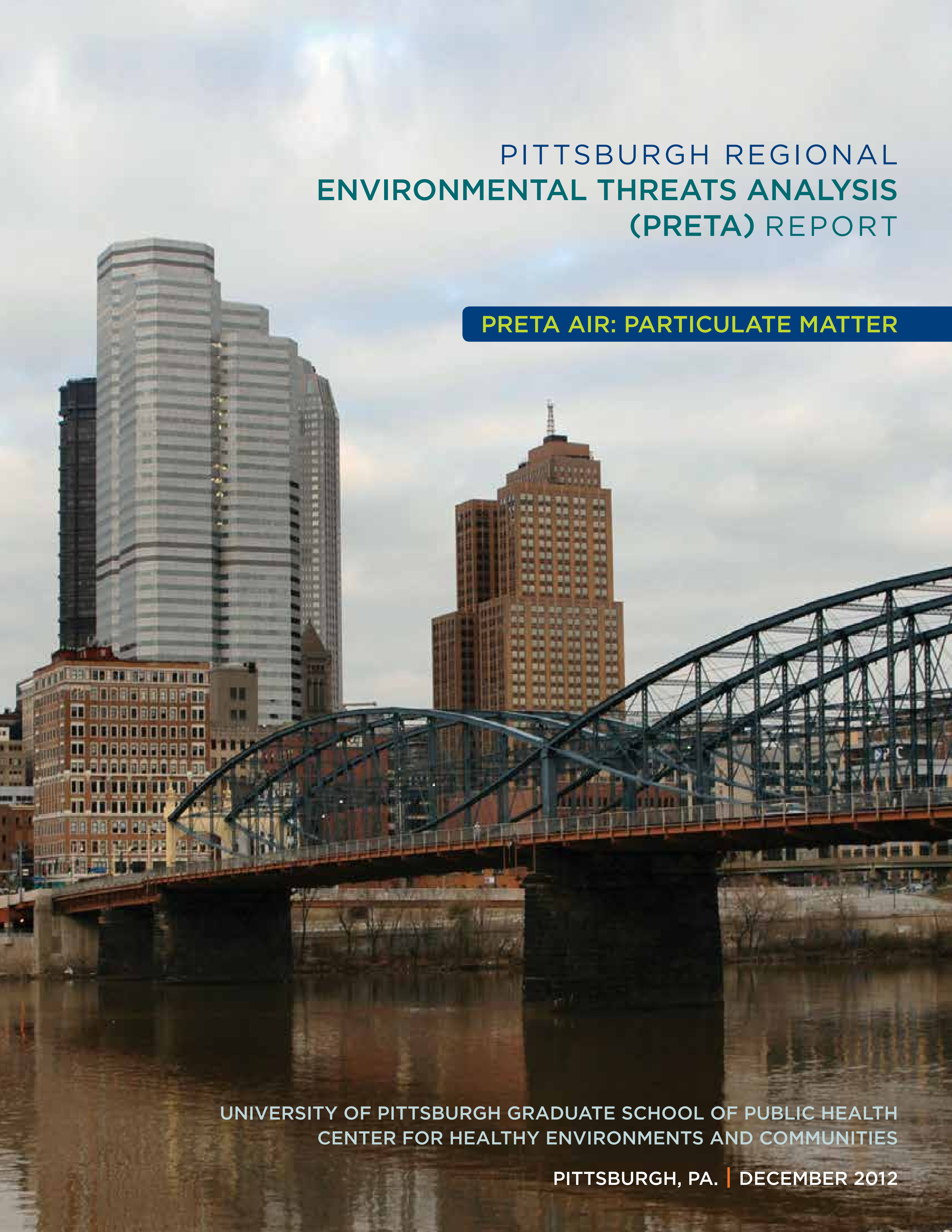
PITTSBURGH REGIONAL ENVIRONMENTAL THREATS ANALYSIS (PRETA) REPORT

PRETA AIR: PARTICULATE MATTER



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PRETA AIR: PARTICULATE MATTER

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The Center for Healthy Environments and Communities (CHEC), part of the University of Pittsburgh Graduate School of Public Health's Department of Environmental and Occupational Health, was founded in 2004 under a grant from The Heinz Endowments. CHEC's mission is to improve environmental health in Western Pennsylvania through community-based research.

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TABLE OF CONTENTS

THE PURPOSE OF PRETA

The Pittsburgh Regional Environmental Threats Analysis (PRETA) project puts together information about the major threats to human health and the environment within southwestern Pennsylvania. PRETA is intended to cover the core public health functions—assessment, policy development, and assurance—and relies heavily on figures, maps, and other visuals. PRETA is meant to encourage stakeholders to take into account scientific analysis and public values for sound policy development and remedial action against environmental threats. PRETA also is meant to be informative, highlighting the populations most at risk to those threats. Ideally, PRETA will inspire initiatives to address the highest risks to human health and the environment in southwestern Pennsylvania. The preliminary assessments employed in the project identified air quality as the number one current environmental threat to the welfare of the greater Pittsburgh region. The second of a series of reports on the environmental threats to the region, titled *PRETA Air*, focuses on particulate matter and its environmental and public health impacts.

PRETA STUDY AREA

10 southwestern Pennsylvania counties:

- Allegheny
- Armstrong
- Beaver
- Butler
- Fayette
- Greene
- Indiana
- Lawrence
- Washington
- Westmoreland

The photographs of facilities and their locations published in this document are representational of typical plants that may emit particulate matter.

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EXECUTIVE SUMMARY

As researchers from the Graduate School of Public Health at the University of Pittsburgh, we focus this report on the exposure to and human health effects from particulate matter (PM) in the air we breathe within southwestern Pennsylvania. PM is composed of microscopic particles that usually, but not exclusively, arise from combustion and remain suspended in the atmosphere. As we breathe, these particles can enter the lungs, where, depending on their amount, size, and chemical composition, they can exert adverse health effects. These effects include aggravation of cardiovascular disease (including premature death), exacerbation of asthma, and poor reproductive outcomes, among others.

STUDYING PARTICULATE MATTER EFFECTS

To further understand this relationship, we describe the research and science concerning particulate matter pollution, including:

- the recent scientific research and research performed within the region,
- what and where the sources of PM are,
- how the region compares to national air quality standards, and
- how the concentrations of PM have varied spatially and temporally across the region over the past 10 years.

Particulate matter remains a significant health threat in urban and highly industrial areas as demonstrated by global, national, and local air pollution studies. Research conducted within southwestern Pennsylvania directly correlates regional fluctuations in PM levels with such adverse health effects as cardiovascular disease and poor reproductive outcomes.

Residents and communities within the PRETA area are exposed to PM from many sources. The predominant sources of both primary and secondary PM pollutants within the PRETA area are large coal-fired power plants, vehicular traffic, and atmospheric transport from sources outside our area. Sixty-five percent of primary PM in the PRETA region results from electrical generation, with 3/4 of this derived from three local major power plants (the Hatfield's Ferry Power Station, the Keystone Station, and the Homer City Station). Pennsylvania and Ohio combined are home to eight of the top 50 coal-fired power plants in the nation producing sulfur dioxide (SO_2), a major precursor chemical to the formation of secondary PM. Diesel traffic accounts for only 6 percent of the vehicle miles traveled within the region; however, those vehicles emit more than half the $PM_{2.5}$ emissions from mobile sources. Within Allegheny County, the Liberty/Clairton area in proximity to the Clairton Coke Works currently experiences some of the highest levels of PM pollution in the country. In the downtown area of Pittsburgh, diesel exhaust has been identified as a major driver of cancer risk.

The U.S. Environmental Protection Agency (EPA) sets ambient air quality standards for $PM_{2.5}$ that are enforced using a network of air quality monitors, although the majority of these are located primarily in the more densely populated Allegheny County. Nine out of the 10 counties in the PRETA region have been previously found to be completely or partially in nonattainment of the federal health-based ambient air standards for both the annual and 24-hour $PM_{2.5}$ standards. On December 14, 2012, EPA revised the National Ambient Air Quality Standards for $PM_{2.5}$. The annual standard was made more stringent from 15 $\mu g/m^3$ to 12 $\mu g/m^3$. The existing 24-hour $PM_{2.5}$ standard and the PM_{10} standard were not updated in this revision. The majority of this document was formulated prior to this revision, and attainment/nonattainment designations are not expected to occur until 2015, though the majority of the PRETA region is not in attainment of an annual 12 $\mu g/m^3$ ambient standard. The majority of the population within the PRETA region is often exposed to PM levels above the current and proposed health-based standards, and research has shown that significant health effects occur even below the current standards. Based on monitoring data, regional and local source contributions to PM levels are of concern, and spatial distribution of PM within the region is heterogeneous. While the existing monitoring network covers several of the areas of concern, it fails to capture the PRETA region in its entirety. Other areas in proximity to specific industrial sites or high traffic activity may be experiencing similar exposures, and improved monitoring capabilities are recommended.

WHAT IS PARTICULATE MATTER?

Outdoor air pollution ranks as the eighth leading risk factor for mortality among high-income countries[1]. Outdoor and indoor air pollution contribute to 1.3 million and 2 million deaths, respectively, worldwide per year[2], ranking them second only to unsafe drinking water as leading environmental factors[a] in disease[3].

When one thinks of air pollution, one usually thinks about gases (such as ozone) or vapors (such as benzene) contained in the air we breathe. Particulate matter—or PM—is a term used to describe the sum of tiny solid and liquid particles suspended in the atmosphere. Airborne PM is currently considered by scientists, regulators, and policymakers to be one of the most important air pollutants impacting human health[4]. PM can also harm the environment. The common soiling of urban buildings arises from black carbon diesel exhaust particles. When PM settles to the ground, it can adversely affect water quality and vegetation as well as contribute to climate change[5].

PM is a chemically, physically, and biologically diverse mixture of materials, including dusts, organic chemicals, smoke, soot, metals, acids, and liquid droplets that originate from numerous natural and man-made sources. In fact, anything that burns will produce PM to some degree. The "fuel" or material being burned and the efficiency of combustion will determine the chemical and physical nature of the particles produced. Not surprisingly, the PM produced by diesel engines, coal-fired power plants, and incineration of municipal waste are not all the same.

In addition to processes that directly emit PM into the air (**primary PM**), PM also can be formed when certain gaseous pollutants, including sulfur dioxide (SO_2), various oxides of nitrogen (NO_X), volatile organic chemicals (VOCs), and ammonia (NH_3), condense into particulates (**secondary PM**) after they have been released from a source. Both primary and secondary PM can persist in the atmosphere and can travel long distances. Environmental and human health effects from PM are related to particle size and concentration in the air as well as to chemical composition.

Airborne PM is currently considered by scientists, regulators, and policymakers to be one of the most important air pollutants potentially impacting human health.

Historically, southwestern Pennsylvania has been notorious for poor air quality. Although the air has improved significantly over the years, people living here still breathe some of the most polluted air in the country. Therefore, it is important to pay attention to the trends in PM within the area to understand how and what type of PM becomes part of the air we breathe and the possible adverse health effects that follow PM exposure.

PARTICLE SIZE AND COMPOSITION

Particles come in a wide variety of shapes and sizes, which affects their impact on the environment and human health. When particles are inhaled into the lungs, where they localize is in large part determined by their size. Particles larger than 10 microns (μm; $PM_{>10}$) are generally filtered by the nose and throat, while the smaller particles ($PM_{10-2.5}$) can enter the lungs, though not as deeply as the fine ($PM_{<2.5}$) and ultrafine particles. PM2.5 and smaller ultrafine particles

[a] Personal choice factors such as tobacco and alcohol are excluded.

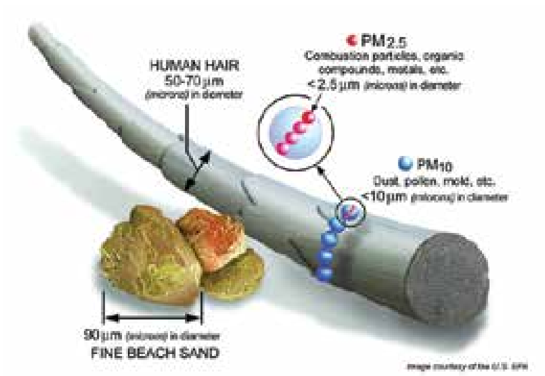


Figure 1. Particle size comparison of $PM_{2.5}$ and PM_{10} with fine beach sand and human hair. Reprinted with permission from EPA[7].

WHAT IS PM?

Particulate matter (PM) or particulates include a wide variety of the chemical and physical materials that exist as particles (liquid or solids) over a wide range of sizes. The subscripts 2.5 and 10 next to PM indicate the relative upper limit for size in micrometers (µm); 1 micrometer is one-millionth of a meter, or 1 micron. In contrast, the average diameter of a human hair is 50–70 µm. Approximately 25,000 microns fit into an inch (see Figure 1). Concentrations of particles in air are typically measured by the amount of mass (microgram) present in a volume of air (cubic meter), written as µg/m³.

deposit within the alveoli (gas-exchanging region of the lung) and can even enter the systemic circulation[6].

Airborne particulates also have varying shapes; some like asbestos are long extended fibers, although most particulates relevant to outdoor air pollution are relatively spherical in nature. Therefore, to compare different particle types, relative size is expressed by a derived diameter based on the way the particles' aerodynamic behavior resembles that of a perfect sphere (mean aerodynamic diameter, or MADD). In other words, MADD assumes the particle is a sphere. Figure 1 gives some appreciation about the relative sizes of air pollution particles. For perspective, a diameter of 2.5 µm corresponds to 1/100th of an inch, which is approximately 40 times smaller than the width of a human hair. EPA extensively monitors and characterizes PM. PM is classified into the following four size categories by EPA.

SIZE CATEGORIES OF PM

SUPERCOARSE: particles larger than 10 micrometers (µm) in MADD

COARSE: particles less than 10 µm in MADD, indicated by the notation PM_{10} (pronounced "P-M-ten")—*specifically regulated by EPA*

FINE: particles less than 2.5 µm in MADD, indicated by the notation $PM_{2.5}$—*specifically regulated by EPA*

ULTRAFINE: particles less than 0.1 µm in MADD

The chemical composition of PM is also very important, both in determining the pollutant's effects and in reflecting from where and how PM originates or forms. Road dust, mold spores, smoke, and pollen are relatively large structures that can be seen by the human eye, while smaller particles, invisible without a microscope, often are made up of burned materials such as coal, diesel fuel, and incinerated waste. Smaller particles can remain in the air for longer periods of time and tend to be composed of more metals, organic compounds, and other toxic chemicals not shared in their larger counterparts. It is important to realize that PM at any single time and place must be considered to be a complex mixture of materials and chemicals derived from multiple sources.

HEALTH EFFECTS OF PARTICULATE MATTER

People are exposed to PM primarily via the air they breathe. On average, each breath delivers about 6 liters of air to the lungs, with at least 17,000 breaths per day. Exposures to high levels of PM over short periods of time or lower levels over longer time periods are both cause for concern. Both short-term and long-term effects of PM on health have been shown. The magnitude or risk of the adverse effects (response) is proportional to the amount (dose) to which one is exposed. No evidence has been obtained for a threshold below which adverse effects do not occur. This means that there is no established "safe" level where health is not potentially affected by exposure to PM[8].

Over the decades, many human health studies have convincingly linked exposure to certain levels of air pollution to increased hospitalization for a variety of cardiopulmonary (heart and lung) diseases, deterioration of lung function, respiratory symptoms, more frequent medication use, and premature death. The most severe adverse human health effects associated with PM exposure include premature death from illnesses such as heart[9] and respiratory[10] diseases, asthma[11], and lung cancer[12]. The references cited to document these effects are typical of a large body of accumulating scientific literature. (For reviews, see [13, 14].)

PM effects are not restricted to the lung, because small particles may actually be absorbed into the circulatory system and exposure is linked to markers of systemic inflammation and oxidative stress throughout the body[15, 16]. It is likely that such responses are linked with numerous health outcomes, including asthma and chronic bronchitis, and from triggering premature death from preexisting heart and lung disease. Described below are some of the major health effects that have been specifically attributed to PM exposure worldwide followed by a listing of specific research findings relevant to southwestern Pennsylvania (the PRETA region).

PREMATURE DEATH

The World Health Organization estimates that PM pollution exposure is associated with an estimated 50,000 premature deaths every year in the United States (approximately 800,000 deaths worldwide). A considerable number of epidemiological studies (research based on large numbers of people) have shown a significant association between PM exposure and increased mortality risk[17, 18, 19]. Based on a national analysis of 112 U.S. cities, it was estimated that every 10 μg/m^3 increase in $PM_{2.5}$ contributed to a 0.98 percent increase in overall mortality[20]. Exposure in this study was determined by the two-day average on the day of death.

A similar study of more than 13.2 million Medicare recipients found that a 10 μg/m^3 increase in six-year average $PM_{2.5}$ is associated with a 6.8 percent increase in mortality in the eastern portion of the United States[21]. The difference in these studies probably reflects the age difference in the study populations, indicating that older individuals' risk is approximately seven times greater than the general population. In addition, the exposure variable was assessed over a much longer time period in the latter study. The landmark Harvard Six Cities Cohort Study[22] and follow-up[23] confirmed the association between long-term exposures to PM and premature deaths (16 percent increase in risk for every 10 μg/m^3 increase in $PM_{2.5}$). Conversely, reducing $PM_{2.5}$ in similar increments improved overall mortality (relative risk = 0.73; 95 percent confidence internal (CI): 0.57–0.95). This translates to an increase in life expectancy of approximately 7.3 months for every 10 μg/m^3 reduction in $PM_{2.5}$[24]. An important factor in these types of studies will be to ascertain the relative roles of long-term levels verses short-term fluctuations in PM exposure.

HEART DISEASE

Particulate air pollution is associated with cardiovascular outcomes, including hypertension[25], atherosclerosis[26], and myocardial infarction[9]. PM exposure alters various cardiovascular indexes, including heart rate, heart rate variability, blood pressure, and the blood's ability to clot[27, 28, 29]. Across nine major cities, including Pittsburgh, researchers at Harvard University found a 1 percent increase in the risk of ischemic stroke—one that occurs when an artery to the brain is blocked—on days with higher air pollution (PM_{10}, carbon monoxide, nitrogen oxide, and sulfur dioxide)[30].

A similar association with hospital admission for congestive heart failure and daily PM_{10} concentrations was found for Medicare recipients

Over the decades, many human health studies have convincingly linked exposure to certain levels of air pollution to increased hospitalization. … the most severe adverse human health effects associated with PM exposure include premature death from illnesses such as heart and respiratory diseases, asthma, and lung cancer.

(aged 65 or older) as part of a seven-city study[31]. Notably, this effect was still significant at PM_{10} levels below the current air quality standards set by EPA. A further study of 112 U.S. cities found increases of 0.85 percent (95 percent CI: 0.46–1.24) in cardiovascular disease, 1.18 percent (95 percent CI: 0.48–1.89) in myocardial infarction, and 1.78 percent (9 percent CI: 0.92–2.62) in stroke for every 10 µg/m³ increase in two-day average $PM_{2.5}$[20]. Recent research has shown that there is a six-hour window after pollution exposure when there is an increased risk of heart attack[32].

RESPIRATORY DISEASE AND ASTHMA

The rates of asthma throughout the United States have risen steadily over recent years. Many studies have demonstrated a clear association among PM exposure and increased symptom severity, emergency room visits, hospitalizations, and frequency of medication use among asthmatics.

In Pittsburgh, a positive association was found between $PM_{2.5}$ levels and emergency department visits for asthma up to the day after increased exposure[33]. Research conducted in North Carolina demonstrated that small temporal variations in coarse PM were sufficient enough to affect important markers of airway inflammation in adults with asthma[34]. Reduced lung function in asthmatic children has been observed several days after peak PM_{10} and $PM_{2.5}$ episodes in Detroit, Mich.[35]. A time series examining more than 4 million hospital visits in Atlanta, Ga., has shown positive relationships between ambient PM_{10} levels and upper respiratory infections as well as between $PM_{2.5}$ and pneumonia in infants and children[36].

In a group of 150 asthmatic children in Baltimore, Md., each 10 µg/m³ incremental rise in indoor level of $PM_{2.5-10}$ resulted in a 6 percent increase in overall asthma symptoms, an 8 percent increase in nocturnal symptoms, and a 6 percent increase in the use in of rescue medication[37]. In the same study, a 10 µg/m³ increment in ambient $PM_{2.5-10}$ increased exercise-induced asthma by 26 percent. The Children's Health Study conducted in Southern California found that decreases in lung function among school-aged children were associated with three major PM size classes[38]. The relationship between new onset asthma to long-term PM exposure in children ages 10–18 has been found[39]. An association also was observed within the first four years of life between ambient PM data and doctor-diagnosed asthma[40]. The strength and consistency of the relationship between PM and respiratory-related outcomes is enhanced by results being reported by several researchers from different countries using varying study designs.

ADVERSE REPRODUCTIVE EFFECTS

A growing list of studies has supported a positive association between PM air pollution and adverse pregnancy outcomes[41, 42]. Maternal exposure to higher levels of atmospheric PM during pregnancy has been linked to low birth weight[43, 44, 45, 46], preterm delivery[47, 48, 49], stillbirths[50], and even birth defects[51, 52]. It is difficult to determine the size of this effect, given the inconsistencies between various studies in methods used to assess exposure, use of multiple size classifications of PM pollution ranging from $PM_{2.5}$ to PM_{10}, and total suspended particulates (TSP). However, a meta-analysis of multiple studies estimates a 9 percent increase in risk of low birth weight and a 15 percent increase in risk of preterm delivery for each 10 µg/m³ increase in $PM_{2.5}$[40].

An issue that remains to be clarified is identifying the most sensitive time during pregnancy for PM exposure, as the first, second, and third trimesters has each been implicated by different studies. In addition, some studies have been unable to completely exclude various confounding factors such as maternal smoking history and socio-economic status (which themselves markedly affect reproductive outcomes) in their analyses. Future studies also will have to address the mechanisms of these effects. For example, does PM (or any of its components) directly affect the fetus, or does exposure alter maternal cardiovascular and hormonal biology in such a way as to impact fetal development? A very recent study showed that PM_{10} exposure during the last trimester of pregnancy was associated with mitochondrial DNA damage within the placenta, suggesting that PM might disrupt the function of this important maternal-fetal interface[53].

What is the evidence for PM-dependent health effects within the PRETA region?

Table 1 summarizes some of the findings specifically relevant to health effects of PM within Pennsylvania and the PRETA region. Some of these can be characterized as simple **risk estimates**, findings that do not actually measure an effect or response but simply attempt to predict a risk based on measured PM levels within an area and applying the findings that have been determined in other studies from other areas (like those described above). Others are classified as **epidemiological studies** where both exposure estimates and health outcomes are directly obtained from within the PRETA region. Most are classified as a case crossover design in which the subjects are those who experience an episode of the health effect in question and associate the distribution of cases to level of PM pollution at the time of diagnosis. Because these simultaneously compare both PM exposure and disease incidence, they are considered the most robust, or representative, results. The last can be considered **anecdotal observations**, whereby interesting trends in disease are noted to emerge in an area known to have high levels of PM pollution. However, they do not substantiate a cause-and-effect relationship.

Most of the direct epidemiological studies conducted in the PRETA region have focused on hospitalization for various cardiovascular diseases and birth outcomes. Their results directly demonstrate that PM levels encountered in the PRETA region are often sufficient to produce adverse health effects and are very comparable to similar studies conducted in other regions of the country. Further research would be needed to directly demonstrate PM effects on premature mortality and other health outcomes within the PRETA region, although this is likely based on the weight of evidence collected from studies conducted in other areas. In addition, the poor ambient air quality is one factor among many that contribute to the alarming asthma burden in our area.

Table 1. Summary of evidence for PM-dependent health effects within the PRETA study area

MAJOR FINDING	TYPE OF STUDY	AREA/POPULATION	TIME PERIOD	SOURCE
CARDIOVASCULAR DISEASE				
1.3% increase in rate of hospitalization for congestive heart failure is associated with a 10 μg/m^3 increase in same-day PM_{10}.	Case Crossover Epidemiologic Study	Medicare recipients in Allegheny County hospitalized for heart failure	1987–99	Wellenius, G.A., Bateson, T.F., Mittleman, M.A., and Schwartz, J. (2005)[54]
0.6% increase in rate of hospitalization for any lung- or heart-related problem is associated with a 10 μg/m^3 increase in same-day PM_{10}.	Case Crossover Epidemiologic Study	Adults (>65 years) residing in Allegheny County hospitalized for cardiopulmonary disease	1995–2000	Arena, V.C., Mazumdar, S., Zborowski, J.V., Talbott, E., He, S., Chuang, Y., and Schwerha, J. (2006)[55]
PM_{10} levels were correlated with increased hospitalization for cardiovascular disease in the area of LTC Coke Works while it was operative. Closure of the plant reduced the risk of hospitalization.	Case Crossover Epidemiologic Study	Adults (>65 years) hospitalized for lung or heat disease residing in zip codes around the LTC Coke Works in Hazelwood; the plant closed in 1998	1996–2000	Xu, X., Zborowski, J.V., Arena, V.C., Rager, J., and Talbott, E.O. (2008)[56]
For people over the age of 30, 12% of deaths from heart attacks (1.1% of total mortality) were attributed to PM pollution.	Risk Estimate	Pittsburgh, Pa., urban area	2007	EPA. (2011).[57] EPA 452/R-11-003
ASTHMA				
$PM_{2.5}$ is associated with increased asthma emergency room visits up to one day after exposure.	Case Crossover Epidemiologic Study	6,979 people with a primary discharge diagnosis of asthma in Pittsburgh, Pa.	2002–05	Glad, J.A., Brink, L.A., Talbott, E.O., Lee, P.C., Xu, X., Saul, M., Rager, J. (2012)[33]
PM pollution accounts for approximately 5,000 premature deaths, 7,000 hospital admissions for lung disease, and 500,000 asthma attacks annually.	Risk Estimate	Commonwealth of Pennsylvania	2003	Madsen, T., and Willcox, N. (2006)[58]
Lifetime asthma prevalence for Pennsylvania adults (>18 years old) is approximately 13%, or about 1.2 million adults. For children <18 years old, it is approximately 15%, or about 427,500 children.	Survey Data	U.S. adults and children	2009	Centers for Disease Control and Prevention (2009)[59]
Children's Hospital of Pittsburgh experiences asthma-related emergency room visits and hospitalizations at 300–400% and 200–300%, respectively, above the national average.	Anecdotal Observation	Admissions to Children's Hospital of Pittsburgh of UPMC (Pennsylvania)	2009	Heinrichs, A. (2009)[60]
REPRODUCTIVE OUTCOMES				
Exposure to PM_{10} is associated with increase in number of low birth weight infants.	Cohort Study	Birth data from Allegheny County Health Department	1994–2000	Xu, X., Sharma, R.K., Talbott, E.O., Zborowski, J.V., Rager, J., Arena, V.C., Volz, C.D. (2011)[61]
First-trimester PM_{10} and ozone exposures were associated with blood pressure changes between the first 20 weeks of gestation and late pregnancy, most strongly in nonsmokers.	Cohort Epidemiologic Study	1,684 pregnant women in Allegheny County	1997–2001	Lee, P.C., Talbott, E.O., Roberts, J.M., Catov, J.M., Bilonick, R.A., Stone, R.A., Sharma, R.K., Ritz, B. (2012)[62]
Increased first-trimester exposure to $PM_{2.5}$ and ozone increased the risk of preeclampsia and gestational hypertension as well as preterm delivery and low birth weight.	Cohort Epidemiologic Study	34,705 births from Magee-Womens Hospital of UPMC (Pittsburgh, Pa.)	1997–2002	Lee, P.C., Roberts, J.M., Catov, J.M., Talbott, E.O., Ritz, B. (2012)[63]

Who is susceptible to PM exposure?

It is clear that those people living in environments characterized by high PM levels (such as communities near major point sources or certain occupational settings) will receive the greatest exposure and therefore are more vulnerable to adverse effects than those living in less polluted areas. Everyone is susceptible to PM pollution to some degree. However, some groups of people may be particularly sensitive to PM exposure, including children (less than 18 years of age) and the elderly (65 years of age or older). The World Health Organization has found that a child's vulnerability to air pollution is related to factors such as ongoing lung growth and development, incomplete metabolic systems, immature host defenses, and high rates of infections by airborne pathogens[64]. Children also are likely to be exposed to more outdoor particle pollution compared to adults because children breathe faster and more deeply for their size. They also are more likely to be outdoors during the warm summer months, when particulate pollution levels are highest in the PRETA region.

Recent epidemiological studies continue to show that older adults are at greater risk of non-accidental mortality associated with short-term exposure to both $PM_{2.5}$ and PM_{10} compared to younger individuals. Physiological sensitivity to PM pollution increases with advancing age due to longer cumulative exposures and decreased ability of lung tissues to repair themselves as well as the increased likelihood of preexisting cardiovascular and respiratory conditions. While older adults are most affected by the cardiovascular effects associated with short- and long-term $PM_{2.5}$ exposures, children show heightened responses for respiratory-related effects such as asthma exacerbation[40]. According to the latest census data, the elderly and children represent approximately 17 percent and 20 percent, respectively, of the 1.2 million residents of Allegheny County. A similar distribution exists for other counties in the PRETA area[65].

It is clear that PM exposure is especially problematic for those already afflicted by lung diseases such as asthma and chronic bronchitis as well as those with heart disease. PM most likely acts in concert with other known risk factors and aggravates preexisting conditions such as coronary artery disease, hypertension, and congestive heart failure. Thus, people who have been diagnosed with heart disease, hypertension, asthma, or other lung diseases should be especially mindful of places and time periods with high PM pollution. Personal susceptibility also can change based on environmental factors, social factors, and personal behaviors such as smoking and stress. Evidence suggests that children exposed to indoor tobacco smoke may be more vulnerable to outdoor pollutants[66]. People with diabetes demonstrate decreased vascular reactivity associated with exposures to PM pollution, especially sulfate particulates[67].

Children also are likely to be exposed to more outdoor particle pollution compared to adults because children breathe faster and more deeply for their size.

COMMON PM SOURCES

Where does PM come from?

Sources of PM can be man-made or natural. **Primary PM** is formed and directly emitted into the atmosphere usually through abrasive and combustion processes. Dust occurs naturally as well as during such activities as road construction or sandblasting. Ash and soot generated from the combustion of fossil fuels and forest fires are also sources of primary PM. Another important type of PM is **secondary PM**, which is formed when certain gaseous pollutants undergo physical changes such as condensation that allow them to form into small liquid droplets. The important **precursor pollutants** that give rise to secondary PM are gaseous compounds such as sulfur dioxide (SO_2), oxides of nitrogen (NO_X), and ammonia (NH_3). Once pollutants are released into the air, they can mix vertically and horizontally, becoming diluted by dispersion and the physical movement of air. Both primary and secondary pollutants can persist in the atmosphere and can travel long distances before settling to the earth's surface as solid particles or as chemicals dissolved in precipitation.

In order to understand how best to control PM exposure, it is meaningful to consider how and where PM is released and formed.

Outdoor sources of human-produced primary and secondary PM can include the following:

- Burning fossil fuels such as coal, charcoal, wood, heating oil, and natural gas
- Industrial processes such as metallurgy, mining, oil and gas production and refining, and chemical manufacturing
- Motor vehicle combustion emissions and road dust
- Construction operations
- Nonroad equipment
- Locomotives
- Marine vessels
- Agricultural practices

Natural or biogenic sources of PM can include:

- windblown dusts,
- wildfires,
- volcanoes, and
- water vapor.

Primary PM is emitted directly into the air from both stationary and mobile sources such as power plants, cars, trucks, and industrial processes. Particles also can form in the atmosphere (secondary PM) from precursor gases emitted into the air, such as oxides of nitrogen (NO_X), sulfur dioxide (SO_2), and ammonia (NH_3). Particles in the air also exist from natural sources such as forest fires, ocean spray, and volcanoes. Therefore, any ambient PM for any single place and time may contain matter from many sources.

MULTIPOLLUTANT EMISSIONS IN PENNSYLVANIA

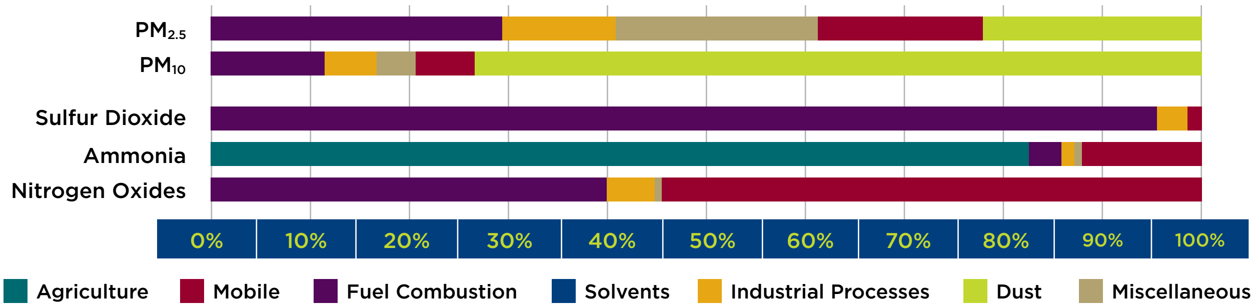


Figure 2. Major source types and activities that contribute emissions of primary particulates ($PM_{2.5}$ and PM_{10}) and precursor pollutants to secondary PM (sulfur dioxide, ammonia, and nitrogen oxides) in the state of Pennsylvania; data acquired from EPA 2008 National Emissions Inventory[68]

Seven source types sufficiently summarize the major sources of PM pollution emissions in Pennsylvania based on the 2008 emissions inventory[68]. The two largest pollution sources in Pennsylvania are motor vehicles and coal-fired power plants. Primary $PM_{2.5}$ originates mainly from five sources, the largest being fossil fuel combustion (30 percent), with fuel combustion by motor vehicles (mobile) contributing another 15 percent. PM_{10}, on the other hand, is much more dominated by dust sources. With regard to the precursors of secondary PM, mobile sources account for approximately 50 percent of nitrogen oxides, whereas sulfur dioxide is almost exclusively produced by coal combustion used primarily for the generation of electric power.

What are the sources of PM within the PRETA region?

SOURCES OF PRIMARY PM IN THE PRETA REGION

Based on the National Emissions Inventory administered by EPA, total primary emissions of $PM_{2.5}$ in 2008 amounted to approximately 55,788 tons across the entire 10-county PRETA region and just more than 8,000 tons for Allegheny County alone[68]. These emissions volumes are predominately self-reported by the individual facilities and, in some cases, are estimated by state and local agencies. Such estimates are based on sampling during normal operating conditions, computer modeling, and use of industry-specific emission factors. Emission factors are an attempt to relate the quantity of a pollutant released to a specific activity associated with the release of the pollutant. Hence, the actual release may be more or less than the estimate. Thus, this approach has certain inherent limitations and bias. The Allegheny County Health Department (ACHD) oversees the emissions estimates and reports to EPA for sources within Allegheny County, while the Pennsylvania Department of Environmental Protection (DEP) oversees the other counties within the PRETA region. Figure 3 shows the distribution of $PM_{2.5}$ released across various sectors for the PRETA region as a whole.

Within the PRETA region, the predominant source of PM is from electrical generation units, which are dominated by coal-fired power plants (65 percent). The majority is driven by the three largest emitters in the PRETA region. These electric power plants include the Hatfield's Ferry Power Station (Greene County), the Keystone Station (Armstrong County), and the Homer City Station (Indiana County). Together, these constitute 3/4 of the PM derived from electrical generation. No other single source over the entire area contributes more than 10 percent of the total.

Allegheny County, like other counties that do not have large electrical energy generation facilities, has a relatively diverse composition of PM sources (Figure 4). The largest aggregated source is industrial processing (22 percent of total emissions), including coke battery production, steel mills, metals processing, and chemical manufacturing. Examples include the Clairton Coke Works; Shenango, Inc.; and the Edgar Thompson Works. The second most common source of PM in Allegheny County is residential fuel consumption for heating. Interestingly, burning of wood (fireplaces, wood stoves, etc.) contributes the vast majority of this source (1,600 tons) compared with less than 20 tons from the use of gas or oil heat. Although dust emissions are considered separately from direct mobile combustion emissions, most dust stems from on-road and off-road traffic/construction activities. When all these sources are considered collectively, this aggregation would constitute up to approximately 30 percent of PM emissions in the county.

$PM_{2.5}$ EMISSIONS BY SECTOR, PRETA 2008

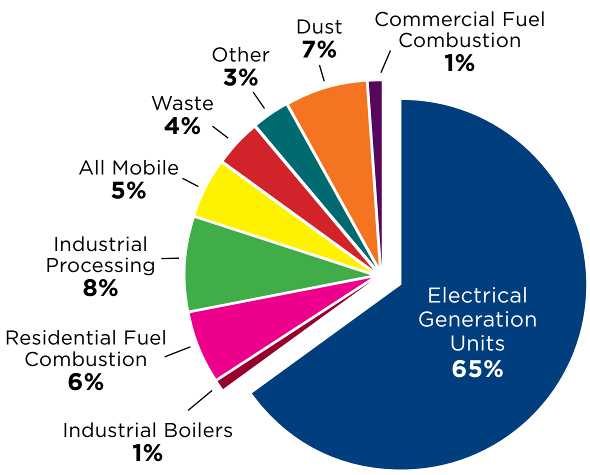


Figure 3. Sources of $PM_{2.5}$ emissions in the 10-county PRETA region for 2008 from the National Emissions Inventory v. 2.0[68]

$PM_{2.5}$ EMISSIONS BY SECTOR, ALLEGHENY COUNTY 2008

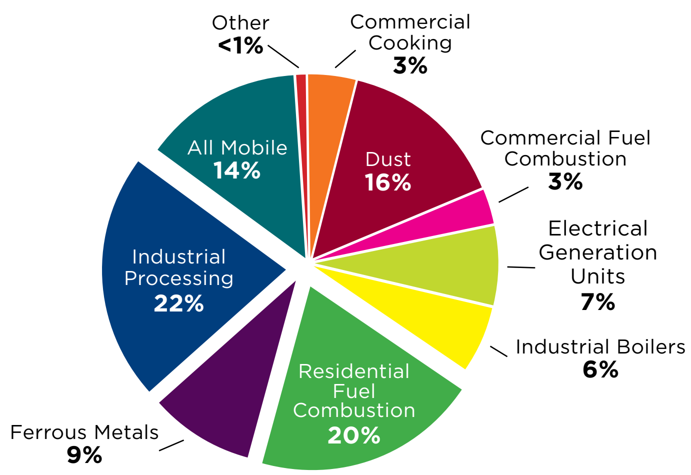


Figure 4. Sources of $PM_{2.5}$ emissions in Allegheny County for 2008 from the National Emissions Inventory v. 2.0[68]

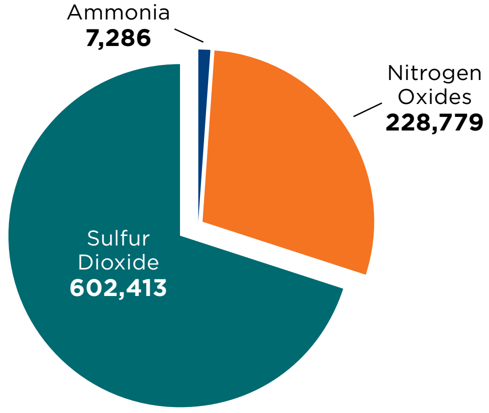
SOURCES OF SECONDARY PM IN THE PRETA REGION

Research from the Pittsburgh Air Quality Study compared secondary and primary contributions to $PM_{2.5}$ in the Pittsburgh area and has demonstrated that $PM_{2.5}$ concentrations are dominated by secondary source emissions (secondary PM), especially on high concentration days[69]. Because secondary PM takes considerable time to form in the atmosphere, this could mean that the ultimate source of the PM emission may be located some distance away. Formation of secondary PM within the PRETA area may involve precursors emitted outside the PRETA region. According to the Pittsburgh study, sources of primary PM showed very little contribution to the ambient $PM_{2.5}$ fraction in the summer and slightly more in the nonsummer months[70]. However, this referenced data set was collected more than 10 years ago. Current ambient air sampling (2011–12) and analysis to be performed by the University of Pittsburgh Graduate School of Public Health should provide an updated source apportionment profile as well as improved spatial coverage in the near future.

Figure 5 shows the 2008 emissions of the major secondary PM precursor chemicals within the 10-county PRETA region. The estimated emissions of secondary PM precursors within the region in 2008 totaled more than 800,000 tons. This includes all sources from cars and trucks, industry, waste disposal, and agriculture. Sulfur dioxide emissions were the largest contributor, representing nearly 75 percent of total PM precursors in 2008. SO_2 has a greater potential to produce secondary PM compared to oxides of nitrogen. In addition, because sulfur is heavier than nitrogen, an equal number of sulfate particulates will contribute a greater mass than the same number of particulates generated from NO_X; hence, SO_2-derived particulates will likely represent close to 90 percent of the mass of secondary PM found within the PRETA region. The SO_2 monitor located in Liberty (see p. 14) exceeded the new one-hour National Ambient Air Quality Standards (NAAQS) 75 ppb standard 53 times in 2011, and a maximum value of 450 ppb was recorded[71].

Within the PRETA region, the predominant source of PM is from electrical generation units, which are dominated by coal-fired power plants (65 percent).

SECONDARY PM EMISSIONS, PRETA 2008



Total Secondary PM Emissions = **838,478 tons**

Figure 5. This represents the total 2008 emissions of secondary PM precursor chemicals (in tons) by sources within the 10-county PRETA region. Data include both point and mobile sources (EPA National Emissions Inventory[68]).

Numerous point sources of sulfur dioxides exist in both rural areas and cities across the PRETA region as well as in surrounding states, as indicated by the many colored symbols in Figures 6 and 7. Smaller point sources of less than 500 tons (emitted in 2008), shown by blue dots, cluster in and around urban areas like Philadelphia and Pittsburgh, Pa.; Washington, D.C.; Baltimore, Md.; Cleveland, Columbus, and Cincinnati, Ohio. Major point sources of SO_2 do not cluster in populated areas but are instead predominantly located in rural areas and near major waterways like the Monongahela and Ohio rivers and Chesapeake Bay. Three of the five largest SO_2 emitters are within the 10-county area of southwestern Pennsylvania. Many other sources exist upwind of the PRETA region throughout the Ohio River Valley and the Midwest. Coal-fired power plants are by far the single largest contributor of SO_2 pollution, accounting for 67 percent nationwide.

POINT SOURCES OF SULFUR DIOXIDE

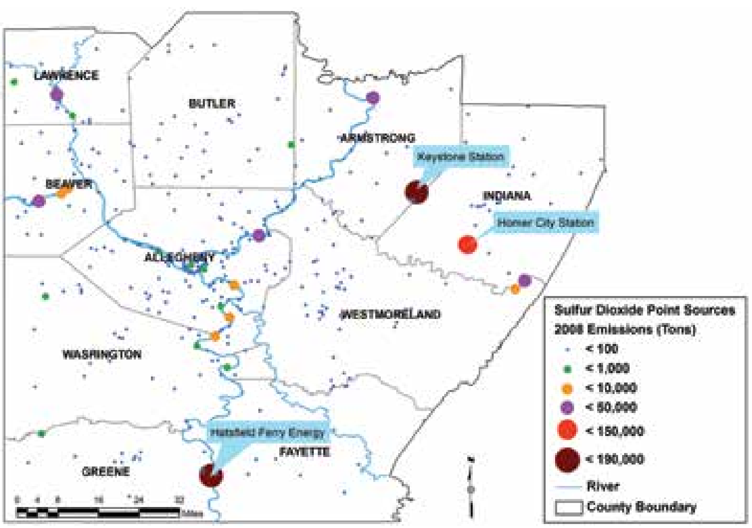


Figure 6. Locations of all sulfur dioxide (SO_2) emissions within the 10-county PRETA area in 2008

WHAT DO THESE MAPS TELL US?

The largest SO_2 emitters in both the PRETA and four-state regions are coal-fired power plants, located in rural areas near large bodies of water. Many smaller SO_2 point sources are centered in densely populated urban areas. These sources contribute to regional secondary PM pollution, particularly in downwind communities.

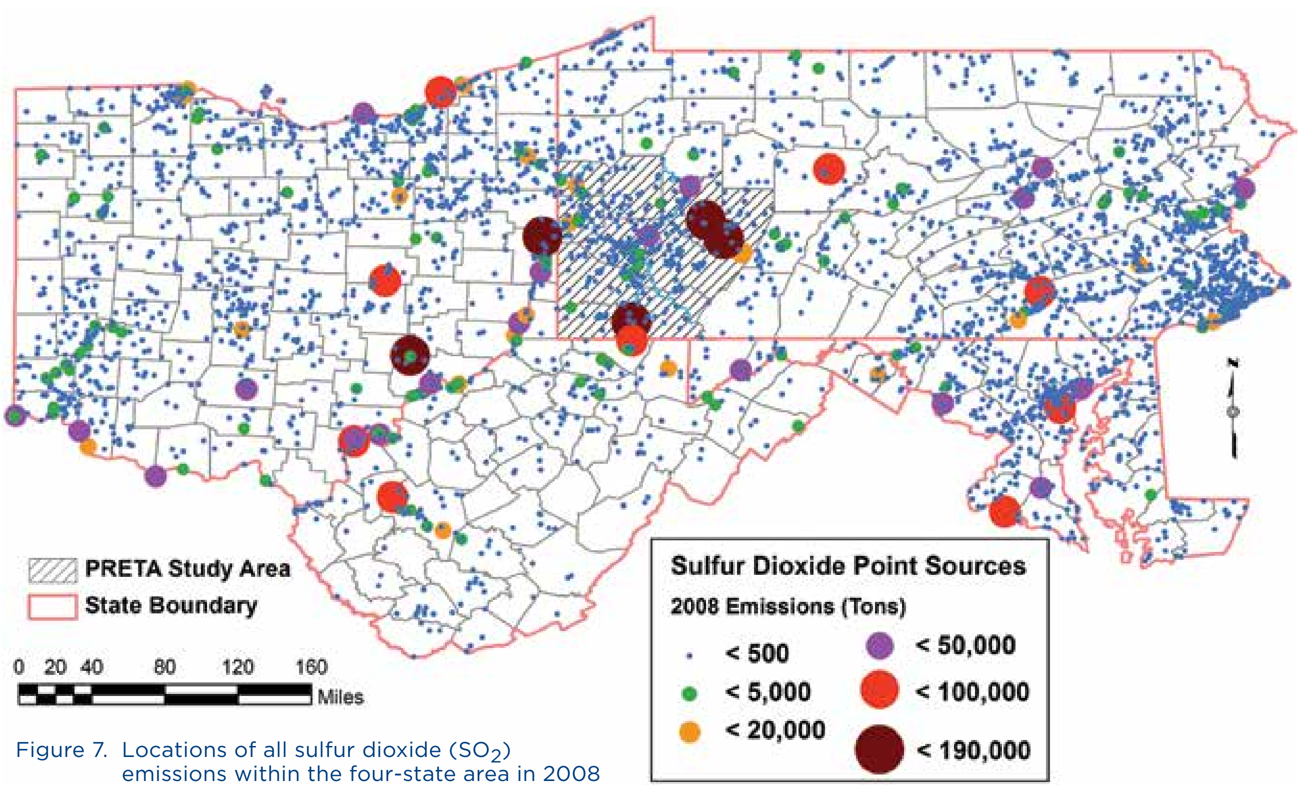


Figure 7. Locations of all sulfur dioxide (SO_2) emissions within the four-state area in 2008

According to EPA's emissions tracking system of the top 50 SO_2 emitters in the United States, both Ohio and Pennsylvania lead the list with eight power plants each.

According to EPA's emissions tracking system of the top 50 SO_2 emitters in the United States, both Ohio and Pennsylvania lead the list with eight power plants each[a]. Reliant Energy's Keystone Station plant in Indiana County was ranked as the second-largest emitter of SO_2 in the nation in 2006. Both the Keystone and Hatfield's Ferry stations installed desulfurization controls in 2009, significantly reducing their emissions of SO_2 and primary particulates. The Homer City Station is currently the largest stationary source of SO_2 in the four-state region, emitting almost 113,000 tons in 2010. From 2000 to 2009, sulfur dioxide emissions in the PRETA region fell only 10 percent compared to 30 percent from all other facilities in Pennsylvania, Ohio, and West Virginia and 16.7 percent nationally.

PM FROM MOBILE SOURCES IN THE PRETA REGION

Primary and secondary PM also can arise from mobile emission sources such as cars, trucks, buses, airplanes, and barges. Including dusts from on- and nonroad sources, approximately 2,400 tons of PM were emitted from mobile sources in the PRETA region in 2008. Emissions from mobile sources vary by engine technology, engine condition, driving patterns, and fuel specifications[72], and PM emissions from gasoline engines have dropped significantly with the widespread use of catalytic converters and other technology. Diesel emissions, however, remain a persistent problem. Because diesel exhaust is released at ground level, frequently in highly populated areas, there is an increased risk of human exposure compared to pollutants released from industrial smokestacks. Diesel engine exhaust is composed of a gas and a particle phase, the latter composed mostly of organic carbon particles that can absorb metals, polycyclic aromatic hydrocarbons, and other toxic chemicals. The gas phase also contains such toxic chemicals as benzene, formaldehyde, and acrolein. Human and laboratory studies provide substantial evidence establishing diesel particulate matter (DPM) as a carcinogen[73]. When determining whether or not an environmental factor poses a significant risk of cancer, EPA uses a threshold level of "one-in-a-million" probability of lifetime cancer risk above which EPA deems unacceptable. Nationwide, diesel pollution has a cancer risk that exceeds this threshold by approximately 200-fold.

Table 2 shows an annual regional mobile source inventory for estimated emissions of $PM_{2.5}$, PM_{10}, and NO_X by on-road vehicles for the year 2009 for all on-road vehicular traffic within an eight-county PRETA region. (Fayette and Indiana counties are omitted[b]). $PM_{2.5}$ and PM_{10} represent primary particulates, while NO_X represents the major precursor pollutant for secondary PM released by vehicular traffic. Estimates are based

[b] Because these counties are in attainment of the NAAQS standards, no state implementation plan is in place for these areas and, hence, data are unavailable.

on approximations of both diesel and nondiesel vehicle miles traveled (VMT) obtained from traffic counts taken from a network of permanent and in-pavement automatic recorder locations maintained by the Pennsylvania Department of Transportation and EPA's MOBILE6.3 emission modeling program. Estimates in Table 2 include all types of on-road vehicles, from light-duty gasoline vehicles and motorcycles to heavy-duty diesel trucks and buses. Total emissions values for all vehicular traffic are shown in black, with the percent contribution from diesel sources highlighted in red.

Table 2. Estimated on-road mobile source (vehicular) emissions of primary and secondary (NO_X) PM for eight counties within the PRETA region for 2009

COUNTY	VMT[a] (% DIESEL) {in millions of miles}	GROWTH FROM 2002 {in %}[b]	$PM_{2.5}$ (% DIESEL) {in tons}	PM_{10} (% DIESEL) {in tons}	NO_x (% DIESEL) {in tons}
ALLEGHENY	10,037.2 (4.8%)	9.2	224 (43%)	390 (52%)	12,111 (38%)
ARMSTRONG	57.6 (11.3%)	35.2	2 (64%)	3 (78%)	112 (50%)
BEAVER	1,611.5 (5.9%)	9.4	40 (48%)	67 (59%)	2,255 (42%)
BUTLER	1,921.9 (7.1%)	13.1	52 (53%)	85 (64%)	3,058 (46%)
GREENE	24.5 (6.2%)	10.6	0.6 (47%)	1 (58%)	35 (34%)
LAWRENCE	31.9 (6.6%)	13.1	0.8 (50%)	1 (62%)	51 (34%)
WASHINGTON	2,736.5 (7.8%)	20.1	78 (55%)	126 (67%)	4,665 (52%)
WESTMORELAND	3,844.8 (7.9%)	7.2	111 (55%)	178 (67%)	6,451 (52%)
TOTAL PITTSBURGH-BEAVER VALLEY	**20,266.1 (6.1%)**	**14.7[c]**	**509 (49%)**	**852 (59.1%)**	**28,739 (44.6%)**

[a]Vehicle miles traveled
[b]Growth of VMT represents percent increase for 2009 compared to 2002.
[c]Average percent growth of all eight counties

Of all PRETA counties, Allegheny County had boasted the most miles traveled in 2009, with more than 10 billion estimated miles on major and minor roadways. Westmoreland and Washington counties rounded out the top three counties, with approximately 3/4 of the estimated 20 billion miles traveled in the entire region. These trends reflect the location of the major urban centers within the area as well as the location of interstate highways and other major thoroughfares. All eight counties showed percent increases in vehicle miles traveled, with an almost 15 percent overall increase in 2009 compared to 2002. Armstrong and Washington counties had the largest growth at 35 percent and 20 percent, respectively. Factors in this growth are such things as urban sprawl, new highway construction, growing population, and increased truck traffic from such operations as natural gas drilling. Increasing trends of vehicle miles traveled indicate that on-road pollutant emissions have increased across the region over the last decade. If such growth continues, then it is likely that mobile PM emissions will become a larger contributing source to PM in the future.

As expected, VMT correlate to the volume of pollutant emissions for the respective counties. Along with direct $PM_{2.5}$ and PM_{10} emissions, NO_X and other precursor chemicals contribute to PM in the ambient air through secondary formation, therefore making mobile emissions a significant contributor to PM pollution within the PRETA region. It is striking that although diesel vehicles make up only a small percentage of the total traffic throughout the region (<10 percent), they account for about half of the primary mobile PM emissions as well as mobile NO_X. From these 2009 estimates, it is clear that mobile diesel vehicles contribute substantially more to pollution emissions compared to all gasoline vehicles even though gasoline vehicles make up more than 90 percent of the miles traveled in the region. The diesel construction vehicle retrofit legislation passed on July 12, 2011, by Pittsburgh City Council as well as the commonwealth's Diesel-powered Motor Vehicle Idling Act (Act 124 of 2008)[74] are laudable responses that help to address a major air pollution factor. It will be important, however, to determine their effectiveness by documenting the decrease in diesel exhaust pollution over the coming years.

According to the recent Pittsburgh Air Toxics Study conducted by Carnegie Mellon University, DPM was the greatest contributor of cancer risk in Allegheny County of the 65 air toxics studied[75], though only limited data were available for the DPM levels in the county. The University of Pittsburgh and the Allegheny County Health Department are currently collaborating to investigate the spatial variation of air pollutants, including diesel concentrations, in downtown Pittsburgh. Based on the measured concentrations of DPM on location, the cancer risk attributed to diesel in downtown Pittsburgh is one in 1,000 for an individual lifetime estimate. According to the Carnegie Mellon study, this risk is "well above typical regulatory thresholds for environmental pollutants"[76]. Reducing DPM exposures should be given the highest priority because the risk is comparable to that of a car accident. The downtown Pittsburgh area was identified as a DPM "hot spot," with levels three to four times greater than other areas of the country. DPM also is the greatest driver of cancer risk in other areas of Allegheny County, even though DPM levels are lower outside the county than in downtown Pittsburgh. Of note also is the fact that estimates of the total $PM_{2.5}$ and PM_{10} emitted by off-road vehicles and engines (off-road vehicles, construction equipment, lawn mowers, farm machinery, river barge traffic, etc.) are, in fact, about 2.2 and 1.4 times greater, respectively, than those seen from on-road sources. This likely reflects the fact that a greater majority of these nonroad sources are diesel powered and/or lack pollution control technology present in on-road vehicles.

It is striking that although diesel vehicles make up only a small percentage of the total traffic throughout the region (<10 percent), they account for about half of the primary mobile PM emissions as well as mobile NO_X.

REGULATORY STANDARDS FOR PM

PM is one of six criteria air pollutants for which National Ambient Air Quality Standards (NAAQS) have been established by EPA under authority of the federal Clean Air Act (CAA) of 1963. Guided by CAA, EPA must review the standards every five years and adjust them based on the current scientific research and an understanding of what levels protect human health with an appropriate margin of safety[76], although, in reality, reviews are less frequent than prescribed. As one might imagine, this process can be subject to debate and some degree of subjective interpretation. It is currently achieved by a two-step process in which consensus-based recommendations are first put forth by the Clean Air Scientific Advisory Committee (CASAC), which is composed of independent, knowledgeable, and impartial scientists and other experts. These recommendations are not binding, as final EPA implementations of risk management include consideration of cost-benefit ratios and other factors. The situation is further complicated by PM, because a threshold level below which adverse effects are absent has not been established. The 24-hour $PM_{2.5}$ standard was revised on October 17, 2006, when it was strengthened from 65 µg/m³ to 35 µg/m³. The new 24-hour standard was lowered based on numerous health studies that showed an association among short-term $PM_{2.5}$ exposure and increased mortality, aggravation of lung disease, asthma attacks, and heart-related health effects. The annual $PM_{2.5}$ standard was last revised in 1997 to 15 µg/m³.

As shown in Table 3, EPA monitors and regulates both the PM_{10} and $PM_{2.5}$ particle sizes; however, because most of the adverse health effects appear to be associated with the smaller-sized particles, the $PM_{2.5}$ standard receives the most attention. The measured PM concentrations are averaged over two time periods: one year and 24 hours. This is done to capture a snapshot of what PM levels look like over a prolonged period of time as well as the number of short-term "peaks." However, newly published research suggests that adverse health effects may be occurring even with very short intervals of high exposures on the scale of a few hours, suggesting that subdaily or hourly averages are important exposure periods to consider as well[32]. The annual standards are set lower than the 24-hour values because a reciprocal relationship is assumed between PM concentration and duration of exposure with regard to risk. In other words, the incidence and/or severity of a toxic effect depends on the total exposure to an agent, which is an integrated function between level and duration of exposure[79]. Due to a lack of evidence linking health problems to long-term exposure to coarse particle pollution, the agency revoked the annual PM_{10} standard in 2006. However, because air pollution has been a persistent problem in southwestern Pennsylvania, Allegheny County continues to maintain a PM_{10} standard averaged over an eight-hour time span.

More recently, both EPA staff and CASAC have concluded that the "currently available information clearly calls into question the adequacy of the current 15 µg/m³ standard"[80]. More than 2,000 studies have been published on PM pollution since the previous standard-setting review in 1997[81, 82]. More than 50 of those published since 2006 have been used as evidence in favor of setting more stringent standards in the most recent policy review for PM regulations[57]. CASAC recommended new limits for $PM_{2.5}$ to include a lowering of the annual standard to between 13 and 11 µg/m³, and a 24-hour standard of 30 µg/m³. On December 14, 2012, EPA revised the National Ambient Air Quality Standards for $PM_{2.5}$. The annual standard was made more stringent from 15 µg/m³ to 12 µg/m³ [83]. The existing 24-hour $PM_{2.5}$

Table 3. EPA National Ambient Air Quality Standards (NAAQS) and Allegheny County standards for atmospheric particulate matter (PM). These standards do not reflect the recent revisions signed on December 14th (12 µg/m³ $PM_{2.5}$ annual standard).

POLLUTANT	AGENCY	AVERAGE TIME	STANDARD
PM_{10}	EPA[77]	1 year	NA
		24 hours	150 µg/m³
	Allegheny County[78]	8 hours	450 µg/m³
$PM_{2.5}$	EPA[77]	1 year	15 µg/m³
		24 hours	35 µg/m³

standard and the PM_{10} standard were not updated in this revision. The majority of this document was formulated prior to this revision, and attainment/nonattainment designations are not expected to occur until 2015, though the majority of the PRETA region is not in attainment of an annual 12 µg/m^3 ambient standard[84].

MEETING CURRENT STANDARDS NATIONWIDE

To determine an attainment or nonattainment designation, the concentrations at each EPA monitor are averaged over a three-year period to obtain what is called a **design value**. The annual design value for $PM_{2.5}$ is calculated as a mean of the annual average ambient concentration at a monitor for three consecutive years. The 24-hour design value is calculated by averaging the 98th percentile concentrations over 24-hour periods at each monitor. In other words, the third highest concentration recorded out of 100 monitoring readings over a 24-hour period is recorded at each monitor and those values are averaged over three years to obtain the regulatory design value. When a specific design value exceeds that of the corresponding regulatory standard, then that area is classified as being in **nonattainment** of the standard.

On November 13, 2009, EPA published its most recent listing of nonattainment designations for the $PM_{2.5}$ 24-hour and annual standards. Nonattainment areas in the United States (shown in Figure 8) include 120 counties (89 total counties and partial areas within 31 counties) located in 18 different states, including Pennsylvania, West Virginia, Ohio, and Maryland. The designations were based on air quality monitoring data for 2006–08. Though the number of total counties and areas in nonattainment is small in comparison to the entire United States (see Figure 8), these areas tend to be densely populated. Approximately 70 million people, or just less than 25 percent of the U.S. population, live in the 120 counties designated to be in nonattainment for the 2006 $PM_{2.5}$ NAAQS[85].

EPA DESIGNATED NONATTAINMENT AREAS FOR $PM_{2.5}$ STANDARDS

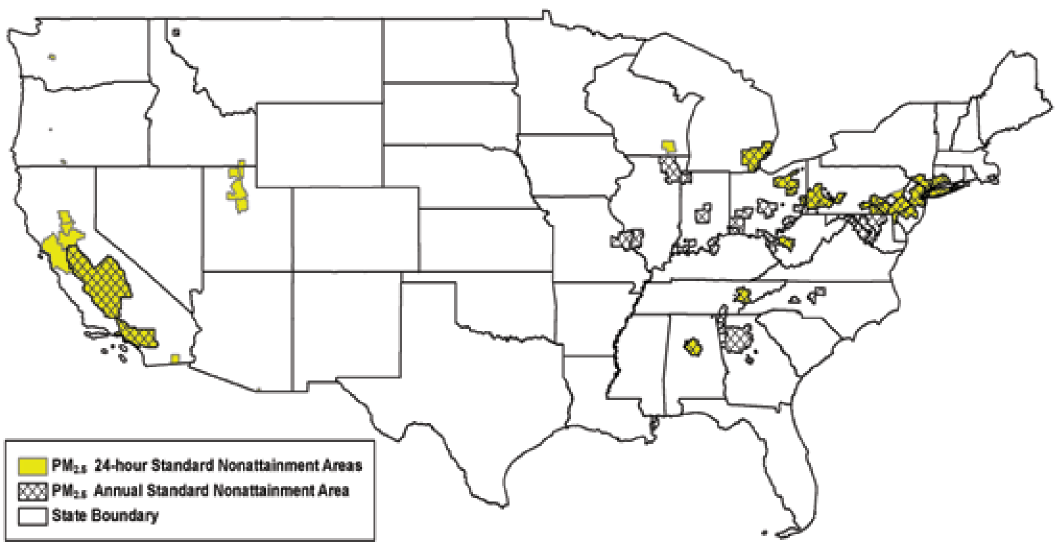


Figure 8. $PM_{2.5}$ 24-hour and annual standard nonattainment areas throughout the United States based on air monitoring data from 2006

WHAT DOES THIS MAP SHOW?

The yellow portions of the map represent the areas that did not meet the health-based 24-hour standard for $PM_{2.5}$ in 2006–08. The cross-hatched areas represent nonattainment areas under the annual $PM_{2.5}$ standard of 15 µg/m^3. The majority of these areas are present in major cities and urban areas of dense population. Large portions of California, Ohio, Pennsylvania, Maryland, and New Jersey remain in nonattainment for the health-based $PM_{2.5}$ standards.

Are the regulatory standards met in the PRETA region?

Nine of the 10 counties in the PRETA region are considered completely or partially in nonattainment of the federal health-based ambient air standards for both the annual and 24-hour $PM_{2.5}$ standards (Fayette County is the exception). The Pittsburgh/Beaver Valley $PM_{2.5}$ Nonattainment Area includes the counties of Allegheny, Beaver, Butler, Washington, and Westmoreland and portions of Armstrong, Greene, and Lawrence counties. Five municipalities near the Clairton Coke Works within Allegheny County are designated as a separate nonattainment area named the Liberty/Clairton $PM_{2.5}$ Nonattainment Area. This separate designation was implemented because this area possesses a unique and localized air quality problem arising from a local source of heavy air pollution (the Clairton Coke Works and the Edgar Thompson Steel Works) and is confined in a narrow river valley. This in effect creates two air basins of concern for monitoring within the PRETA area: the small area of Allegheny County downwind of US Steel's Clairton Coke Works that includes Clairton, Liberty, Port Vue, Glassport, and Lincoln and the much larger seven-county Pittsburgh/Beaver Consolidated Metropolitan Area. Specific areas of nonattainment in the latter include Elderton Borough and Plumcreek and Washington townships (Armstrong County), Monongahela Township (Greene County), and Taylor Township (Lawrence County). Other specific areas of concern, however, may go unrecognized because of limited number of air monitors and their placements.

NONATTAINMENT AREAS FOR $PM_{2.5}$ STANDARDS IN PENNSYLVANIA, MARYLAND, OHIO, AND WEST VIRGINIA

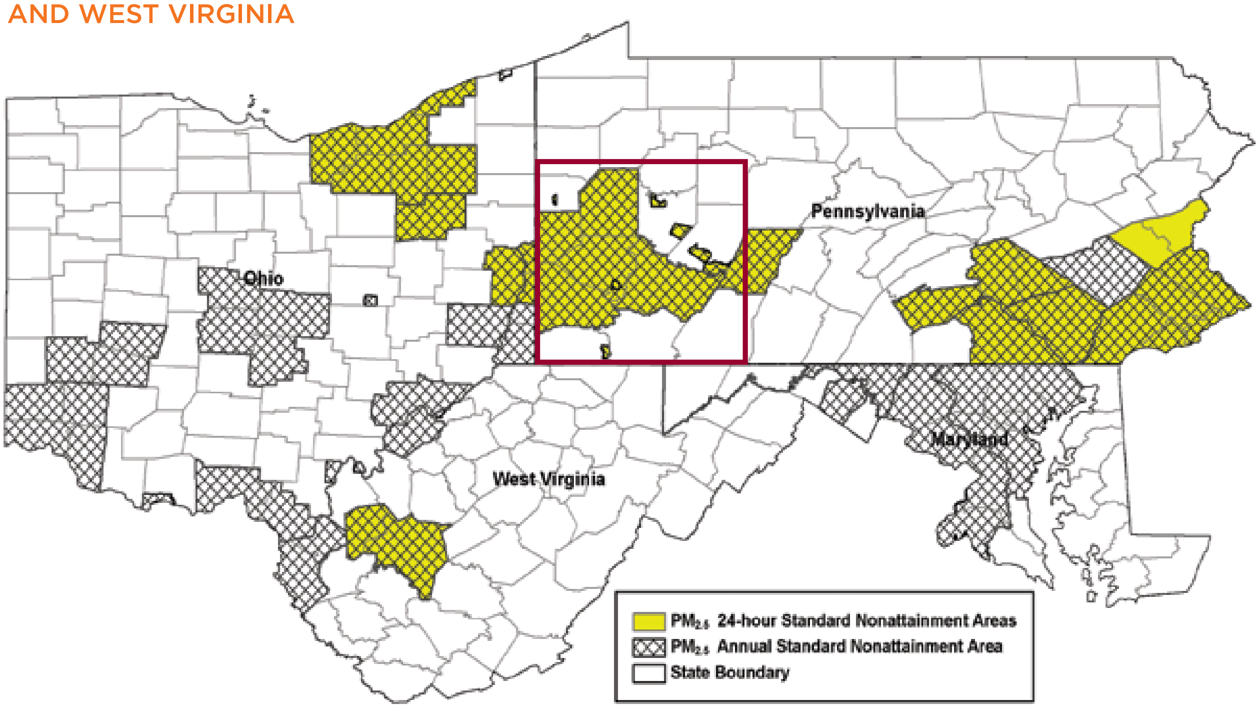


Figure 9. This represents $PM_{2.5}$ 24-hour and annual standard nonattainment areas throughout Pennsylvania, Ohio, Maryland, and West Virginia based on air monitoring data from 2006. The red outlined box approximates the 10-county PRETA region.

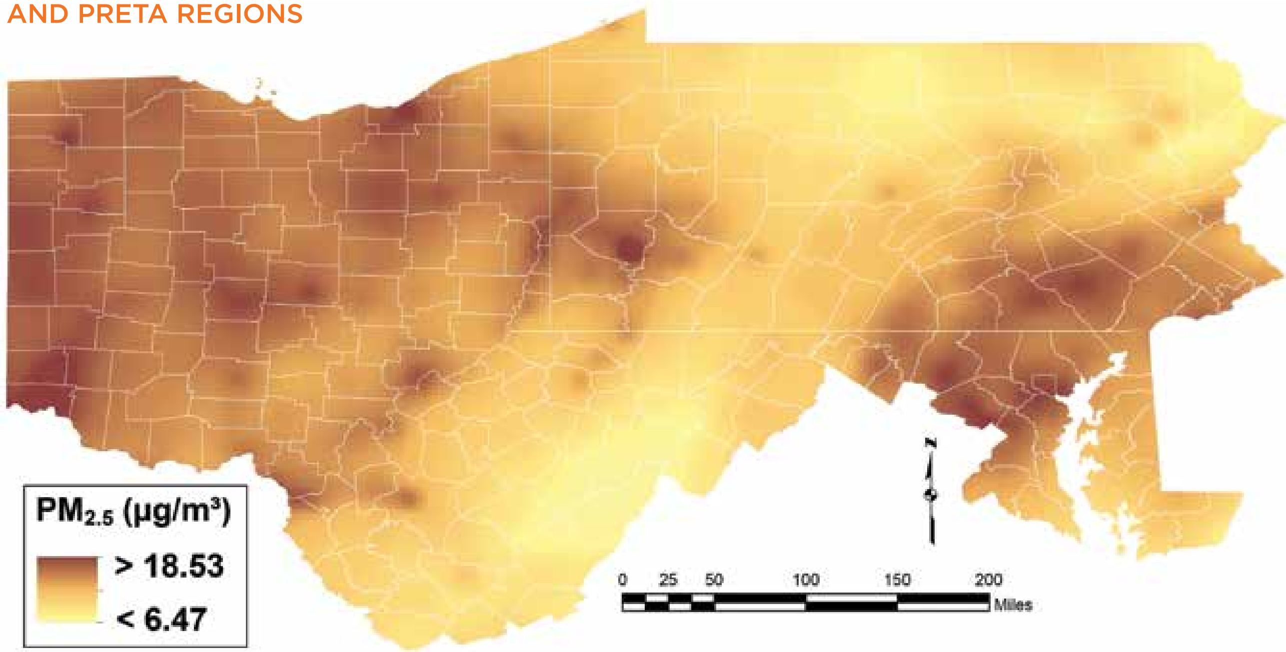
WHAT DOES THIS MAP SHOW?

A closer look at the areas of nonattainment for PM within the PRETA region from Figure 8 shows that many millions of people live in areas of unhealthy air. Nine of the 10 counties in the PRETA region are designated as whole or partial nonattainment areas for both annual and 24-hour $PM_{2.5}$ standards. This four-state view also highlights the nonattainment areas directly upwind of southwestern Pennsylvania in Ohio and West Virginia.

MONITORING PM LEVELS

The goals of ambient air monitoring are to evaluate attainment of national and state air quality standards and provide real-time monitoring data of pollution episodes and trends in air quality. EPA provides this information to the public on a daily basis by publishing the Air Quality Index. Federal, state, and other regulatory agencies also use this information to track changes in air quality, gauge remedial measures, and refine future standards. Because the region has historically experienced poor air quality and is densely populated, the state and federal governments require a relatively extensive air monitoring network for PM. Some of the first air pollution monitors were designed in Pittsburgh, and some of the earliest researchers and institutions committed to monitoring the air originated in the area[86].

ESTIMATES OF AMBIENT $PM_{2.5}$ CONCENTRATIONS FOR THE FOUR-STATE AND PRETA REGIONS



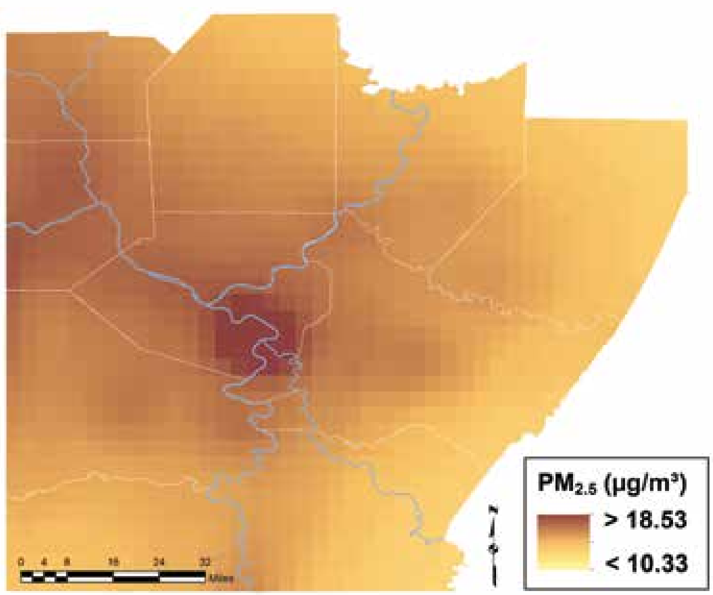


Figure 10. Estimated 2005 annual $PM_{2.5}$ concentrations in the four-state region (Pennsylvania, Ohio, West Virginia, and Maryland; top panel) and the 10-county PRETA region (bottom panel). Data were obtained from EPA's Hierarchical Bayesian Model-derived Estimates of Air Quality for 2005.

WHAT DO THESE MAPS TELL US?

The highest ambient levels of $PM_{2.5}$, estimated by daily average concentrations, occur throughout Ohio and in northern parts of West Virginia, southwestern Pennsylvania (including Pittsburgh), southeastern Pennsylvania (including Philadelphia), and central Maryland (including Baltimore and Washington D.C.). These areas tend to be densely populated urban areas and heavy industrial sites. Ambient levels are also influenced by weather patterns and the geographic landscape, such as river valleys.

Figure 10 shows the 2005 estimated average ambient air concentrations of $PM_{2.5}$ across the greater four-state region (top panel) as well as the PRETA area (bottom panel). These data were obtained from EPA's Estimates of Air Quality and represent the estimated average daily concentration of PM over a broad area based on data collected from air monitors (see Figure 11 below) and predictions as to how PM will disperse in the atmosphere. Dark brown colors indicate higher particle pollution, while light brown to yellow areas indicate progressively lower concentrations. Notably, these estimates do not reflect short-term spikes in PM levels that can arise from changes in source activities or specific weather patterns that cause PM levels to rise.

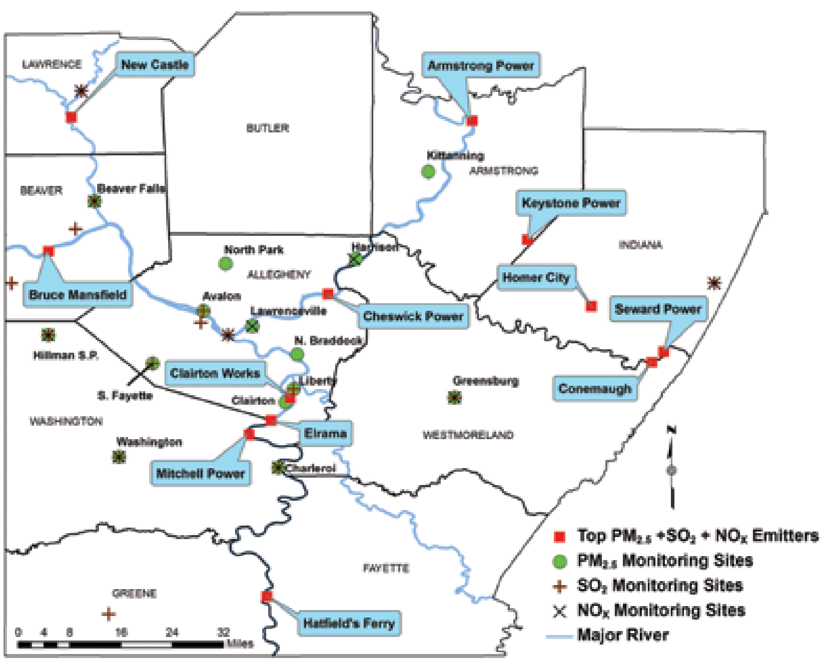
The highest levels of $PM_{2.5}$ pollution appear throughout most of Ohio, northern parts of West Virginia, southwestern Pennsylvania (including Pittsburgh), southeastern Pennsylvania (including Philadelphia), and central Maryland (including Baltimore and Washington, D.C.). The majority of West Virginia and central and northern Pennsylvania contain relatively lower average $PM_{2.5}$ concentrations. Within the 10-county PRETA region, the highest $PM_{2.5}$ levels in 2005 were estimated to be southwest of downtown Pittsburgh, in the Monongahela River Valley centered between West Mifflin and Port Vue.

The region of highest PM within the PRETA region centers on several heavy industrial sites, such as the Clairton Coke Works and Edgar Thompson Steel Works, long known as contributing to high levels of PM pollution in the area. The specific communities within this area include Liberty, Glassport, Clairton, Pleasant Hills, McKeesport, Munhall, Homestead, Versailles, East Pittsburgh, Braddock, Braddock Hills, Chalfant, Forest Hills, Rankin, Swissvale, Glenwood, Hazelwood, and Greenfield. Although PM levels are not as severe as seen in the Liberty/Clairton area, other areas within the PRETA region also show notable levels of PM—including central Westmoreland County, regions of Washington County, much of Allegheny County, and sections along the Ohio River corridor to the northwest—compared to other areas in the PRETA region. Reasons for this uneven distribution throughout the PRETA region deserve further study in terms of geographic and demographic factors and the location of potentially contributing point/mobile sources.

Where are the air monitors located within the PRETA region?

The locations of the PM air monitoring stations in the PRETA area are shown in Figure 11. The PRETA area contains 14 air monitoring stations capable of assessing primary PM. Regarding

MAJOR PM AND PM PRECURSOR POINT SOURCES AND AMBIENT AIR MONITORS



WHAT DOES THIS MAP TELL US?

Monitors are not always placed in the most effective locations for estimating exposures to PM and monitoring PM and PM precursors. The majority of monitors are located in the densely populated Allegheny County, while few monitors are located in rural areas and counties that contain some of the largest point sources of PM and SO_2.

Figure 11. Proximity of ambient monitoring stations to the top point source emitters of PM, SO_2, and NO_X

Because of their small size, PM can remain airborne for long periods of time and can travel extended distances from their point of origin.

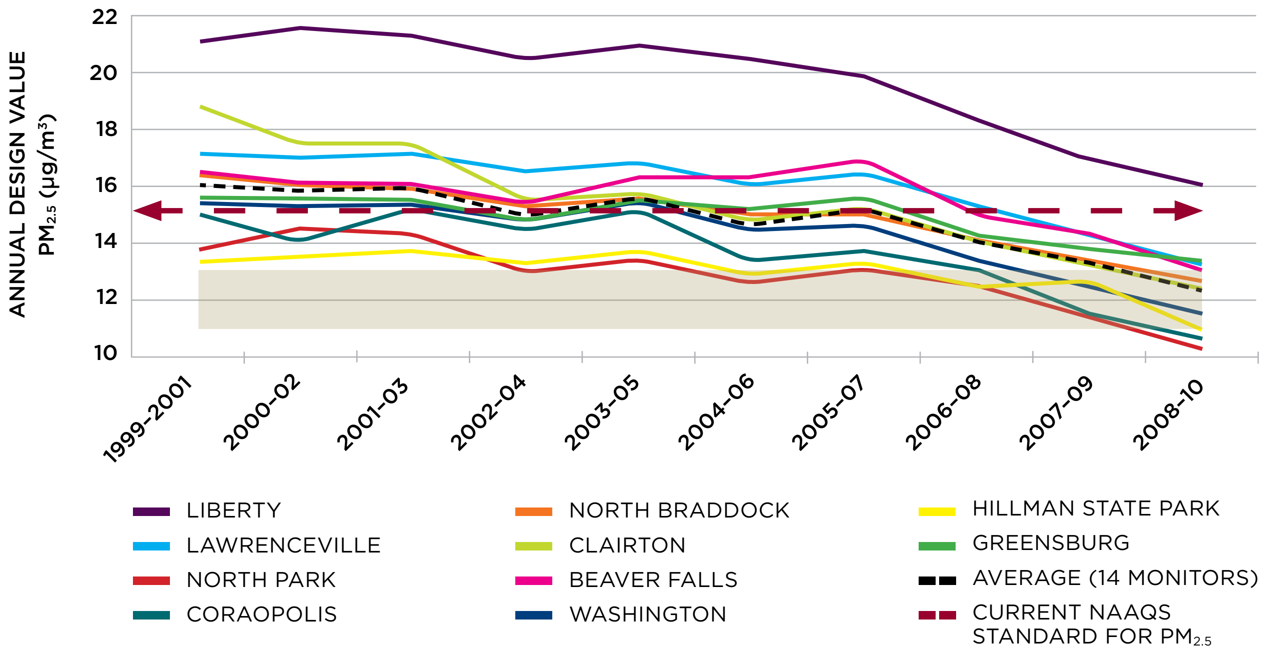
precursors to secondary PM, 15 stations monitor SO_2 and 10 stations monitor NO_X. Because population density is one factor determining monitor placement, it is no surprise that the majority of the monitors are located within Allegheny County and are maintained by the Allegheny County Health Department. Of the remaining nine counties within the PRETA region, only four contain a stationary monitor capable of directly measuring $PM_{2.5}$. Figure 11 also shows the location of some of the major sources of PM (or its precursors) within the region. The high density of monitors placed in southeastern Allegheny County (Liberty, Clairton, and Elizabeth) reflects the need to monitor PM pollution levels from the Clairton Coke Works, Edgar Thompson Steel Works, and other nearby industries. Other major point sources in the area, such as numerous coal-fired power plants, however, are predominantly located in other counties that possess relatively few monitors. For example, the five major point sources located in or immediately adjacent to Indiana and Armstrong counties are served by only a single non-PM-measuring monitor located some distance from any of these sources. Similarly, only a single PM monitor located midway between the Bruce Mansfield and New Castle power stations serves to capture local levels of PM produced from these sources. The smokestacks of these facilities are relatively high so that dispersion of emissions occurs and limits local impacts in the immediate vicinity. But given the lack of monitoring devices near these facilities, their overall contribution to the airborne PM in the PRETA region is uncertain. Though the population densities are not as high as other areas within the PRETA region, people do reside downwind from these sources. Without ambient air monitoring stations downwind of these facilities, only model estimates can be used to predict distribution and, therefore, the magnitude of exposure from these major sources.

How have PM levels varied with time and place in the PRETA region?

As already mentioned, PM can emanate from numerous sources, including cars and trucks; burning of coal, oils, and natural gas; and various industrial sources. Importantly, the location of these sources may be within the boundaries of the PRETA 10-county region (**local sources**) or outside the PRETA region, many miles away (**regional sources**). Recall the relatively high levels of PM pollution encountered in Ohio and other areas of the Midwest (see Figures 7, 8, and 10). Because the prevailing winds in our vicinity are from west to east, the PRETA region is immediately downstream for transport of any PM or PM precursors generated in this area. Remember that because of its small size, PM can remain airborne for long periods of time and can travel extended distances from its point of origin. The South Fayette and Hillman State Park monitors located in western Allegheny County (see Figure 11) measure the PM concentration upwind of the greater Pittsburgh region. Because few point sources of PM are located nearby, these monitors most likely reflect PM that is transported from regional sources located to the west and southwest of the PRETA region, with little contribution from local urban or industrial sources within the region. In attempting to identify PM produced locally, the values measured at these monitors represent the "background" level of PM transported to our region from distant sources. Thus, the concentrations measured at other monitors above these average background concentrations can be considered the "urban excess" concentration of PM produced directly within our area.

TIME SERIES (1999–2010) OF ANNUAL $PM_{2.5}$ CONCENTRATIONS MEASURED AT SELECT AIR MONITORS IN THE PRETA REGION

Figure 12. Values are expressed as "design values" (see p. 19). The red dashed arrow shows the current NAAQS annual standard for $PM_{2.5}$ (15 μg/m³) and the tan box represents the newly proposed standard recommended by the Clean Air Act Scientific Advisory Committee (11–13 μg/m³).



A "snapshot" of the long-term temporal patterns in PM pollution within the different locales of the PRETA region can be obtained by examining ambient PM levels recorded over the last decade at various monitoring stations within the area. The selected PM monitors in Figure 12 include six in Allegheny County, two in Washington County, and one from each of Beaver and Westmoreland counties (see Figure 11 for reference). The $PM_{2.5}$ concentrations represented on the Y-axis are the annual design values from 1999–2001 through 2008–10 (refer to p. 20). The black dashed line in Figure 12 represents the average for the 14 $PM_{2.5}$ monitors within the 10-county region that operated continuously from 1999 to 2010.

As recently as 2006 (2005–07), $PM_{2.5}$ annual design values from monitors in Lawrenceville, North Braddock, Clairton, Greensburg, and Beaver Falls were above the EPA annual standard of 15 μg/m³ shown by the red dashed arrow, though the trend for all monitors in the region has been substantially downward. Over the past decade, $PM_{2.5}$ concentrations from the 14 monitors decreased an average of 2.8 μg/m³ in southwestern Pennsylvania, although considerable differences are still seen between various monitors with many above the "background" levels measured at Hillman State Park. Declines in ambient $PM_{2.5}$ concentrations were significant throughout southwestern Pennsylvania over the last 10 years, although these reductions were most dramatic after the 2005–07 period.

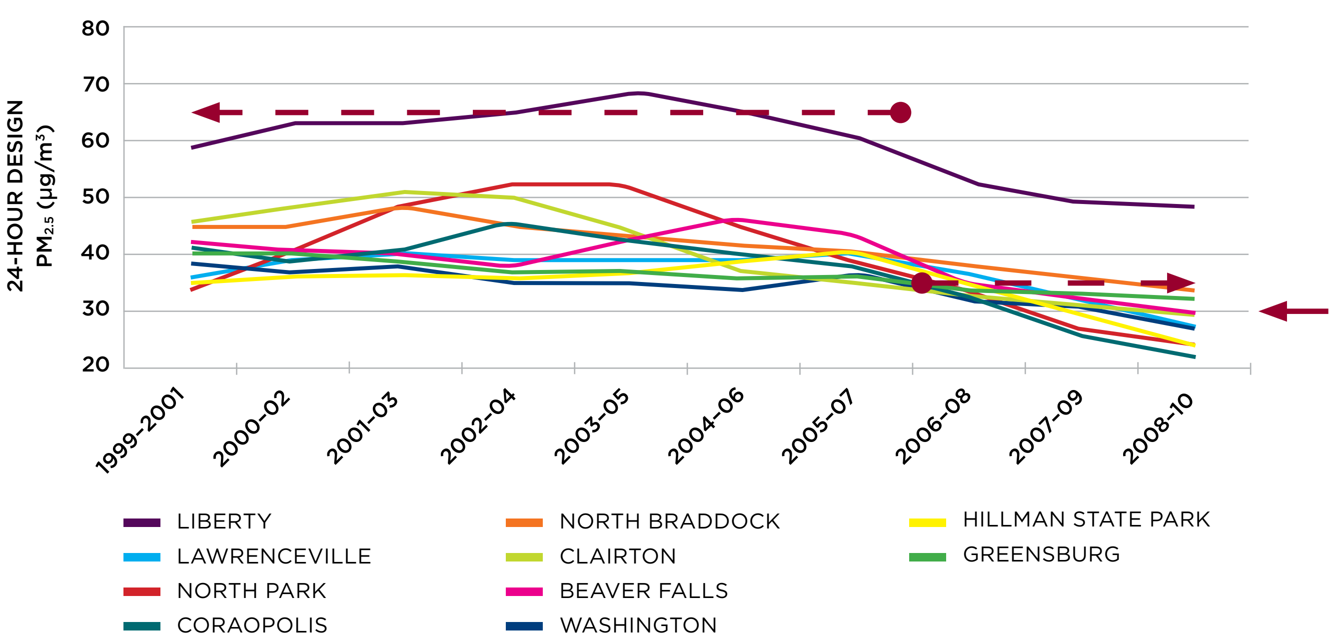
The tan-colored box in Figure 12 indicates the range of the newly proposed annual $PM_{2.5}$ standards currently under review by EPA. Adoption of the most stringent limit of the newly proposed standards being considered by EPA (11–13 μg/m³) would most likely result in the majority of the monitors being classified as in nonattainment for the annual standard. Nine of the 14 PM monitors within southwestern Pennsylvania are currently in the top 25th percentile for highest recorded $PM_{2.5}$ of all air monitors in the United States, with six of the monitors among the highest 11 percent in the nation.

Figure 13 displays the 24-hour $PM_{2.5}$ design values over the last decade for the same 10 monitors referenced in Figure 12. The red dashed lines represent EPA 24-hour $PM_{2.5}$ standards, which declined from 65 μg/m³ to 35 μg/m³ in 2006. The 24-hour $PM_{2.5}$ values do not display the similar gradual downward trend of the annual design values over the past decade. Instead, they show a relative increase throughout the middle of the decade, especially at monitors in North Park, Clairton, Liberty, and Beaver Falls and, to a lesser extent, in Lawrenceville. The remaining five air monitors displayed relatively steady 24-hour design values for the first five to seven years and then displayed a downward trend over the last three time periods. Only since the most recent design value periods has the majority of the air monitors obtained averages below NAAQS. The design values at Liberty and North Braddock remain above the 35 µg/m³ standard according to the latest criteria. Short-term particle pollution at the Liberty monitor remains one of the major threats within the southwestern Pennsylvania region, as the most recent 24-hour design value was just below 48 µg/m³, approximately 13 µg/m³ above the current standard.

Whether other areas with problematic PM pollution similar to the Liberty/Clairton area exist within the PRETA region remains an important question. Given the limitations in resources needed to maintain a large network of air monitors, it is obviously difficult to provide detailed analyses of actual PM levels encountered throughout all areas of southwestern Pennsylvania. The *Pittsburgh Post-Gazette* reported: "The most recent data collected by the Pennsylvania Department of Health found that close to 38 percent of Northgate School District students suffered from asthma in 2008–09, the highest rate of any school district in southwestern Pennsylvania"[87]. This is more than triple the national and state average of 11 percent. In late 2009, the Allegheny County Health Department installed a new air monitor in Avalon, a community on the northern bank of the Ohio River across from Neville Island. The area is home to several industries that produce PM and release other hazardous air pollutants into the atmosphere. One is the Shenango Coke Works, located on Neville Island. This facility has been cited numerous times in the past for violating environmental regulations. The Shenango Coke Works, which processes almost 400,000 tons of metallurgical coke annually, has been operating since 1962. Generation of good air quality data from this monitor will be essential in assessing the potential impact of such industries on this community. However, because of the short time

TIME SERIES (1999–2010) OF 24-HOUR THREE-YEAR DESIGN VALUES FOR $PM_{2.5}$ CONCENTRATIONS MEASURED AT SELECT AIR MONITORS IN THE PRETA REGION

Figure 13. The red dashed arrow corresponds to the NAAQS 24-hour standard in place at the time of the survey and reflects the change from 65 µg/m³ to 35 µg/m³ in the 2006 standard for $PM_{2.5}$, and the solid red arrow represents the newly proposed standard recommended by the Clean Air Act Scientific Advisory Committee (30 µg/m³).



There is clearly a need for future research within the PRETA region in order to more accurately document the health impact of air quality at current levels.

that this monitor has been online and the fact that it uses a differing methodology from many of the other monitors in the PRETA region, we were unable to make any conclusions regarding PM levels in this community at this time.

Given these circumstances, it is critical to continue air monitoring within the PRETA region and to expand, if possible, the number of monitoring stations to serve additional areas not currently sampled. Citizens and policymakers should be mindful of potential current and future PM sources, especially within a shifting landscape of new industrial development. For example, the emerging Marcellus Shale gas extraction initiative creates increased on-road and off-road diesel traffic as well as new potential point sources of fossil fuel combustion. An effective monitoring network is needed to meet the requirements put forth by EPA in order to meet air quality attainment standards. It should also be extensive enough to serve as many communities within the region as possible and flexible enough to monitor existing and emerging sources. There is clearly a need for future research within the PRETA region in order to more accurately document the health impact of air quality at current levels, determine the efficacy of proposed changes in air quality standards, adequately quantify the extent of exposure of individual communities within our region, and identify specific problem areas that might be at high risk for the deleterious effects of PM pollution.

Where can I find additional information about particulate matter?

Allegheny County Health Department Air Quality/Pollution Control: www.achd.net/air/index.html

American Lung Association: www.lungusa.org/healthy-air/

U.S. Environmental Protection Agency Particulate Matter: www.epa.gov/pm

Group Against Smog and Pollution (GASP): www.gasp-pgh.org

Pennsylvania Department of Environmental Protection:
www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/pollutants.htm

Pennsylvania Department of Environmental Protection Monitoring Principal Pollutants:
www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/principal.htm

Southwest Pennsylvania Air Quality Partnership, Inc.: www.spaqp.org

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GLOSSARY

AMBIENT AIR
Air found in the outdoors to which the general population is exposed

ATTAINMENT
Desired designation issued by EPA indicating that a pollution standard has not been exceeded (violated)

CRITERIA POLLUTANTS—see National Ambient Air Quality Standards

DESIGN VALUE
Term used by EPA to designate the measured level of a pollutant for pollution control or a level for an area on which attainment is based

DIESEL PARTICULATE MATTER (DPM)
Particulate matter emitted from diesel-powered motor vehicles

DPM—see Diesel Particulate Matter

EPA—see U.S. Environmental Protection Agency

HYDROCARBONS
Simplest organic compounds, containing only carbon and hydrogen; hydrocarbons can be gases, liquids, waxes, low-melting solids, or polymers. Their main use is as a combustible fuel source.

NAAQS—see National Ambient Air Quality Standards

NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS)
The Clean Air Act, which was last amended in 1990, requires EPA to set NAAQS for pollutants considered harmful to public health and the environment. The six common NAAQS air pollutants, or "criteria pollutants," are ozone, fine particulates, nitrogen dioxide, sulfur dioxide, carbon monoxide, and lead.

NONATTAINMENT
Term used by EPA to indicate that the area is above the pollutant level that has been established as permissible under certain regulations

OZONE (O_3)
Gas composed of three oxygen atoms. It is not usually emitted directly into the air but at ground level and is created by a chemical reaction between oxides of nitrogen (NO_X) and volatile organic compounds (VOCs) in the presence of sunlight.

PARTICULATE MATTER (PM)
Small particles of solids and liquids commonly formed as by-products of combustion. Sometimes particulate emissions are visible in the form of soot or smoke because the particles are so large. However, most are not visible, which is part of what makes them dangerous, because people do not realize that the emissions are occurring. Small particles also are more dangerous because they are less likely to be trapped in the mucus linings of the nose and throat and thus are taken deeply into the lungs.

PITTSBURGH REGIONAL ENVIRONMENTAL THREATS ANALYSIS (PRETA)
Environmental assessment project developed by the Center for Healthy Environments and Communities in the Department of Environmental and Occupational Health at the University of Pittsburgh Graduate School of Public Health, with generous support from The Heinz Endowments. The 10-county region in which this project was conducted includes the following counties in southwestern Pennsylvania: Allegheny, Armstrong, Beaver, Butler, Fayette, Greene, Lawrence, Indiana, Washington, and Westmoreland.

PM—see Particulate Matter

PRECURSOR
Gaseous chemical such as sulfur dioxide, nitrogen oxide, and ammonia that can condense over time in the atmosphere to form PM

PRETA—see Pittsburgh Regional Environmental Threats Analysis

PRIMARY STANDARDS
Pollutant standards based on human health

PRIMARY PM
Particulate matter that is formed at the same time that it is introduced into the atmosphere

SECONDARY STANDARDS
Pollutant standards based on protecting ecosystems and on other welfare considerations

SECONDARY PM
Particulate matter that is formed by condensation of such gaseous pollutants as sulfur dioxide, oxides of nitrogen, and ammonia after their introduction into the atmosphere

TOXICITY
Degree to which a substance can cause damage to an organism

U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)
Federal agency whose mission is to protect human health and the environment

VOLATILE ORGANIC COMPOUND (VOC)
Chemical or compound that contains such vapor pressure that it does not require excessive heat to vaporize the compound into a gaseous form

PITTSBURGH AND ITS SURROUNDING COUNTIES

With Lake Erie to the northwest and the Laurel Mountains to the east, the city of Pittsburgh and the surrounding counties shape the gateway to the Ohio River Valley, located in the eastern United States. The U.S. Census Bureau 2010 decennial census estimates 2,666,258 people live within the 10-county southwestern Pennsylvania region. The urban core of the greater Pittsburgh region is situated at the point where the Allegheny and Monongahela rivers converge to form the Ohio River, but vast urban sprawl continues to occur. The meeting point of the three rivers marks one of the lowest elevations in the region, sitting just 710 feet above sea level. This is in stark contrast with the surrounding area, where, for example, in Westmoreland County, the elevation reaches a height of 2,950 feet. The 10-county region is full of valleys, rivers, and mountains, making up 6,755 square miles. It is home to 528 municipalities, 197,970 acres of floodplains, and nine distinct river-based watersheds.

The 10-county region consists of irregular topography; a history of industry and pollution; a relatively stable political and economic environment; and a number of environmental concerns, including legacy and emerging threats. While some of these environmental and public health issues are experienced in other places around the world, Pittsburgh exhibits a cumulation of unique factors that warrants a comprehensive analysis of the regional environmental public health threats.

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