AIR POLLUTION IN NEW YORK STATE - OZONE AND PARTICULATE MATTER: A PRIMER

January 2006

This primer provides a short summary of the causes and consequences of two important atmospheric pollutants, ozone and particulate matter, and briefly recounts the history of policies intended to reduce this form of air pollution in New York State. With a better understanding of the issue and current research relating to it, New York's citizens and policymakers can address the problem more effectively.

WHAT ARE OZONE AND PARTICULATE MATTER?

Ozone (O_3) is a highly oxidative molecule found in the air. It forms both in the high atmosphere (stratosphere) and in the lower atmosphere (troposphere), where we live. Ironically, stratospheric ozone is critical to survival of life on Earth because it absorbs harmful ultraviolet radiation from the sun. Conversely, tropospheric ozone has adverse effects on human health, vegetation, and other materials when present at high concentrations. Tropospheric ozone is produced from sunlight induced photochemical processes involving the precursors; nitrogen oxides (NO_x) and volatile organic compounds (VOCs). Ozone is considered a secondary pollutant; that is, it is not generally emitted directly by a source, but rather is formed in the atmosphere through chemical reactions. Ozone's precursor compounds, however, are emitted from natural and human activities. Ozone concentrations vary seasonally, temporally, and spatially; higher concentrations usually occur May through September (the "ozone season"), especially as temperatures rise at midday, and in areas around and downwind from sources of precursors. Because airborne precursors and ozone can be transported long distances, concentrations of the pollutant at a site can reflect emissions from sources hundreds of miles upwind.

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NYSERDA is a public benefit corporation created in 1975 by the New York State legislature. NYSERDA administers the **New York Energy $martSM** program, which is designed to support certain public benefit programs during the transition to a more competitive electricity market. The **New York Energy $martSM** program provides energy efficiency services, including those directed at the low-income sector, research and development, and environmental protection activities.

NYSERDA has been developing innovative solutions to environmental problems associated with energy production through its support for research and development of energy-efficiency projects. Through its EMEP program, NYSERDA continues to provide scientifically credible and objective information on the environmental impacts of energy systems and to assist the State in developing science-based and cost-effective policies to mitigate these impacts. Research in the areas of air quality and related health effects include projects focusing on ozone, $PM_{2.5}$, ultrafine particles and precursors. The EMEP program currently sponsors 18 projects related to air quality and health effects.

For more information, visit www.nyserda.org/programs/environment/emep/

Particulate matter (PM) is an airborne mixture of tiny particles and droplets (aerosols), often referred to as dust, haze, or smoke. PM is both a primary and a secondary pollutant: it can be directly emitted by sources, or it can form in the atmosphere through physical or chemical processes. The U.S. Environmental Protection Agency (EPA) characterizes PM levels as the mass of particles found in a specific volume of air, commonly as micrograms of particles per cubic meter of air ($\mu g/m^3$). Unlike ozone, PM lacks a unique chemical identity and is commonly described in terms of particle size, usually by the particle's aerodynamic diameter (a measure of size based on particle aerodynamic characteristics). Like ozone, fine PM (particles with aerodynamic diameters smaller than 2.5 micrometers, $PM_{2.5}$) can be carried long distances from a source. Coarse PM (particles with aerodynamic diameters of 2.5 to 10 micrometers, PM_{10}), generally remains closer to the source. The ability of fine PM to travel great distances from its source is demonstrated by smoke from wildfires. In 2002, a wildfire in northern Quebec raised PM concentrations and dramatically impaired visibility in New York State and the eastern United States as far south as Maryland.

WHY ARE THEY IMPORTANT?

Ozone and particles are regulated as EPA "criteria pollutants"—indicators of air quality—under the federal Clean Air Act of 1970 and its subsequent amendments, as well as under New York State environmental provisions. Both pollutants affect human health and the environment. Ozone exposure is associated with eye and respiratory irritation and aggravation of respiratory problems. The young, the elderly, and those involved in strenuous outdoor activity appear to be more susceptible. A long-term Children's Health study in California found that days with higher ozone concentrations had higher school absences due to respiratory illness (CARB, http://www.arb.ca.gov/research/chs/chs.htm). In addition, young adults with histories of long-term residence in high-ozone areas were found to have diminished lung function and more chronic respiratory symptoms (Galizia and Kinney, 1999). Ozone also causes damage to vegetation, including agricultural crops and forests.

The health and environmental concerns related to PM depend somewhat on particle size. As they are inhaled, large particles are likely to be intercepted in the nose and upper airways. However, smaller particles are able to travel deeper into the respiratory tract. Epidemiological studies have found associations between increasing PM concentrations and respiratory symptoms, aggravation of existing respiratory and cardiovascular disease, and mortality. Young children, the elderly, and those with existing cardiopulmonary disease may be more susceptible to the effects of PM. The Children's Health Study found children who moved from their community had increased lung development if their new community had lower particulate levels, and they had decreased lung development if their new community had higher particulate pollution. (CARB, http://www.arb.ca.gov/research/chs/chs.htm)

Environmental concerns regarding PM include acidic deposition ("acid rain"), damage to crops and forests, and corrosion of materials. Particle size is also important to environmental effects of PM. As concentrations of fine PM increase, visibility deceases, making the control of fine PM a crucial component of regional haze reduction programs.

HOW ARE OZONE AND PM REGULATED?

The Clean Air Act authorizes the Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for criteria pollutants. The current standard for ozone is based on a maximum concentration of 0.08 parts per million by volume parts of air averaged over an eight-hour period.

PM in ambient air is regulated using two size classifications. The current standards, promulgated in 1997, address PM_{10}, which by definition includes the subset fine particles, $PM_{2.5}$, and thus do not regulate the coarse particle fraction directly. There are both daily and annual standards for PM_{10} and $PM_{2.5}$. For PM_{10}, the 24-hour standard is set at 150 $\mu g/m^3$, and the annual standard is 50 $\mu g/m^3$. For $PM_{2.5}$, the 24-hour standard is 65 $\mu g/m^3$, and the annual standard is 15 $\mu g/m^3$.

EPA determines whether an area is in attainment of the NAAQS based on data from a network of air quality monitoring stations. Nonattainment areas can be counties, parts of counties, or groups of counties and can also include several states. For example, New York City, Long Island, and two counties in the lower Hudson River valley are part of EPA's New York–New Jersey–Connecticut nonattainment area for the eight-hour ozone standard. By law, state and local authorities for an area designated as nonattainment must submit to EPA a plan for how this locale will achieve compliance with the standards. A state implementation plan (SIP) identifies the mitigation measures that are projected to achieve the NAAQS in a specified time frame.

WHAT ARE THE CONDITIONS IN NEW YORK STATE?

Figure 1 indicates the areas designated as nonattainment for the eight-hour ozone standard. Included in these areas of concern are some parts of New York State.

Figure 2 shows the areas that have been identified as nonattainment for $PM_{2.5}$. In New York State, the $PM_{2.5}$ nonattainment area consists of 10 counties in and around New York City.

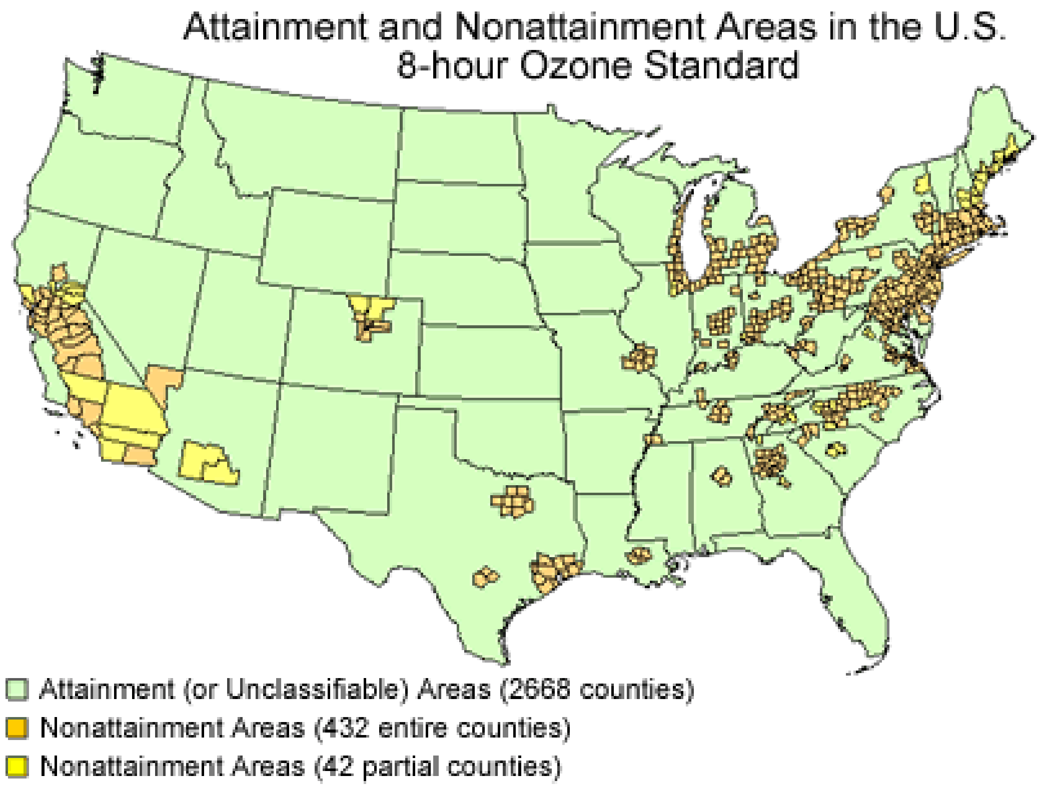

Figure 1. Ozone Attainment and Non-Attainment Areas. Source: U.S. EPA, http://www.epa.gov/air/oaqps/glo/designations/nonattaingreen.htm

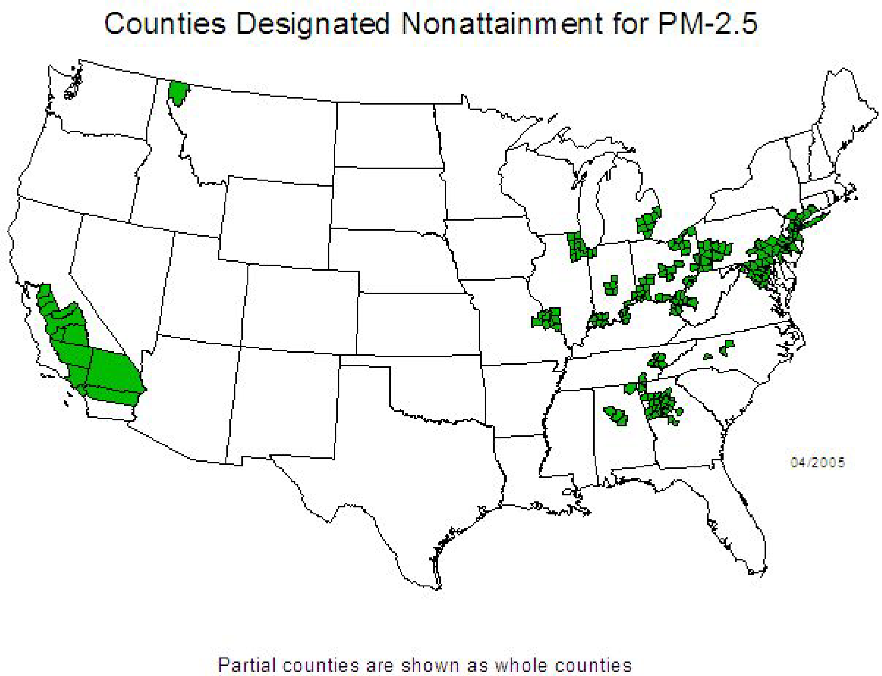

Figure 2. $PM_{2.5}$ Non-Attainment Areas. Source: http://www.epa.gov/oar/oaqps/greenbk/mappm25.html

Unlike O_3, which is a gas molecule, $PM_{2.5}$ contains a large number of chemical compounds. An illustrative composition for particles found in New York is shown in Figure 3. The diagram indicates that the $PM_{2.5}$ mass concentration comprises mostly carbon, sulfate, nitrate, and ammonium. Other material, including metal oxides and other components of the Earth's crust, are smaller contributors. Compared with sulfate and nitrate, less is known about the carbon fraction, which is generally separated into black carbon (sometimes referred to as soot) and organic carbon. The latter fraction is composed of many chemical compounds, fewer than a quarter of which have been identified.

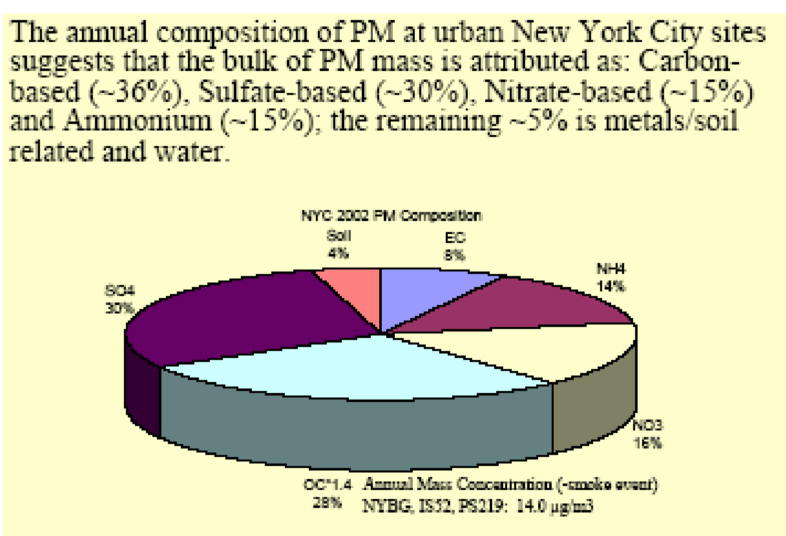

Figure 3. Annual composition of PM at urban New York City sites. Source: Demerjian, pers. communication.

The high levels of ozone and $PM_{2.5}$ in New York's nonattainment areas are partly due to emissions associated with large metropolitan areas and industrialization in and around the state. However, an important atmospheric phenomenon is also responsible: through long-range transport, pollutants are carried from many up-wind sources into New York on prevailing winds, thereby supplementing locally generated O_3.

At ground level, ozone reacts with surfaces and other airborne chemicals, processes that reduce ground-level ozone concentrations. Ozone above the ground, however, can last for days. Likewise, fine particles can float in the air for many days if not precipitated in rain or snow or affected by contact with the ground. Long-range transport from up-wind sources has been found to be a factor in the spread of acidic deposition that affects vulnerable ecosystems in New York State, New England, and southeastern Canada (Figure 4).

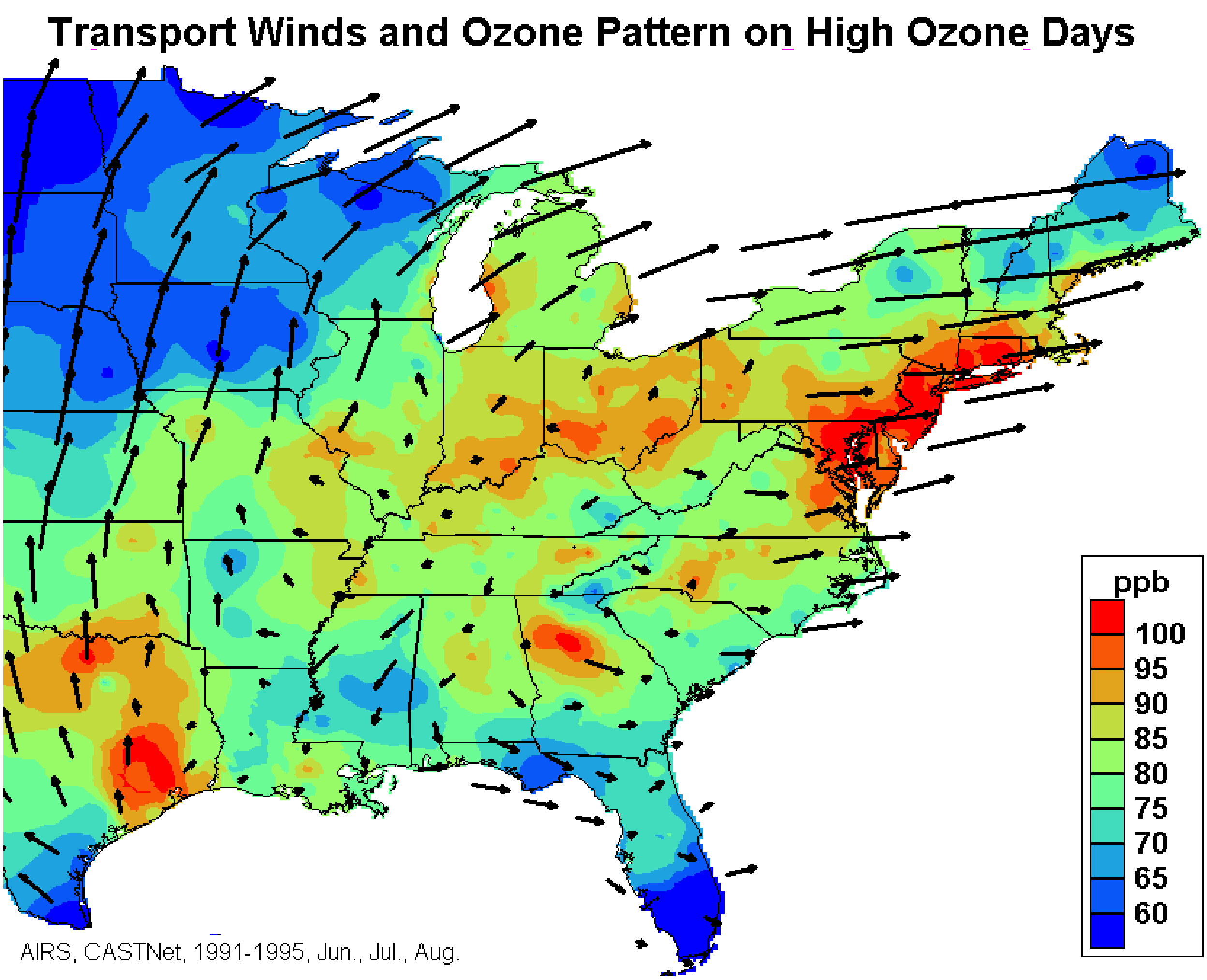

Figure 4. Prevailing winds and long-range transport. Source: Ozone Transport Assessment Group, 1997.

Studies of long-range transport have indicated that, under typical meteorological conditions, ozone and other airborne pollutants travel eastward or northeastward from large industrial and energy generation sources in the Midwest and mid-Atlantic toward New York State and the sensitive ecosystems of the Catskill and Adirondack Mountains. While recognizing the contribution of interstate pollution transport, authorities in New York and neighboring states are developing plans to reduce local sources of ozone precursors and $PM_{2.5}$.

WHAT ARE THE SOURCES OF OZONE AND PM?

Management of ozone and PM requires detailed knowledge of precursor gases and primary particle emissions. These emissions are either measured directly or estimated from samples of characteristic sources. EPA and state environmental agencies maintain emissions inventories that are continually updated to account for improving estimation methods and changing technology.

The anthropogenic sources of O_3 precursors, NO_x and VOCs, primarily come from fuel combustion. The largest sources of NO_x, for example, are associated with transportation and electric power generation (Figure 5). Other important NO_x sources include industrial and commercial operations, as well as residential fuel combustion. Smaller amounts of NO_x are emitted from soils and created by lightning during storms. Emissions of VOCs are identified with mobile sources and internal combustion engines, but industrial sources, including oil refineries and chemical plants, and commercial and residential activity are of concern. Biogenic activity in vegetation also produces VOC emissions. The natural sources of both VOC and NO_x have complicated the management of ozone in the East.

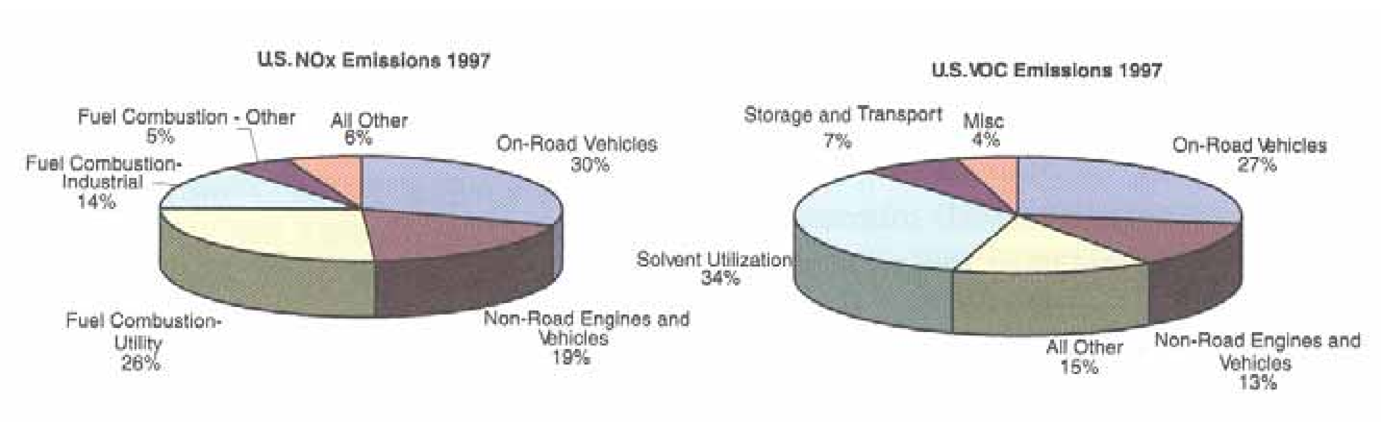

Figure 5. NOx and VOC sources. Source: NARSTO, 2000.

Sources of PM differ. The coarse fraction generally includes windblown and road dust, sea spray, and biological material like bacteria, fungi, and detritus. The primary sources of fine particles are associated with fuel combustion, including internal combustion engines, and industrial, commercial and residential heaters and processing, as well as wood burning and vegetation fires.

In addition to particles emitted directly from a source, PM includes secondary fine particles, which are formed from the cooling or reacting of sulfur dioxide (SO_2), NO_x, VOCs, and ammonia (NH_3). These gases come from many sources. Fuel combustion accounts for most of the SO_2, NO_x, and VOCs found in New York State. Ammonia is generally associated with agricultural activity and waste treatment facilities, but small amounts of this gas come from motor vehicles and chemical processing. The reactive VOCs of concern for $PM_{2.5}$ formation differ from the main O_3 precursors. The $PM_{2.5}$ precursors include a group of compounds found in gasoline and chemical processing called aromatics; these are large VOC molecules that form compounds that under some conditions will condense out of the air. A potentially important, naturally occurring VOC group that readily forms particles is the biogenic vapors from vegetation, called terpenes. In New York State, scientists do not know what part of the organic particles comes from vegetation emissions, but they suspect that this natural source is important, especially in the summer when emissions are largest.

WHAT'S BEING DONE TO REDUCE OZONE AND PM CONCENTRATIONS?

Beginning about 30 years ago, EPA and state environmental agencies instituted major pollutant emissions reduction programs with industry, including electric utilities and motor vehicle manufacturers, as well as commercial and residential sources. Major public investments have resulted in substantial reductions in PM emissions and ozone, as well as secondary PM precursor gases (Figure 6).

Some emissions reductions have been offset by industrial, transportation, and population growth throughout New York State and elsewhere. Recognizing that emissions increase with population and economic growth, policymakers have begun aggressive efforts to reduce emissions on local and regional scales.

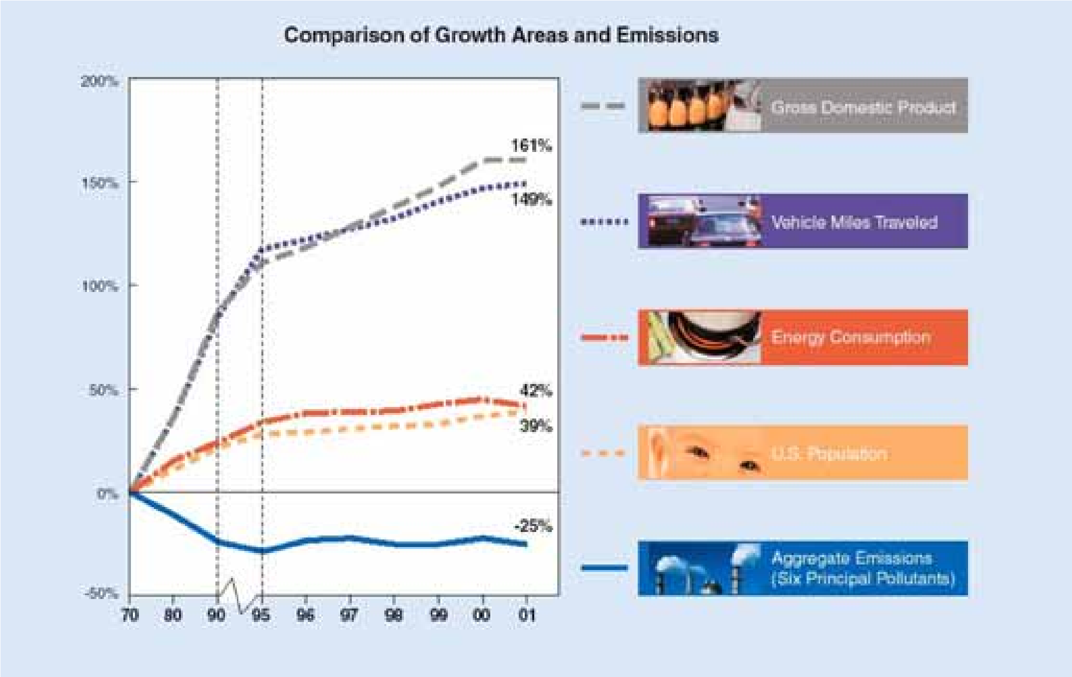

Figure 6. Air Emission Trends. Source: U.S. EPA, http://www.epa.gov/airtrends/2005/econ-emissions.html

The realization in the 1980s that pollution can travel across state and international borders through long-range transport has prompted initiatives to reduce regional emissions to help New York State achieve its air quality goals. One such initiative addressed SO_2 and NO_x emissions to reduce acidity in precipitation and led to the 1990 Clean Air Act Amendments, which required electric utilities to reduce SO_2 emissions by approximately 50% and reduce NO_x emissions substantially by the year 2010. In 1997, state governments in the Northeast reached an agreement in principle to reduce NO_x emissions to achieve ozone reduction. This agreement was furthered in EPA's NO_x SIP call, a requirement for states to develop plans for regional NO_x reductions beyond those called for in the 1990 Clear Air Act amendments. At the same time, the New York State Department of Environmental Conservation continued to review statewide emissions to seek additional reductions that would lead to local compliance. In 2003, Governor Pataki initiated the nation's strictest regulations on electricity generators' emissions of SO_2 and NO_x. The regulations require New York generators to reduce SO_2 emissions to 50% below levels allowed under the Clean Air Act. It also extends the NO_x emissions limits currently required for the ozone season throughout the year.

In addition to regulations directed at reducing emissions, voluntary emissions reduction initiatives are underway, including clean transit bus and school bus programs (Figure 7), diesel idle reduction programs with the trucking industry, emissions reduction efforts with the marine sector, and cleaner fuels for oil heat.

Other, broader energy initiatives in New York are also helping to reduce emissions. The **New York Energy $mart**^{SM} program administered by NYSERDA has resulted in annual emissions reductions of 1,265 tons of NO_x and 2,175 tons of SO_2 through a variety of energy efficiency and renewable energy programs.

Figure 7. Clean air school bus.

HOW ARE IMPROVEMENTS IN AIR QUALITY MEASURED?

Air Quality

It is important for the public to know whether its investments in pollution control are paying off in improved public health and environmental quality. The methods for measuring air quality have improved enormously since 1970, and the number of observation sites has expanded dramatically. Today, New York State has 30 ozone monitoring sites that cover both urban centers and surrounding rural areas, plus 39 sites for monitoring $PM_{2.5}$. Ozone and PM precursor gases also are being measured at a few locations, and electric power plants are required to measure and report continuous observations of NO_x and SO_2 in their stack gases. And motor vehicles are subject to an inspection and maintenance program that includes emissions checks.

The emissions measurements and inventory, combined with ambient air monitoring, have provided a long-term picture of air quality change. Observed reductions in ozone and its precursor gases are attributed to emissions reductions. The long-term record of PM monitoring is difficult to interpret because the NAAQS for particulate matter have changed three times since 1970—from total suspended particulates, to PM_{10}, to PM_{10} and $PM_{2.5}$. Concentrations of PM_{10} have declined across the United States in response to emissions controls, as have concentrations of particle sulfate. Particle nitrate, however, has not declined. $PM_{2.5}$ has been monitored only since 1999. However, this measure of air quality will improve with the accumulation of new data in the coming years.

Human Health

Perhaps the most important measure of air quality is human health, but changes attributable to air quality improvements have proven very difficult to measure. Simply isolating the effects of individual pollutants is a challenge because ambient pollutant concentrations tend to vary together with weather and human activity patterns. An important consideration is the difference between ambient concentrations of pollutants and actual exposure to pollutants. People spend much of their time indoors, where there are numerous sources of PM but few sources of ozone. Ventilation rates vary among buildings depending on design, season, and the heating and air conditioning equipment, but are important factors for determining how much ambient pollution enters a building. In addition, improvements in health measures depend on many factors that confound the effects of air pollution, including smoking, weather, health care, and socioeconomic status.

The Environment

Measuring the environmental response to changes in air pollution relies on a variety of efforts. The measurement of wet and dry deposition, water quality parameters and soil chemistry are all necessary to begin to understand how various components of ecosystems are reacting to varying levels of air quality. Also important is the study of flora and fauna bio-indicators, which provide an indication of how biological communities are responding to improvements in the physical environment. In addition to this monitoring activity, focused process-level studies help shed light on the mechanisms of pollutant flow and transformation throughout the environment. Data collected by the Adirondack Lake Survey Corporation indicate that some Adirondack water chemistry has improved, albeit slightly, in response to changes in deposition, but many waters are still incapable of supporting healthy biota.

Although we now have the ability to measure air quality change in response to emissions reductions, at least qualitatively, the much more difficult measurements of human health and environmental improvement remain a challenge.

WHAT NEW INITIATIVES WILL ADDRESS AIR QUALITY?

Policy

The public has continued to press for cleaner air in New York State and elsewhere, inspiring a sustained effort not only to comply with federal and state laws, but also to continue supporting initiatives to improve air quality while encouraging economic growth. The milestones for future improvements are established mainly by the Clean Air Act and its amendments, which require state implementation plans to meet the NAAQS for both ozone and $PM_{2.5}$. The SIPs are scheduled to be submitted to EPA by 2007. Once they have been approved, New York State and EPA will ensure that regulated sources comply with the SIP commitments.

Statewide planning will necessarily include complementary regional and interstate planning, following the requirements of the 1990 Clean Air Act amendments and a new EPA regulation called the Clean Air Interstate Rule (CAIR). The CAIR will schedule reductions in SO_2 and NO_x from power plants beyond the requirements for 2010–2015. Another dimension of the SIP preparation is regional haze. EPA has committed to steady improvement of regional visibility to pristine or natural conditions by 2064 by reducing $PM_{2.5}$. Since a large fraction of $PM_{2.5}$ originates with SO_2 and NO_x, this rule will help reduce emissions of these gases across the United States. Much of the pressure for reductions will fall on the electric utilities, especially power plants burning coal.

Attention to the transportation sector also continues. New vehicles in the next several years are scheduled to meet federal ultralow emissions standards, which are intended to minimize VOCs and NO_x from light-duty vehicles. New cars already have very low PM emissions; as the on-road fleet converts to newer vehicles, emissions will drop significantly. Heavy-duty diesel vehicles are scheduled for emissions reductions of VOC, NO_x and $PM_{2.5}$, to be achieved through cleaner engines, ultralow-sulfur diesel fuel, and pollution control devices. Nonroad vehicles and stationary engines, including emergency power generators, are also targeted for emissions reductions. New York City passed a law requiring the use of ultralow-sulfur diesel fuel and the best available control technology for nonroad vehicles and equipment for all City construction projects; the regulations apply first in Lower Manhattan and will eventually be city-wide.

The Renewable Portfolio Standard, approved by the New York State Public Service Commission in 2004, will also have a positive effect on the environment by diversifying the state's electricity generation mix to include a higher proportion of renewable energy sources, such as wind power and other “green” alternatives to fossil fuels. With a target date of 2013, this initiative will increase the amount of renewable energy purchased by New York consumers from 19.3 percent to more than 25 percent. Also under consideration is the Regional Greenhouse Gas Initiative. This multi-state effort to cap carbon dioxide emissions associated with the generation of electricity in the Northeast and mid-Atlantic could help transform the mix of fuels used to meet our energy needs, potentially reducing ozone precursors and PM.

Research

In recent years O_3 research has been considered a lower priority than $PM_{2.5}$ investigation. Much of the effort in New York and nationally has concentrated on the linkages with particle formation in the atmosphere. Studies of VOC reactivity have initiated thinking about ways of managing O_3 formation, while at the same time addressing organic particle formation. The chemistry of O_3 and other oxidant formation has been integrated with $PM_{2.5}$ chemistry in large, complex air quality modeling development. The new models are being used effectively to develop integrated management strategies that include these pollutants and their precursors. This direction is sometimes called the “one atmosphere” approach to the next generation of policy for improving air quality.

The regional issue of the significance of long-range transport of O_3 and $PM_{2.5}$ has received continued attention, especially in New York since the State’s approach to reaching attainment for both these pollutants will depend on advancing our knowledge about regional processes in the Northeast. As a part of these studies, scientists have expanded their attention to the role of natural emissions of VOC and PM. In the last decade, research on the role of natural VOCs such as isoprene and terpene compounds has shown their importance in coupled O_3 production and $PM_{2.5}$ formation.

With the finding that black carbon and organic carbon are major components of $PM_{2.5}$, researchers are giving particular attention to this material, and the techniques for measuring black carbon and organic carbon are being revised. Fewer than 25% of the organic carbon compounds in $PM_{2.5}$ have been identified. Since many of the compounds show potentially toxic properties, efforts to identify them and their sources will continue.

The component(s) in the particles (e.g. metals, carbon) or particle characteristics responsible for health effects and the specific physiological pathways by which PM affects the body have not yet been identified and are the subject of ongoing research through the EPA PM Health Effects Research Centers Program.

Our knowledge of the health effects of $PM_{2.5}$ exposure, as well as the exposure to ultrafine particles less than 0.1-1 micrometer has improved substantially, both in terms of epidemiological results, and toxicological advancements. New studies are focusing increasingly on the apparent toxicological properties of particles by physical and chemical characteristics, and much less on particle mass concentration per se. With the monitoring of carbon concentrations, and species, the role of the particulate component is beginning to be appreciated in health-related work.

Periodic reviews of the NAAQS under the Clean Air Act take into account new air quality and health research results. PM standards are currently under review. In December 2005, EPA proposed revisions to the fine particle NAAQS and some coarse particles. The proposal would lower the 24-hour fine particle standard from 65µg/m^3 to 35 µg/m^3. The proposal does not change the annual fine particle standard of 15 µg/m^3. EPA's proposal sets a new 24-hour standard for inhalable coarse particles ($PM_{10-2.5}$) at 70 µg/m^3. These particles are defined as those between 10 and 2.5 µm in diameter. There is a 90-day comment period on the proposal. EPA's timeline for implementing the proposed revision is September 2006.

WHERE DO NYSERDA'S PROGRAMS FIT IN?

NYSERDA sponsors environmental research through its Environmental Monitoring, Evaluation, and Protection program (EMEP). This program seeks to (a) enhance understanding of the nature and characteristics of energy-related pollution and its impact on the environment and human health, and (b) characterize sources of energy-related pollution and define opportunities for emissions reduction.

In the field of fine particle and ozone research, EMEP is supporting work on source characterization, transport, health effects, and technology evaluation. Among the important results of EMEP research in the area of fine particles and ozone are the following:

- advanced understanding of the relative importance of local versus long-range transport contributions of O_3 and $PM_{2.5}$;

- substantially improved understanding of the properties and sources of $PM_{2.5}$ in New York City and parts of upstate New York, including the important organic fraction;
- knowledge about emissions of ultrafine particles (< 0.1 µm in diameter) from combustion sources;
- characterization of daily and seasonal patterns of ultrafine particles, including the growth of particles in an urban atmosphere;
- advanced knowledge about health effects of ultrafine particles on cardiac health; and
- support for monitoring networks and intensive research sites throughout New York State to provide accountability for emissions reduction strategies.

In addition to those environmental research efforts, NYSERDA, through the **New York Energy $mart**SM program, is sponsoring numerous initiatives to improve energy efficiency and support clean, renewable energy in New York State.

FOR MORE INFORMATION ON OZONE AND PM

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EMEP website: http://www.nyserda.org/environment/emep.html

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