Requirements: Response to Comments*, EPA 420-R-00-024 (December 1999), p. 14-2.

with the timetable which you've suggested."[49] In addition, the NPRA commented that virtually all of the necessary refinery modifications will trigger major New Source Review (NSR) due to increases in nitrogen oxides, volatile organic compounds, and particulate matter emissions, further complicating the permitting process.[50]

Fewer Refineries – The very stringent desulfurization requirements will force many smaller refineries either to close or to cease making one or more of the products subject to the standards. This especially will be the case among refineries in the Rocky Mountain States ("PADD IV")[51] that tend to be smaller, less technologically sophisticated, and less diverse in their product streams, compared to larger refineries. As one industry representative stated, "For some refiners, EPA's proposed regulation will be the straw that broke the camel's back. Facilities will close and jobs will be lost."[52]

Fuel Shortages – The closure of refineries, decisions by refiners not to produce low sulfur products, and delays in deployment of desulfurization technology will reduce the volume of product for sale. The NPRA stated that "more than 30 percent of the current supply of highway diesel could be lost" in the short term.[53] Refiners that choose to remain in the low sulfur fuel markets will not have sufficient refining capacity to keep up with demand. Because demand will remain high, shortages will result. Applying supply and demand principles, prices for low sulfur gasoline and diesel will rise considerably. An oil company projected that the supply of gasoline would be reduced by 10 to 15 percent as a result of the standards and this would increase the cost of gasoline by 10 to 15 cents per gallon.[54] A representative of the Society of Independent Gasoline Marketers of America said that if the highway diesel sulfur regulation caused a 10 percent reduction in supply, something he characterized as "not an unreasonable prediction," then $2 per gallon diesel would become the

[49] Testimony of Urvan R. Sternfels, President, National Petrochemical & Refiners Association. *USEPA Public Hearing on Proposed Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements*, Philadelphia, PA (June 9, 1999). Hearing transcript available at http://www.epa.gov/tier2/nprm/t2phila1.txt.

[50] USEPA. 1999. *Tier 2 Motor Vehicle Emission Standards and Gasoline Sulfur Control Requirements: Response to Comments*, EPA 420-R-99-024 (December 1999), p. 20-17.

[51] The U.S. Department of Energy divides the United States into regional Petroleum Administration for Defense Districts (PADDs) for planning purposes. PADD IV covers the states of Colorado, Idaho, Montana, Utah, and Wyoming.

[52] Testimony of J. Louis Frank, President, Marathon Ashland Petroleum LLC. *Clean Air Act: Sulfur in the Tier 2 Standards for Automobiles*, U.S. Senate Committee on Environment and Public Works, Subcommittee on Clean Air, Wetlands, Private Property, and Nuclear Safety, 106th Congress, Senate Hearing 106-503, Washington, DC (May 18, 1999), p. 16. Available at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=106_senate_hearings&docid=f:59385.pdf.

[53] Testimony of Robert Slaughter, NPRA (footnote 47).

[54] USEPA. 1999. *Tier 2 Motor Vehicle Emission Standards and Gasoline Sulfur Control Requirements: Response to Comments,* EPA 40-R-99-04 (December 1999), p. 14-3.

norm.[55] At the time this comment was made, the U.S. average price of a gallon of diesel was $1.42.

High Refining Costs – Conventional sulfur removal technology at the refinery is costly. New desulfurization technologies, purported by EPA to be more cost-effective, are unproven and/or would be unavailable within the required timeframe.[56] Rather than risk capital on unproven technologies, refiners may choose to increase their conventional capabilities at a higher cost.[57] While some refiners may be able to produce 15 ppm diesel sulfur fuel, many others would be forced to limit or forego participation in the highway diesel market.[58] The refining industry was viewed as very short on the financial capital necessary to comply with the series of new federal regulations mandating certain fuel characteristics, including low sulfur.[59] The implication was the operating and capital costs for refineries that survived the regulatory onslaught would have a marked effect on industry-wide profitability. The NPRA characterized the economic impacts of the regulations in combination as a "crushing burden on refiners and fuel distributors."[60]

Table 7-1 summarizes the USEPA and refining industry projections on the cost of a gallon of fuel, based on increased refining costs. As illustrated, the USEPA's refining cost projections consistently were lower or at the low end of the range cited by the industry. Note that projected fuel price increases due to supply shortages would be in addition to the price impacts in Table 7-1. Using the benefit of hindsight, a retrospective analysis by the USEPA of the costs of fuel quality regulations after their implementation found that both the USEPA and the petroleum industry overestimated the costs of cleaner fuels prior to their introduction, with the USEPA estimates typically being closer to actual costs.[61]

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[55] Testimony of Michael Ports, on behalf of the Society of Independent Gasoline Marketers of America. *Public Hearing: Proposal for Cleaner Heavy Duty Trucks and Buses and Cleaner Diesel Fuel,* Atlanta, GA (June 22, 2000). Hearing transcript available at http://www.epa.gov/otaq/regs/fuels/diesel/atltrans.pdf.

[56] USEPA. 1999. *Tier 2 Motor Vehicle Emission Standards and Gasoline Sulfur Control Requirements: Response to Comments*, EPA 420-R-99-024 (December 1999), p. 16-4.

[57] Testimony of J. Louis Frank, President, Marathon Ashland Oil Company. *USEPA Public Hearing on Proposed Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements,* Philadelphia, PA (June 9, 1999). Hearing transcript available at http://www.epa.gov/tier2/nprm/t2phila1.pdf.

[58] Testimony of Robert Slaughter, NPRA (footnote 47).

[59] National Petroleum Council. 2000. *U.S. Petroleum Refining: Assuring the Adequacy and Affordability of Cleaner Fuels* (June 2000).

[60] Testimony of Robert Slaughter, NPRA (footnote 47).

[61] Anderson, J.F. and T. Sherwood. 2002. *Comparison of EPA and Other Estimates of Mobile Source Rule Costs to Actual Price Changes*, SAE Technical Paper 2002-01-1980.

Table 7-1. Price Impact Estimates on Low Sulfur Fuels (cents per gallon).

Fuel Type	USEPA Estimate	Industry Estimate
Gasoline	< 2	5 – 15
Highway Diesel	4.5 – 5	4 – 13
Non-Road Diesel	7	7 – 9

7.4. Actual Impact on Numbers and Capacities of Refineries

The low sulfur gasoline and diesel regulations have had little effect on the numbers or capacities of operable refineries nationally or in the Rocky Mountain States where refineries were deemed most at risk. Refinery operating capacities continued to increase as did the available supply of gasoline and diesel fuel. In 2003, the year before any of the new low sulfur fuel standards began to be phased-in, there were 149 operable U.S. refineries. Between 2004 and the beginning of 2011, the number of operable refineries ranged between 148 and 150, finally ending up at 148; a net reduction of one operable refinery.[62,63] In the Rocky Mountain States (PADD IV), there was a net gain of one refinery (from 16 to 17) between 2000 and 2011. Refining activity in the U.S. increased over the same period. Desulfurization capacity increased by 40 percent from 2000 to 2010, indicating that the refining industry responded positively to the regulatory challenge and succeeded in dramatically reducing the sulfur content of fuels.

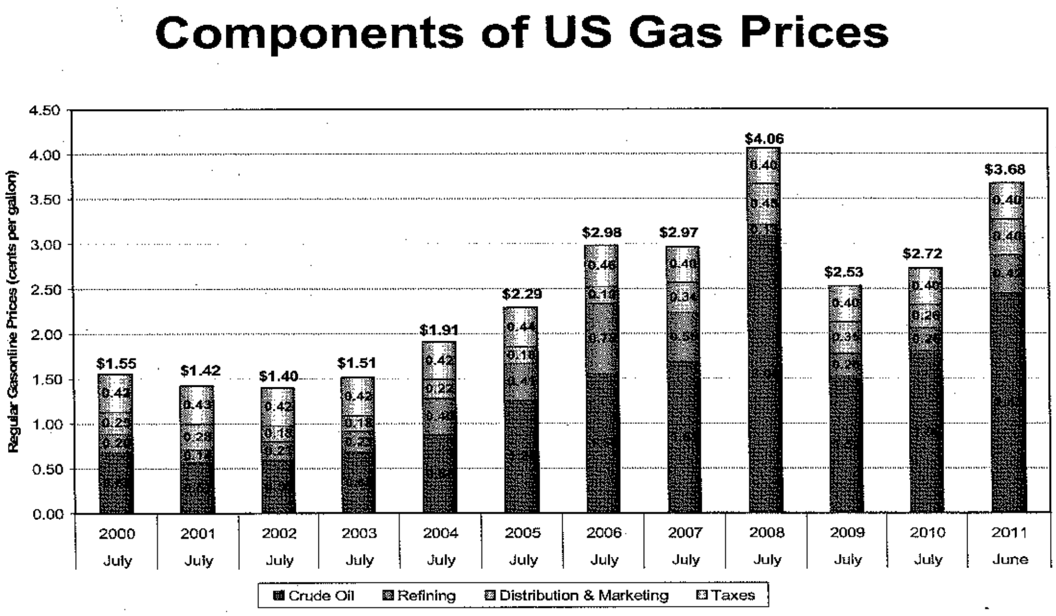
PADD IV refiners realized a modest increase in their share of U.S. distillation capacity, from 3.3 percent in 2000 to 3.5 percent in 2010. PADD IV refiners increased their desulfurization capacities by 55 percent from 2000 to 2010. This suggests that these refiners significantly upgraded their operations, choosing to stay in these markets rather than withdrawing.

Refinery closures that have occurred in recent years appear to be due to capacity expansions at more efficient refineries and a drop in consumer demand during the prolonged economic recession. Refiners also expect that demand will not rise much after the economy recovers as a result of higher vehicle fuel economy standards and an increase in alternative fuel supplies, such as ethanol.[64]

[62] U.S. Energy Information Administration (EIA). 2011. *Workbook: U.S. Number of Operable Refineries as of January 1* (June 24, 2011).
[63] Operable refineries include those presently in operation and those that are idled but capable of returning to production within 30 days or, if down for repairs, within 90 days. Of the 148 operable refineries at the beginning of 2011, 11 were idled for unspecified reasons but not considered to be permanently shut down.
[64] New York Times. 2009. *Chilly Climate for Oil Refiners* (December 23, 2009).

7.5. Refinery Operating Costs and the Price of Gasoline

As shown in Figure 7-1, refining is a relatively small percentage of the overall cost of gasoline. The price of crude oil is the primary determinant of gasoline prices. During the 12 year period covered in the graph, refining costs range from 3 percent to 23 percent of the total price of gasoline and averaged 14 percent. Figure 7-1 suggests that the refining component increased as a portion of total gasoline costs during the initial ramp-up to meet the federal sulfur requirements, but quickly declined and leveled off at pre-regulatory levels. Note that refining represented 10 percent of total price of gasoline in both 2001 and 2011.



Source: EIA, http://www.eia.gov/oog/info/gdu/gaspump.html.

Figure 7-1. Components of U.S. Gasoline Prices.

It is difficult to separate out environmental compliance-related desulfurization costs from other operating costs. The U.S. Energy Information Administration (EIA) does not require a level of reporting detail that would make it easy to separate out such costs, and the refining industry has not added desulfurization capacity solely to meet the regulatory requirements. At least some, and likely a significant amount, of the investment in desulfurization improvements have been made for the dual purposes of environmental compliance and enhancing the ability to process increasingly heavier and more sour (i.e., higher sulfur) crude. The shift to heavier crudes, such as from oil sands, is to provide a more secure crude supply for refineries as conventional supplies of lighter crudes diminish.[65]

[65] *See, for example,* (1) BP, *Whiting Refinery Facility Fact Sheet*, available at http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/bp_us_assets/downloads/a/ab p_wwd_us_whiting_refining_fact_sheet_2012_june.pdf (accessed November 16, 2011); (2) BP, *Toledo Refinery Facility Fact Sheet*, available at

7.6. How Refiners Are Meeting the Low Sulfur Fuel Rules

Early estimates of the cost of lowering sulfur in transportation fuels were principally based on the assumption that refiners would continue to deploy traditional conventional technology to achieve compliance. In actual practice, refiners opted for a combination of technology and facility efficiency improvements to cost-effectively remove the additional sulfur. In addition, refiners were able to generate a surplus of credits for compliance with the rules as a result of the flexibility provided by the averaging, banking, and trading programs.[66,67]

Refiners also made a number of process improvements; some directly involving desulfurization technology and others that optimized energy consumption in various refinery processes. For example ConocoPhillips Petroleum developed an innovative sulfur removal technology known as "S Zorb."[68] These process improvements helped offset the cost of investment in new desulfurization equipment and reduced ongoing operating costs. In addition, these improvements reduced facility-wide emissions, allowing refiners to net out of major New Source Review (NSR) stationary source permitting that otherwise may have been required as a consequence of significant process modifications. The oil industry has historically used conservative (i.e., high) estimates of the predicted costs for complying with federal fuel sulfur standards, but has found innovative and less costly ways to achieve these standards.

7.7. Effect of Low Sulfur Fuel Rules on Product Supply

Predicted gasoline and diesel fuel supply shortages as a result of past USEPA fuel rulemakings have not occurred. The U.S. gasoline supply increased 9.3 percent, comparing the year 2000 to the year 2007. Over the same time period, the combined supply of 15 ppm sulfur and 500 ppm sulfur diesel fuel increased by 35.4 percent. The supply of 15 ppm sulfur diesel fuel increased almost 7,000 percent between 2004 and 2008, as the regulations took effect and 15 ppm sulfur diesel fuel took its place as the standard highway fuel. As expected during this same timeframe, the supply of 500 ppm sulfur diesel fuel decreased by 92 percent as this fuel was relegated to the non-road market.[69]

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http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/A/abp_wwd_us_husky_refining_fact_sheet_june_2011v1.pdf (accessed November 16, 2011).

[66] USEPA. 2006. *Summary and Analysis of the 2005 Highway and Nonroad Diesel Fuel Pre-Compliance Reports,* EPA 420-R-06-012 (June 2006).

[67] USEPA. 2010. *Summary and Analysis of the 2010 Nonroad Diesel Fuel Pre-Compliance Reports,* EPA 420-R-10-028 (December 2010).

[68] Vander Laan, J. 2004. *S Zorb Gasoline Sulfur Removal Technology*, Refining Processes 2004, pp.237-249. Article reprint available at http://www.icheh.com/Files/Posts/Portal1/S-Zorb.pdf (accessed September 26, 2011).

[69] U.S. Energy Information Administration (EIA). 2011. *Petroleum and Other Liquids: Product Supplied,* (release date July 28, 2011). Available at http://www.eia.gov/dnav/pet/pet_cons_psup_dc_nus_mbbl_a.htm (accessed September 26, 2011).

8. CONCLUSION

The results of this analysis indicate that lowering the sulfur content of gasoline to an average of 10 ppm can cost-effectively reduce NOx emissions. Low sulfur gasoline could be one of the most significant strategies available to address ground-level ozone pollution in the OTR. The projected NOx reductions associated with the Tier 3 / low sulfur gasoline proposal would also help mitigate fine particle concentrations, acid rain, waterbody eutrophication, and regional haze; all significant challenges in the Northeast and Mid-Atlantic region. A key advantage to lowering sulfur in gasoline is that the emission reductions will occur immediately and come from all gasoline vehicles equipped with catalytic converters, regardless of the vehicle's model year. As a federal requirement, the low sulfur gasoline rule would result in very significant NOx reductions across the eastern U.S., thus diminishing the adverse public health and environmental outcomes in the OTR related to NOx emissions.

Given the stringency of existing state controls in the OTR, federal constraints on state regulation of motor vehicle fuels, and the fact that the OTR is significantly affected by pollution transport from sources outside the region, national emission control measures for light-duty vehicles are critical to achieving further improvements in air quality. Emission reductions not achieved through this and other federal measures would have to be accomplished by further controlling local sources in the OTR.

Appendix A:
Tables of Avoided Incidences and Monetized Health Benefits in OTR Jurisdictions from Introduction of 10 ppm Low Sulfur Gasoline

Appendix A: Tables of Avoided Incidences and Monetized Health Benefits in OTR Jurisdictions from Introduction of 10 ppm Low Sulfur Gasoline

Table A-1. Summary of 2018 Monetized Health Benefits from Reduced Ozone During Ozone Season Due to Low Sulfur Gasoline in OTR Jurisdictions.

State/DC	Total Value of Avoided Respiratory Endpoints* [Millions of 2006$]	Mortality (Range of 6 Studies) [Millions of 2006$]
CT	$0.95	$9.50 - $43.0
DE	$0.31	$2.85 - $13.0
DC	$0.14	$1.48 - $6.77
ME	$0.26	$2.48 - $11.2
MD	$2.08	$20.4 - $93.0
MA	$1.54	$15.3 - $68.8
NH	$0.26	$3.92 - $11.6
NJ	$2.81	$28.8 - $129
NY	$4.15	$39.8 - $178
PA	$3.76	$43.3 - $196
RI	$0.31	$3.24 - $14.7
VT	$0.09	$0.84 - $3.84
VA	$2.86	$23.6 - $108
OTR Total	**$19.5**	**$196 - $877**

Note: This table includes health benefits estimated for all of Virginia.

Table A-2. Summary of the 2018 Annual Number and Monetized Value of Avoided Incidences from Reduced PM2.5 Due to Low Sulfur Gasoline in OTR Jurisdictions.

	OTR Total	
	Incidences	Value [Millions of 2006$]
Mortality (Adults ages 30 and older)	2.6 - 38.6	14.6 - 285
Mortality (Infants less than 1 year of age)	0.036	0.263
Chronic Bronchitis (Adults aged 27 and older)	8.3	3.3
Acute Bronchitis (Children, ages 8-12)	16.9	0.0012
Acute Myocardial Infarctions (Adults ages 18 and older)	3.3	0.350
Hospital Admissions - Respiratory		0.0085
Hospital Admissions, Chronic Lung Disease (Adults ages 65 and older)	*0.14 - 0.22*	
Hospital Admissions, Chronic Lung Disease (Adults ages 18 to 64)	*0.087*	
Hospital Admissions, Pneumonia (Adults ages 65 and older)	*0.59*	
Hospital Admissions, Asthma (Ages 64 and younger)	*0.32*	
Hospital Admissions - Cardiovascular		0.0369
Hospital Admissions, Ischemic Heart Disease (Adults ages 65 and older)	*0.21*	
Hospital Admissions, Dysrythmia (Adults ages 65 and older)	*0.15*	
Hospital Admissions, Congestive Heart Failure (Adults ages 65 and older)	*0.58*	
Hospital Admissions, All Cardiovascular not including Myocardial Infarction (Adults ages 65 and older)	*0.88*	
Hospital Admissions, All Cardiovascular not including Myocardial Infarction (Adults ages 18 to 64)	*0.45*	
Emergency Room Visits, Asthma (Children 17 years and younger)	3.0	0.0011
Asthma Exacerbation Symptoms, Cough, Wheeze, Shortness of Breath (Asthmatic children, 6-18)	48.0	0.0024
Lower Respiratory Symptoms (Children ages 7 to 14)	53.1	0.0010
Upper Respiratory Symptoms (Children ages 9 to 11)	40.1	0.0012
Work Loss Days (Adults ages 18 to 64)	382	0.0638
Acute Respiratory Symptoms, Minor Restricted Activity Days (Adults ages 18 to 64)	2274	0.135

Table A-3. Summary of Avoided Incidences During Ozone Season in 2018 from Reduced Ozone Due to Low Sulfur Gasoline in OTR Jurisdictions.

State/DC	ER Visits, Asthma	Hospital Admissions, All Respiratory Endpoints, >64 Years and <2 Years	School Loss Days	Loss of Income Due to Decreased Worker Productivity	Minor Restricted Activity Days, 18-64	Mortality (Range of 6 Studies)
CT	4.5	12.7	2,257	36,240	7,859	1.2 - 5.8
DE	1.3	4.8	697	22,272	2,323	0.4 - 1.8
DC	0.7	1.9	364	1,808	1,260	0.2 - 0.9
ME	0.9	2.4	441	53,446	1,731	0.5 - 1.5
MD	11.4	20.6	5,582	86,652	18,411	2.7 - 12.6
MA	7.5	18.1	3,700	64,725	13,049	2.1 - 9.3
NH	1.2	2.5	612	20,669	2,228	0.3 - 1.6
NJ	16.3	33.0	7,297	88,708	24,333	3.9 - 17.5
NY	29.2	45.8	10,559	173,258	36,522	5.4 - 24.1
PA	17.1	51.1	8,496	234,759	29,512	5.8 - 26.5
RI	1.5	3.7	700	18,655	2,591	0.4 - 2.0
VT	0.3	0.8	160	17,301	651	0.1 - 0.5
VA	12.3	43.3	6,684	156,678	220,243	3.2 - 14.6
OTR Total	**104.2**	**241**	**47,549**	**975,171**	**360,713**	**26.2 - 119**

Table A-4. Summary of 2018 Annual Avoided Incidences from Reduced PM2.5 Due to Low Sulfur Gasoline in OTR Jurisdictions.

	CT	DE	DC	ME	MD	MA	NH	NJ	NY	PA	RI	VT	VA
Mortality (Adults ages 30 and older)	0.17 - 1.5	0.044 - 0.39	0.002 - 0.29	0.06 - 0.56	0.78 - 3.0	0.16 - 3.7	0.04 - 0.62	0.2 - 5.6	0.38 - 12.7	0.4 - 7.0	0.05 - 0.46	0.02 - 0.19	0.2 - 2.6
Mortality (Infants less than 1 year of age)	0.001	0.001	0.001	0.000	0.004	0.002	0.000	0.005	0.013	0.006	0.000	0.000	0.003
Chronic Bronchitis (Adults aged 27 and older)	0.3	0.1	0.1	0.1	0.6	0.8	0.1	1.2	3.0	1.2	0.1	0.0	0.6
Acute Bronchitis (Children, ages 8-12)	0.6	0.2	0.1	0.1	1.4	1.6	0.3	2.5	6.2	2.4	0.2	0.1	1.3
Acute Myocardial Infarctions (Adults ages 18 and older)	0.2	0.0	0.0	0.1	0.2	0.3	0.1	0.5	1.0	0.6	0.0	0.0	0.3
Hospital Admissions - Respiratory													
Hospital Admissions, Chronic Lung Disease (Adults ages 65 and older)	*0.008 - 0.0051*	*0.0019 - 0.003*	*0.0012 - 0.0018*	*0.0019 - 0.003*	*0.0107 - 0.0168*	*0.0143 - 0.0224*	*0.0022 - 0.0034*	*0.0196 - 0.0307*	*0.0443 - 0.0695*	*0.0217 - 0.0341*	*0.0016 - 0.0026*	*0.0006 - 0.0009*	*0.0136 - 0.0231*
Hospital Admissions, Chronic Lung Disease (Adults ages 18 to 64)	*0.004*	*0.001*	*0.001*	*0.001*	*0.007*	*0.009*	*0.001*	*0.011*	*0.025*	*0.015*	*0.001*	*0.000*	*0.011*
Hospital Admissions, Pneumonia (Adults ages 65 and older)	*0.03*	*0.01*	*0.00*	*0.01*	*0.03*	*0.06*	*0.01*	*0.08*	*0.17*	*0.12*	*0.01*	*0.00*	*0.05*

	CT	DE	DC	ME	MD	MA	NH	NJ	NY	PA	RI	VT	VA
Hospital Admissions, Asthma (Ages 64 and younger)	*0.01*	*0.00*	*0.00*	*0.00*	*0.02*	*0.02*	*0.00*	*0.04*	*0.15*	*0.04*	*0.00*	*0.00*	*0.02*
Hospital Admissions - Cardiovascular													
Hospital Admissions, Ischemic Heart Disease (Adults ages 65 and older)	*0.01*	*0.00*	*0.00*	*0.00*	*0.01*	*0.02*	*0.00*	*0.03*	*0.08*	*0.04*	*0.00*	*0.00*	*0.01*
Hospital Admissions, Dysrythmia (Adults ages 65 and older)	*0.01*	*0.00*	*0.00*	*0.00*	*0.01*	*0.01*	*0.00*	*0.02*	*0.05*	*0.03*	*0.00*	*0.00*	*0.01*
Hospital Admissions, Congestive Heart Failure (Adults ages 65 and older)	*0.02*	*0.01*	*0.00*	*0.01*	*0.04*	*0.06*	*0.01*	*0.09*	*0.19*	*0.10*	*0.01*	*0.00*	*0.05*
Hospital Admissions, All Cardiovascular not including Myocardial Infarction (Adults ages 65 and older)	*0.04*	*0.01*	*0.01*	*0.01*	*0.06*	*0.08*	*0.01*	*0.13*	*0.30*	*0.16*	*0.01*	*0.00*	*0.07*
Hospital Admissions, All Cardiovascular not including	*0.02*	*0.01*	*0.00*	*0.00*	*0.03*	*0.03*	*0.00*	*0.06*	*0.16*	*0.08*	*0.00*	*0.00*	*0.04*

	CT	DE	DC	ME	MD	MA	NH	NJ	NY	PA	RI	VT	VA
Myocardial Infarction (Adults ages 18 to 64)													
Emergency Room Visits, Asthma (Children 17 years and younger)	0.1	0.0	0.0	0.0	0.3	0.2	0.0	0.4	1.4	0.3	0.0	0.0	0.1
Asthma Exacerbation Symptoms, Cough, Wheeze, Shortness of Breath (Asthmatic children, 6-18)	1.7	0.5	0.3	0.5	3.9	4.5	0.7	7.2	17.7	6.8	0.5	0.2	3.6
Lower Respiratory Symptoms (Children ages 7 to 14)	1.9	0.5	0.4	0.6	4.3	5.0	0.8	8.0	19.5	7.6	0.5	0.2	4.0
Upper Respiratory Symptoms (Children ages 9 to 11)	1.4	0.4	0.3	0.4	3.3	3.7	0.6	6.0	14.7	5.7	0.4	0.1	3.0
Work Loss Days (Adults ages 18 to 64)	14	4	3	4	29	37	6	56	142	53	4	2	27
Acute Respiratory Symptoms, Minor Restricted Activity Days (Adults ages 18 to 64)	82	21	16	26	175	222	36	333	847	319	24	10	162

Table A-5. Monetized Value in 2018 of Annual Avoided Morbidity and Mortality from Reduced PM2.5 Due to Low Sulfur Gasoline in OTR Jurisdictions [Millions of 2006$].

	CT	DE	DC	ME	MD	MA	NH	NJ	NY	PA	RI	VT	VA
Mortality (Adults ages 30 and older)	1.28 - 11	0.32 - 2.9	0.004 - 2.1	0.47 - 4.1	1.39 - 22	1.15 - 27	0.32 - 4.6	1.6 - 41	2.8 - 94	3.1 - 52	0.38 - 3.4	0.14 - 1.4	1.7 - 19
Mortality (Infants less than 1 year of age)	0.007	0.004	0.003	0.003	0.026	0.015	0.003	0.035	0.096	0.043	0.002	0.001	0.025
Chronic Bronchitis (Adults aged 27 and older)	0.12	0.03	0.02	0.04	0.25	0.32	0.05	0.47	1.20	0.48	0.04	0.02	0.23
Acute Bronchitis (Children, ages 8-12)	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0002	0.0004	0.0002	0.0000	0.0000	0.0001
Acute Myocardial Infarctions (Adults ages 18 and older)	0.017	0.004	0.002	0.007	0.023	0.035	0.006	0.048	0.104	0.069	0.004	0.001	0.029
Hospital Admissions - Respiratory	0.0003	0.0001	0.0001	0.0001	0.0006	0.0008	0.0001	0.0012	0.0031	0.0013	0.0001	0.0000	0.0008
Hospital Admissions - Cardiovascular	0.0016	0.0004	0.0003	0.0004	0.0026	0.0031	0.0004	0.0055	0.0128	0.0065	0.0003	0.0001	0.0029
Emergency Room Visits, Asthma (Children 17 years and younger)	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0005	0.0001	0.0000	0.0000	0.0001
Asthma Exacerbation Symptoms, Cough, Wheeze, Shortness of Breath (Asthmatic children, 6-18)	0.0001	0.0000	0.0000	0.0000	0.0002	0.0002	0.0000	0.0004	0.0009	0.0003	0.0000	0.0000	0.0002
Lower Respiratory Symptoms (Children ages 7 to 14)	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0004	0.0001	0.0000	0.0000	0.0001
Upper Respiratory Symptoms (Children ages 9 to 11)	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0002	0.0005	0.0002	0.0000	0.0000	0.0001
Work Loss Days (Adults ages 18 to 64)	0.0025	0.0005	0.0005	0.0006	0.0051	0.0066	0.0009	0.0103	0.0238	0.0079	0.0006	0.0002	0.0043

	CT	DE	DC	ME	MD	MA	NH	NJ	NY	PA	RI	VT	VA
Acute Respiratory Symptoms, Minor Restricted Activity Days (Adults ages 18 to 64)	0.005	0.001	0.001	0.002	0.010	0.013	0.002	0.020	0.050	0.019	0.001	0.001	0.010