

**Cleaner Cars, Cleaner Fuel,  
Cleaner Air:**

**The Need for and Benefits of  
Tier 3 Vehicle and Fuel Regulations**

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National Association of Clean Air Agencies

October 2011

## About NACAA

The National Association of Clean Air Agencies (NACAA) is the association of air quality agencies in 50 states and territories and over 165 metropolitan areas throughout the country. The members of NACAA have primary responsibility for implementing our nation's air pollution control laws and regulations. The association serves to encourage the exchange of information and experience among air pollution control officials; enhance communication and cooperation among federal, state and local regulatory agencies; and facilitate air pollution control activities that will result in clean, healthful air across the country.

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## Acknowledgements

On behalf of NACAA, we are pleased to provide *Cleaner Cars, Cleaner Fuel, Cleaner Air: The Need for and Benefits of Tier 3 Vehicle and Fuel Regulations*. Our association prepared this document to inform the U.S. Environmental Protection Agency's (EPA's) efforts to develop "Tier 3" vehicle and fuel standards to affect emissions reductions that will lead to cleaner, more healthful air and better protect public health and the environment.

The recommendations included in this report are ones previously conveyed by NACAA to EPA.<sup>1</sup> Based on the analyses underlying this report, NACAA has concluded that the more rigorous vehicle emissions standards and 10-parts-per-million average gasoline sulfur level that we have recommended can be achieved at a price of around \$150 per new vehicle and less than a penny per gallon of gasoline. In return, vehicle-related emissions of air pollutants that lead to a host of adverse public health and environmental consequences will be reduced substantially, greatly assisting states and localities in achieving their clean air goals.

NACAA expresses gratitude to Michael P. Walsh for his expert assistance in conducting analyses and preparing this report.

We believe that *Cleaner Cars, Cleaner Fuel, Cleaner Air: The Need for and Benefits of Tier 3 Vehicle and Fuel Regulations* will serve as a valuable resource as our nation moves forward to examine and adopt air pollution control programs.



David J. Shaw  
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<sup>1</sup> See NACAA Letter to EPA Administrator Lisa P. Jackson (June 27, 2011), available at <http://www.4cleanair.org/Documents/Tier3NACAALettertoEPAFinal062711.pdf>.

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## Executive Summary

*Ozone levels throughout the country would be reduced overnight if the U.S. Environmental Protection Agency (EPA) requires cleaner gasoline and low-emission passenger vehicles. The analysis presented by the National Association of Clean Air Agencies (NACAA) in this report finds that the amount of air pollution that would be immediately reduced from lowering the sulfur content of gasoline is equivalent to removing 33 million cars and light trucks – approximately one in eight – from our roads. This dramatic result would come at a price of less than a penny per gallon of gasoline. Cleaner gasoline would also enable improved technologies on cars and light trucks that could yield substantial vehicle emissions reductions at a cost of about \$150 per car. Moreover, this highly cost-effective program would yield significant health and welfare benefits.*

Although motor vehicle emissions have improved dramatically since the federal mobile source program was introduced in 1968, they remain a primary source of the volatile organic compound (VOC) and nitrogen oxide (NO<sub>x</sub>) emissions that result in the formation of ozone. Accordingly, if we are to achieve and sustain healthful air quality across the country, we must further control motor vehicle emissions and fuels.

In December 1999, EPA adopted landmark regulations to clean up light-duty motor vehicles and the gasoline that fuels them. This “Tier 2” program, which took effect in 2004, required light-duty vehicles, including sport utility vehicles, to be 90 to 95 percent cleaner. To enable automakers to meet the new standards, EPA required oil refiners to remove about 90 percent of the sulfur in gasoline. Sulfur poisons catalysts that control vehicle exhaust and inhibits the performance of catalytic converters thereby increasing vehicle emissions.

A dozen years later, notwithstanding a substantial and sustained effort and remarkable progress, more must be done to reduce emissions and protect public health. Air pollution in the U.S. remains a serious and widespread problem. More than 125 million people still live in areas that exceed at least one of the health-based National Ambient Air Quality Standards (NAAQS), with 120 million of these residing where ozone (also known as smog) levels exceed that federal standard.

Fortunately, additional controls are available at very modest cost. EPA is expected to introduce, later this year, a “Tier 3” program of tougher light-duty vehicle emissions standards that follow closely the Low-Emission Vehicle (LEV) III requirements being pursued by the California Air Resources Board (CARB).

A critical piece of this program, and one that will ensure cost-effective implementation of these stricter standards, is further improved gasoline quality, particularly a reduction in average gasoline sulfur levels from approximately 30 parts per million (ppm) today, enacted as part of the 1999 Tier 2 program, to an average of 10 ppm. Such a reduction in sulfur levels will immediately improve the NO<sub>x</sub> control effectiveness on all existing Tier 2 cars and will be equivalent to eliminating over 33 million cars from the nation’s highways. Further, overall, this program has the potential to yield reductions in emissions of NO<sub>x</sub>, carbon monoxide and VOCs on the order of 29 percent, 38 percent and 26 percent, respectively, by 2030.

CARB has estimated the costs of its LEV III program to be about \$100 per vehicle. The cost of the federal Tier 3 program would likely be slightly higher, approximately \$150 per vehicle on

average, because under California's existing requirements new vehicles in the state are almost halfway to achieving the LEV III standards.

Based upon a new study conducted by MathPro – an expert refinery consulting firm – the price of reducing the average gasoline sulfur content to 10-ppm would be similarly modest, likely less than one cent per gallon. Further, lowering sulfur in gasoline is a very cost-effective means by which to achieve substantial emissions reductions, at about \$3,300 per ton of NO<sub>x</sub> removed.

Reducing emissions that cause air pollution is a zero-sum game. Forgoing reductions from one source category means garnering reductions from another. In the absence of a federal Tier 3 program with low-sulfur gasoline, states and localities will have no choice but to turn to other, more expensive, less cost-effective measures – for example, placing additional controls on small “mom and pop” businesses and instituting transportation control measures – to achieve the emissions reductions needed to attain and sustain clean air goals. Further, this could prove to be very difficult in areas where there may not be sufficient sources to control in order to gain emissions reductions on the order of those that will result from Tier 3, or where state and local controls on certain sources will be politically unacceptable.

The emissions reductions to be achieved from Tier 3 vehicles and gasoline will be accompanied by substantial health and welfare benefits. For example, the NO<sub>x</sub> reductions anticipated to result from this program will lead to reduced levels of ambient particulate matter (PM) that, in turn, will translate into more than 400 avoided premature deaths and 52,000 avoided lost workdays each year. The benefits of the ozone reductions to occur from Tier 3 vehicles and gasoline will lead to even greater health protection.

Just as NACAA supported EPA's efforts in the late 1990s to adopt the Tier 2 motor vehicle and fuel program, the association firmly supports the agency's efforts to seek additional reductions from light-duty vehicles and fuels. An appropriately stringent Tier 3 program based on a systems approach that addresses both the vehicle and its fuel will yield critically needed, and extremely cost-effective, emissions reductions. These reductions will enable state and local air pollution control agencies' efforts to achieve and maintain clean air goals and protect public health and welfare.

EPA assumed a Tier 3 program with strong fuel standards in its baseline analysis for attainment of the ozone NAAQS (i.e., 0.075 parts per million) adopted in 2008. Now states and localities are also facing, or preparing to face, the challenge of meeting new NAAQS for particulate matter, nitrogen dioxide and sulfur dioxide. In addition, EPA has confirmed that tailpipe emissions will increase as a result of the federal renewable fuels standard enacted by Congress in the Energy Independence and Security Act of 2007, further heightening the need for the Tier 3 program. Moreover, EPA's most recent National Air Toxics Assessment data show that every person in the U.S. has an increased cancer risk of over 10 in one million (one in one million is generally considered “acceptable”); and the majority of compounds that cause this risk comes from motor vehicles.

In short, EPA should take full advantage of the opportunity to establish a meaningful and effective Tier 3 program – including vehicle and fuel standards – to ensure that states and localities across the nation, which face increasing air quality challenges, can meet their statutory obligations.

Therefore, as NACAA recommended to EPA Administrator Lisa P. Jackson in June 2011,<sup>2</sup> EPA should take immediate action to propose this year and promulgate next year Tier 3 vehicle standards modeled after California's LEV III program, including improved tailpipe emissions standards for NO<sub>x</sub> and non-methane organic gases and an average gasoline sulfur concentration of 10 ppm or lower.

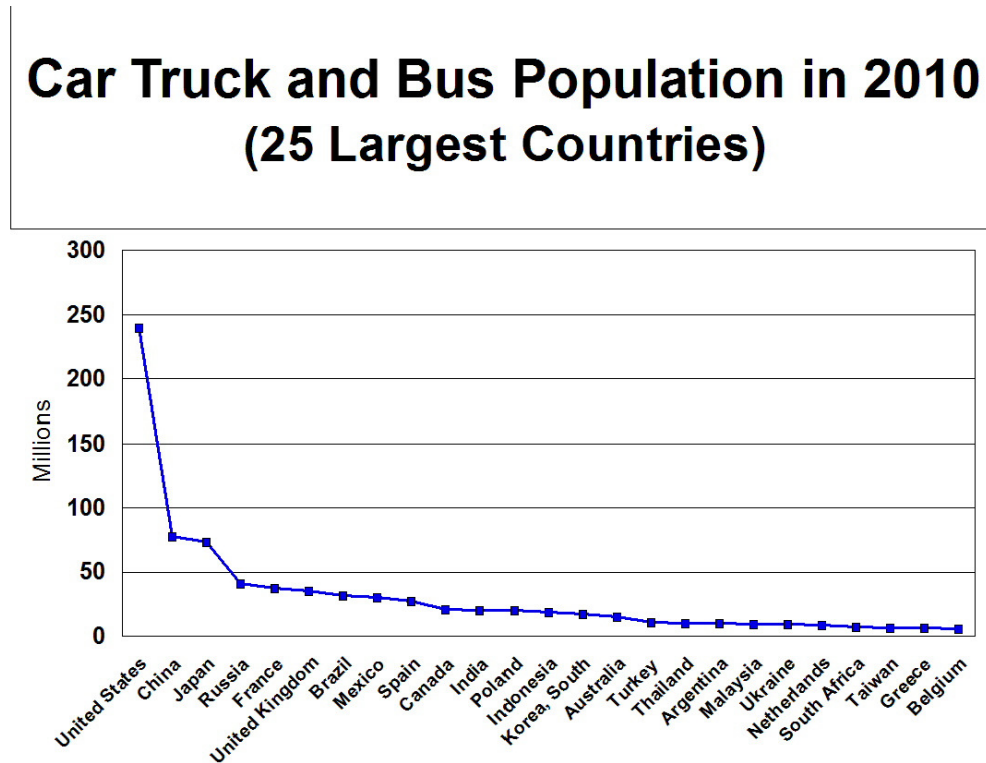
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<sup>2</sup> *Id.*

# Cleaner Cars, Cleaner Fuel, Cleaner Air: The Need for and Benefits of Tier 3 Vehicle and Fuel Regulations

## I. Introduction: The Problem

The U.S. has the proud distinction of having the strongest motor vehicle pollution control program in the world. As illustrated below, our nation also has the largest vehicle population on the planet. Although air quality in the U.S. has improved substantially, serious problems remain. Emissions from motor vehicles continue to be a key contributor to these problems. The good news is that there is still more we can do to reduce motor vehicle emissions and enhance our ability to protect public health and welfare. Additional cost-effective vehicle controls are available for passenger cars and light trucks, but availing ourselves of this opportunity will require reduced sulfur in gasoline.

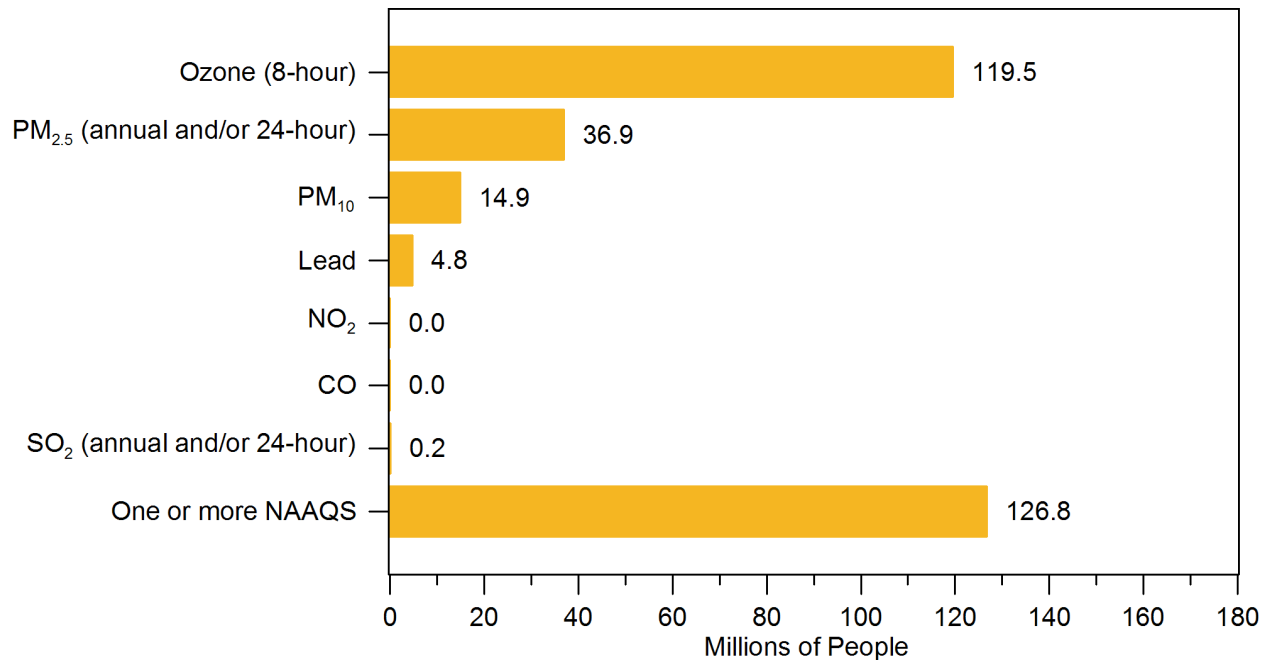


Source: Prepared by MP Walsh based on Data from Ward's World's Motor Vehicle Data (2011).

### A. Widespread Nonattainment

In spite of a significant and sustained effort spanning more than 40 years, the air pollution problem in the U.S. remains serious and widespread. As illustrated below, according to the U.S. Environmental Protection Agency (EPA), more than 125 million people still live in areas across the nation where air pollutant levels exceed at least one of the health-based National Ambient Air Quality Standards (NAAQS).

## Number of People Living in Counties with Air Quality Concentrations Above the Level of the Primary Health-Based NAAQS



Source: [http://www.epa.gov/airtrends/2010/dl\\_graph.html](http://www.epa.gov/airtrends/2010/dl_graph.html).

### B. The Special Problem of Ozone

#### Health and Environmental Impacts of Ozone

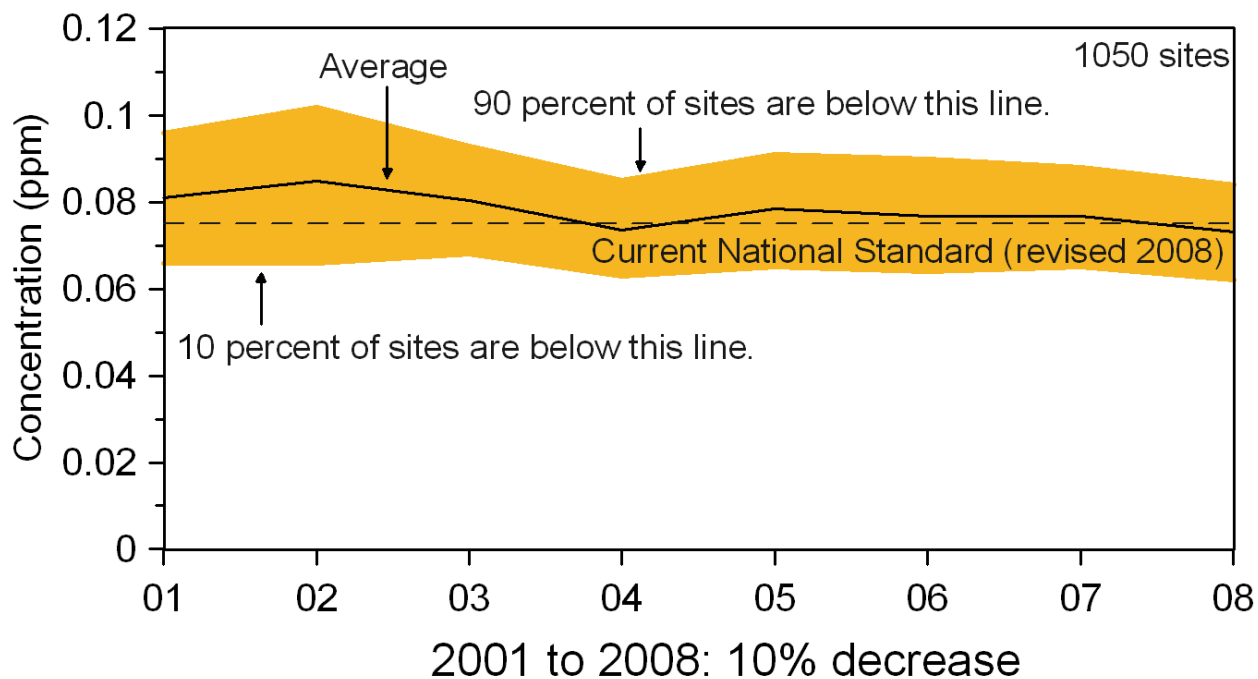
Ozone, commonly referred to as smog, is the most widespread of these pollutants with almost 120 million Americans still exposed to unhealthy levels. Exposure to ozone imperils human health in a host of ways and has been proven to result in premature mortality. Among the more immediate effects of exposure to ozone are shortness of breath, chest pain when inhaling, wheezing and coughing, asthma attacks and increased susceptibility to respiratory and pulmonary problems. In addition, ozone poses a threat to healthy ecosystems. Information provided in Appendices A and B elaborates on these adverse health and welfare impacts.

#### Ozone Levels Across the Country

As shown below, from 2001 to 2008, average ozone levels across the country decreased by only 10 percent, with more sites exceeding the standard than achieving it.



## National 8-Hour Ozone Air Quality Trends, 2001-2008



Source: [http://www.epa.gov/airtrends/2010/dl\\_graph.html](http://www.epa.gov/airtrends/2010/dl_graph.html).

In 2008, EPA revised the ozone NAAQS to 0.075 parts per million (ppm). In 2009, the agency announced it would undertake an initiative to reconsider that standard. In September 2011, the President asked the EPA Administrator to withdraw the reconsideration. Subsequently, on September 22, 2011, EPA issued a memorandum outlining the steps for moving forward to implement the 2008 0.075-ppm standard. At the same time, the agency provided the results of its preliminary review of ozone air quality data from 2008 through 2010 showing that 52 areas are initially estimated to exceed the 0.075-ppm standard, including areas such as Los Angeles, San Joaquin Valley, Baltimore, Dallas-Fort Worth, New York-New Jersey-Long Island, Philadelphia-Wilmington-Atlantic City, Charlotte-Gastonia-Rock Hill, Atlanta, Cincinnati, Boston, Baton Rouge, Denver, Sheboygan, Knoxville, Phoenix and St Louis.<sup>3</sup> (The agency has noted that actual nonattainment areas will be determined through the designations process, which will include extensive input and review by the states and an opportunity for public comment.)

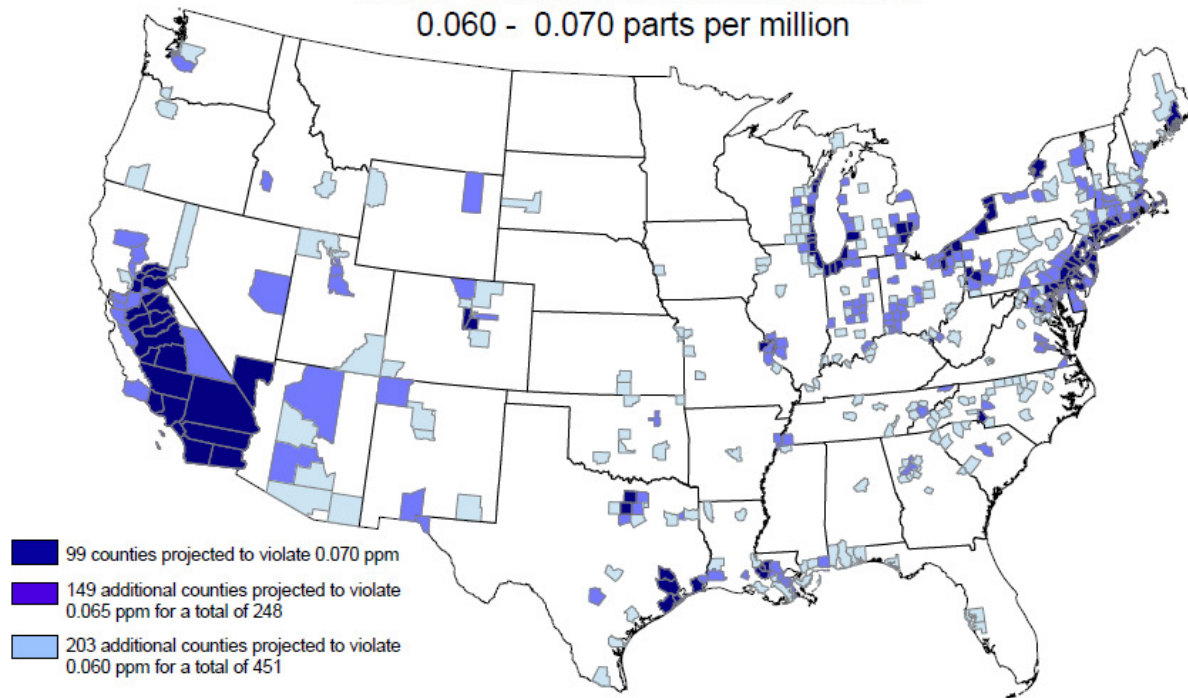
In addition, EPA is currently reviewing the 2008 ozone standard, consistent with its statutory obligation to review and, as necessary, revise each NAAQS every five years. Upon completion of that review in 2013/2014, if EPA revises the standard consistent with levels recommended several years ago by the Clean Air Scientific Advisory Committee – EPA’s independent science advisors – many additional areas of the country would be in violation. EPA has estimated that tighter ozone standards would save as much as \$100 billion in health costs and help prevent as many as 12,000 premature deaths.<sup>4</sup>

<sup>3</sup> See EPA’s initial estimate of areas exceeding the 2008 ozone standard (September 28, 2011), available at <http://www.epa.gov/ozonepollution/pdfs/OzoneTable9-22-11.pdf>.

<sup>4</sup> January 2010 Proposal to Revise the National Ambient Air Quality Standard for Ground-Level Ozone: General Overview, EPA Presentation (2010), available at <http://www.epa.gov/air/ozonepollution/pdfs/20100106present.pdf>.

The areas projected (via modeling) to violate an ozone standard in the range of 0.060 to 0.070 ppm in 2020 are shown below. As the map illustrates, 99 counties are projected to violate a 0.070-ppm ozone standard in 2020; 149 additional counties are projected to violate a 0.065-ppm standard for a total of 248; and 203 additional counties on top of that are projected to violate 0.060 ppm for a total of 451.

### Counties With Monitors Projected to Violate Primary 8-hour Ground-Level Ozone Standards in 2020 0.060 - 0.070 parts per million



#### Notes:

1. The modeled emissions in 2020 reflect the expected emissions reductions from federal programs by 2020 including: the Clean Air Interstate Rule, the Clean Air Mercury Rule, the Clean Air Visibility Rule, the Clean Air Nonroad Diesel Rule, the Light-Duty Vehicle Tier 2 Rule, the Heavy Duty Diesel Rule, the proposed rules for Locomotive and Marine Vessels and for Small Spark-Ignition Engines, and an estimate of State-level mobile and stationary source controls that were projected to be needed to attain pre-existing PM 2.5 and ozone standards.
2. Controls applied are illustrative. States may choose to apply different control strategies for implementation.
3. EPA did not model future violations outside the continental U.S.
4. EPA is proposing to determine compliance with a revised primary ozone standard by rounding the 3-year average to three decimal places.

Source: <http://www.epa.gov/air/ozonepollution/pdfs/20100104maps.pdf>.

Clearly, additional controls on mobile sources, the largest contributor to ozone precursors, will be extremely helpful to states and localities as they strive to attain ozone air quality levels under the current standard and any potential new standard.

### The Air Quality Index

To help people determine the quality of the outdoor air on any given day, EPA has developed the Air Quality Index – or AQI.<sup>5</sup> The AQI communicates information using six color-coded

<sup>5</sup> For further information about the AQI, see <http://www.airnow.gov/index.cfm?action=aqibasics.aqi>.

categories: green = good; yellow = moderate; orange = unhealthy for sensitive groups; red = unhealthy; purple = very unhealthy; and maroon = hazardous.<sup>6</sup>

The number of “Code Orange” and “Code Red” days experienced in the summer of 2011 bears out the need for tougher controls on motor vehicles and gasoline. Nationwide, through August 2011, 39 states plus the District of Columbia declared a total of 4,275 Code Orange and Code Red days – days when the air quality was either unhealthy for sensitive groups or unhealthy for all. This number is 40 percent higher than the 3,123 Code Orange and Code Red days declared by 40 states during the same period in 2010.

### Ozone in National Parks

The ozone problem exists even in our national parks. This year, from April through September 2011, there have been nearly 260 exceedances in parks with ozone monitors. Even with data for October 2011, the final month of this year’s ozone season, not yet in, national park ozone exceedances are greater than in either of the full ozone seasons in the past two years – 2010, when there were 223 exceedances, and 2009, when there were 196.<sup>7</sup>

### **C. Motor Vehicles Remain the Major Contributor**

Motor vehicles emit large quantities of carbon monoxide (CO), non-methane organic gases (NMOG), nitrogen oxides (NO<sub>x</sub>), particulate matter (PM), sulfur oxides (SO<sub>x</sub>) and such toxic substances as benzene, formaldehyde, acetaldehyde and 1,3-butadiene. Each of these, along with secondary by-products such as ozone and small particles (e.g., nitrates and sulfates), can cause serious adverse effects on health, as discussed in Appendix A.

Motor vehicle-related pollutants also endanger the environment. Ozone has detrimental effects on vegetation and ecosystems and makes sensitive plants more susceptible to diseases and damage. Ozone also inhibits plant growth and crop yields, and may impair biodiversity. Beyond their contribution to ozone, motor vehicle NO<sub>x</sub> emissions contribute to a variety of other adverse health and environmental effects including NO<sub>2</sub> and secondary PM levels, visibility impairment, acid rain, eutrophication and nitrification of water bodies and soiled materials, as discussed in Appendix B.

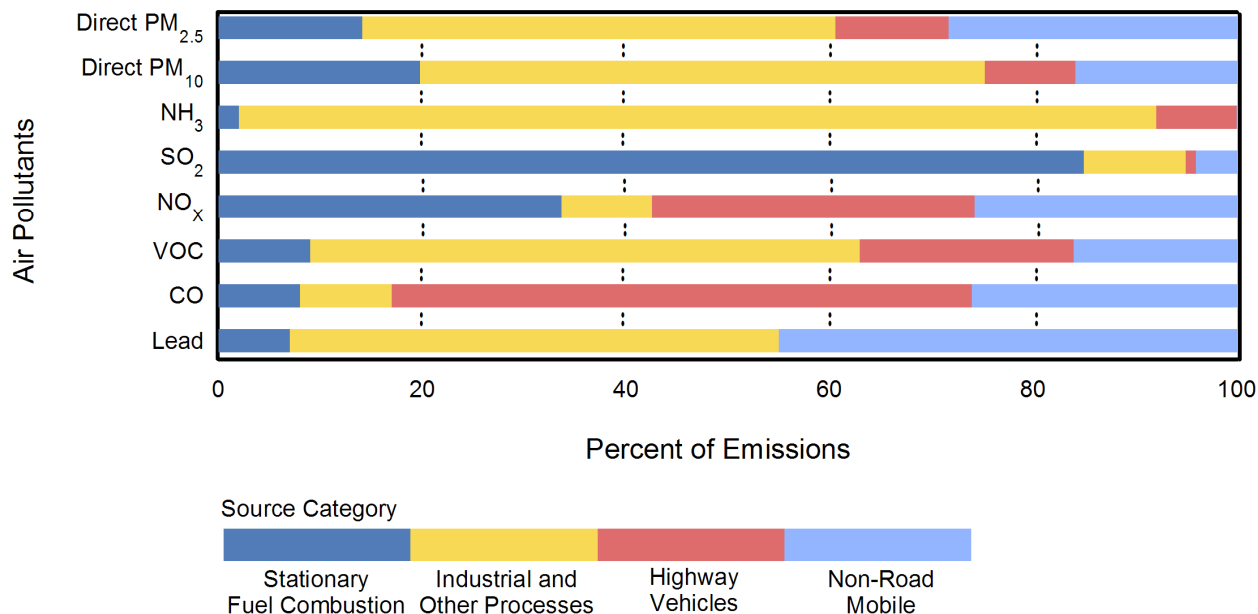
Many sources contribute to air pollution levels but, despite great progress, motor vehicles remain key, as the chart below illustrates. This is especially true with regard to NO<sub>x</sub> and VOCs, which are precursors to ozone. Therefore, further control of vehicle emissions is necessary if healthy air quality levels are ever to be attained and maintained.

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<sup>6</sup> When AQI values are between 101 and 150, a Code Orange alert is issued. Members of sensitive groups may experience adverse health effects at this time. For example, people with lung disease are at greater risk from exposure to ozone. When AQI values are between 151 and 200, a Code Red alert is issued. Everyone may begin to experience adverse health effects and members of sensitive groups may experience more serious health effects.

<sup>7</sup> See table of 2011 ozone standard exceedances at national parks, National Parks Service (accessed October 25, 2011), available at <http://www.nature.nps.gov/air/monitoring/exceed.cfm>.

## Distribution of National Total Emissions Estimates by Source Category for Specific Pollutants



Source: [http://www.epa.gov/airtrends/2010/dl\\_graph.html](http://www.epa.gov/airtrends/2010/dl_graph.html).

It is important to note, in particular, that EPA assumed more stringent mobile source controls (characterized as “additional technology changes in the onroad transportation sector”) in its primary analysis baseline for attainment of the ozone NAAQS adopted in 2008.<sup>8</sup> The additional technology changes contemplated by EPA in its Regulatory Impact Analysis of the 2008 ozone standard equate to the Tier 3 program. Therefore, the ability of states and localities to attain the 2008 ozone standard is tied directly to timely promulgation and implementation of Tier 3 vehicle and gasoline standards.

### D. Special Concerns with Proximity to Traffic

Children, older adults and people with existing respiratory problems are at even greater risk if they live, work or go to school near major roadways. Several studies estimate the national population, including children, residing near major roads and other transportation sources. For example, the American Housing Study (AHS)<sup>9</sup> – conducted by the U.S. Census Bureau every other year in odd-numbered years – surveys over 50,000 housing units nationwide. One question asked is whether the house is located within “half a block” or 300 feet of a railroad, airport or highway with four or more lanes. In the most recent AHS, for 2009, the estimated number of homes that met that description was 22,064,000, which is approximately 17 percent of all U.S. housing units.<sup>10</sup> Assuming that housing units are distributed fairly evenly among the 308 million residents of the U.S., approximately 52 million people live in those homes. Further,

<sup>8</sup> See Final Ozone NAAQS Regulatory Impact Analysis, Appendix 7a, EPA (March 2008), available at [http://www.epa.gov/ttn/ecas/regdata/RIAs/452\\_R\\_08\\_003.pdf](http://www.epa.gov/ttn/ecas/regdata/RIAs/452_R_08_003.pdf).

<sup>9</sup> See American Housing Survey, U.S. Census Bureau (2009), available at <http://www.census.gov/hhes/www/housing/ahs/ahs.html>.

<sup>10</sup> See American Housing Survey, Table 1-6, U.S. Census Bureau (2009), available at <http://www.census.gov/hhes/www/housing/ahs/ahs09/ahs09.html>.

a review of historical surveys shows that the fraction of homes within 300 feet of a railroad, airport or four-plus-lane highway has been increasing since about the late 1990s.

In another study,<sup>11</sup> researchers examined the number of public schools and students near interstate, U.S. and state highways. The metropolitan areas studied contained about 25 percent of the national population residing in Metropolitan Statistical Areas (MSAs) with population over 1,000,000. In total, among the surveyed schools and students, over 30 percent fell within 400 meters of a major roadway and over 10 percent were within 100 meters. For some MSAs, almost half of the student population attended schools near (within 400 meters) major roadways, resulting in a potentially increased risk for asthma and other chronic respiratory problems.

Most recently, the Health Effects Institute (HEI) investigated proximity of the general population to roadways. HEI summarizes the literature as follows: "Estimates of the percentage of the population exposed to pollution from traffic range from 30% to about 45%, depending on the distance chosen to represent near-source effects. Traffic-related pollution, in short, affects a large percentage of the urban population."<sup>12</sup>

## **II. The Recommended Tier 3 Program: Vehicle Standards**

To address our continuing air pollution problems it is necessary to take advantage of the improved vehicle emissions control technologies that have already entered the marketplace and to require nationwide the same low-sulfur gasoline that is already available in California.

EPA is expected soon to propose so-called Tier 3 requirements. Based on plans already announced by the California Air Resources Board (CARB) to tighten California's vehicle emissions standards, this NACAA study estimates what requirements would be feasible for EPA to adopt at the national level.

Fortunately, additional control technologies are already available and at very modest cost. EPA should capitalize on this and introduce a Tier 3 program of more rigorous light-duty vehicle emissions standards that harmonize with the Low-Emission Vehicle (LEV) III requirements being pursued by the California Air Resources Board.

### **A. Emissions Standards**

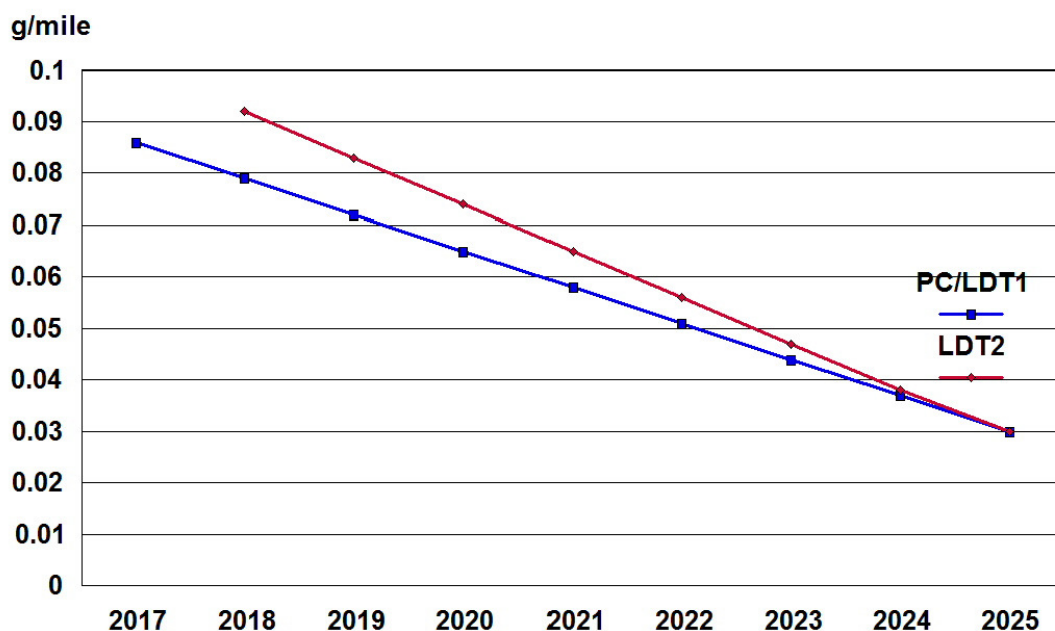
The figure below charts the declining NMOG+NO<sub>x</sub> standards anticipated to occur if EPA harmonizes federal Tier 3 standards with California's LEV III standards beginning with Model Year (MY) 2017 for cars and MY 2018 for light trucks.

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<sup>11</sup> Appatova, A.S.; Ryan, P.H.; LeMasters, G.K., et al. Proximal Exposure of Public Schools and Students to Major Roadways: A Nationwide U.S. Survey, *Journal of Environmental Planning and Management* 51: 631-646 (2008).

<sup>12</sup> Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects, Health Effects Institute Special Report 17, Health Effects Institute (January 12, 2010), available at <http://pubs.healtheffects.org/view.php?id=334>.

# Potential Tier 3 NMOG + NOx Emissions Standards



Source: MP Walsh (2011).

Not only should EPA harmonize as much as possible with CARB's LEV III program, matching the LEV III fleet average in 2017, the agency should also match its vehicle "bin" structure<sup>13</sup> with CARB's LEV vehicle categories and standards (see table below).

<sup>13</sup> EPA's "bin" structure is a set of ranked vehicle emission standards to which manufacturers can certify their vehicles. Bin 1 represents the cleanest standards.

**EPA and California Federal Test Procedure  
Exhaust Emission Standard Categories for Cars and Light Trucks**

Reference		Standards		
EPA Tier 2	CARB	NMOG	NO <sub>x</sub>	NMOG+NO <sub>x</sub>
Bin 5	LEV	0.090	0.070	0.160
	ULEV	0.055	0.070	0.125
	ULEV70	-	-	0.070
	ULEV50	-	-	0.050
Bin 2	SULEV30	0.010	0.020	0.030
	SULEV20	-	-	0.020
Bin 1	ZEV	0.000	0.000	0.000

Source: MP Walsh (2011).

**B. Technologies Needed To Comply with Tier 3 and Associated Costs**

The technologies needed to comply with such a Tier 3 program are almost entirely the same as those already on California's Partial Zero-Emissions Vehicle (PZEV)/Super Ultra-Low-Emissions Vehicle (SULEV) (i.e., EPA Tier 2 bin 2) models of today: 1) increased precious metal (platinum/palladium/rhodium) catalyst loading, 2) optimized close-coupled catalysts, 3) secondary air injection pumps and 4) evaporative control systems. The only advanced technology that may be needed is an active hydrocarbon (HC) adsorber, but this would most likely be limited to just a few, if any, larger V8 engines.

Light-duty diesel vehicles need urea-selective catalytic reduction (SCR) for NO<sub>x</sub>, diesel oxidation catalysts for HC, CO and PM and diesel particulate filters for PM – essentially the same technologies used to comply with Tier 2, although only the German automakers (which represent less than 10 percent of U.S. sales) are bringing diesels into the U.S. in significant numbers.

CARB has estimated the costs of its LEV III program to be about \$100 per vehicle. The cost of the federal Tier 3 program would likely be slightly higher, approximately \$150 per vehicle on average, because under California's existing requirements new vehicles in the state are almost halfway to achieving the LEV III standards (2008 sales in California were about 22 percent SULEV, 55 percent ULEV and 23 percent LEV).

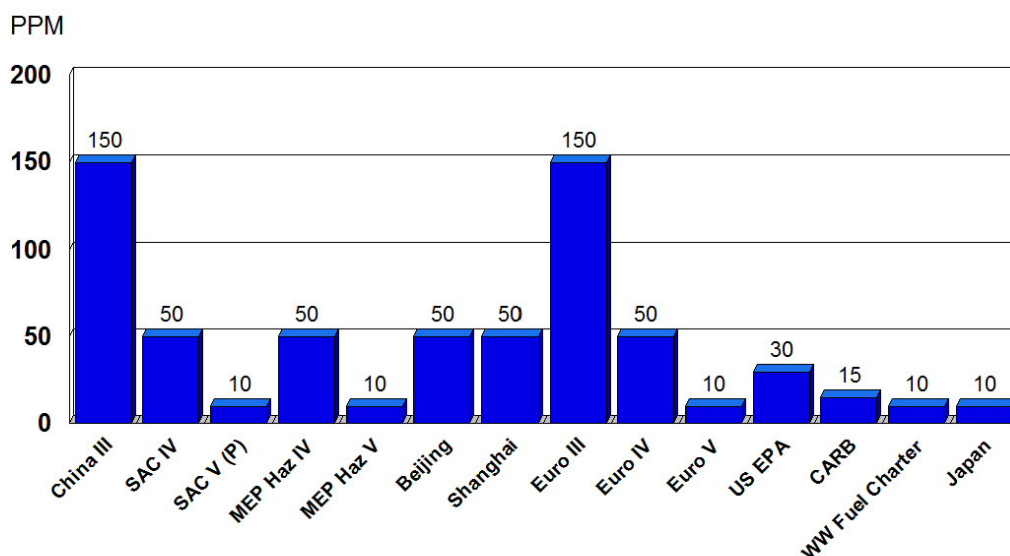
**III. The Recommended Tier 3 Program: Fuel Standards**

**A. Global Trends**

As indicated above, in order to achieve the stricter emissions standards at minimal cost, and to take advantage of technologies already in the market place, EPA will need to lower sulfur levels in gasoline from the current average of about 30 parts per million (ppm) to approximately 10 ppm. Such a reduction in national sulfur levels will immediately improve the NO<sub>x</sub> control

effectiveness on all existing Tier 2 cars and will be equivalent to eliminating over 33 million cars from the nation’s highways in 2017. California’s gasoline already achieves this level and, and as illustrated by the chart below, there is a global movement toward lower-sulfur gasoline. In fact, it is expected that the city of Beijing, China will introduce a 10-ppm sulfur limit for its gasoline next year.

## Sulfur Content in Gasoline Worldwide Comparison



Source: MP Walsh (2011).

### B. The Cost of Reducing Sulfur in Gasoline

To independently determine the cost implications of lower sulfur gasoline, the International Council on Clean Transportation (ICCT) contracted with an expert refinery consulting company, MathPro, to update and slightly modify an earlier study MathPro carried out in 2009. In this new study,<sup>14</sup> MathPro estimates the cost of reducing sulfur in gasoline to 10 ppm under differing sets of assumptions. As detailed below, based on conservative assumptions, producing 10-ppm-sulfur fuel could be accomplished for less than a penny a gallon.

In its study, MathPro found the following:

“All U.S. refineries currently produce gasoline with an average sulfur content of 30 ppm (the Tier 2 standard). In a typical U.S. conversion or coking refinery, FCC [fluidized catalytically cracked] naphtha is the primary source of sulfur in the gasoline pool. It constitutes approximately 35% of

<sup>14</sup> Refinery Economics of a National Low Sulfur, Low RVP Gasoline Standard, MathPro, Inc. (October 25, 2011), available at <http://www.theicct.org>.



the gasoline pool, and by virtue of its volume and its sulfur content accounts for about 95% of the sulfur content of untreated gasoline. Consequently, the primary task in meeting a tighter gasoline sulfur standard is reducing the sulfur content of FCC naphtha. Meeting the current 30-ppm standard requires that the FCC naphtha have an average sulfur content of  $\approx$  50 ppm.

“U.S. refineries achieve this level of sulfur control by one of three means:

- FCC feed hydrotreating (“pre-treating”) to reduce the sulfur content of FCC feed to a level sufficiently low that the FCC naphtha produced by the FCC unit has a sulfur content of around 50 ppm. (This requires a suitable crude slate and severe FCC feed hydrotreating.)
- FCC naphtha hydrotreating (“post-treating”) to reduce the sulfur content of the FCC naphtha to about 50 ppm.
- A combination of pre-treating and post-treating.

“Producing gasoline with average sulfur content of 10 ppm (the proposed standard) requires reducing the average sulfur content of FCC naphtha to  $\approx$  10 ppm. In general, there are three prospective routes for doing so, all of which are represented in the regional refining models.

- Revamp an existing FCC feed hydrotreater (“pre-treater”) to reduce the sulfur content of FCC feed to a level sufficiently low that the FCC naphtha produced by the FCC unit has sulfur content of around 10 ppm.
- Revamp an existing FCC naphtha hydrotreater (“post-treater”) to reduce the sulfur content of the FCC naphtha to about 10 ppm.
- Install a new, grassroots FCC naphtha hydrotreater to reduce the sulfur content of the FCC naphtha to about 10 ppm.

“Each of these requires additions to hydrogen supply, refinery energy supply, sulfur recovery facilities and off-sites [e.g., terminal management systems, flare systems, utilities, environmental treatment units].

“The refineries that now meet the Tier 2 sulfur standard with post-treating (with or without pre-treating) would most likely follow the second route: revamp the existing post-treater. [MathPro] understand[s] that many of the FCC naphtha hydrotreaters installed to meet the Tier 2 sulfur standard are already capable of producing treated FCC naphtha with sulfur content  $<$  10 ppm. Only those units that do not have this capability would require revamping. However, to be conservative, [MathPro] assumed that all existing FCC naphtha hydrotreating capacity would require revamping to meet the 10 ppm standard.

“The refineries that now meet the Tier 2 sulfur standard *solely* with pre-treating (i.e., no post-treating) could adopt either the first or the third route: revamp the existing pre-treater to further reduce the sulfur content of the FCC feed or install a grassroots post-treater. [MathPro] assumed that refineries now meeting the Tier 2 sulfur standard *solely* with pre-treating would adopt the third route: install a grassroots post-treater. If the refinery’s sole focus is on gasoline sulfur control, then installing a grassroots post-treater is likely to be the less costly route, in terms of both investment and operating cost.”<sup>15</sup>

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<sup>15</sup> *Id.* at 14-15.

Based on the MathPro study, it appears the most reasonable, but still conservative, assumptions would be:

- All existing FCC post-treaters would require revamping to meet the 10-ppm sulfur standard;
- The average capital expenditure for revamping the fleet of FCC post-treaters is 30 percent of the expenditure for grassroots post-treaters (even though some of the existing units may require no revamping); and
- The target rate of return on refinery investments is 7 percent before tax.

Using these conservative assumptions, MathPro concluded that the per-gallon price of 10-ppm-sulfur fuel would be just \$0.008 – eight-tenths of a penny.

### C. Relative Cost Effectiveness

Not only is cleaner gasoline modest in price, it is also highly cost effective at about \$3,300 per ton of NO<sub>x</sub> reduced. This cost effectiveness makes low-sulfur gasoline especially appealing given that other NO<sub>x</sub> control measures being considered by states and localities are far less cost-effective, as shown in the chart below, which depicts NO<sub>x</sub> control measures being pursued by states in the Ozone Transport Region.

#### Cost Effectiveness of Tier 3 Low-Sulfur Gasoline Relative to Other NO<sub>x</sub> Reduction Measures

NO <sub>x</sub> Reduction Measure	Cost Per Ton of NO <sub>x</sub> Reduced
Tier 3 Low-Sulfur Gasoline	\$3,300
Oil/Gas Boilers Serving EGUs	\$1,100 - 8,700
New Small Gas Boilers	\$3,300 - 16,000
Municipal Waste Incinerators	\$2,140 (SNCR)
HEDD EGUs	\$45,000 - \$300,000 per unit
Stationary Generators	\$39,700 - 79,700
Minor New Source Review	\$600 - \$18,000

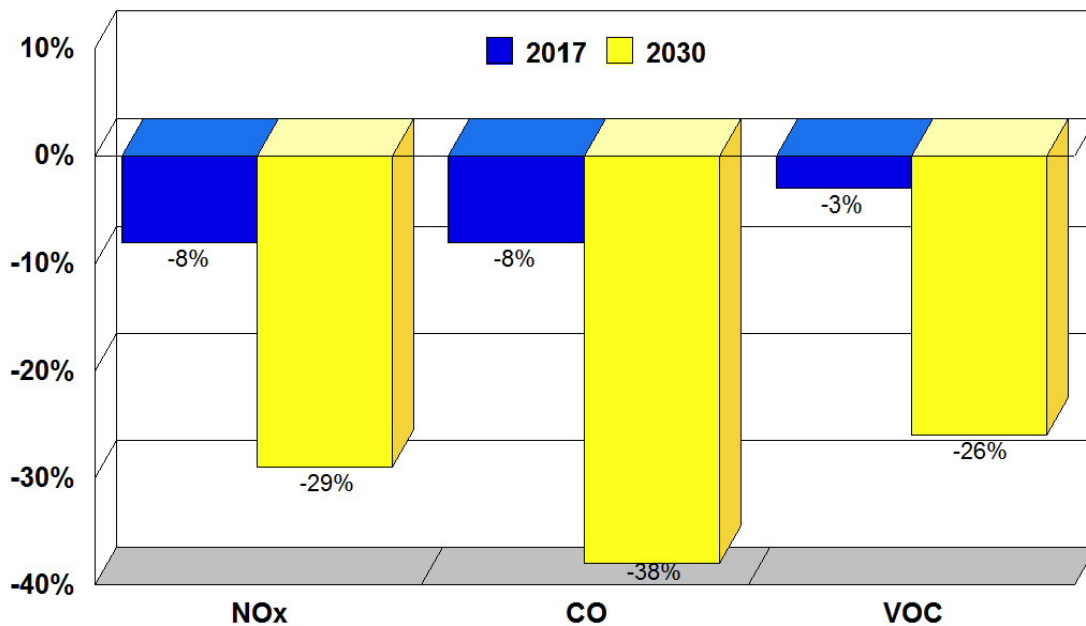
*Source: Senate Staff Briefing on the Need for Strong NO<sub>x</sub> Caps in the Eastern U.S – OTC, ICAC, NACAA and Maryland (July 2010).*

Reducing emissions that cause air pollution is a zero-sum game. Forgoing reductions from one source category means garnering reductions from another. In the absence of a federal Tier 3 program with low-sulfur gasoline, states and localities will have no choice but to turn to other, more expensive, less cost-effective measures – for example, placing additional controls on small “mom and pop” businesses and instituting transportation control measures – to achieve the emissions reductions they need to attain and sustain clean air goals. Further, this could prove to be very difficult in areas where there may not be sufficient sources to control in order to gain emissions reductions on the order of those that will result from Tier 3, or where state and local controls on certain sources will be politically unacceptable.

## IV. Emissions Reductions

A systems-based Tier 3 program as described above has the potential to yield truly meaningful emissions reductions. As shown in the figure below, by 2030, overall emissions of NO<sub>x</sub>, CO and VOCs would be expected to decline by 29 percent, 38 percent and 26 percent, respectively.

# Overall Emissions Reductions From Onroad Mobile Sources



Source: MP Walsh (2011).

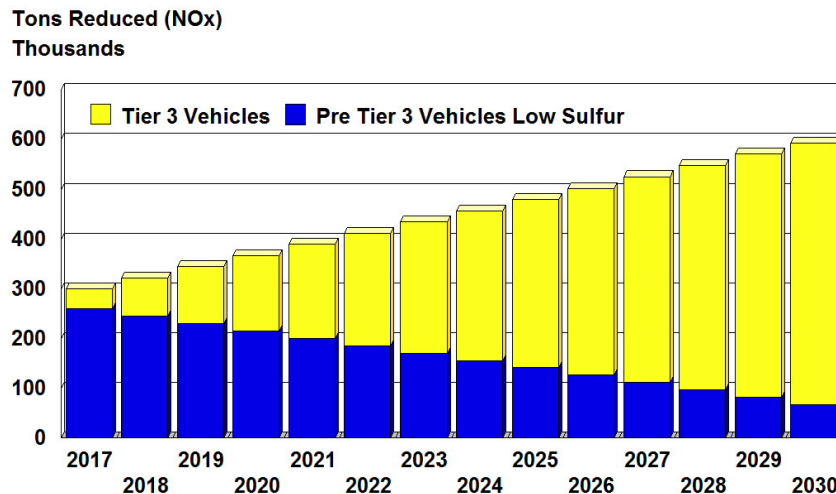
Sulfur in gasoline is a poison that reduces the efficiency and performance of catalysts designed to limit vehicle emissions and adversely affects heated exhaust-gas oxygen sensors. Laboratory testing of catalysts has demonstrated reductions in efficiency resulting from higher sulfur levels across a full range of air/fuel ratios. The effect is greater in percentage for low-emission vehicles than for traditional vehicles. Studies have also shown that sulfur adversely affects heated exhaust-gas oxygen sensors; slows the lean-to-rich transition, thereby introducing an unintended rich bias into the emission calibration; and may affect the durability of advanced on-board diagnostic systems.

The combustion of sulfur produces SO<sub>2</sub>, an acidic irritant that also leads to acid rain and the formation of sulfate particulate matter.

A more recent study indicates especially significant NO<sub>x</sub> reductions with the cleanest existing Tier 2/SULEV vehicles from lowering sulfur levels down almost to zero.<sup>16</sup> Thus it is clear that reducing sulfur levels in gasoline will not only enable the introduction of tighter emissions standards for new vehicles but will also immediately reduce emissions from the existing fleet, particularly the large proportion of Tier 2 vehicles already on the nation's highways.

The fuel quality changes, especially lowering the sulfur content of gasoline, have significant benefits for the existing pre-Tier 3 fleet. The NO<sub>x</sub>-reduction benefits from introducing low-sulfur gasoline to the existing fleet in 2017 has an immediate benefit equivalent to removing 33 million Tier 2 cars from the nation's highways. The three figures below illustrate the emissions reduction benefits of Tier 3 vehicles and gasoline. Over time, and especially by 2030 when a substantial fraction of the light-duty fleet will have turned over to Tier 3 vehicles, the emissions reduction for the Tier 3 vehicles will dominate for each pollutant shown (NO<sub>x</sub>, CO and VOC).

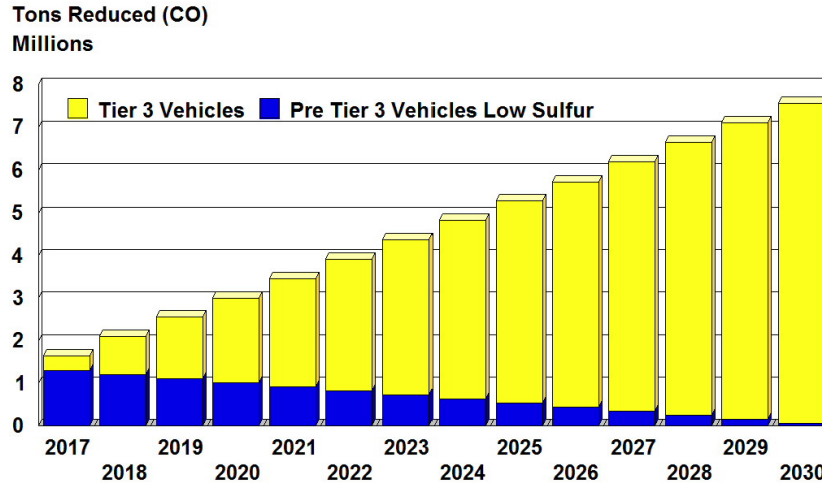
## Emissions Reduction Benefits From Tier 3 Vehicle and Fuels Requirements



Source: MP Walsh (2011).

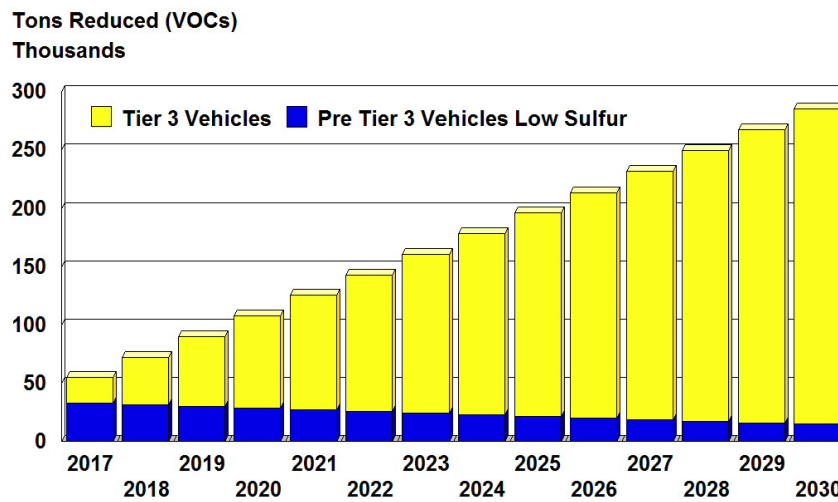
<sup>16</sup> Douglas Ball et al., Effects of Fuel Sulfur on FTP NO<sub>x</sub> Emissions from a PZEV 4 Cylinder Application, SAE Paper 2011-01-0300 (April 12, 2011).

# Emissions Reduction Benefits From Tier 3 Vehicle and Fuels Requirements



Source: MP Walsh (2011).

# Emissions Reduction Benefits From Tier 3 Vehicle and Fuels Requirements



Source: MP Walsh (2011).

Of course, reducing emissions in and of itself is not the ultimate goal. Rather, the goal is to better protect public health and the environment. The emissions reductions to be achieved from the Tier 3 vehicles and gasoline will lead to tremendous strides in this regard. As an example, the NO<sub>x</sub> reductions anticipated to result from this program will lead to reduced levels of ambient particulate matter that, in turn, would translate into more than 400 avoided premature deaths and 52,000 avoided lost workdays each year. Again, these are based only on reductions in ambient PM. The benefits of the ozone reductions to occur from Tier 3 vehicles and gasoline will lead to even greater health protection.

## **V. Conclusion**

Promulgation and implementation of a systems-based Tier 3 program, with vehicle standards modeled after CARB's LEV III program and an average fuel sulfur level of about 10 ppm, would result in dramatically reduced ozone levels across the U.S. Such a program has the potential to reduce emissions of NO<sub>x</sub>, CO and VOCs by 29 percent, 38 percent and 26 percent, respectively, by 2030. In addition, the introduction of 10-ppm-sulfur gasoline would bring about overnight-reductions from the existing Tier 2 fleet, equivalent to removing 33 million cars and trucks from the roads in 2017. Moreover, the price of this highly effective and much-needed program is modest, at less than a penny per gallon for 10-ppm-sulfur fuel and about \$150 per vehicle. Further, this highly cost-effective program would yield substantial health and welfare benefits.

## Appendix A: Health Effects Associated with Vehicle-Related Pollutants<sup>17</sup>

Exposure to air pollution has been associated with a variety of adverse health effects. Based on available information, the World Health Organization (WHO) sets and periodically updates air quality guidelines. The following summary is based on the guidelines adopted by WHO<sup>18</sup> and standards adopted by EPA.

### 1. Ozone

Ground-level ozone pollution is formed by the reaction of volatile organic compounds (VOCs) and nitrogen oxides (NO<sub>x</sub>) in the atmosphere in the presence of heat and sunlight. The science of ozone formation, transport and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically would occur on a single high-temperature day. Ozone also can be transported from pollution sources into areas hundreds of miles downwind, resulting in elevated ozone levels even in areas with low local VOC or NO<sub>x</sub> emissions.

The health and welfare effects of ozone are well documented.<sup>19</sup> Ozone can irritate the respiratory system, causing coughing, throat irritation and/or an uncomfortable sensation in the chest. It can reduce lung function and make it more difficult to breathe deeply, and breathing may become more rapid and shallow than normal, thereby limiting a person's activity. Ozone can also aggravate asthma, leading to more asthma attacks that require a doctor's attention and/or the use of additional medication. Animal toxicological evidence indicates that with repeated exposure, ozone can inflame and damage the lining of the lungs, which may lead to permanent changes in lung tissue and irreversible reductions in lung function. People who are more susceptible to effects associated with exposure to ozone include children, the elderly and individuals with respiratory disease such as asthma. There is suggestive evidence that certain people may have greater genetic susceptibility. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., children and outdoor workers), are also of concern.

Short-term exposure to current levels of ozone in many areas is likely to contribute to premature death, according to the National Research Council (NRC).<sup>20</sup> Evidence of a relationship between short-term – less than 24 hours – exposure to ozone and mortality has been mounting, but interpretations of the evidence have differed, prompting EPA to request the NRC report. Based on a review of recent research, the NRC committee found that deaths related to ozone exposure are more likely among individuals with pre-existing diseases and other factors that

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<sup>17</sup> Derived from Walsh, MP, Mobile Source-Related Air Pollution: Effects on Health and the Environment, *Encyclopedia of Environmental Health*, Volume 3, pp. 803-809; Nriago J (ed.), Burlington: Elsevier (2011).

<sup>18</sup> Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global Update 2005, Summary of Risk Assessment, World Health Organization (2006), available at [www.who.int/phe/health\\_topics/outdoorair\\_agg/en/](http://www.who.int/phe/health_topics/outdoorair_agg/en/).

<sup>19</sup> See Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. Environmental Protection Agency, EPA 600/R-05/004aF-cF (2006); Review of the National Ambient Air Quality Standards for Ozone, Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper Second Draft, U.S. Environmental Protection Agency, EPA-452/D-05-002 (2006).

<sup>20</sup> See Committee on Reducing Mortality Risk Reduction Benefits from Decreasing Tropospheric Ozone Exposure, National Research Council, *Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution*, National Academies Press (2008).

could increase their susceptibility. However, premature deaths are not limited to people who are already within a few days of dying.

In addition, the committee examined research based on large population groups to find how changes in ozone air concentration could affect mortality, specifically to determine the existence of a threshold – a concentration of ozone below which exposure poses no risk of death. The committee concluded that if a threshold exists, it is probably at a concentration below the current public health standard. As people have individual susceptibilities to ozone exposure, not everyone may experience an altered risk of death if ozone air concentration also changes. The research on short-term exposure does not account for all ozone-related mortality, and the estimated risk of death may be greater than if based solely on these studies, the committee noted.

Since the mid-1990s, there has been no major addition to the evidence from chamber studies or field studies. There has, however, been a marked increase in health effects evidence from epidemiological time-series studies. Combined evidence from those studies shows convincing, though small, positive associations between daily mortality and ozone levels, independent of the effects of particulate matter. Similar associations have been observed in North America and Europe. These time-series studies have shown effects at ozone concentrations below the previous WHO guideline of 120 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) without clear evidence of a threshold. Evidence from both chamber and field studies also indicates that there is considerable individual variation in response to ozone.

## **2. Nitrogen Dioxide**

Evidence from animal toxicological studies indicates that long-term exposure to nitrogen dioxide ( $\text{NO}_2$ ) at concentrations above current ambient concentrations has adverse effects. In population studies,  $\text{NO}_2$  has been associated with adverse health effects even when the annual average  $\text{NO}_2$  concentration complied with the WHO-2000 annual guideline value of  $40 \mu\text{g}/\text{m}^3$ . Also, some indoor studies suggest effects on respiratory symptoms among infants at concentrations below  $40 \mu\text{g}/\text{m}^3$ . Together these results support a lowering of the annual  $\text{NO}_2$  guideline value. However,  $\text{NO}_2$  is an important constituent of combustion-generated air pollution and is highly correlated with other primary and secondary combustion products; it is unclear to what extent the health effects observed in epidemiological studies are attributable to  $\text{NO}_2$  itself or to other correlated pollutants.

Many short-term experimental human toxicology studies show acute health effects at levels higher than  $500 \mu\text{g}/\text{m}^3$ , and one meta-analysis has indicated effects at levels exceeding  $200 \mu\text{g}/\text{m}^3$ .

The California Air Resources Board approved staff recommendations to amend its  $\text{NO}_2$  standard on February 22, 2007. The recommendations were based on a review of the scientific literature on the health effects of  $\text{NO}_2$  that was conducted by staff from the Air Resources Board and the Office of Environmental Health Hazard Assessment. On January 5, 2007, staff recommended lowering the existing 1-hour-average standard for  $\text{NO}_2$  of 0.25 ppm to 0.18 ppm, not to be exceeded, and established a new annual-average standard of 0.030 ppm, not to be exceeded.

An EPA final risk assessment finds evidence from recent studies is "sufficient to infer a likely causal relationship" between short-term exposure to  $\text{NO}_2$  and adverse effects on the respiratory



system.<sup>21</sup> According to the report, a 30-minute exposure to NO<sub>2</sub> concentrations between 0.2 ppm and 0.3 ppm has been shown to irritate airways in asthmatics. Children, whose lung function continues to develop into adolescence, and adults over the age of 65, are also particularly susceptible to NO<sub>2</sub> exposure. The risk assessment also identified as an at-risk group those whose jobs require significant periods of driving. Mean NO<sub>2</sub> levels inside vehicles are often two to three times the outdoor concentrations.

### 3. Carbon Monoxide

Carbon monoxide – an odorless, invisible gas created when fuels containing carbon are burned incompletely – also poses a serious threat to human health. Persons afflicted with heart disease and fetuses are especially at risk. Because the affinity of hemoglobin in the blood is 200 times greater for carbon monoxide than for oxygen, carbon monoxide hinders oxygen transport from blood into tissues. Therefore, more blood must be pumped to deliver the same amount of oxygen. Numerous studies in humans and animals have demonstrated that those individuals with weak hearts are placed under additional strain by the presence of excess CO in the blood. In particular, clinical health studies have shown a decrease in time to onset of angina pain in those individuals suffering from angina pectoris and exposed to elevated levels of ambient CO.<sup>22</sup> Some recent epidemiologic studies have found relationships between increased CO levels and increases in mortality and morbidity.<sup>23</sup>

Healthy individuals also are affected, but only at higher levels. Exposure to elevated CO levels is associated with impairment of visual perception, work capacity, manual dexterity, learning ability and performance of complex tasks.

### 4. Particulate Matter

Particulate matter (PM) represents a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. PM<sub>10</sub> refers to particles generally less than or equal to 10 micrometers (µm). PM<sub>2.5</sub> refers to fine particles, generally less than or equal to 2.5 µm in diameter. Inhalable (or “thoracic”) coarse particles refer to those particles generally greater than 2.5 µm but less than or equal to 10 µm in diameter. Ultrafine PM refers to particles less than 100 nanometers (0.1 µm). Larger particles tend to be removed by the respiratory clearance mechanisms (e.g., coughing), whereas smaller particles are deposited deeper in the lungs.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (e.g., SO<sub>x</sub>, NO<sub>x</sub> and VOCs) in the atmosphere. Thus, PM<sub>2.5</sub> may include a complex mixture of different pollutants including sulfates, nitrates, organic compounds, elemental carbon and metal compounds. These particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers.

The evidence on airborne PM and public health is consistent in showing adverse health effects at exposures experienced by urban populations in cities throughout the world, in both developed and developing countries. The range of effects is broad, affecting the respiratory and

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<sup>21</sup> Risk and Exposure Assessment to Support the Review of the NO<sub>2</sub> Primary National Ambient Air Quality Standard (Final), U.S. Environmental Protection Agency, EPA-452/R-08-008a (November 2008).

<sup>22</sup> See Aronow, et. al., Effect of Carbon Monoxide on Exercise Performance in Chronic Obstructive Pulmonary Disease, *Am. J. Med.*, (1977); Ferris, Health Effects of Exposure to Low Levels of Regulated Air Pollutants, A Critical Review, *Journal of the Air Pollution Control Association*, (May 1978).

<sup>23</sup> See Air Quality Criteria for Carbon Monoxide, EPA Office of Research and Development (June 2000).

cardiovascular systems and extending to children and adults and to a number of large, susceptible groups within the general population. The risk for various outcomes has been shown to increase with exposure and there is little evidence to suggest a threshold below which no adverse health effects would be anticipated. In fact, the lower range of concentrations at which adverse health effects have been demonstrated is not greatly above the background concentration that has been estimated at 3-5  $\mu\text{g}/\text{m}^3$  in the U.S. and Western Europe for particles smaller than  $\text{PM}_{2.5}$ . The epidemiological evidence shows adverse effects of particles after both short-term and long-term exposures.

Health effects associated with short-term exposures (hours to days) to ambient PM include premature mortality, increased hospital admissions, heart and lung diseases, increased cough, adverse lower-respiratory symptoms, decrements in lung function and changes in heart rate rhythm and other cardiac effects. Studies examining populations exposed to different levels of air pollution over a number of years, including the Harvard Six-Cities Study<sup>24</sup> and the American Cancer Society (ACS) Study,<sup>25</sup> show associations between long-term exposure to ambient  $\text{PM}_{2.5}$  and both total and cardiovascular and respiratory mortality. In addition, a reanalysis of the ACS Study shows an association between fine particle and sulfate concentrations and lung cancer mortality.<sup>26</sup>

The health effects of  $\text{PM}_{2.5}$  have been further documented in local impact studies that have focused on health effects due to  $\text{PM}_{2.5}$  exposures measured on or near roadways. Taking account of all air pollution sources, including both spark-ignition (gasoline) and diesel-powered vehicles, these latter studies indicate that exposure to  $\text{PM}_{2.5}$  emissions near roadways, dominated by mobile sources, are associated with potentially serious health effects. For instance, a recent study found associations between concentrations of cardiac risk factors in the blood of healthy young police officers and  $\text{PM}_{2.5}$  concentrations measured in vehicles.<sup>27</sup> Also, a number of studies have shown associations between residential or school outdoor concentrations of some constituents of fine particles found in motor vehicle exhaust and adverse respiratory outcomes, including asthma prevalence in children who live near major roadways.<sup>28,29,30</sup>

The WHO annual average guideline value of 10  $\mu\text{g}/\text{m}^3$  for  $\text{PM}_{2.5}$  was chosen to represent the lower end of the range over which significant effects on survival have been observed in the ACS Study.<sup>31</sup> Adoption of a guideline at this level places significant weight on the long-term exposure studies using the ACS and Harvard Six-Cities data. In these studies, robust associations were reported between long-term exposure to  $\text{PM}_{2.5}$  and mortality. Thresholds were not apparent in either of these studies.

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<sup>24</sup> Dockery, DW; Pope, CA III; Xu, X; et al., An Association between Air Pollution and Mortality in Six U.S. Cities, *N Engl J Med.* 329:1753–1759 (1993).

<sup>25</sup> Pope CA, III; Thun, MJ; Namboodiri, MM; Dockery, DW; Evans, JS; Speizer, FE; Heath, CW, Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults, *Am J Respir Crit Care Med* 151:669–674 (1995).

<sup>26</sup> Krewski D et al., Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality, *Health Effects Institute Special Report* (July 2000).

<sup>27</sup> Riekider, M; Cascio, WE; Griggs, TR; Herbst, MC; Bromberg, PA; Neas, L; Williams, RW; Devlin, RB, Particulate Matter Exposures in Cars Is Associated with Cardiovascular Effects in Healthy Young Men, *Am. J. Respir. Crit. Care Med* 169:934–940 (2003).

<sup>28</sup> Van Vliet, P; Knape, M; de Hartog, J; Janssen, N; Harssema, H; Brunekreef, B, Motor Vehicle Exhaust and Chronic Respiratory Symptoms in Children Living Near Freeways, *Env. Research* 74:122–132 (1997).

<sup>29</sup> Brunekreef, B, Janssen, NAH; de Hartog, J; Harssema, H; Knape, M; van Vliet, P, Air Pollution from Truck Traffic and Lung Function in Children Living Near Roadways, *Epidemiology* 8:298–303 (1997).

<sup>30</sup> Kim, JJ; Smorodinsky, S; Lipsett, M; Singer, BC; Hodgson, AT; Ostro, B, Traffic-Related Air Pollution Near Busy Roads: The East Bay Children's Respiratory Health Study, *Am. J. Respir. Crit. Care Med* 170: 520–526 (2004).

<sup>31</sup> Pope, CA et al., Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution, *Journal of the American Medical Association* 287:1132–1141 (2002).

In addition to PM<sub>2.5</sub> and PM<sub>10</sub>, ultra-fine (UF) particles have recently attracted significant scientific and medical attention. These are particles smaller than 0.1 µm and are measured as a number concentration. While there is considerable toxicological evidence of potential detrimental effects of UF particles on human health, the existing body of epidemiological evidence is insufficient in the view of WHO to reach a conclusion on the exposure/response relationship to UF particles. Therefore, no recommendations have been provided by WHO as to guideline concentrations of UF particles at this point.

A study led by UCLA researchers has revealed that the smallest particles from vehicle emissions may be the most damaging components of air pollution in triggering plaque buildup in the arteries, which can lead to heart attack and stroke.<sup>32</sup> In the study, researchers exposed mice with high cholesterol to one of two sizes of air pollutant particles from downtown Los Angeles freeway emissions and compared them with mice that received filtered air that contained very few particles. Researchers found that mice exposed to UF particles exhibited 55 percent greater atherosclerotic-plaque development than animals breathing filtered air and 25 percent greater plaque development than mice exposed to fine-sized particles.

Another study, published in the New England Journal of Medicine, linked exposure to diesel exhaust with asthma.<sup>33</sup> The researchers recruited 60 adults with either mild or moderate asthma to participate in a randomized, crossover study. Each participant walked for 2 hours along a London street (Oxford Street) and, on a separate occasion, through a nearby park (Hyde Park). Detailed real-time exposure, physiological and immunologic measurements were taken. Participants had significantly higher exposures to fine particles (less than 2.5 µm in aerodynamic diameter), UF particles, elemental carbon and NO<sub>2</sub> on Oxford Street than in Hyde Park. Walking for 2 hours on Oxford Street induced asymptomatic but consistent reductions in the forced expiratory volume in 1 second (FEV<sub>1</sub>) (up to 6.1%) and forced vital capacity (FVC) (up to 5.4%) that were significantly larger than the reductions in FEV<sub>1</sub> and FVC after exposure in Hyde Park (P = 0.04 and P = 0.01, respectively, for the overall effect of exposure, and P<0.005 at some time points). The effects were greater in subjects with moderate asthma than in those with mild asthma. These changes were accompanied by increases in biomarkers of neutrophilic inflammation (sputum myeloperoxidase, 4.24 ng per milliliter after exposure in Hyde Park versus 24.5 ng per milliliter after exposure on Oxford Street; P = 0.05) and airway acidification (maximum decrease in pH, 0.04% after exposure in Hyde Park and 1.9% after exposure on Oxford Street; P = 0.003). The changes were associated most consistently with exposures to UF particles and elemental carbon.

## 5. Air Toxics

People experience elevated risk of cancer and other noncancerous health effects from exposure to air toxics. Mobile sources are a major source of this exposure. According to the most recent U.S. National Air Toxic Assessment (NATA), for 2005,<sup>34</sup> mobile sources were responsible for 43

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<sup>32</sup> Araujo, JA; Barajas, B; Kleinman, M; Wang, X; Bennett, BJ; Gong KW; Navab, M; Harkema, J; Sioutas, C; Lusis; AJ; and Nel AE, Ambient Particulate Pollutants in the Ultrafine Range Promote Early Atherosclerosis and Systemic Oxidative Stress, *Circulation Research* (January 17, 2008).

<sup>33</sup> James McCreanor, M.R.C.P., Paul Cullinan, M.D., Mark J. Nieuwenhuijsen, Ph.D., James Stewart-Evans, M.Sc., Eleni Malliarou, M.Sc., Lars Jarup, Ph.D., Robert Harrington, M.S., Magnus Svartengren, M.D., In-Kyu Han, M.P.H., Pamela Ohman-Strickland, Ph.D., Kian Fan Chung, M.D., and Junfeng Zhang, Ph.D., Respiratory Effects of Exposure to Diesel Traffic in Persons with Asthma, *N Engl J Med* 357:2348-2358 (December 6, 2007).

<sup>34</sup> See EPA's 2005 National-Scale Air Toxics Assessment, available at <http://www.epa.gov/ttn/atw/nata2005/index.html>.

percent of outdoor toxic emissions and almost 21 percent of the cancer risk among the 139 pollutants quantitatively assessed. Formaldehyde was the largest contributor to cancer risk of all the assessed pollutants, contributing 44 percent of the total risk, and mobile sources were responsible for about 46 percent of all formaldehyde emissions in 2005. Benzene contributed 15 percent of the total risk with mobile sources responsible for about 60 percent of all benzene emissions in 2005.

According to the 2005 NATA, nearly the entire U.S. population was exposed to an average level of air toxics that has the potential for adverse respiratory noncancerous health effects. Mobile sources were responsible for 33 percent of the potential noncancerous hazard from outdoor air toxics. It is important to note that NATA estimates of noncancerous hazard do not include the adverse health effects associated with particulate matter.

The following section provides a brief overview of the air toxics associated with vehicles, and includes a discussion of the health risks associated with each.

### ***a. Diesel Exhaust***

Diesel exhaust is a complex mixture comprised of carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, nitrogen compounds, sulfur compounds and numerous low-molecular-weight hydrocarbons. A number of these gaseous hydrocarbon components are individually known to be toxic including aldehydes, benzene and 1,3-butadiene. The diesel particulate matter present in diesel exhaust consists of fine particles (less than 2.5  $\mu\text{m}$ ), including a subgroup with a large number of UF particles (less than 0.1  $\mu\text{m}$ ). These particles have a large surface area, which makes them an excellent medium for adsorbing organics, and their small size makes them highly respirable and able to reach the deep lung. Many of the organic compounds present on the particles and in the gases are individually known to have mutagenic and carcinogenic properties. Diesel exhaust varies significantly in chemical composition and particle sizes between different engine types (heavy-duty, light-duty), engine operating conditions (idle, accelerate, decelerate) and fuel formulations (high-sulfur, low-sulfur). After being emitted, diesel exhaust undergoes chemical and physical changes in the atmosphere.

#### ***Diesel Exhaust: Potential Cancer Effects***

In EPA's 2002 Diesel Health Assessment Document (Diesel HAD),<sup>35</sup> diesel exhaust was classified as likely to be carcinogenic to humans by inhalation at environmental exposures, in accordance with the revised draft 1996/1999 EPA cancer guidelines. A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA and the U.S. Department of Health and Human Services) have made similar classifications.

For the Diesel HAD, EPA reviewed 22 epidemiologic studies on the subject of the carcinogenicity of workers exposed to diesel exhaust in various occupations, finding increased lung cancer risk, although not always statistically significant, in eight out of 10 cohort studies and 10 out of 12 case-control studies within several industries, including railroad workers. Relative risk for lung cancer associated with exposure ranged from 1.2 to 1.5, although a few studies show relative risks as high as 2.6. Additionally, the Diesel HAD also relied on two independent meta-analyses, which examined 23 and 30 occupational studies, respectively, and found statistically significant increases in smoking-adjusted relative lung cancer risk associated

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<sup>35</sup> Health Assessment Document for Diesel Engine Exhaust, EPA Office of Research and Development, EPA/600/8-90/057F (2002).

with diesel exhaust, of 1.33 to 1.47. These meta-analyses demonstrate the effect of pooling many studies and in this case show the positive relationship between diesel exhaust exposure and lung cancer across a variety of diesel exhaust-exposed occupations.<sup>36, 37</sup>

The EPA Diesel HAD concluded that environmental risks from diesel exhaust exposure could range from a low of  $10^{-4}$  to  $10^{-5}$  to as high as  $10^{-3}$ , reflecting the range of occupational exposures that could be associated with the relative and absolute risk levels observed in the occupational studies.

Retrospective health studies of railroad workers have played an important part in determining that diesel exhaust is a likely human carcinogen. Key evidence of the diesel exhaust exposure linkage to lung cancer comes from two retrospective case-control studies of railroad workers.

### ***Diesel Exhaust: Other Health Effects***

Noncancerous health effects of acute and chronic exposure to diesel exhaust emissions are also of concern. EPA derived a Reference Concentration (RfC) from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects.<sup>38,39,40,41</sup> The RfC is  $5 \mu\text{m}^3$  for diesel exhaust as measured by diesel PM. This RfC does not consider allergenic effects such as those associated with asthma or immunologic effects even though there is growing evidence that exposure to diesel exhaust can exacerbate these effects.

#### ***b. Other Air Toxics***

Vehicles contribute to ambient levels of other air toxics known or suspected as human or animal carcinogens, or that have non-cancer health effects. These other compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter and naphthalene. All of these compounds, except acetaldehyde, were identified as national or regional risk drivers in the 2005 NATA. For a substantial segment of the population, these compounds pose a significant portion of the total cancer and noncancerous risk from breathing outdoor air toxics.

Noncancerous health effects resulting from inhalation exposures include neurological, cardiovascular, liver, kidney and respiratory effects as well as effects on the immune and reproductive systems.

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<sup>36</sup> Bhatia, R; Lopipero, P; Smith, A., Diesel Exposure and Lung Cancer, *Epidemiology* 9(1):84–91 (1998).

<sup>37</sup> Lipsett, M; Campleman, S, Occupational Exposure to Diesel Exhaust and Lung Cancer: A Meta-Analysis, *Am J Public Health* 80(7): 1009–1017 (1999).

<sup>38</sup> Ishinishi, N; Kuwabara, N; Takaki, Y; et al., Long-Term Inhalation Experiments on Diesel Exhaust, Results of the HERP Studies, Ibaraki, Japan: Research Committee for HERP Studies (1988) pp. 11–84.

<sup>39</sup> Heinrich, U; Fuhst, R; Rittinghausen, S; et al., Chronic Inhalation Exposure of Wistar Rats and Two Different Strains of Mice to Diesel Engine Exhaust, Carbon Black, and Titanium Dioxide, *Inhal. Toxicol.* 7:553–556 (1995).

<sup>40</sup> Mauderly, JL; Jones, RK; Griffith, WC; et al., Diesel Exhaust Is a Pulmonary Carcinogen in Rats Exposed Chronically by Inhalation, *Fundam. Appl. Toxicol.* 9:208–221 (1987).

<sup>41</sup> Nikula, KJ; Snipes, MB; Barr, EB; et al., Comparative Pulmonary Toxicities and Carcinogenicities of Chronically Inhaled Diesel Exhaust and Carbon Black in F344 Rats, *Fundam. Appl. Toxicol.* 25:80–94 (1995).

## **Appendix B: Environmental Effects Associated with Vehicle-Related Pollutants**

### **1. Visibility**

Visibility can be defined as the degree to which the atmosphere is transparent to visible light. Visibility impairment manifests in two principal ways: as local visibility impairment and as regional haze.<sup>42</sup> Local visibility impairment may take the form of a localized plume, a band or layer of discoloration appearing well above the terrain as a result of complex local meteorological conditions. Alternatively, local visibility impairment may manifest as an urban haze, sometimes referred to as a “brown cloud.” This urban haze is largely caused by emissions from multiple sources in the urban areas and is not typically attributable to only one nearby source or to long-range transport. The second type of visibility impairment, regional haze, usually results from multiple pollution sources spread over a large geographic region. Regional haze can impair visibility in large regions and across states.

Visibility is important because it has direct significance to people’s enjoyment of daily activities. Individuals value good visibility for the well being it provides them directly, where they live and work and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas such as national parks and wilderness areas and special emphasis is given to protecting visibility in these areas.<sup>43, 44</sup>

### **2. Plant and Ecosystem Effects of Ozone**

Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure.<sup>45</sup> Ozone effects also tend to accumulate over the growing season of the plant, so that even lower concentrations experienced for a longer duration have the potential to create chronic stress on vegetation. Ozone damage to plants includes visible injury to leaves and a reduction in food production through impaired photosynthesis, both of which can lead to reduced crop yields, forestry production and use of sensitive ornamentals in landscaping. In addition, the reduced food production in plants and subsequent reduced root growth and storage below ground, can result in other, more subtle plant and ecosystems impacts. These include increased susceptibility of plants to insect attack, disease, harsh weather, interspecies competition and overall decreased plant vigor. The adverse effects of ozone on forest and other natural vegetation can potentially lead to species shifts and loss from the affected ecosystems, resulting in a loss or reduction in associated ecosystem goods and services. Lastly, visible ozone injury to leaves can result in a loss of aesthetic value in areas of special scenic significance like national parks and wilderness areas.

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<sup>42</sup> See discussion in National Ambient Air Quality Standards for Particulate Matter; Proposed Rule, 71 *Federal Register* 2676 (January 17, 2006).

<sup>43</sup> See Air Quality Criteria for Particulate Matter, U.S. Environmental Protection Agency, EPA600/P-99/002aF and EPA600/P-99/002bF (October 2004).

<sup>44</sup> See Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, EPA OAQPS Staff Paper. EPA-452/R-05-005 (2005).

<sup>45</sup> See Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. Environmental Protection Agency, EPA 600/R-05/004aF-cF (2006).

### 3. Acid Deposition

Acid deposition, or acid rain as it is commonly known, occurs when NO<sub>x</sub> and SO<sub>2</sub> react in the atmosphere with water, oxygen and oxidants to form various acidic compounds that later fall to earth in the form of precipitation or dry deposition of acidic particles. It contributes to damage of trees at high elevations and in extreme cases may cause lakes and streams to become so acidic that they cannot support aquatic life. In addition, acid deposition accelerates the decay of building materials and paints, including irreplaceable buildings, statues and sculptures that are part of a nation's cultural heritage.

Nitrogen oxides have also been found to contribute to ocean acidification, thereby amplifying one of the many deleterious impacts of climate change.<sup>46</sup> Approximately one third of all nitrogen oxide emissions end up in the oceans. The impact of these emissions on acidification is intensely felt in specific, vulnerable areas; in some areas it can be as high as 10 to 50 percent of the impact of carbon dioxide. The hardest hit areas are likely to be those directly around the release site, so these emissions are especially significant in and around coastal waters.

### 4. Eutrophication and Nitrification

Eutrophication is the accelerated production of organic matter, particularly algae, in a water body. Nitrogen deposition contributes to eutrophication of watersheds, particularly in aquatic systems where atmospheric deposition of nitrogen represents a significant portion of total nitrogen loadings. This increased growth can cause numerous adverse ecological effects and economic impacts, including nuisance algal blooms, dieback of underwater plants due to reduced light penetration and toxic plankton blooms. Algal and plankton blooms can also reduce the level of dissolved oxygen, which can adversely affect fish and shellfish populations. In recent decades, human activities have greatly accelerated nutrient impacts, such as nitrogen and phosphorus, causing excessive growth of algae and leading to degraded water quality and associated impairment of freshwater and estuarine resources for human uses.<sup>47</sup>

Severe and persistent eutrophication often directly impacts human activities. For example, losses in the nation's fishery resources may be directly caused by fish kills associated with low dissolved oxygen and toxic blooms. Declines in tourism occur when low dissolved oxygen causes noxious smells and floating mats of algal blooms create unfavorable aesthetic conditions. Risks to human health increase when the toxins from algal blooms accumulate in edible fish and shellfish, and when toxins become airborne, causing respiratory problems due to inhalation.

### 5. Materials Damage and Soiling

The deposition of airborne particles can reduce the aesthetic appeal of buildings and culturally important structures through soiling, and can contribute directly (or in conjunction with other pollutants) to structural damage by means of corrosion or erosion.<sup>48</sup> Particles affect materials principally by promoting and accelerating the corrosion of metals, by degrading paints and by deteriorating building materials such as concrete and limestone. Particles contribute to these effects because of their electrolytic, hygroscopic and acidic properties, and their ability to adsorb corrosive

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<sup>46</sup> See Doney, Scott C., et al., Impact of Anthropogenic Atmospheric Nitrogen and Sulfur Deposition on Ocean Acidification and the Inorganic Carbon System, *PNAS* 104:14580-14585, at 14580 (2007).

<sup>47</sup> See Deposition of Air Pollutants to the Great Waters, Third Report to Congress, EPA-453/R-00-005 (June 2000).

<sup>48</sup> See Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information, EPA OAQPS Staff Paper (2005).

gases (principally sulfur dioxide). The rate of metal corrosion depends on a number of factors, including the deposition rate and nature of the pollutant; the influence of the metal protective corrosion film; the amount of moisture present; variability in the electrochemical reactions; the presence and concentration of other surface electrolytes; and the orientation of the metal surface.