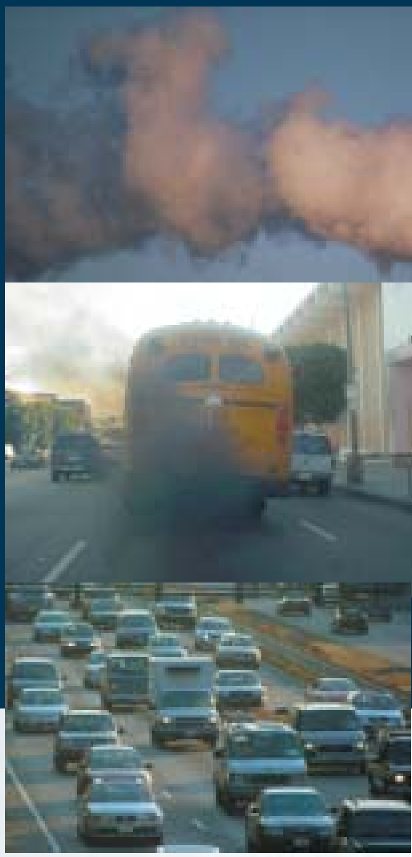

Air Pollution and Public Health in Pennsylvania

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April 2006

Acknowledgments

The authors greatly appreciate the timely input and insightful review offered by Dr. Jeanne Zborowski and Dr. Evelyn Talbott of the University of Pittsburgh Graduate School of Public Health. In addition, the authors appreciate the advice of Dr. David Bates, Professor Emeritus of Medicine, University of British Columbia; Dr. J.C. Chen and Dr. David Richardson of the University of North Carolina School of Public Health, Department of Epidemiology; and Dr. David Leith of the University of North Carolina Department of Environmental Sciences and Engineering in refining the methods used in drafts of this report. Susan Rakov, Tony Dutzik and Elizabeth Ridlington of the Frontier Group generously provided editorial assistance.

The financial support of the Energy Foundation made this project possible.

Any factual errors are strictly the responsibility of the authors. The views and opinions expressed here are those of the authors and do not necessarily reflect the views of our funders or of individuals who reviewed drafts of the report or provided advice. The recommendations are those of the PennEnvironment Research & Policy Center.

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Executive Summary

Air pollution in Pennsylvania makes people sick and cuts lives short.

Air pollution irreparably damages lung tissues in ways similar to second-hand tobacco smoke, leading to a wide range of health impacts. Air pollution triggers heart attacks and strokes. It causes diseases like chronic bronchitis and lung cancer. It sends people to the emergency room with respiratory problems, causes asthma attacks, and contributes to respiratory illness in otherwise healthy people.

In this report, we estimate the health impact of outdoor air pollution in Pennsylvania. The estimates cover particulate pollution (or "soot"), which comes from smokestacks and vehicle exhaust, and ground-level ozone (or "smog"), which develops across much of the state on hot summer days as a result of emissions from cars, trucks, smokestacks and other sources. The estimates rely on research, data and methods produced by thousands of scientists from around the world, the U.S. Environmental Protection Agency (EPA), the Pennsylvania Department of Health and the World Health Organization. Taken together, information gathered from these sources reveals that air pollution places a significant burden on the health of Pennsylvanians.

Every year, air pollution kills thousands of people in Pennsylvania.

- Soot pollution causes about 5,000 premature deaths in Pennsylvania annually.
- At this rate, air pollution ranks as the third highest risk factor for premature death, behind smoking and poor diet/physical inactivity.

Air pollution causes thousands of people to be admitted to Pennsylvania hospitals every year and increases the burden of chronic disease.

- Smog pollution leads to an estimated 7,000 hospital admissions for respiratory disease and soot pollution contributes to roughly 4,000 admissions for cardiovascular disease annually.
- In addition, air pollution causes approximately 4,000 new cases of chronic bronchitis in adults every year.
- Among asthmatics, soot pollution causes an estimated 500,000 asthma attacks annually, with an additional 300,000 asthma attacks caused by smog.

Air pollution also causes illness in otherwise healthy people, leading to hundreds of thousands of missed work days each year in Pennsylvania.

- Air pollution causes roughly 800,000 missed work days each year, and millions of cases where Pennsylvanians experience symptoms such as shortness of breath. (See Tables ES-1 and ES-2 for a summary of the estimates.)

Children are especially vulnerable to the effects of air pollution.

- Every year, air pollution causes roughly 20 post-neonatal infant deaths and 900,000 missed school days due to illness. (See Table ES-3.)
- Injuries caused by air pollution early in life can have permanent effects, reducing lung capacity and potentially causing chronic diseases like asthma.

Many Pennsylvania residents suffer health problems caused by pollution even at levels that meet air pollution standards.

- Despite the fact that air pollution levels in Pennsylvania meet health standards during much of the year, even "safe" levels of pollution can cause damage. For instance, public transit use during the 1996 Atlanta Olympics reduced smog pollution and prevented emergency room visits—even though average smog levels were below current health standards before and after the event. Similarly, for soot, many of the more than 2,000 studies carried out since the last standard-setting review in 1997 show health damage at pollution levels below current standards.

Aggressive action to reduce air pollution can improve public health and reduce the societal cost of illnesses caused by pollution.

The two largest sources of Pennsylvania's air pollution are vehicles and coal-fired power plants. Reducing smog pollution from these sources will help prevent respiratory disease and reducing soot pollution will increase life expectancies and protect respiratory health. Thankfully, the state has many policy options to reduce pollution—at the state, regional and federal level.

State Level Actions:

- Implement the Clean Vehicles Program and its air pollution standards for automobiles that go beyond weaker federal standards; joining New York, Massachusetts, New Jersey, Connecticut, Rhode Island, Maine, Vermont, California, Oregon and Washington in requiring sales of cleaner cars. The Clean Vehicles Program will help reduce smog and prevent respiratory disease.
- Adopt limits on air pollution, including soot and smog, from power plants, requiring facilities grandfathered under the federal Clean Air Act to meet modern standards.
- Require retrofitting of diesel engines—including those of bus fleets and construction equipment—with particulate filtration systems.
- Reduce car-dependent land use practices and sprawl.
- Increase transportation funding for transit, rail freight, and other alternative transportation projects.

Federal and Regional Level Actions:

- Advocate for adoption of similar policies in neighboring states, especially in the Midwest.
- Restore and enforce the New Source Review provision of the federal Clean Air Act and require the oldest coal-fired power plants and other industrial facilities in the country to install modern pollution control technology.

- Limit nationwide industrial emissions of sulfur dioxide, nitrogen oxides, and mercury to between 10 percent and 30 percent of 2000 levels.
- Strengthen national emission standards for cars and trucks to match or exceed standards adopted by California and other states.

How to Interpret Health Effect Estimates

The numbers reported here are estimates illustrating the likely health impacts of outdoor air pollution commonly found in Pennsylvania. The estimates are subject to sources of scientific uncertainty, which could make the actual numbers higher or lower. Where possible, we attempted to make assumptions that would lead to an under-estimate rather than an over-estimate—meaning the scope and scale of the impacts of air pollution may be larger than reported here.

Sources of uncertainty include:

- The report does not capture or quantify all the effects of air pollution—for example, air pollution could affect development before birth, predisposing adults to disability or disease.
- Population exposures to air pollution are estimated based on readings at fixed monitors. Errors in extrapolating exposure to the whole population, either in this report or in published scientific literature, could affect the accuracy of our estimates.
- We assume that scientific studies carried out in other U.S. and Canadian cities would produce similar results if repeated in Pennsylvania. To the extent that conditions in Pennsylvania are different from other locations, it could affect the accuracy of the estimates.
- Health tracking systems currently do not track events like asthma attacks. The estimates we relied upon for the frequencies of these events were developed for the U.S. as a whole and may not reflect local conditions perfectly.
- There may be some degree of overlap between the effects of particulate matter and ground level ozone. However, we consider the two pollutants separately because ozone levels are more independent of particulate levels than other combustion-related pollutants.
- See "Methodology" on page 32 for a full discussion.

Table ES-1: Annual Public Health Impact of Soot (PM_{10}) in Pennsylvania

Health Effect	Estimated Cases	Range
Premature Death (Adults)	5,000	3,000 – 6,600
Respiratory Hospital Admissions	5,000	3,900 – 5,900
Cardiovascular Hospital Admissions	4,000	2,300 – 6,200
New Cases of Chronic Bronchitis	4,000	460 – 7,500
Asthma Attacks	500,000	210,000 – 790,000
Missed Work Days	800,000	740,000 – 870,000
Restricted Activity Days	8 million	6.9 million – 9.2 million
Increased Symptom Days	20 million	12 million – 40 million

Table ES-2: Annual Public Health Damage from Smog (Ground-Level Ozone) in Pennsylvania

Health Effect	Estimated Cases	Range
Respiratory Hospital Admissions	7,000	5,100 – 9,000
Asthma Attacks	300,000	150,000 – 420,000
Restricted Activity Days	1 million	1.0 million – 1.8 million
Increased Symptom Days	4 million	1.8 million – 5.5 million

Table ES-3: Annual Air Pollution Damage to Children's Health in Pennsylvania

Health Effect	Estimated Cases	Range
Infant Deaths (Post-neonatal)	20	12 – 22
Asthma ER Visits	3,000	400 – 7,300
Acute Bronchitis	40,000	21,000 – 51,000
Asthma Attacks	150,000	120,000 – 180,000
Missed School Days	900,000	700,000 – 1 million

The tables above present central estimates of the effects of air pollution on public health in Pennsylvania, including upper and lower boundaries of statistical precision that were derived from the scientific studies linking air pollution and health problems. (See "Methodology" on page 32 for a full discussion of how the estimates were calculated and see "How to Interpret Health Effect Estimates" on page 6 for a discussion of factors that could affect the accuracy of the estimates.)

Introduction

Air pollution in Pennsylvania is a serious and persistent problem.

The American Lung Association gives 28 counties in Pennsylvania an "F" for air quality—and that's just for smog pollution.[1] Pennsylvania as a whole has the second-worst chronic soot pollution problem—worse than every state but California.[2]

Air pollution poses major health risks for Pennsylvanians, especially children and the elderly. Air pollution shortens lives, sends people to the hospital and the emergency room, and triggers asthma attacks. And these are merely the most visible signs of the health threat posed by polluted air, as air pollution affects every individual by reducing lung function and increasing the risk of illness.

Nor are we safe on days when air pollution levels are below those recognized by the government as meeting federal "safe" standards. Ozone smog and particulate soot can cause health problems even on days when pollution levels are within the "safe" standards set by federal officials.

This is especially true for people who live, work or play near busy roadways. Pollution from traffic can be high near roadways, even when overall air pollution levels are relatively low. In fact, the American Academy of Pediatrics notes that, "In numerous cities in the United States, the personal automobile is the single greatest polluter, because emissions from millions of vehicles on the road add up."[3] Scientists are now finding that children who live or go to school near major highways are more likely to have respiratory problems, including asthma.[4]

It wasn't supposed to be this way—not in 2006. When Congress adopted the federal Clean Air Act in 1970, it established the goal of setting and achieving air quality standards protective of human health by 1975. Nearly three decades later, Pennsylvania's air still fails to meet established health standards—standards that may not be fully protective of human health.

With the rollback of key air pollution policies at the federal level—and with increased motor vehicle traffic, population, and overall energy use threatening to undermine the progress we have made toward cleaner air—Pennsylvania has reached a critical juncture. Solutions do exist. From modern emission controls for cars and power plants to effective transit systems, we have the technological know-how to significantly reduce air pollution in Pennsylvania.

By adopting public policies that put these technologies to work, Pennsylvania can reduce air pollution and help millions of its citizens to live longer and healthier lives.

Exposure to Air Pollution and How it Causes Harm

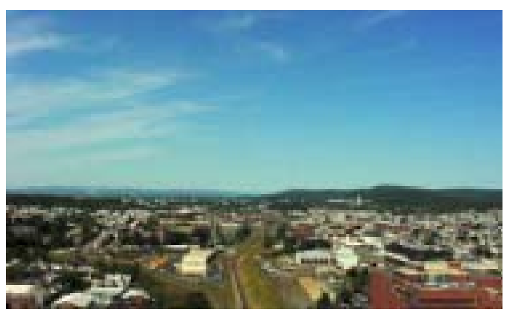
Most people think of air pollution only on days when the news announces an air quality alert, warning of high levels of smog and advising citizens to limit outdoor activity because of the health threat posed by smog pollution. Unfortunately, people in Pennsylvania aren't exposed to air pollution just a few dozen times a year on bad air days. Pennsylvanians breathe polluted air day in and day out throughout their entire lives.

Much of the pollution comes from burning fossil fuels for energy—in cars, trucks, power plants and industrial facilities. Many of these pollutants are invisible, and they are everywhere. They mix together in the atmosphere and react in complicated ways to form a toxic soup.

On bad air days, visibility plummets and the air looks thick and hazy. (See Figure 1.) Sometimes the sun even looks red as it sets due to pollutants in the air. These clouds of haze contain hundreds of toxic chemicals.

Two of the most harmful air pollutants are soot and smog. Soot, or particulate pollution, contaminates the air year-round. Power plants, diesel engines and related sources emit soot directly into the air. Chemical reactions between gaseous pollutants in the air can also create fine particles. Smog plagues summer days when intense sunlight transforms air pollutants and oxygen into toxic gases such as ozone. The main sources of smog-forming pollutants—which can be harmful in and of themselves, even before they are transformed into ozone—are power plants and motor vehicles.

Figure 1: Clear and Polluted Days in Berks County, Pennsylvania



August 25, 2005—a clear day.

June 22, 2005—a polluted day, with high levels of soot and smog forming a thick haze.

Haze Cam, Berks County Environmental Advisory Council

Figure 2: Average Soot Levels in Pennsylvania, 2003 ($PM_{2.5}$)[7]

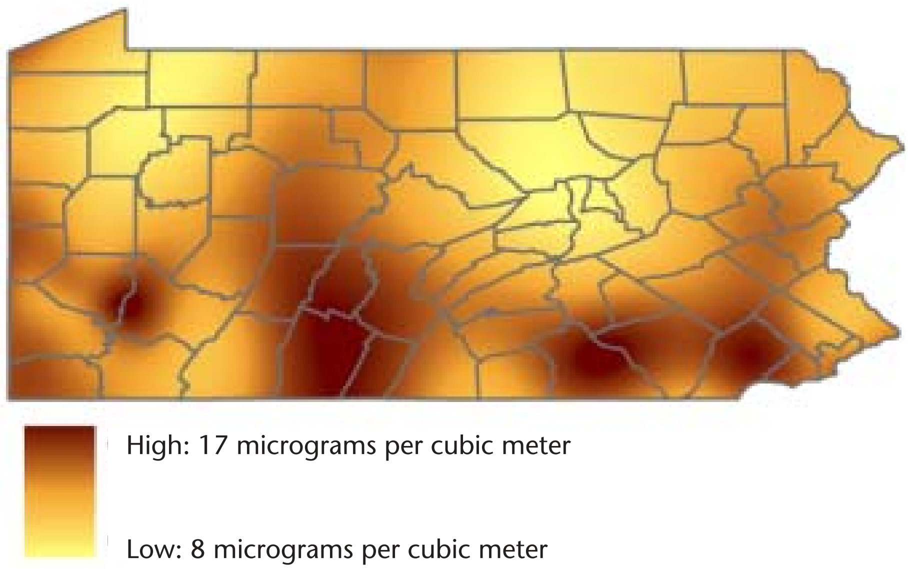
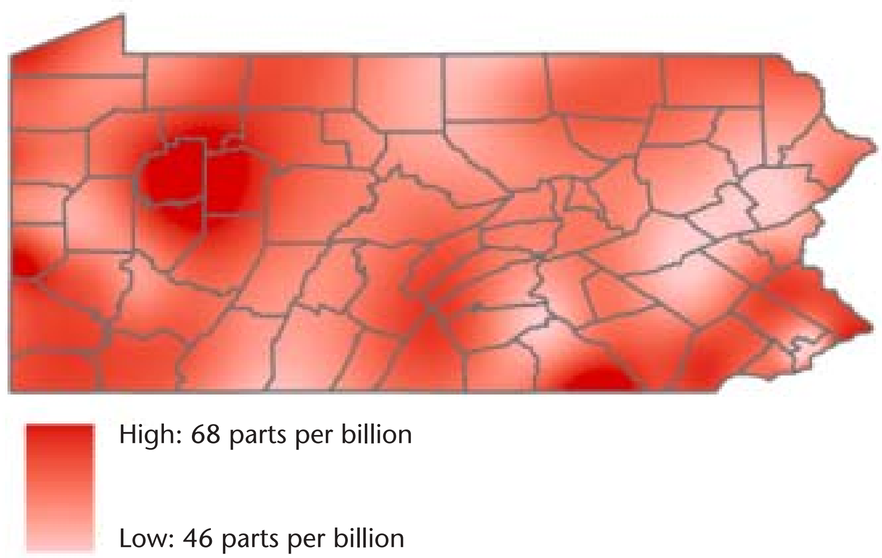


Figure 3: Average Daily 1-Hour Peak Smog Levels in Pennsylvania, April to October 2003[8]



Strengthening National Air Quality Standards

The Environmental Protection Agency (EPA) sets national air quality standards under the authority of the federal Clean Air Act. Under the law, the EPA is supposed to review the standards every five years and adjust them based on the latest scientific knowledge of what will protect public health with an adequate margin of safety.[11]

Because of industry resistance, the standards fail to reflect the scientific community's understanding of how dangerous air pollution really is. For example, EPA tightened standards for both soot and smog in 1997, based on accumulating evidence that soot and smog were more harmful than previously believed. However, the American Trucking Association led a coalition of industries in a lawsuit against the new standards. Ultimately, the Supreme Court rejected industry arguments and upheld the standards in 2001.[12] But this legal battle delayed implementation of the new standards for years.

Researchers have published more than 2,000 studies on particle pollution since the last standard-setting review in 1997, showing serious health risks at pollution levels well below current "safe" standards.[13] In 2005, the independent Clean Air Scientific Advisory Committee and staff scientists at the U.S. EPA both concluded that the standards for particulate matter were not adequate and recommended strengthening them.[14]

However, the Bush administration disregarded the advice of these experts. In December 2005, the administration proposed standards weaker than recommended by its own scientists. As a result, the administration's proposed standards would leave millions of Americans exposed to particulate pollution at levels that pose clear risks to health.

Air Pollution in Pennsylvania

Smog and soot reach unhealthy levels regularly in many parts of Pennsylvania. Annual average soot concentrations in the state (measured as particulate matter (PM) less than 2.5 micrometers in diameter) range from about 12 micrograms per cubic meter in the least polluted parts of the state to 24 micrograms per cubic meter in the most polluted areas.[6] (See Figure 2.)

From April through October, the average daily peak one-hour ozone levels reach 40-58 parts per billion (ppb) across the state. (See Figure 3.) On hot summer days, ozone levels routinely exceed EPA health standards across most of Pennsylvania.

If there was no human-induced air pollution emitted in North America, PM_{10} levels would be between 5 and 10 micrograms per cubic meter, and afternoon smog levels in the spring, summer and fall would be 15 to 30 ppb.[9] If pollution was not emitted from other countries in the world as well, background pollution levels would be even lower.[10]

Soot and smog cause damage when they come in contact with our lung tissues. Ozone quickly reacts with airway tissues and produces inflammation similar to a sunburn on the inside of the lungs. Particulates travel deep into the lower passages of the lungs and become trapped there, delivering a payload of toxic chemicals. Constant exposure to these pollutants over time permanently damages lung tissues, decreases the ability to breathe normally, and exacerbates or even causes chronic disease.

Smog (Ground-Level Ozone)

Smog can plague summer days in Pennsylvania, and results when a mixture of pollutants reacts under intense sunlight to form ozone.

In the past five years, ozone levels in Pennsylvania have exceeded federal health standards on as few as 14 days and as many as 50 days, with an average of 28 days per year.[23] However, ozone chronically contaminates the air at lower, but still harmful, levels from April through October.

A natural layer of ozone exists high in the atmosphere, absorbing ultraviolet radiation from the sun. However, when pollutants create ozone near the ground, it becomes a threat to public health.

Ozone is a powerful chemical gas sometimes used to kill bacteria in drinking water. Bubbling it through contaminated water destroys any infectious organisms in the water and makes it safe to drink. Not surprisingly, the chemical has the same effect on our lungs—when inhaled, it damages lung tissue and causes short-term swelling. With long-term exposure at even low levels, it causes permanent and irrevocable damage.

Scientists have known for well over a decade that ozone at levels routinely encountered in Pennsylvania causes reddening and swelling of lung tissue and reduces the elasticity of the tissue over time.[24] Ozone makes lung tissues more sensitive to allergens and less able to ward off infections.[25] It scars airway tissues. Children exposed to ozone develop lungs with less flexibility and capacity than normal. During high smog days, otherwise healthy people who exercise can't breathe normally.[26]

New scientific evidence continues to show dramatic evidence of the severe and long-term impact ozone exposure has on respiratory health:

- College freshmen who were raised in less polluted areas have lungs that work better than their schoolmates who grew up in polluted cities. For example, University of California-Berkeley freshmen who have lived in places with less ozone pollution can exhale more forcefully than students from more polluted areas.[27] Yale freshmen who have lived for four or more years in a county with high ozone levels can't breathe as well as freshmen from cleaner areas.[28]
- Recent studies show that the lungs of asthmatic infant rhesus monkeys suffer irreversible structural damage when exposed to ozone.[29] Ozone exposure reduces the number of branches formed by nerves and airway passages in the lung and forces lung muscles to reorganize, and long recovery periods do not improve the damage. The immune system and cellular responses to ozone are like those seen with asthma. Dr. Charles Plopper of the University of California-Davis, the author of the studies, commented, "From a public health standpoint, it's a pretty disquieting situation."[30] Researchers believe the same damage happens to human infants when exposed to air pollution.
- Striking results from the Southern California Children's Study indicate that exposure to ozone may cause asthma in children.[31] Children who exercise frequently in smoggy areas are more than three times as likely to develop asthma as those in cleaner parts of the country.

Taken together, these studies paint a picture of profound and irreversible respiratory damage beginning with an infant's first breath of ozone-tainted air, leading to impaired lung development and chronic respiratory disease.

Soot (Particulate Matter)

Back in the early days of the industrial revolution, thick black smoke poured from factories and coal-fired furnaces. During the

1952 "Great Fog," one of the most notorious pollution events in history, 12,000 Londoners died from intense pollution exposure.[39] Here in Pennsylvania, a dangerous cloud of pollution fell on Donora, outside of Pittsburgh on October 26, 1948. Half of the people in the town (7,000) were hospitalized because of breathing difficulties over the next five days.[40]

Today, the thick, black smoke characteristic of uncontrolled pollution has been replaced with the more subtle and insidious dirty haze that can almost look natural because of its frequent presence over the eastern United States. However, this pollution is anything but natural. It comes from burning fossil fuels, and mostly consists of extremely small and practically invisible particles in the air, often referred to as soot.

Some types of soot are simply unburned fuel particles. Other types of soot are created when pollutants react with each other in the atmosphere. Particles can contain hundreds of different chemicals from cancer-causing agents like polycyclic aromatic hydrocarbons, as well as metals like arsenic and zinc.

Forty to 1,000 times smaller than the width of a human hair, these fine particles result from burning fossil fuels like coal, gasoline, and diesel. For example, burning a pound of jet fuel creates 100 quadrillion particles.[41] Gasoline and diesel engines with and without catalytic converters emit particles

How Pollution Levels Have Changed in Pennsylvania

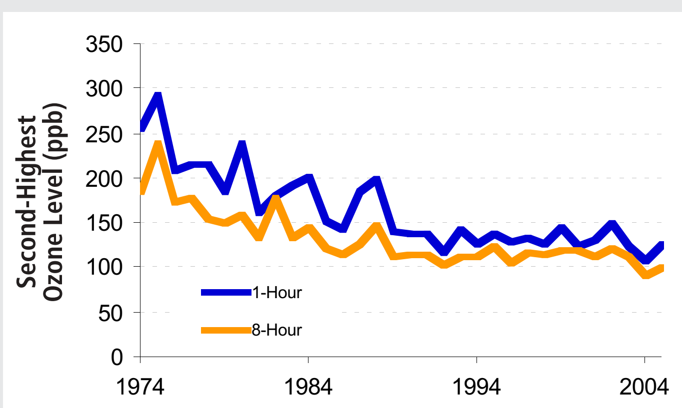
Air quality has improved significantly in Pennsylvania since the 1970s.[19] There was more smog and soot than exists in the air now.

Passage of the Clean Air Act in 1970 signaled the beginning of a period of progress. Levels of soot and smog dropped in response to the implementation of Clean Air Act policies within the state—in some areas, dramatically.[20]

However, progress in reducing smog levels stalled out in the 1990s. (See Figure 4.) Increases in the number of cars on the road and the miles they drive contributed to a plateau in smog levels. Particulate levels improved slightly during the 1990s, but are falling more slowly than in the period before 1982.[21]

Meanwhile, scientific research in the last three decades has shown that levels of air pollution once considered to be safe may in fact cause serious health concerns. As a result, heath agencies are recommending tougher standards to protect the public. In order to continue making progress toward clean and healthy air for Pennsylvanians to breathe, stronger and more comprehensive clean air policies will be necessary.

Figure 4: Trend in Smog Levels in Pennsylvania Since 1990[22]



The Dangers of Pollution from Traffic

Cars and trucks directly emit dangerous pollutants near roadways, in addition to contributing to soot and smog in ambient air. Fuel combustion produces pollutants like nitrogen oxides, small particles, benzene, formaldehyde, and 1,3-butadiene. In sufficient amounts, these pollutants irritate airways and lungs, cause asthma, worsen asthma symptoms, and cause leukemia and other types of cancers.[32]

Exhaust from highways and major roads poses a serious health hazard for anyone who lives, works or goes to school in or near heavy traffic. Scientific studies have shown that automobile exhaust causes serious illnesses and increases the risk of death.

Children directly exposed to traffic pollution develop respiratory problems.

- Researchers in Europe found that children who live or go to school close to busy highways and roads are more likely to suffer from coughing, wheezing, and upper respiratory infections. Significantly, these children are also more likely to suffer from asthma.[33]
- Researchers in southern California found that children living closer to a highway are more likely to have asthma, more likely to wheeze and more likely to use asthma medication.[34]
- The damage begins at birth; studies have found that infants exposed to traffic-related air pollution during their first year of life are more likely to suffer from coughs, which could later translate into chronic respiratory problems.[35]

Air pollution from traffic causes damage that increases the risk of death.

- People living near highways or highly traveled roads face an increased risk of death from stroke, lung disease and heart disease.[36]

Many people assume that being inside a car offers some protection from exhaust—but pollution levels in cars are higher than in the air outdoors, especially in congested traffic.

- On congested roadways, levels of dangerous pollutants inside vehicles can be up to 10 times higher than in general city air.[37]
- U.S. EPA researchers studied a group of North Carolina highway patrol troopers who regularly work on the road. After breathing elevated levels of particulates while on duty, the troopers' heart rhythms and blood chemistry changed in ways associated with increased risk of heart attack.[38]

In order to improve public health, state leaders must implement policies to reduce pollution directly emitted from vehicles on busy roadways.

with a size of 0.1 to 1 micrometers, with the smallest particles coming from gasoline and medium-duty diesel engines.[42]

Fine particles can remain suspended in the air for weeks. They can travel through building shells and conventional heating and air conditioning filters. When inhaled, they are able to penetrate deep into the lung where they deliver their toxic payload. In contrast, larger particles such as dust or pollen travel shorter distances and are more effectively trapped in the body's upper airway.

Fine particles penetrate to the deepest part of the lung, where they are attacked and absorbed by immune cells. In an experiment in England, ultra fine carbon particles showed up in the immune cells of every child tested—even in a three-month old infant.[43] The particles were of the same size emitted by motor vehicles, and children who lived close to busy roads had up to three times more particles in their bodies.

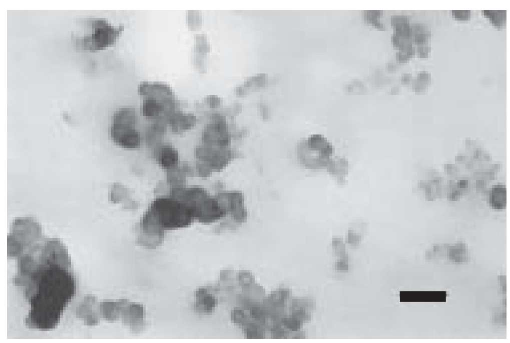
Some of the particles remain trapped in the lung, while others travel through the blood to the rest of the body.[44] Scientists have counted particulates in the lung tissue of cadavers. People from highly polluted Mexico City had two billion particles in every gram of lung tissue, and people from less polluted Vancouver, Canada had about 280 million.[45]

The chemicals delivered into the body by inhaled particulates are very dangerous. Some of them cause cancer, some cause irritation to lung tissues, and some cause changes in the function of the heart.[46] As a result, particulates cause and aggravate a host of health problems, including lung cancer and cardiovascular disease.

Particulate pollution can cause irreversible damage to children, interfering with the growth and development of the lungs. For example, researchers at the University of Southern California followed the health of over 1,000 ten-year-olds until they reached 18. Children who lived in areas with higher levels of particulate pollution were less able to breathe with normal capacity.[47]

Particulate pollution is also deadly, killing upwards of 50,000 Americans every year. In fact, according to the largest study of the effects of particulates on mortality, breathing the air in major U.S. cities is about as dangerous as living or working with a smoker.[48]

Figure 5: Soot Particles[49]



Very small soot particles found in diesel exhaust. The scale bar represents 10 nanometers.

Indoor Air Pollution and Second-hand Smoke

While this study focuses only on the health impacts of outdoor air pollution, indoor air pollution—including cigarette smoke, mold and pollutants from heating or cooking—also poses threats to public health.

According to the Pennsylvania Department of Health, 23 percent of all adults in Pennsylvania regularly smoke.[15] Cigarette smoke, inhaled directly or second-hand, causes serious health problems including heart disease and cancer.[16] Public health professionals estimate that cigarette smoking is the leading cause of death in the U.S., responsible for 18 percent of all deaths.[17]

In addition, scientists have connected exposure to mold and combustion pollutants indoors to asthma exacerbation and other respiratory problems.[18]

Health Damage Caused by Air Pollution in Pennsylvania

Health researchers have made significant progress in mapping out the consequences of breathing polluted air, and the results aren't pretty. The most serious impacts include premature death from diseases like cancer and heart disease, respiratory deaths in infants, and new cases of persistent diseases like chronic bronchitis and asthma.

However, these impacts are just the most visible indicators of widespread health damage that affects everyone in Pennsylvania. Air pollution irreparably damages lung tissues in ways similar to second-hand tobacco smoke, leading to increased emergency room visits, more frequent asthma attacks, and missed work days due to respiratory illness in otherwise healthy people.

In this report, we quantify the health impacts of outdoor air pollution in Pennsylvania. Our estimates stem from three basic sources of information:

- The estimated exposure of people to air pollutants,
- Scientific studies documenting how the risk of a relevant health impact changes with increasing air pollution levels, and
- The number of deaths, hospital admissions, and other relevant events in Pennsylvania in 2003.

Air pollution monitors placed throughout Pennsylvania by the Department of Environmental Protection help provide the first piece of information. A vast body of scientific literature in which researchers tracked pollution and health effects provides the second piece of information. And the third comes from health statistics maintained by the Pennsylvania Department of Health and the Pennsylvania Health Care Cost Containment Council, along with estimates by the U.S. Environmental Protection Agency and additional information from surveys and estimates by other governmental agencies.

Using this information, we estimate that every year in Pennsylvania, thousands die prematurely because of soot in the air, thousands are admitted to area hospitals with air pollution-aggravated heart and lung disease, and hundreds of thousands miss work because of air pollution-induced respiratory illness (see Table 1).

Additionally, during the summer smog season, we estimate that smog causes

Table 1: Public Health Damage from Soot in Pennsylvania (PM_{10})

Health Effect	Estimated Cases	Range
Premature Death (Adults)	5,000	3,000 – 6,600
Respiratory Hospital Admissions	5,000	3,900 – 5,900
Cardiovascular Hospital Admissions	4,000	2,300 – 6,200
New Cases of Chronic Bronchitis	4,000	460 – 7,500
Asthma Attacks	500,000	210,000 – 790,000
Missed Work Days	800,000	740,000 – 870,000
Restricted Activity Days	8 million	6.9 million – 9.2 million
Increased Symptom Days	20 million	12 million – 40 million

Table 2: Public Health Damage from Smog in Pennsylvania (Ground-level Ozone)

Health Effect	Estimated Cases	Range
Respiratory Hospital Admissions	7,000	5,100 – 9,000
Asthma Attacks	300,000	150,000 – 420,000
Restricted Activity Days	1 million	1.0 million – 1.8 million
Increased Symptom Days	4 million	1.8 million – 5.5 million

hundreds of thousands of asthma attacks and millions of days of increased respiratory symptoms like shortness of breath (see Table 2).

Premature Death

The most serious health impact of exposure to air pollution is premature death. Fine particulates are tied to deaths from respiratory disease, heart disease, lung cancer, and other types of diseases commonly associated with smoking.

The Evidence

Several decade-long studies have made it quite clear that long-term exposure to pollution shortens lives:

- In 2002, Dr. C. Arden Pope at Brigham Young University and his colleagues published a study tracking more than 500,000 people in 51 metropolitan areas in America for longer than 16 years. He found that when fine particulate levels increased by 10 micrograms per cubic meter, deaths from all causes rose by 4 percent; deaths from cardiopulmonary illness by 6 percent, and deaths from lung cancer by 8 percent.[51] Dr. Pope saw no evidence for a safe level of particulate pollution not tied to increased death rates. Pope estimated that chronic exposure to air pollution in the most polluted cities shortens life expectancy between 1.8 and 3.1 years.[52] He concluded that breathing polluted air like that commonly found in the Eastern U.S. causes an increased risk of lung cancer similar to that of breathing secondhand smoke.[53]

- Researchers with the World Health Organization in Europe found that air pollution caused 6 percent of all deaths in Switzerland, France and Austria (40,000 per year). Motor vehicle pollution (likely dominated by diesel) caused about half of these deaths.[54]

Dozens of studies also link short-term pollution exposure to acute increases in the death rate:

- In a study of heart attack patients in Boston, Dr. Annette Peters and her colleagues at the Harvard University School of Public Health found that as pollution levels rose, so did the frequency of heart attacks a few hours to a day later.[55] An increase in fine particles of 25 micrograms per cubic meter resulted in a 69 percent increase in the relative risk of having a heart attack over the following day.
- Dr. Jonathan Samet from Johns Hopkins University's Bloomberg School of Public Health and his colleagues studied health and air pollution data from 90 cities in the U.S. and found a link between pollution levels and acute death rates from

How We Estimated the Health Effects of Air Pollution

In the 1990 amendments to the Clean Air Act, Congress required the EPA to report on the benefits and costs of Clean Air Act regulations. In November 1999, the EPA released a report outlining the health and economic impact of clean air efforts. In addition, scientists with the World Health Organization produced a report in 2000 estimating the public health impact of particulate air pollution from motor vehicles.[50]

The PennEnvironment Research & Policy Center adapted methodology developed by these experts to estimate the health effects of outdoor air pollution in Pennsylvania.

First, we gathered statistics on how many deaths, hospital admissions and other relevant events happened in Pennsylvania in 2003. Next, we estimated how much air pollution (above natural background levels) Pennsylvanians are exposed to by looking at data from soot and smog monitors throughout the state. Finally, we obtained estimates of how much the risk of health problems increases with exposure to a specific amount of air pollution. Combining these three pieces of information allowed us to estimate what fraction of deaths and other relevant health problems could be attributed to air pollution.

We report the effects of air pollution including a range of values to emphasize that the estimates have an inherent level of uncertainty. The range represents the 95 percent confidence interval derived by scientists for the relationship between air pollution and the frequency of health outcomes, or where the estimate would be expected to be 95 times out of 100 observations. While additional sources of scientific uncertainty apply, the range of values presented here is our best estimate of the public health toll of air pollution in Pennsylvania. For more specific details on how the estimates were made and a discussion of factors that could make the actual impacts higher or lower, see the Methodology section.

chronic heart and lung disease. The link was strongest in the Northeast, the industrial Midwest, and in Southern California.[56]

- Dr. Kazuhiko Ito and his colleagues at New York University found that increases in ozone levels lead to a higher risk of death. As daily 1-hour maximum ozone concentrations in seven U.S. cities rose by 10 parts per billion, risk of death rose by 0.4 percent.[57]

Pollution associated with burning fossil fuels is specifically tied to increased mortality, as opposed to particles from duststorms and other natural events.[58] Other studies show that these effects are not merely accelerating the death of elderly individuals, but also kill some infants and adults who otherwise would have many years of health remaining.[59]

Pennsylvania Estimate

We estimate that soot pollution causes about 5,000 deaths each year in Pennsylvania, or 3 to 6 percent of all deaths not caused by injuries or accidents. This estimate is comparable to the World Health Organization study of air pollution impacts, which reported that 6 percent of all mortality in Switzerland, France and Austria is linked to air pollution.[60]

This finding ranks air pollution as the third leading cause of mortality in Pennsylvania, behind smoking and poor diet/physical inactivity. In 2004, researchers published estimates for the leading causes of death in the U.S. as a whole.[61] According to these estimates, smoking causes 18 percent of all deaths, poor diet and physical inactivity causes 15.2 percent of all deaths and alcohol consumption leads to 3.5 percent of all deaths. Air pollution in Pennsylvania—causing roughly 4 percent of all deaths—ranks just above alcohol consumption as a risk factor in premature mortality.

Table 3: Yearly Premature Deaths Caused by Air Pollution in Pennsylvania

Health Effect	Estimated Cases	Range
Premature Death (Adults)	5,000	3,000 – 6,600

Hospital Stays and Emergency Room Visits

As levels of air pollution increase, so do the number of people admitted to hospital wards and emergency rooms suffering from severe respiratory and cardiovascular disease.

The Evidence

- Dr. Jonathan Samet from Johns Hopkins University's Bloomberg School of Public Health and his colleagues found that increases in daily pollution levels were linked to increased hospital admissions for cardiovascular disease, pneumonia, and chronic obstructive pulmonary disorder.[67]

- Dr. Joel Schwartz of Harvard University and his colleagues documented links between air pollution and hospitalization rates for cardiovascular and respiratory disease in Birmingham, Detroit, Minneapolis-St. Paul, Spokane and Tucson, using data from the late 1980s and early 1990s.[68] An increase of daily soot levels by 10 micrograms per cubic meter and peak hour ozone levels by 5 micrograms per cubic meter increased the risk of hospitalization for chronic respiratory disease in the range of 2 percent to 6 percent.

Global Warming and Public Health

Soot and smog are not the only pollutants in Pennsylvania's air. Global warming pollution also has serious consequences for the health and well being of all Pennsylvanians.

Scientists project that global warming could raise average temperatures in Pennsylvania by between 2 and 9 degrees Fahrenheit over the next century.[62] Among a host of negative impacts—from coastal flooding to ecosystem disruption—such a temperature increase would increase air pollution and harm public health.[63]

Scientific evidence shows that as temperatures grow hotter in the summer, so does the risk of death. For example, scientists tracking hospitalization of patients for cardiovascular diseases in Denver in the summer months of 1993 to 1997 found that higher temperatures increased the number of elderly people suffering from heart attacks and congestive heart failure.[64] In the summer of 2003 a severe heat wave passed through France, killing an estimated 15,000 people.[65]

The U.S. Environmental Protection Agency estimates that by 2050, heat-related deaths in Philadelphia could increase by 90 percent as a result of global warming.[66]

- Dr. George Thurston at the New York University School of Medicine and Dr. Richard Burnett at Environment Canada have repeatedly linked respiratory and cardiovascular hospital admissions with levels of summertime haze air pollution.[69] According to these studies, summertime haze pollution was responsible for 24 percent of respiratory hospital admissions in Toronto, and up to half of admissions on particularly bad air days.
- Dr. Paul Lioy and his colleagues at the Rutgers Environmental and Occupational Health Sciences Institute and Robert Wood Johnson Medical School saw increases in the number of asthma emergency room visits in central and northern New Jersey on high-smog summer days.[70] Emergency room visits occurred 28 percent more frequently when the average ozone levels were greater than 60 ppb than when they were lower than this level. This study demonstrates health effects of ozone exposure at levels well below the EPA health standard of 80 ppb over an 8 hour period.
- Dr. Joel Schwartz from Harvard University and his colleagues at the U.S. EPA found that as fine soot levels increased in the Seattle area, so did emergency room visits for asthma.[71] An increase in fine soot levels of 30 micrograms per cubic meter increased the relative risk of needing emergency medical attention for asthma by 12 percent. The daily fine soot levels never exceeded 70 percent of the EPA health standard at the time.
- Dr. Jennifer Peel and her colleagues at Emory University looked at air pollution levels and emergency room visits at 31 hospitals in Atlanta from 1993 to 2000—a statistically

powerful sample comprised of more than 4 million patients. She found that increased levels of soot and smog pollution led to increased emergency room visits for upper respiratory infections, pneumonia and other respiratory conditions.[72]

Pennsylvania Estimate

We estimate that smog causes 7,000 respiratory hospital admissions during the summer smog season and soot pollution causes 5,000 respiratory and 4,000 cardiovascular hospital admissions each year. This represents between 5 and 8 percent of respiratory hospital admissions in 2003, and between 0.6 and 2 percent of cardiovascular hospital admissions.

New Cases of Chronic Disease—Bronchitis

Air pollution can cause chronic diseases in addition to triggering short-term health damage. Air pollution contributes to the development of chronic bronchitis in elderly people and may contribute to asthma in children and adults.

The Evidence

- Dr. Rob McConnell at the University of Southern California School of Medicine and his colleagues found that children who exercise a lot develop asthma at higher rates in more polluted areas. The researchers followed for five years more than 3,500 children from the fourth, seventh, and tenth grades with no history of asthma. During that time, 265 children became asthmatic. Children who played three or more sports in communities with high smog levels developed asthma at over three times the rate of children in low-smog communities. Children who spent relatively high amounts of time outdoors were 1.4 times more likely to get asthma in polluted areas compared to cleaner ones.[73] The average levels of air pollution in all of the communities examined were well below the U.S. EPA health standard of 80 ppb over an eight-hour period.
- In a follow-up study, Dr. McConnell and his colleagues found that children living closer to a major highway were more likely to have asthma, pointing to traffic-related pollution as a possible cause of the disease.[74]

Table 4: Annual Hospital Admissions Caused by Air Pollution in Pennsylvania

Health Effect	Estimated Cases	Range
Respiratory Hospital Admissions (Smog)	7,000	5,100 – 9,000
Respiratory Hospital Admissions (Soot)	5,000	3,900 – 5,900
Cardiovascular Hospital Admissions (Soot)	4,000	2,300 – 6,200

Table 5: New Cases of Chronic Respiratory Disease Caused by Air Pollution in Pennsylvania Annually

Health Effect	Estimated Cases	Range
New Cases of Chronic Bronchitis (Soot)	4,000	460 – 7,500

- Dr. William McDonnell at the U.S. EPA National Health and Environmental Effects Research Laboratory and his colleagues found a connection between long-term exposure to smog and development of asthma in adults. The researchers followed more than 3,000 non-smoking adults for 15 years in California. During this period, just over 3 percent of the men and just over 4 percent of the women reported a diagnosis of asthma. Several factors increased the risk of developing asthma, including: history of exposure to tobacco smoke, childhood pneumonia or bronchitis; and exposure to ozone in men.[75]
- In Taiwan, researchers linked development of asthma with several individual air pollutants: fine soot, sulfur dioxide, nitrogen dioxide, and carbon monoxide. The scientists surveyed more than 160,000 schoolchildren and looked at levels of air pollutants, finding that air pollution increased asthma prevalence by as much as 29 percent, independent of exposure to second-hand tobacco smoke.[76] Similar research in Hong Kong showed that children living in areas with higher air pollution had higher levels of asthma and less healthy lungs.[77]
- Dr. Joel Schwartz and others identified links between particulate levels and physician diagnoses of chronic bronchitis by looking at health records and air pollution levels in 53 U.S. metropolitan areas.[78] For every 10 microgram per cubic meter increase in total particulates, the relative risk for chronic bronchitis rose about 7 percent.

Asthma prevalence is increasing in the U.S. and worldwide, for unknown reasons. In the U.S., the Centers for Disease Control and Prevention (CDC) estimates that prevalence among persons up to 17 years old increased about 5 percent per year from 1980 to 1995.[79] Deaths due to asthma have doubled, and now amount to 5,000 per year.[80] The trend in the number of children with active asthma in Pennsylvania also has been increasing over the past few decades, to the point where nearly one in ten children are affected.[81] According to a survey carried out by the CDC in 2003, 8.3 percent of Pennsylvania adults—roughly 780,000 individuals—have been diagnosed with active asthma.[82]

Pennsylvania Estimate

We estimate that air pollution causes 4,000 new cases of chronic bronchitis among Pennsylvania residents every year.[83] Traffic-related pollution may contribute to asthma prevalence, but further study will be required.[84]

Asthma Attacks

When pollution levels rise, so does the frequency of asthma attacks suffered by asthmatic children and adults.

The Evidence

- Dr. George Thurston and his colleagues at the New York University School of Medicine documented increased asthma attacks, respiratory difficulty, and reduced lung function in children on high pollution days.[85] The researchers tracked children attending the American Lung Association's Connecticut "Asthma Camp" during summer months. On the highest pollution days, the risk of asthma attacks requiring medication and chest tightness climbed 40 percent higher than usual.
- In the mid 1970s, the Environmental Protection Agency collected asthma attack diaries from Los Angeles residents. Asthma attacks were reported more frequently when smog and soot levels were high, as well as when the weather was cool.[86]

Table 6: Annual Asthma Attacks Triggered by Air Pollution in Pennsylvania

Health Effect	Estimated Cases	Range
Asthma Attacks (Smog)	300,000	150,000 – 420,000
Asthma Attacks (Soot)	500,000	210,000 – 790,000

Pennsylvania Estimate

We estimate that smog pollution causes another 300,000 asthma attacks and soot pollution causes 500,000 asthma attacks among Pennsylvania asthmatics every year.

Missed Work Days and Sick Days

Air pollution can also affect the health of people with no chronic respiratory illness. On high pollution days, the number of people feeling ill with symptoms like shortness of breath, runny or stuffy noses, coughs, burning eyes, wheezing and chest pain increases dramatically. These symptoms can cause people to miss work or school, or force them to limit their usual activity levels.

The Evidence

- Dr. Bart Ostro at the California EPA linked high air pollution levels with missed work days and illness days reported in the Health Interview Survey collected yearly by the U.S. Centers for Disease Control and Prevention.[87]
- Dr. Joel Schwartz of Harvard and his colleagues found that elementary school children in six U.S. cities suffered from coughs and other lower respiratory symptoms more often on days when soot and smog levels were high.[88]

Pennsylvania Estimate

We estimate that that smog causes 1 million person-days when air pollution limits normal activity and 4 million person-days with respiratory symptoms such as shortness of breath, runny or stuffy noses, coughs, burning eyes, wheezing, or chest pain. In addition, we estimate soot pollution causes 800,000 missed work days, 8 million person-days when illness limits normal activity levels, and 20 million person-days with the presence of respiratory symptoms.

Table 7: Annual Missed Work Days and Increased Respiratory Symptom Days Caused by Air Pollution in Pennsylvania

Health Effect	Estimated Cases	Range
Restricted Activity Days (Smog)	1 million	1.0 million – 1.8 million
Increased Symptom Days (Smog)	4 million	1.8 million – 5.5 million
Missed Work Days (Soot)	800,000	740,000 – 870,000
Restricted Activity Days (Soot)	8 million	6.9 million – 9.2 million
Increased Symptom Days (Soot)	20 million	12 million – 40 million

Air Pollution and Pennsylvania's Children

Children are especially vulnerable to the effects of air pollution.[89] First, children are growing into adults, and their lungs are still developing. Injuries sustained during this time can cause permanent damage that will have life-long effects. Second, children breathe more air per pound of body weight and thus inhale larger doses of pollutants than adults.

Children in Pennsylvania are constantly exposed to air pollution, breathing it day in and day out. Recent science has shown that this exposure causes a range of lung injuries, even among otherwise healthy infants and children.[90] Children exposed to air pollution can't breathe as well as children growing up in cleaner areas. Their lungs are scarred and less flexible than they should be, their lungs hold less air, and they aren't as able to breathe normally. These injuries manifest themselves in respiratory illness, missed school days, increased doctor visits, hospitalizations, and for a small group, death.[91]

The PennEnvironment Research & Policy Center compiled air pollution data, scientific reports about how air pollution levels affect children's health, and baseline

Table 8: Air Pollution Damage to Children's Health in Pennsylvania

Health Effect	Estimated Cases	Range
Infant Deaths (Post-neonatal) (Soot)	20	12 – 22
Asthma ER Visits (Smog)	3,000	400 – 7,300
Acute Bronchitis (Soot)	40,000	21,000 – 51,000
Asthma Attacks (Soot)	150,000	120,000 – 180,000
Missed School Days (Soot)	900,000	700,000 – 1 million

The estimates in Table 8 deal mostly with soot. However, smog also contributes to asthma attacks, missed school days and other respiratory problems, and may be a cause of asthma. Although we did not quantify these impacts for technical reasons, they are an important indicator of how smog damages children's health.

Table 9: Yearly Infant Deaths from Air Pollution in Pennsylvania

Health Effect	Estimated Cases	Range
Infant Deaths (Post-neonatal) (Soot)	20	12 – 22

health statistics maintained by the state Center for Health Statistics and the EPA. We used this information to estimate the health impacts of pollution on children in Pennsylvania. (For more details, see the Methodology section.)

We estimate that air pollution kills over a dozen infants a year and causes thousands of emergency room visits for childhood asthma, tens of thousands of cases of acute bronchitis, hundreds of thousands of asthma attacks and nearly one million missed school days. (See Table 8.)

Infant Death

Air pollution not only kills elderly and sick people. It also causes premature death in infants and young children. Experiments have tied particulate levels to deaths from both respiratory disease and sudden infant death syndrome.

The Evidence

- Dr. Tracey Woodruff at the U.S. EPA and her colleagues linked fine soot pollution levels to post-neonatal deaths in 86 U.S. metropolitan areas.[92] Normal-weight infants less than one year old born in high soot areas were 40 percent more likely to die of respiratory disease and 26 percent more likely to die from sudden infant death syndrome than infants born in low soot areas.
- Researchers in the Czech Republic found that infant deaths due to respiratory causes were linked to increased levels of fine soot, sulfur dioxide, and oxides of nitrogen.[93] The study concluded, "The effects of air pollution on infant mortality are specific for respiratory causes in [the period between one month and one year of age], are independent of socioeconomic factors, and are not mediated by birth weight or gestational age."
- The National Bureau of Economic Research found that as levels of particles fell during a recession in the early 1980s, so did rates of death in newborn children younger than 28 days old. Specifically in Pennsylvania, researchers found that when total fine particulate levels dropped 25 percent, newborn death rates from cardiopulmonary and respiratory causes fell 14 percent.[94]

Pennsylvania Estimate

We estimate that soot pollution causes 20 post-neonatal infant deaths in Pennsylvania each year, or 4 to 8 percent of all post-neonatal infant deaths. This estimate compares favorably to a calculation that air pollution in 23 U.S. metropolitan areas, including Philadelphia, causes 6 percent of all post-neonatal infant deaths (24 percent of all deaths due to respiratory causes).[95]

Hospitalization and Emergency Room Trips

As air pollution levels rise, children end up in the emergency room with respiratory problems at higher rates. Some of them require hospitalization for longer-term care.

Reducing Air Pollution Protects Children's Health: The Case of the 1996 Olympics in Atlanta

The 1996 Summer Olympic Games in Atlanta offered researchers a unique opportunity to observe the connection between lowered pollution levels and improved health.[97]

Atlanta implemented a comprehensive transit plan as a part of the Olympic Games. The plan was designed to reduce congestion in the downtown area and reduce travel delays. Atlanta launched an expanded 24-hour-a-day public transportation network, added 1,000 buses for park-and-ride service, encouraged local employers to institute alternative work hours and telecommuting, and closed the downtown area to private vehicles.

The transit plan produced impressive results, despite the million or so additional visitors to the city. Weekday morning traffic trips declined by 22.7 percent and public transportation ridership increased by 217 percent.

The plan produced some unintended benefits for air quality and health that were equally impressive. The average daily maximum ozone levels decreased by 28 percent, from 81 ppb before and after the Olympics to 59 ppb during the Olympics. Presumably, this effect resulted from the decreased levels of traffic-related air pollution building up in the morning rush hour. Nearby cities did not experience similar reductions in ozone pollution.

At the same time, asthma-related emergency room visits for children decreased by 41.6 percent in a Medicaid database, 44.1 percent in an HMO database, and 11.1 percent in two major pediatric emergency departments. Additionally, hospitalizations for asthma decreased by 19.1 percent. Unfortunately, Atlanta discontinued the transit program at the conclusion of the Olympics, and pollution levels and emergency room visit rates returned to normal.

This experience powerfully demonstrates how reducing pollution levels would benefit the health of children. It also highlights the role that motor vehicles play in creating high levels of urban pollution and how better public transit can quickly reduce air pollution levels.

Dr. Michael Friedman of the U.S. Centers for Disease Control and Prevention, one of the authors of the study, said that the results "provide evidence that decreasing automobile use can reduce the burden of asthma in our cities and that citywide efforts to reduce rush-hour automobile traffic through the use of public transportation and altered work schedules is possible in America."[98]

The Evidence

- Dr. Michael Friedman of the U.S. Centers for Disease Control and Prevention and his colleagues found that reduced traffic levels and higher public transit use during the 1996 Summer Olympics in Atlanta significantly reduced smog levels and also emergency room visits for childhood asthma.[96] One-hour peak ozone levels decreased by 27 percent, while the number of children visiting the emergency room for asthma fell 41.6 percent in a Medicaid database, 44.1 percent in an HMO database, and 11.1

Table 10: Yearly Pediatric Respiratory ER Visits Caused by Air Pollution in Pennsylvania

Health Effect	Estimated Cases	Range
Asthma ER Visits (Smog)	3,000	400 – 7,300

percent in two major pediatric emergency departments. In other words, every 10 ppb decrease in smog levels reduced the relative risk of children needing emergency medical attention for asthma by roughly 8 percent.

Pennsylvania Estimate

We estimate that smog pollution causes 3,000 asthma emergency room visits among Pennsylvania children each year.

Asthma Attacks, Acute Bonchitis and Missed School Days

Air pollution triggers asthma attacks and increases cases of acute bronchitis in children. Asthma is the leading chronic illness in children and the number one cause of missed school days in the United States.[99] The Centers for Disease Control and Prevention estimates that asthma prevalence among persons up to 17 years old increased about 5 percent per year from 1980 to 1995.[100] Air pollution worsens the impact of this disease, causes other acute respiratory illnesses, and increases school absence rates.

The Evidence

- Dr. Janneane Gent at the Yale University School of Medicine and her colleagues recently published a study showing that children with asthma are vulnerable to air pollution well below EPA health standards.[101] According to the study, every 50 ppb ozone increase yields a 35 percent increased likelihood of wheezing, and a 47 percent increased likelihood of chest tightness. A follow-up study showed that infants, particularly those with asthmatic mothers, suffer from increased wheezing and difficulty breathing on days with high ozone levels.[102]

- Dr. Douglas Dockery at Harvard University and his colleagues showed that children living in areas with high levels of acidic particle pollution were 66 percent more likely to have had an episode of bronchitis in the last year than children in low pollution areas.[103]

- Researchers participating in the Southern California Children's Health Study found that increased smog pollution causes more children to stay home from school.[104] When ozone levels rose by 20 ppb, illness-related absence rates went up by 63 percent,

Table 11: Asthma Attacks and Acute Bronchitis Caused by Air Pollution in Pennsylvania

Health Effect	Estimated Cases	Range
Acute Bronchitis	40,000	21,000 – 51,000
Asthma Attacks	150,000	120,000 – 180,000
Missed School Days	900,000	700,000 – 1 million

and by 174 percent for lower respiratory illnesses with wet cough.

- Researchers in Korea found the same relationship between air pollution and school absences.[105] When air pollution levels rose, so did illness-related absences. When pollution levels fell, more children attended school.

Pennsylvania Estimate

We estimate that air pollution causes 40,000 cases of acute bronchitis and 150,000 asthma attacks among Pennsylvania children each year. Additionally, air pollution causes roughly 900,000 missed school days each year.

Clean Air Policy Recommendations

Solutions to Pennsylvania's air quality problems are readily available. Strategies already in widespread use—from modern emission controls for cars and power plants to expanded transit systems—can cut air pollution in Pennsylvania and help people to live healthy lives.

Aggressive action will be required on both the state and federal level to reduce air pollution and reduce the costs society pays to support the use of polluting fuels. In order to have the greatest impact, action should focus first on the largest sources of pollution.

Sources of Dirty Air

In Pennsylvania, mobile sources (cars, trucks, buses, and off-road vehicles) and power plants are the largest sources of air pollution. Mobile sources are particularly important in urban areas where large numbers of people live. Additional pollution comes from industrial facilities and chemical use. Pollution sources in neighboring states are also a significant part of the problem.

Within the state in 1999, approximately half of smog-forming emissions and particulates came from on-road and off-road mobile sources like cars, trucks, and construction equipment (see Table 12). Traffic is an area of particular importance, since pollutants are emitted at ground level and in close proximity to areas where people live. Electricity generation produces the vast majority of sulfur dioxide pollution—one of the precursors of soot particles. Area sources (including the use of paint or solvents and other relatively small and dispersed sources) are a major source of smog-forming organic chemicals.[106]

Pennsylvania could be doing much more to reduce pollution from mobile sources and electricity generation beyond minimum federal requirements.

Policies Aimed at the Largest Pollution Sources

Pennsylvania can take action at the state level to reduce pollution from the largest sources, making up for shortfalls in federal law. At the federal level, policies are available to drive similar progress nationwide. These policies include:

State Level Actions:

- ***Implement the Pennsylvania Clean Vehicles Program and its air pollution standards for automobiles that go beyond weaker federal requirements.*** Pennsylvania should join New York, Massachusetts, New Jersey, Connecticut, Rhode Island, Maine, Vermont, California, Oregon and Washington in requiring sales of cleaner cars that emit less pollution. DEP has proposed implementing the program in Pennsylvania beginning with the 2008 model year.[108] The standards will cut smog-forming pollution from cars and trucks by roughly 10 percent below federal standards by 2025, and reduce toxic benzene pollution—a known carcinogen—from cars and trucks by up to 15 percent below federal standards by 2025.[109] Additional limits on global warming pollution beginning in model year 2009 will reduce vehicle operating costs and save money for consumers.[110]

- ***Adopt limits on air pollution from power plants.*** Pennsylvania should require power plants, especially coal-fired generators that pre-date the Clean Air Act, to install modern emission control systems to curb smog-forming and particulate-forming pollution. For example, in 2002 North Carolina adopted the Clean Smokestacks Act, a law that will reduce nitrogen oxide emissions from power plants 77 percent by 2009 and sulfur dioxide emissions 73 percent by 2013.[111]

- ***Require diesel engines to be retrofitted with particulate filtration systems and to use low-sulfur fuel.*** Diesel engines are a significant source of fine particles. New federal diesel standards will be phased in starting in 2007, reducing emissions from new highway and off-road vehicles. Pennsylvania can reduce emissions from older vehicles by retrofitting their emission control systems for lower pollution. State-owned vehicle fleets such as school buses and road construction equipment should be included, as well as off-road diesel vehicles like bulldozers.

- ***Reduce car-dependent land use practices and sprawl. Pennsylvania should ensure that future growth, development and redevelopment focuses on creating livable, transit-oriented communities to reverse the trend of yearly increases in vehicle miles traveled that lead to greater pollution.*** Pennsylvania should also establish a dedicated funding source for the state's public transportation systems, and increase the proportion of transportation funding for clean public transit to provide residents with alternatives to driving.

Table 12. Emissions of Selected Air Pollutants in 1999 by Source Source in Pennsylvania[107]

	Total (Tons)	Mobile Sources	Area Sources	Point Sources
Oxides of Nitrogen	940,299	49%	14%	37%
Volatile Organic Compounds	621,954	45%	45%	10%
PM_{10}	443,168	52%	39%	8%
Sulfur Dioxide	1,241,745	3%	7%	90%

Federal And Regional Level Actions

- ***Advocate adoption of these state policies among neighboring and upwind states.*** Reducing air pollution emissions in Pennsylvania will have benefits for neighboring states. Pennsylvania should work with New Jersey and New York to encourage other states, especially those upwind, to adopt similar air pollution control policies. Ultimately, regional cooperation will be required to reduce overall air pollution levels.

- ***Restore and enforce the New Source Review provision of the Clean Air Act and require the oldest coal-fired power plants and other industrial facilities in the country to install modern emissions control technology.*** The EPA recently enacted regulations relieving power plants and industrial facilities grandfathered under the original Clean Air Act of responsibility to upgrade their emissions controls when upgrading their facilities. This change limits the effectiveness of the Clean Air Act and effectively subsidizes a few industries at the expense of public health. It should be reversed as soon as possible.

- ***Limit nationwide industrial emissions of sulfur dioxide, nitrogen oxides, and mercury to between 10 percent and 30 percent of 2000 levels.*** Placing a national cap on point-source emissions of air pollutants could dramatically reduce the levels of pollution plaguing the eastern seaboard of the U.S., and contribute to a regional solution to the air pollution problem.

- ***Strengthen national emission standards for cars, trucks, and off-road vehicles.*** The EPA sets national emission standards for cars, trucks, and off-road vehicles. However, California has designed a more effective and ambitious mobile-source emissions control program that includes a requirement for manufacturers to produce cleaner vehicles with modern technologies. The EPA should update its standards to match or exceed the California program.

Methodology

To quantify the health impacts of air pollution, we relied on three basic pieces of information:

- The exposure of people to air pollutants,
- How the risk of a given health impact changes with increasing air pollution levels, and
- The number of deaths, hospital admissions, and other relevant events in Pennsylvania in 2003.

Air pollution monitors placed throughout the state by the Pennsylvania Department of Environmental Protection helped provide the first piece of information. A vast body of scientific literature in which researchers tracked pollution and health effects provided the second piece of information. And the third came primarily from health statistics maintained by the state Department of Health, Bureau of Health Statistics and Research, plus additional information from estimates and surveys by governmental agencies and in the scientific literature.

We compiled this information to estimate the health impacts of pollution in Pennsylvania, adapting methodology used by the U.S. EPA in a study on the benefits and costs of the Clean Air Act and the World Health Organization in a study on the health impact of vehicle pollution in Europe.[112] The sections below outline the sources of this information and how we used it to derive our results.

Air Pollution Exposure

We obtained annual mean levels of pollution from the U.S. EPA *AIRData* online database of air pollution monitoring data for the year 2003.[113] We obtained the average daily one-hour peak ozone levels reported during the summer smog season from April through October and annual mean particulate levels including both particulates less than 10 micrometers in diameter (PM_{10}) and smaller particulates less than 2.5 micrometers in diameter ($PM_{2.5}$).

We translated $PM_{2.5}$ data into PM10 data, because many of the scientific studies linking air pollution and health effects were carried out in terms of PM_{10}, and the relative risk figures obtained from the World Health Organization were listed in terms of PM_{10}.[114] Because $PM_{2.5}$ is a subset of PM_{10}, their concentrations are related. In accordance with assumptions made by the World Health Organization, we assumed that $PM_{2.5}$ levels were 60 percent of PM_{10} levels.[115]

We interpolated air pollution data from Pennsylvania and eight surrounding states, including Ohio, West Virginia, Virginia, Maryland, Delaware, New Jersey, New York and Connecticut, to estimate annual mean pollution levels across Pennsylvania. (ArcView 9.1 Spatial Analyst software, spline interpolation, 75 to 100 monitor points used in each iteration, 0.5 weighting factor, regularized output.) The results of this interpolation are graphically shown in Figures 2 and 3 on page 10.

Using the zonal statistics function of ArcView 9.1 software, we mapped air pollution levels to the zip code tabulation area level in Pennsylvania, yielding estimates of the annual average exposure of citizens of the state by location of residence. We used 2003 air pollution levels as representative of current conditions, and did not take into account pollution levels from earlier years or forecasts of pollution levels in the future. Figures 6 and 7 present the exposure estimates in terms of the number of people living in areas with specified levels of air pollution.

Figure 6: Population Distribution of Estimated Particulate Matter Exposure

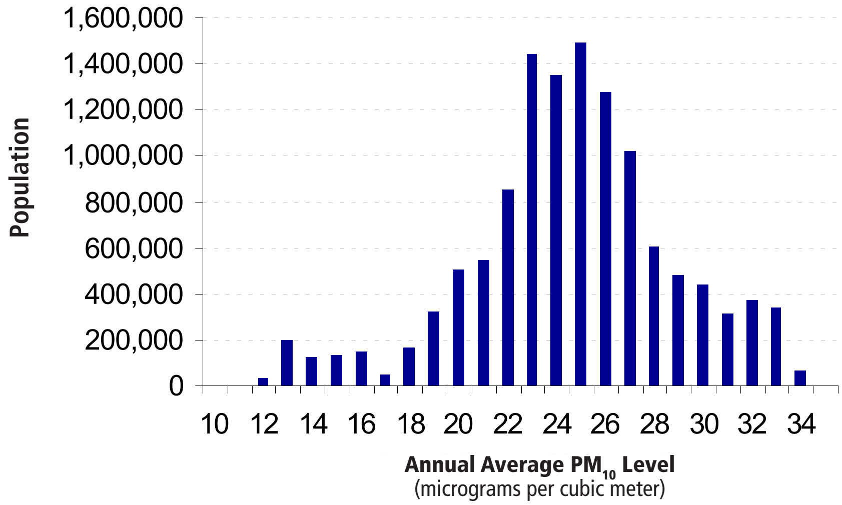


Figure 7: Population Distribution of Estimated Ozone Exposure

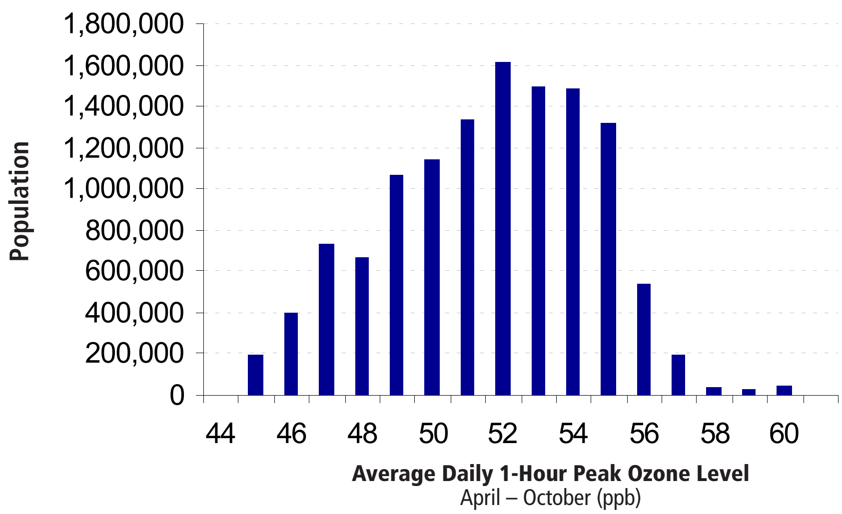


Table 13: Baseline Frequencies of Health Problems in Pennsylvania

Health Outcome	Baseline Frequency in Pennsylvania
Mortality, excluding violence or accidental deaths[119]	2003 data obtained by zip code of residence and by age group from the Pennsylvania Department of Health.
Post-neonatal infant mortality, excluding violence or accidental deaths[120]	2003 data obtained by zip code of residence and by age group from the Pennsylvania Department of Health.
Respiratory hospital admissions[121]	Data obtained by county of residence from the Pennsylvania Health Care Cost Containment Council
Cardiovascular hospital admissions[122]	Data obtained by county of residence from the Pennsylvania Health Care Cost Containment Council.
Annual chronic bronchitis incidence per person[123]	0.0038
Asthma prevalence among adults in PA[125]	8.3 percent (Range of 7.2-9.3)
Asthma attacks per asthmatic per year[126]	9.86
Asthma ER visits per year among all children 0-15 years of age[127]	0.01
Number of children per year who get acute bronchitis[128]	4.4 percent
Yearly missed work days per worker (adults between the ages of 18 and 65)[129]	2.4
School absences per student per year due to illness[130]	6
Restricted activity days per person per year[131]	6.46

We define the impact of air pollution as the change in the number of various health outcomes if air pollution exposure were reduced to natural background levels in the absence of anthropogenic emissions from North America, but with continuing emissions from the rest of the world. For ozone, we used a background level of 20 ppb, in accordance with modeling from Harvard showing the natural background between 15 and 30 ppb, with lower levels during the season when overall ozone levels are highest.[116] For particulate matter (PM_{10}), we estimated a background level of 7.5 micrograms per cubic meter, in accordance with the World Health Organization.[117]

Baseline Frequency of Health Problems in Pennsylvania

We obtained the baseline frequency of health outcomes in Pennsylvania from statistics maintained by the Pennsylvania

Equation 1:[133]

$$\text{Air Pollution Attributable Portion} = [y_o / (1 + ((RR - 1) \times \Delta P))] \times Pop \times (RR - 1) \times \Delta P$$

Where:

y_o = Frequency of health effect;
RR = Relative Risk associated with increased exposure of 1 [unit];
Pop = Relevant Population; and
ΔP = Exposure of relevant population to pollution above natural background levels.

Department of Health and the Pennsylvania Health Care Cost Containment Council, or, when more specific information was unavailable, published estimates for the American population as a whole from the U.S. EPA. Table 13 lists the relevant health outcomes and data sources.

Where specific data was not available, we assumed that 50 percent of all health effects that could be affected by ground-level ozone happened during the April through October ozone monitoring season, and only considered the effects of ozone on that period of time.

We obtained Pennsylvania population figures by zip code and age group from the U.S. Census Bureau to translate the relevant rates in Table 13 to baseline population frequencies for the state.[118]

The Relationship Between Exposure and Frequency of Health Effects

A vast body of scientific literature in which researchers tracked pollution and health effects provides information about how the frequency of health effects changes with changing exposure to air pollution. These studies are known as epidemiological studies. Most epidemiological studies report the exposure-response relationship for air pollution exposure as a relative risk (RR). Most studies report a considerable range in which the relative risk actually lies, because of statistical imprecision. This range is called the 95 percent confidence interval. If the relative risk exceeds one, including the confidence interval, then scientists conclude that an association between an air pollutant and a health outcome likely exists. If the relative risk exceeds one, but the lower confidence limit does not, scientists conclude that there may be an association between the pollutant and the health outcome, but it could also be a chance occurrence.

We relied on similar work by the World Health Organization and the U.S. EPA in the selection of studies used in this report. All of these studies demonstrated statistically significant positive associations. We use the upper and lower bounds of the confidence intervals reported in our chosen studies to derive the ranges for each health effect estimate. Other studies may exist that do not demonstrate statistically significant

Table 14: Concentration-Response Functions for Ozone Exposure and Infant Death from Particulates[136]

Health Effect	Concentration-Response Function
Respiratory Hospital Admissions (daily)	$-[y_o * (EXP(-\Delta O_3 * \beta) - 1)] * Pop$
Asthma Attacks (daily)	$-[(y_o/((1 - y_o)(EXP(\Delta O_3 * \beta)) + y_o)) - y_o] * Pop$
Restricted Activity Days (daily)	$-[y_o * (EXP(-\Delta O_3 * \beta) - 1)] * Pop$
Increased Symptom Days (daily)	$\beta * \Delta O_3 * Pop$
Post-neonatal Infant Deaths (annual)	$-[(y_o/((1 - y_o)(EXP(\Delta PM_{10} * \beta)) + y_o)) - y_o] * Pop$

Table 15: Relative Risk Figures Derived from the Scientific Literature, PM_{10}

Health Effect	Population	Relative Risk of Effect	Lower Confidence Limit	Upper Confidence Limit	Location of Study	Reference
Premature Death	Age 30 +	1.0043	1.0026	1.0061	Metropolitan U.S.A.	137
Respiratory Hospital Admissions	All Ages	1.0017	1.0013	1.0020	Toronto, Birmingham, Detroit, Minneapolis-St. Paul, New Haven, Tacoma, Spokane, Tuscon	138
Cardiovascular Hospital Admissions	All Ages	1.0008	1.0004	1.0011	Detroit, Tuscon, Toronto	139
Asthma Attacks	Age 15 +	1.0039	1.0019	1.0059	Netherlands, France	140
Chronic Bronchitis	Age 25 +	1.0098	1.0009	1.0194	California	141
Work Loss Days	Age 18-65	1.0046	1.0042	1.0050	U.S.A.	142
Restricted Activity Days	Age 20 +	1.0094	1.0079	1.0109	U.S.A.	143
Increased Symptom Days	Age 18 +	1.17	1.08	1.26	California	144

Table 16: Relative Risk Figures and Coefficients Derived from the Scientific Literature, Ozone

Health Effect	Population	Effect Coefficient (β)	Lower Confidence Limit	Upper Confidence Limit	Location of Study	Reference
Respiratory Hospital Admissions (Daily)	All Ages	0.0025	0.0018	0.0032	Toronto	146
Asthma Attacks (Daily)	Asthmatics of all ages	0.0018	0.0011	0.0026	Los Angeles	147
Restricted Activity Days (Daily)	Age 18 +	0.0022	0.0015	0.0029	U.S.A.	148
Increased Symptom Days (Daily)	Age 18 +	0.00014	0.000067	0.00021	California	149

associations (however, the lack of a statistically significant association cannot prove that there is no effect).

Following assumptions made by the World Health Organization in calculating the impact of traffic-related air pollution:[132]

- Our impact assessment includes both short-term and long-term impacts of air pollution.
- Estimates for deaths and incidence of chronic bronchitis are based on the long-term effect of air pollution. (For example, for mortality we used studies that tracked large groups of people over many years (cohort studies), comparing mortality with air pollution exposure. These studies indirectly capture the effects of chronic problems like cancer and heart disease that would not be completely revealed by short-term or time-series studies.)
- For hospital admissions, asthma attacks, acute bronchitis, restricted activity days and respiratory symptom days, we applied short-term effect estimates from studies that looked at

daily variations of air pollution and changes in the frequency of the relevant health outcome.

- We used annual average mean levels of air pollution to estimate exposure levels for both short- and long-term effects. In other words, we assume that the annual impact of the pollutant corresponds to the sum of all the daily effects across one year—or in the case of ozone, the sum of all the daily effects across one monitoring season.

Calculating the impact of air pollution on a given health outcome generally follows Equation 1.

All of the estimates for particulate matter, except for post-neonatal infant deaths, followed this pattern, as described by the World Health Organization.[134] The estimate for childhood asthma ER visits also followed this equation.

The remaining estimates related to ozone (and post-neonatal infant deaths) relied on concentration-response functions developed by the U.S. EPA for its study on the benefits and costs of the Clean Air Act, as listed in Table 14.[135] In the table, y_o represents the frequency of the health effect, EXP is the exponential function with base e, ΔO_3 represents the exposure of the relevant population to ozone pollution above natural background levels during ozone season, β represents the coefficient derived by EPA from epidemiological literature as listed in Table 16, and Pop is the relevant population. All equations are for daily incidences, except for adult onset asthma and infant deaths, which are annual incidences.

Particulates

Table 15 lists the relative risk numbers for an increase in particulate matter pollution of one microgram per cubic meter derived

Table 17: Relative Risk Figures and Coefficients Derived from the Scientific Literature, Children

Health Effect	Population	Effect Coefficient (β)	Lower Confidence Limit	Upper Confidence Limit	Location of Study	Reference
Post-neonatal Infant Death (PM) (Effect Coefficient (β) (Annual)	0 - 1 Years	0.00392	0.0027	0.00514	86 U.S. Metropolitan Areas	150
Asthma ER Visits (Ozone)	0 - 15 Years	1.008	1.001	1.0186	Atlanta	151
Acute Bronchitis (PM)	0 - 15 Years	1.0306	1.0135	1.0502	Six cities in the U.S. (in MA, TN, MO,OH, WI and KS), 24 communities in the U.S. and Canada, and 10 communities in Switzerland	152
Asthma Attacks (PM)	Asthmatics 0 - 15 Yrs	1.0051	1.0047	1.0056	Utah and Los Angeles	153
Missed School Days (PM)	5 - 18 Years	1.004	NA	NA	Utah	154

from epidemiology experiments, the 95 percent confidence interval, and the citation for the original experiment.

Ozone

Table 16 lists risk coefficients for an increase in ground-level ozone pollution of 1 part per billion, derived from epidemiology studies. It also lists confidence limits and the citation for the original study.

For studies that used ozone measurements other than the daily one hour peak concentration, we converted Pennsylvania exposure data to the appropriate measure using the following estimated conversion factors: 12-hour ozone levels are 50 percent of the daily one-hour maximum, 8-hour ozone levels are 70 percent of the daily one-hour maximum, and 5-hour ozone levels are 85 percent of the daily one-hour maximum.

Children, PM_{10}

Table 17 lists the relative risk numbers for children associated with an increase in particulate matter pollution of 1 microgram per cubic meter or ozone of 1 part per billion. The table also lists confidence limits and the citation for the original study.

Factors that Could Affect the Accuracy of the Estimates

As discussed in this report, scientific evidence clearly shows that air pollution causes significant damage to the health of the public across the state and the country. However, the extent and scale of the damage are subject to remaining scientific uncertainties and gaps in knowledge. Where possible, we attempted to make conservative assumptions—meaning the scope and scale of the impacts of air pollution may be larger than reported here.

Possible sources of uncertainty that could affect the accuracy of the estimates in this report include, but are not limited to:

- This report does not capture all the possible effects of air pollution. For example, air pollution could have effects on development in the womb or early in life that predispose adults to disease later in life.[155] Further study could reveal that the impacts of air pollution on human health are more extensive than portrayed here. Additionally, chronic exposure to air pollution has effects, such as reduced lung capacity, that are not quantified in this report.
- In the studies we rely upon to derive the relationship between air pollution exposure and health outcomes, exposure to air pollution is estimated based on readings at fixed pollution monitors. Because pollution levels can differ within a city, using the results from a single monitor or an average of monitors can result in errors or imprecise exposure classifications—and thus potential errors in the relative risk figures cited in tables 14, 15 and 16.[156] However, these errors are likely to underestimate the actual effect of air pollution. A recent study of air pollution and mortality in Los Angeles, using a refined method of exposure measurement, found effects nearly 3 times greater than earlier studies with less precise exposure classifications.[157]
- Similarly, we extrapolate pollution exposure in Pennsylvania based on annual average pollution data from a network of fixed pollution monitors around the state. To the extent our methods fail to capture the actual pollution levels in areas with no monitor, error could result.
- The nature of the statistical models used in scientific studies (specifically time-series studies) could lead to a small level of overestimation for the

short-term effect estimates, as described by the Health Effects Institute.[158] However, the degree to which this bias may affect the studies we relied upon for our estimates is unknown.

- We assume that scientific studies carried out in other U.S. and Canadian cities would produce similar results if repeated in Pennsylvania. To the extent conditions in Pennsylvania are different than other cities, it could affect the accuracy of the estimates.
- Estimates of the overall frequency of events like asthma attacks are often not available at the state or county level. Estimates developed by the U.S. EPA for the U.S. population as a whole, while the best information available, may not fully reflect local conditions.
- There may be some degree of overlap between the effects of particulate matter and ground level ozone. In other words, the estimates for the effects of each of these pollutants may not be 100 percent additive. However, while particulate matter levels are highly correlated with other air pollutants like nitrogen oxides and sulfur dioxide, they are not as correlated with ozone levels. Thus we consider the two pollutants separately within the report.
- Some estimates rely on a single study, where other appropriate research was unavailable. Further research will likely improve understanding and increase the accuracy of similar projects carried out in the future.

Notes

1 American Lung Association, *State of the Air 2005*, Pennsylvania stats available at lunginfo.org, 28 April 2005.

2 PennEnvironment Research & Policy Center, *Plagued by Pollution: Unsafe Levels of Soot Pollution in 2004*, January 2006.

3 American Academy of Pediatrics, Committee on Environmental Health, "Policy Statement; Ambient Air Pollution: Health Hazards to Children," *Pediatrics* 114, 1699-1704, December 2004.

4 See "The Dangers of Pollution from Traffic" on page 14.

5 See Note 3.

6 Soot is measured in terms of two different size fractions: particulate matter less than 10 micrometers in diameter, or PM_{10}, and particulate matter less than 2.5 micrometers in diameter, or $PM_{2.5}$. The federal standard for annual average $PM_{2.5}$ levels and PM_{10} levels is 15 micrograms per cubic meter and 50 micrograms per cubic meter, respectively. Annual average PM_{10} levels in Pennsylvania range from 19 to 32 micrograms per cubic meter. Data compiled from U.S. EPA, *AirData: Access to Air Pollution Data*, 2003 monitoring results, downloaded from www.epa.gov/air/data/ on 20 December 2005.

7 The air pollution data here represents the 2003 annual average for $PM_{2.5}$: U.S. EPA, *AirData: Access to Air Pollution Data*, downloaded from www.epa.gov/air/data/ on 20 December 2005. See Methodology for details on how the maps were generated.

8 The air pollution data here represents the 2003 April – October average one hour daily peak concentration of ozone: U.S. EPA, *AirData: Access to Air Pollution Data*, downloaded from www.epa.gov/air/data/ on 20 December 2005. See Methodology for details on how the maps were generated.

9 U.S. Environmental Protection Agency, *Air Quality Criteria for Particulate Matter, Volume 1*, EPA/600/P-99/002aF, October 2004; A. Fiore et al., Department of Earth and Planetary Sciences, Harvard University, "Variability in Surface Ozone Background in the United States: Implications for Air Quality Policy," *Journal of Geophysical Research* 108: 4787, doi:10.1029/2003JD003855, 2003.

10 A. Fiore et al., Department of Earth and Planetary Sciences, Harvard University, "Variability in Surface Ozone Background in the United States: Implications for Air Quality Policy," *Journal of Geophysical Research* 108: 4787, doi:10.1029/2003JD003855, 2003.

11 Clean Air Act, § 108.

12 *Whitman v. American Trucking Assoc.*, 531 U.S. 457, 2001.

13 See Note 1, 55.

14 Clean Air Scientific Advisory Committee (CASAC), *EPA's Review of the National Ambient Air Quality Standards for Particulate Matter (Second Draft PM Staff Paper, January 2005): A Review by the Particulate Matter Review Panel of the EPA Clean Air Scientific Advisory Committee*, EPA-SAB-CASAC-05-007, June 2005; EPA,

Review of the National Ambient Air Quality Standards for Particle Pollution: Policy Assessment of Scientific and Technical Information, EPA-452/R-05-005, June 2005.

15 Pennsylvania Department of Health, *Behavioral Health Risks of Pennsylvania Adults – 2004*, December 2005.

16 American Lung Association, *Secondhand Smoke*, published at www.lungusa.org, March 2006.

17 A. Mokdad et al., “Actual Causes of Death in the United States, 2000,” *Journal of the American Medical Association* 291, 1238-1245, 10 March 2004.

18 American Lung Association, *Indoor Air Pollution Fact Sheet*, August 1999.

19 Pennsylvania Department of Environmental Protection, Bureau of Air Quality, *Air Quality—The Big Picture*, downloaded from www.dep.state.pa.us/dep/deputate/airwaste/aq/bigpicture.htm on 13 March 2006.

20 Ibid.

21 Ibid.

22 Individual data points represent the second-highest measured ozone concentration, either one-hour or eight-hour running average, from all active monitors in the state in each year. Given that the number of monitors and their locations changed over the past 30 years, this graph is only indicative of the trend in ozone levels. Data from: U.S. EPA, *AirData: Access to Air Pollution Data*, downloaded from www.epa.gov/air/data/ on 13 March 2006.

23 8-hour ozone standard: Pennsylvania Department of Environmental Protection, Bureau of Air Quality, *Ozone Standard Exceedances*, downloaded from www.dep.state.pa.us on 9 February 2006.

24 M. Lippman, “Health Effects of Ozone: A Critical Review,” *Journal of the Air Pollution Control Association* 39: 672-695, 1989; I. Mudway and F. Kelley, “Ozone and the Lung: A Sensitive Issue,” *Molecular Aspects of Medicine* 21: 1-48, 2000.

25 M. Gilmour et al., “Ozone-Enhanced Pulmonary Infection with *Streptococcus Zooepidemicus* in Mice: The Role of Alveolar Macrophage Function and Capsular Virulence Factors,” *American Review of Respiratory Disease* 147: 753-760; I. Mudway and F. Kelley, “Ozone and the Lung: A Sensitive Issue,” *Molecular Aspects of Medicine* 21: 1-48, 2000.

26 W. McDonnell et al., “Pulmonary Effects of Ozone Exposure During Exercise: Dose-Response Characteristics,” *Journal of Applied Physiology* 5: 1345-1352, 1983.

27 N. Kunzli et al., “Association Between Lifetime Ambient Ozone Exposure and Pulmonary Function in College Freshmen – Results of a Pilot Study,” *Environmental Research* 72: 8-16, 1997; I.B. Tager et al., “Chronic Exposure to Ambient Ozone and Lung Function in Young Adults,” *Epidemiology* 16: 751-9, November 2005.

28 A. Galizia et al., “Long-Term Residence in Areas of High Ozone: Associations with Respiratory Health in a Nationwide Sample of Nonsmoking Young Adults,” *Environmental Health Perspectives* 107: 675-679, 1999.

29 M. Fanucchi et al., “Repeated Episodes of Exposure to Ozone Alters Postnatal Development of Distal Conducting Airways in Infant Rhesus Monkeys,” *American Journal of Respiratory Critical Care Medicine* 161: A615, 2000; Kendall Powell, “Ozone Exposure Throws Monkey Wrench Into Infant Lungs,” *Nature Medicine*, Volume 9, Number 5, May 2003.

30 Ibid, Kendall Powell 2003.

31 R. McConnell et al., “Asthma in Exercising Children Exposed to Ozone: A Cohort Study,” *The Lancet* 359: 386-391, 2002.

32 Asthma: Ralph Delfino et al., “Asthma Symptoms in Hispanic Children and Daily Ambient Exposures to Toxic and Criteria Air Pollutants,” *Environmental Health Perspectives* 111(4), 647-656, April 2003; I.L. Bernstein, M. Chan-Yeung, J.L. Malo, and D.I. Bernstein, *Asthma in the Workplace*, (New York, NY: Marcel Dekker), 1999; Cancer: D. Glass et al., “Leukemia Risk Associated with Low-Level Benzene Exposure,” *Epidemiology* 14: 569-577, 2003; A. Blair and N. Kazerouni, “Reactive Chemicals and Cancer,” *Cancer Causes Control* 8: 473-490.

33 P. van Vliet et al., “Motor Vehicle Exhaust and Chronic Respiratory Symptoms in Children Living Near Freeways,” *Environmental Research* 74:122-32, 1997; T. Nicolai et al., “Urban Traffic and Pollutant Exposure Related to Respiratory Outcomes and Atopy in a Large Sample of Children,” *European Respiratory Journal* 21: 956-63, June 2003.

34 W.J. Gauderman et al., “Childhood Asthma and Exposure to Traffic and Nitrogen Dioxide,” *Epidemiology* 16: 737-43, November 2005.

35 Cough: U. Gehrinig et al., “Traffic-Related Air Pollution and Respiratory Health During the First 2 Yrs of Life,” *European Respiratory Journal* 19: 690-8, April 2002; More asthma evidence:.J.J. Kim et al., “Traffic-Related Air

Pollution Near Busy Roads: the East Bay Children's Respiratory Health Study," *American Journal of Respiratory Critical Care Medicine* 170: 520-6, September 2004.

36 R. Maheswaran and P Elliott, "Stroke Mortality Associated With Living Near Main Roads in England and Wales," *Stroke* 34: 2776-80, December 2003; G. Hoek et al., "Association Between Mortality and Indicators of Traffic-Related Air Pollution in the Netherlands: a Cohort Study," *Lancet* 360: 1203-9, 19 October 2002.

37 Bob Weinhold, "Don't Breathe and Drive? Pollutants Lurk Inside Vehicles," *Environmental Health Perspectives* 109: A422-27, September 2001.

38 M. Riediker et al., "Particulate Matter Exposure in Cars is Associated with Cardiovascular Effects in Healthy Young Men," *American Journal of Respiratory Critical Care Medicine* 169: 934-40, 15 April 2004.

39 M. Bell and D. Davis, "Reassessment of the Lethal London Fog of 1952: Novel Indicators of Acute and Chronic Consequences of Acute Exposure to Air Pollution," *Environmental Health Perspectives* 109 Supplement 3: 389-94, 2001.

40 W. Michael McCabe, U.S. Environmental Protection Agency, *Donora Disaster Was Crucible for Clean Air*, available at www.dep.state.pa.us, 26 October 1998.

41 B. Karcher et al., "A Unified Model for Ultra Fine Aircraft Particle Emissions," *Journal of Geophysical Research* 105: D24 29379-29386, 2002.

42 M. Kleeman et al., "Size and Composition Distribution of Fine Particulate Matter Emitted From Motor Vehicles," *Environmental Science and Technology* 34: 1132-1142, 2000.

43 H. Bunn et al., "Ultra fine Particles in Alveolar Macrophages from Normal Children," *Thorax* 56: 932-934, 2001.

44 A. Seaton et al., "Particulate Air Pollution and the Blood," *Thorax* 54: 1027-1032, 1999.

45 M. Brauer et al., "Air Pollution and Retained Particles in the Lung," *Environmental Health Perspectives* 109: 1039-1043, 2001.

46 J. Pekkanen et al., "Daily Variations of Particulate Air Pollution and ST-T Depressions in Subjects with Stable Coronary Heart Disease: The Finnish ULTRA Study," *American Journal of Respiratory Critical Care Medicine* 161: A24, 2000.

47 W.J. Gauderman et al., "The Effect of Air Pollution on Lung Development from 10 to 18 Years of Age," *The New England Journal of Medicine* 351: 1057-67, 9 September 2004.

48 C. Pope 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.

49 J. Grigg, "The Health Effects of Fossil Fuel Derived Particles," *Archives of Disease in Childhood* 86: 79-83, 2002.

50 U.S. Environmental Protection Agency, *Final Report to Congress on Benefits and Costs of the Clean Air Act, 1990 to 2010*, Document # EPA 410-R-99-001, 15 November 1999; N. Kunzli et al., *Air pollution Attributable Cases — Technical Report on Epidemiology; Technical Report of the 'Health Costs Due to Road Traffic-Related Air Pollution — An Impact Assessment Project of Austria, France, and Switzerland*, World Health Organization, Bern 1999.

51 See Note 48.

52 C. Pope, "Epidemiology of Fine Particulate Air Pollution and Human Health: Biologic Mechanisms and Who's at Risk?" *Environmental Health Perspectives* 108: 713-723, August 2000.

53 American Cancer Society, "Air Pollution Linked to Deaths from Lung Cancer," www.cancer.org, 6 March 2002.

54 N. Kunzli et al., "Public Health Impact of Outdoor and Traffic-Related Air Pollution: A European Assessment," *The Lancet* 356: 795-801, 2 September 2002.

55 A. Peters et al., "Increased Particulate Air Pollution and the Triggering of Myocardial Infarction," *Circulation* 103: 2810-2815, 2001.

56 J. Samet et al., The United States Health Effects Institute, *The National Morbidity, Mortality, and Air Pollution Study, Part II: Morbidity and Mortality from Air Pollution in the United States*, Research Report Number 94, June 2000.

57 K. Ito, S.F. de Leon and M. Lippmann, "Associations Between Ozone and Daily Mortality," *Epidemiology* 16: 446-57, July 2005.

58 J. Schwartz et al., "Episodes of High Coarse Particle Concentrations Are Not Associated With Increased Mortality," *Environmental Health Perspectives* 107: 339-342, 1999.

59 J. Schwartz, "Is There Harvesting in the Association of Airborne Particles with Daily Deaths and Hospital Admissions?" *Epidemiology* 12: 55-61, 2001; M. Bobak and D.A. Leon, "The Effect of Air Pollution on Infant Mortality Appears Specific for Respiratory Causes in the Postnatal Period," *Epidemiology* 10: 666-670, 1999.

60 See Note 54.

61 See Note 17.

62 U.S. Environmental Protection Agency, Office of Policy, *Climate Change and Pennsylvania*, September 1997.

63 SM Bernard et al., “The Potential Impacts of Climate Variability and Change on Air Pollution-Related Health Effects in the United States,” *Environmental Health Perspectives* 109: 199-209, May 2001; K Knowlton et al., “Assessing Ozone-Related Health Impacts Under a Changing Climate,” *Environmental Health Perspectives* 112:1557-63, November 2004.

64 PJM Koken et al., “Temperature, Air Pollution, and Hospitalization for Cardiovascular Diseases Among Elderly People in Denver,” *Environmental Health Perspectives* 111: 1312-1317, 2003.

65 John Tagliabue, “Scorching Heat Around Europe Causes Deaths and Droughts,” *The New York Times*, 19 July 2005.

66 U.S. Environmental Protection Agency, *Climate Change and Pennsylvania*, September 1997.

67 See Note 56.

68 Joel Schwartz, “Air Pollution and Hospital Admissions for the Elderly in Birmingham, Alabama,” *American Journal of Epidemiology* 139: 589-98, 15 March 1994; Joel Schwartz, “Air Pollution and Hospital Admissions for the Elderly in Detroit, Michigan,” *American Journal of Respiratory Critical Care Medicine* 150: 648-55, 1994; Joel Schwartz , “PM10, Ozone, and Hospital Admissions for the Elderly in Minneapolis-St. Paul, Minnesota,” *Archives of Environmental Health* 49: 366-374, 1994; Joel Schwartz, “Short-Term Fluctuations in Air Pollution and Hospital Admissions of the Elderly for Respiratory Disease,” *Thorax* 50: 531-538, 1995; J. Schwartz and R. Morris, “Air pollution and hospital admissions for cardiovascular disease in Detroit, Michigan,” *American Journal of Epidemiology* 142: 23-25, 1995; Joel Schwartz, “Air Pollution and Hospital Admissions for Respiratory Disease,” *Epidemiology* 7: 20-28, 1996; Joel Schwartz, “Air Pollution and Hospital Admissions for Cardiovascular Disease in Tucson,” *Epidemiology* 8: 371-377, 1997.

69 George Thurston et al., “Respiratory Hospital Admissions and Summertime Haze Air Pollution in Toronto, Ontario: Consideration of the Role of Acid Aerosols,” *Environmental Research* 65: 271-290, 1994; R. Burnett et al., “The Role of Particulate Size and Chemistry in the Association Between Summertime Ambient Air Pollution and Hospitalization for Cardiorespiratory Disease,” *Environmental Health Perspectives* 105: 614-620, 1997; R. Burnett et al., “Association Between Ozone and Hospitalization for Respiratory Diseases in 16 Canadian Cities,” *Environmental Research* 72: 24-31, 1997.

70 R. Cody et al., “The Effect of Ozone Associated with Summertime Photochemical Smog on the Frequency of Asthma Visits to Hospital Emergency Departments,” *Environmental Research* 58: 184-194, 1992; C. Weisel et al., “Relationship Between Summertime Ambient Ozone Levels and Emergency Department Visits for Asthma in Central New Jersey,” *Environmental Health Perspectives* 103, Supplement 2: 97-102, 1995.

71 Joel Schwartz et al., “Particulate Air Pollution and Hospital Emergency Room Visits for Asthma in Seattle,” *American Review of Respiratory Disease* 147: 826-831, 1993.

72 Jennifer Peel et al., “Ambient Air Pollution and Respiratory Emergency Department Visits,” *Epidemiology* 6:164-174, March 2005.

73 See Note 31; The causal role of ozone in asthma development may be easier to detect in children who exercise because breathing rates during exercise can be up to 17 times higher than during rest, leading to greater exposure to air pollutants: See W.D. McArdle et al., *Exercise Physiology: Energy, Nutrition, and Human Performance*, (Philadelphia, PA: Williams and Wilkins, 1996), 228.

74 See Note 34.

75 W. McDonnell et al., “Long-Term Ambient Ozone Concentration and the Incidence of Asthma in Nonsmoking Adults: the AHSMOG Study,” *Environmental Research* 80: 110-121, 1999.

76 T. Wang et al., “Association Between Indoor and Outdoor Air Pollution and Adolescent Asthma From 1995 to 1996 in Taiwan,” *Environmental Research* 81: 239-247, 1999.

77 T. Yu et al., “Adverse Effects of Low-Level Air Pollution on the Respiratory Health of Schoolchildren in Hong Kong,” *Journal of Occupational Environmental Medicine* 43: 310-316, 2001.

78 Joel Schwartz, “Particulate Air Pollution and Chronic Respiratory Disease,” *Environmental Research* 62: 7-13, 1993; D. Abbey et al., “Long-term Ambient Concentrations of Total Suspended Particles, Ozone, and Sulfur Dioxide and Respiratory Symptoms in a Nonsmoking

Population," *Archives of Environmental Health* 48: 33-46, 1993.

79 U.S. Centers for Disease Control, "Measuring Childhood Asthma Prevalence Before and After the 1997 Redesign of the National Health Interview Survey—United States," *Mortality and Morbidity Weekly Report* 49: 908-911, 13 October 2000.

80 National Institutes of Health, National Heart, Lung, and Blood Institute, *Data Release for World Asthma Day*, May 2001.

81 According to the American Lung Association of Pennsylvania, over 230,000 children in Pennsylvania have been diagnosed with asthma. American Lung Association, *Estimated Prevalence and Incidence of Lung Disease by Lung Association Territory*, July 2005.

82 Division of Adult and Community Health, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, *Behavioral Risk Factor Surveillance System Online Prevalence Data*, 1995-2002.

83 Because ozone exposure had a statistically significant link to asthma development only in males in the McDonnell paper cited in note 75, our estimate is limited to new cases of asthma only in the adult male population. Actual new asthma cases caused by air pollution may be higher.

84 See Note 34.

85 George Thurston et al., "Summertime Haze Air Pollution and Children with Asthma," *American Journal of Respiratory Critical Care Medicine* 155: 654-660, February 1997.

86 A. Whittemore and E. Korn, "Asthma and Air Pollution in the Los Angeles Area," *American Journal of Public Health*, 70: 687-696, 1980.

87 B. Ostro and S. Rothschild, "Air Pollution and Acute Respiratory Morbidity: an Observational Study of Multiple Pollutants," *Environmental Research* 50: 238-47, 1989.

88 J. Schwartz et al., "Acute Effects of Summer Air Pollution on Respiratory Symptom Reporting in Children," *American Journal of Respiratory Critical Care Medicine* 150: 1234-1242, 1994.

89 World Health Organization Europe, Special Programme on Health and Environment, *Effects of Air Pollution on Children's Health and Development: A Review of the Evidence*, 2005.

90 See Note 29.

91 See Note 89.

92 T. Woodruff et al., "The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States," *Environmental Health Perspectives* 105: 608-612, 1997; T. Woodruff et al., "Fine Particulate Matter ($PM_{2.5}$) Air Pollution and Selected Causes of Postneonatal Infant Mortality in California," *Environmental Health Perspectives*, doi:10.1289/ehp.8484 available via dx.doi.org, Online 13 January 2006.

93 See Note 59, Bobak and Leon 1999.

94 K.Y. Chay and M. Greenstone, National Bureau of Economic Research, *The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession*, Manuscript cited in "Spring 2002 References," *Health and Clean Air Newsletter*, www.healthandcleanair.org, 2002.

95 Reinhard Kaiser et al, "Air Pollution Attributable Postneonatal Infant Mortality in U.S. Metropolitan Areas: a Risk Assessment Study," *Environmental Health* 3: doi: 10.1186/1476-069X-3-4, 5 May 2004.

96 M. Friedman et al., "Impact of Changes in Transportation and Commuting Behaviors During the 1996 Summer Olympic Games in Atlanta on Air Quality and Childhood Asthma," *Journal of the American Medical Association* 285: 897-905, 2001.

97 Ibid.

98 U.S. Center for Disease Control, *CDC Study Links Improved Air Quality with Decreased Emergency Room Visits for Asthma*, Press Release, 21 February 2001.

99 American Lung Association, *Asthma in Children Factsheet*, March 2003.

100 See Note 79.

101 Janneane Gent et al., "Association of low-level ozone and fine particles with respiratory symptoms in children with asthma," *Journal of The American Medical Association* 290, 1859-1867, 8 October 2003.

102 E.W. Triche et al, "Low Level Ozone Exposure and Respiratory Symptoms in Infants," *Environmental Health Perspectives* doi:10.1289/ehp.8559 (available at dx.doi.org), Online 29 December 2005.

103 D. Dockery et al., "Health Effects of Acid Aerosols on North American Children: Respiratory Symptoms," *Environmental Health Perspectives* 104: 500-505, May 1996.

104 F. Gilliland et al., "The Effects of Ambient Air Pollution on School Absenteeism Due to Respiratory Illness," *Epidemiology* 12: 43-54, 2001.

105 H. Park et al., "Association of Air Pollution with School Absenteeism Due to Illness," *Archives of Pediatric and Adolescent Medicine* 156: 1235-1239, 2002.

106 Area sources include small stationary engines, businesses that use solvents or other chemicals and other stationary sources of pollution that emit relatively small quantities of pollution. These are important sources of particulates and smog-forming volatile organic compounds, but are much more varied in type than either point or mobile sources—and thus require an equally varied set of regulations to address in large quantities, in contrast to vehicles and industrial facilities.

107 Green Media Toolshed, *Pollution Locator: Smog and Particulates*, available at scorecard.org, viewed on 27 December 2005; U.S. Environmental Protection Agency, *AirData Emissions by Category Report—Criteria Air Pollutants*, 1999, downloaded 27 December 2005.

108 Pennsylvania Department of Environmental Protection, Environmental Quality Board, *Notice of Proposed Rulemaking: Pennsylvania's Clean Vehicle Program, Preamble*, 18 October 2005.

109 Kathleen McGinty, Secretary, Pennsylvania Department of Environmental Protection, *Pennsylvania's Clean Vehicles Program*, Testimony given before the Pennsylvania Senate Transportation and Environmental Resources & Energy Committees, 13 December 2005.

110 Pennsylvania Department of Environmental Protection, *Myths and Facts About the Pennsylvania Clean Vehicles Program*, 31 October 2005.

111 North Carolina Department of Environment and Natural Resources, Division of Air Quality, *North Carolina's Clean Smoketacks Act*, downloaded from http://daq.state.nc.us/news/leg/cleanstacks.shtml, 27 December 2005.

112 See Note 50.

113 U.S. EPA, *AirData: Access to Air Pollution Data*, downloaded from www.epa.gov/air/data on 20 December 2005.

114 N. Kunzli et al., *Air pollution Attributable Cases — Technical Report on Epidemiology; Technical Report of the 'Health Costs Due to Road Traffic-Related Air Pollution — An Impact Assessment Project of Austria, France, and Switzerland*, World Health Organization, Bern 1999.

115 Ibid.

116 See Note 10.

117 See Note 114.

118 U.S. Census Bureau, American Fact Finder, *Census 2000 Summary File 1 (SF 1) 100-Percent Data*, Custom Table by Zip Code Tabulation Area and Age Groups for Pennsylvania, Downloaded from factfinder.census.gov on 24 January 2006.

119 Pennsylvania Department of Health, Bureau of Health Statistics and Research, *Deaths by Zip Code for ICD-10 Codes A00-R99, Pennsylvania Residents, 2003*, Custom Query Run by Timothy Golightly, 31 January 2006. At the instruction of the Pennsylvania Department of Health, we include the following disclaimer: These data were provided by the Bureau of Health Statistics and Research, Pennsylvania Department of Health. The Department specifically disclaims responsibility for any analysis, interpretations or conclusions.

120 Ibid.

121 Pennsylvania Health Care Cost Containment Council, *County Inpatient Hospitalizations, Utilization by Body System*, Data Compiled from 2003 County Reports available at www.phc4.org/countyprofiles/ on 31 January 2006.

122 Ibid.

123 U.S. Environmental Protection Agency, *Final Report to Congress on Benefits and Costs of the Clean Air Act, 1990 to 2010*, Document # EPA 410-R-99-001, 15 November 1999, D-66.

125 Division of Adult and Community Health, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, *Behavioral Risk Factor Surveillance System Online Prevalence Data*, 2003.

126 See Note 123.

127 Weighted average of the 0-5 year old rate of 0.015 and 5 – adult rate of 0.0071: US Department of Health and Human Services, *Tracking Healthy People 2010*, Section 24 - Respiratory Diseases, November 2000.

128 See Note 123.

129 Ibid.

130 In the 2003-2004 school year, the average Pennsylvania public school student missed 11.7 days of school. We assume that roughly 50 percent of these absences were due to illness. Pennsylvania Department of Education, *Child Accounting Database System, Average Daily Attendance Report, School Year 2003-2004*, 3 May 2005; and H. Park et al., "Association of Air Pollution with School Absenteeism Due to Illness," *Archives of Pediatric and Adolescent Medicine* 156: 1235-1239, 2002.

131 See Note 123.

132 See Note 114.

133 Ibid.

134 Ibid.

135 See Note 123.

136 Ibid.

137 See Note 114; Estimate from 2 studies: C. Pope 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; and D. Dockery et al., "An Association Between Air Pollution and Mortality in Six U.S. Cities," *New England Journal of Medicine* 329: 1753-1759, 1993.

138 See Note 114; Estimate from 8 U.S. and Canadian studies: George Thurston et al., "Respiratory Hospital Admissions and Summertime Haze Air Pollution in Toronto, Ontario: Consideration of the Role of Acid Aerosols," *Environmental Research* 65: 271-290, 1994; Joel Schwartz, "Air Pollution and Hospital Admissions for the Elderly in Birmingham, Alabama," *American Journal of Epidemiology* 139: 589-98, 15 March 1994; Joel Schwartz, "Air Pollution and Hospital Admissions for the Elderly in Detroit, Michigan," *American Journal of Respiratory Critical Care Medicine* 150: 648-55, 1994; Joel Schwartz , "PM10, Ozone, and Hospital Admissions for the Elderly in Minneapolis-St. Paul, Minnesota," *Archives of Environmental Health* 49: 366-374, 1994; Joel Schwartz, "Short-Term Fluctuations in Air Pollution and Hospital Admissions of the Elderly for Respiratory Disease," *Thorax* 50:531-538, 1995; J. Schwartz and R. Morris, "Air pollution and hospital admissions for cardiovascular disease in Detroit, Michigan," *American Journal of Epidemiology* 142: 23-25, 1995; Joel Schwartz, "Air Pollution and Hospital Admissions for Respiratory Disease," *Epidemiology* 7: 20-28, 1996; Joel Schwartz, "Air Pollution and Hospital Admissions for Cardiovascular Disease in Tucson," *Epidemiology* 8: 371-377, 1997; R. Burnett et al., "The Role of Particulate Size and Chemistry in the Association Between Summertime Ambient Air Pollution and Hospitalization for Cardio-respiratory Disease," *Environmental Health Perspectives* 105: 614-620, 1997.

139 See Note 114; Joel Schwartz, "Air Pollution and Hospital Admissions for the Elderly in Detroit, Michigan," *American Journal of Respiratory Critical Care Medicine* 150: 648-55, 1994; Joel Schwartz, "Air Pollution and Hospital Admissions for Cardiovascular Disease in Tucson," *Epidemiology* 8: 371-377, 1997; R. Burnett et al., "The Role of Particulate Size and Chemistry in the Association Between Summertime Ambient Air Pollution and Hospitalization for Cardio-respiratory Disease," *Environmental Health Perspectives* 105: 614-620, 1997.

140 See Note 114; Weighted average of 3 European studies: A. Dusseldorp et al., "Associations of PM10 and Airborne Iron with Respiratory Health of Adults Living Near a Steel Factory," *American Journal of Respiratory Critical Care Medicine* 152: 1032-1039, 1995; T. Hiltermann et al., "Asthma Severity and Susceptibility to Air Pollution," *European Respiratory Journal* 11: 686-693, 1996; F. Neukirch et al., "Short-term Effects of Low-level Winter Pollution on Respiratory Health of Asthmatic Adults," *Archives of Environmental Health* 53: 320-328, 1998.

141 See Note 114; D. Abbey et al., "Long-term Ambient Concentrations of Total Suspended Particles, Ozone, and Sulfur Dioxide and Respiratory Symptoms in a Nonsmoking Population," *Archives of Environmental Health* 48: 33-46, 1993.

142 B. Ostro, "Air Pollution and Morbidity Revisited: a Specification Test," *Journal of Environmental Economics and Management*, 14: 87-98, 1987; B. Ostro and S. Rothschild, "Air Pollution and Acute Respiratory Morbidity: an Observational Study of Multiple Pollutants," *Environmental Research* 50: 238-47, 1989.

143 B. Ostro and S. Rothschild, "Air Pollution and Acute Respiratory Morbidity: an Observational Study of Multiple Pollutants," *Environmental Research* 50: 238-47, 1989. B. Ostro, "Associations Between Morbidity and Alternative Measures of Particulate Matter," *Risk Analysis* 10: 421-427, 1990.

144 A. Krupnick, W. Harrington, and B. Ostro, "Ambient Ozone and Acute Health Effects: Evidence from Daily Data." *Journal of Environmental Economics and Management* 18: 1-18, 1990.

146 See Note 123: R. Burnett et al., "Effects of Particulate and Gaseous Air Pollution on Cardio-Respiratory Hospitalizations," *Archives of Environmental Health* 54: 130-139, 1999.

147 See Note 123: A. Whittemore and E. Korn, "Asthma and Air Pollution in the Los Angeles Area," *American Journal of Public Health*, 70: 687-696, 1980.

148 See Note 123: B. Ostro and S. Rothschild, "Air Pollution and Acute Respiratory Morbidity: an Observational Study of Multiple Pollutants," *Environmental Research* 50: 238-47, 1989.

149 See Note 123: A. Krupnick, W. Harrington,

and B. Ostro, "Ambient Ozone and Acute Health Effects: Evidence from Daily Data." *Journal of Environmental Economics and Management* 18: 1-18, 1990.

150 See Note 123: T. Woodruff, "The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States," *Environmental Health Perspectives* 105: 608-612, 1997.

151 M. Friedman et al., "Impact of Changes in Transportation and Commuting Behaviors During the 1996 Summer Olympic Games in Atlanta on Air Quality and Childhood Asthma," *Journal of the American Medical Association* 285: 897-905, 2001.

152 See Note 114: D. Dockery et al., "Effects of Inhalable Particles on Respiratory Health of Children," *American Review of Respiratory Disease* 139: 587-594, 1989; D. Dockery et al., "Health Effects of Acid Aerosols on North American Children: Respiratory Symptoms," *Environmental Health Perspectives* 104: 500-505, 1996; C. Braun-Fahrländer et al, "Respiratory Health and Long-term Exposure to Air Pollutants in Swiss Schoolchildren," *American Journal of Respiratory Critical Care Medicine* 155: 1042-1049, 1997.

153 See Note 114; Joint estimate from two U.S. Studies: C. Pope et al., "Respiratory Health and PM10 Pollution - A Daily Time Series Analysis," *American Review of Respiratory Disease* 144: 668-674, 1991; B. Ostro et al., "Air Pollution and Asthma Exacerbations Among African-American Children in Los Angeles, *Inhalation Toxicology* 7: 711-722, 1995.

154 M.R. Ransom and C.A. Pope, "Elementary School Absences and PM10 Pollution in Utah Valley," *Environmental Research* 58: 204-219, 1992.

155 Ninez Ponce et al, "Preterm Birth: The Interaction of Traffic-Related Air Pollution with Economic Hardship in Los Angeles Neighborhoods," *American Journal of Epidemiology* 162: 140-148; doi:10.1093/aje/kwi173, 2005; Frederica Perera et al, "Molecular Evidence of an Interaction Between Prenatal Environmental Exposures and Birth Outcomes in a Multiethnic Population," *Environmental Health Perspectives* 112: 626-630, 14 January 2004.

156 For a discussion of the variability in particulate levels between different monitors within cities in the U.S., see Joseph Pinto et al, "Spatial Variability of PM2.5 in Urban Areas in the United States," *Journal of the Air and Waste Management Association* 54: 440-449, April 2004.

157 Michael Jerrett et al, "Spatial Analysis of Air Pollution and Mortality in Los Angeles," *Epidemiology* 16: 727-736, November 2005.

158 Health Effects Institute (a partnership between the Auto Industry and the U.S. EPA), *Revised Analyses of Time-Series Studies of Air Pollution and Health*. May 2003.

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