

Cleaning the Air We Breathe

A Half Century of Progress

EPA Alumni Association

April 2020



Contents

Introduction: A View through the Haze	3
1. A Look Back	5
2. Overview of the 1970 Clean Air Act	9
3. Los Angeles Smog.....	12
California Leads the Way.....	12
The 1970 Clean Air Act and its Impact on Smog in the Los Angeles Region	14
4. National Vehicle Emissions	17
5. Smoke, Fire, and Acid Rain.....	20
6. Summarizing the Progress Made under Clean Air Act Programs	24
7. Future Challenges: Air Quality Management in a Changing World	28
Summary.....	34
Glossary.....	35
Appendix. Major Approaches for Managing Air Pollution	39
References.....	45
Photo Credits:	48
EPA Alumni Authors.....	49



Preface

Former managers and staff of the U.S. Environmental Protection Agency (EPA) have formed an [EPA Alumni Association](#) (EPA AA). The Association has developed this and six other web-based environmental reports in support of our *Half Century of Progress* project. An integrated summary based on all of these reports, [Protecting the Environment: A Half Century of Progress](#), is available on the Association website. The Association has developed these materials to inform high school and college students and other members of the public about the major environmental problems and issues encountered in the United States in the 1960s and 70s and the actions taken and progress made in mitigating these problems over the last half-century. We also want to highlight continuing and emerging environmental challenges we face today. We hope that, besides summarizing the history of U.S. environmental programs, these reports might inspire some students and others to consider careers in the environmental field.

A number of retired EPA program managers and subject matter experts worked together to produce the first editions of these reports in 2016. Additional experts have updated these documents in 2020 in recognition of the 50th anniversary of Earth Day and the creation of the EPA. This updated report has been reviewed by relevant members the EPA AA Board of Directors and other alumni. We welcome comments on this document, which you may provide at this [EPA Alumni Association link](#).

The Association has also produced a *Teacher’s Guide* to facilitate the use of these materials by educators interested in including the *Half Century of Progress* in high school and college curricula. The *Guide* contains data interpretation and other questions related to the report topics, with answers. It also includes activities that challenge students to learn more about environmental issues in their communities, web-based resources for additional activities, and three lesson plans related to the HCP materials. These plans were designed and tested by three AP Environmental Science Teachers. Teachers may request a copy [here](#).

Introduction: A View through the Haze

This is the story of a 50-year struggle to deal with the serious problem of air pollution in America. Today, many are not aware that the kind of sky-dimming smoke we now see in pictures from India, China, and some other areas were commonplace in many U.S. cities in the early to mid-20th century. Industrial cities, both large and small, experienced periodic episodes of a choking mixture of smoke and gases that caused increased illness, hospital admissions, and death. By the 1960s it was apparent that limited state and local efforts to curtail air pollution would not be enough, even though the emissions of harmful air pollutants were growing steadily nationwide.

The initial response included successive federal laws that strengthened the capacity of federal and state air pollution programs and mandated development of an increasingly broad and coherent national framework for regulation that culminated in the Clean Air Act Amendments of 1970. This now iconic law transformed America's approach to air pollution, keeping primary responsibility for implementing clean air programs with the states while requiring federal oversight, national science-based air standards as targets for state programs, and national emissions standards for cars and some major stationary sources.

The process was designed to result in continuing improvements over time, and it has: in terms of the pollutants the 1970



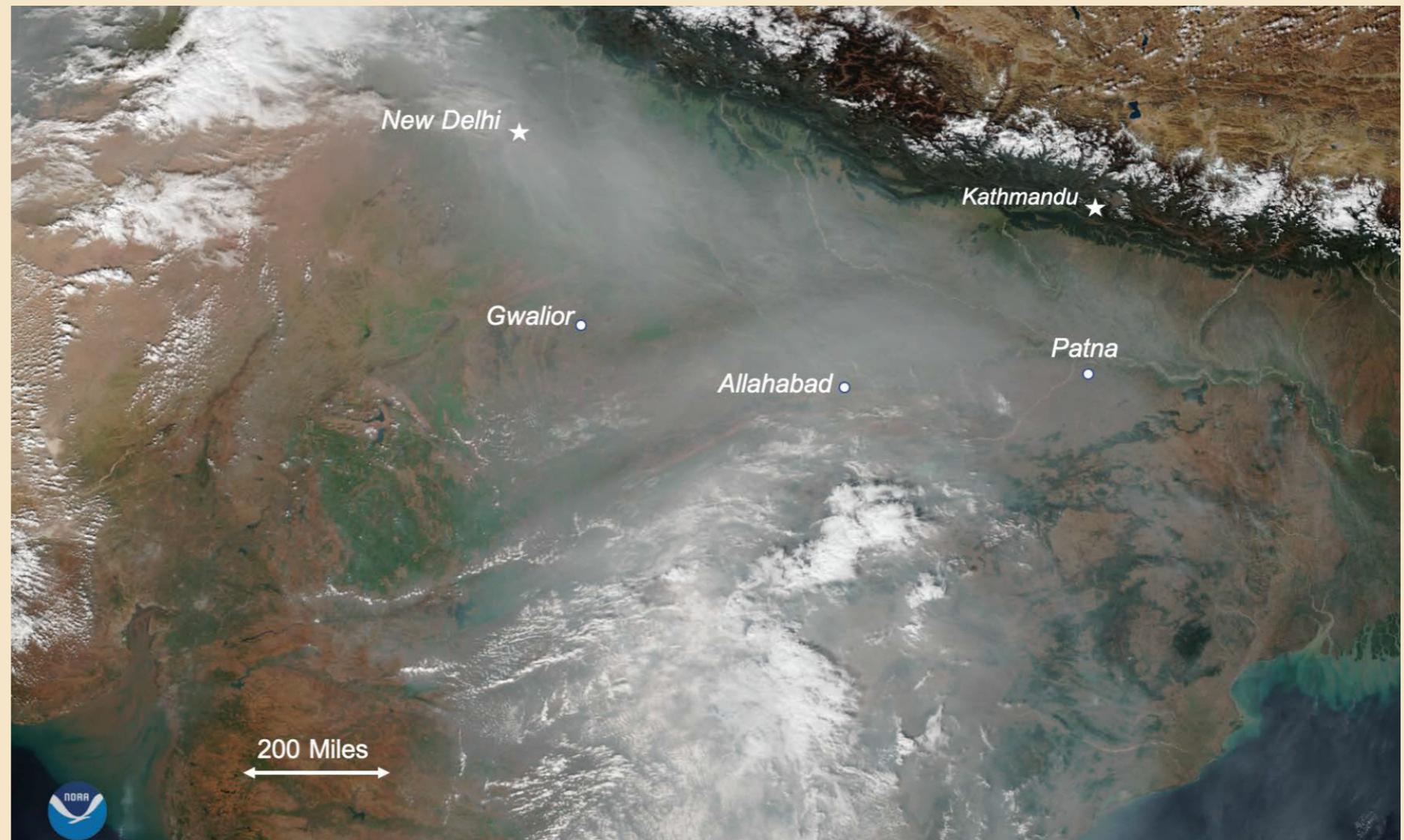
Beijing Smog.

Photo: Daylight in Tiananmen Square. Michael Davis Burchat, flickr. Creative Commons.

Clean Air Act addressed, U.S. air quality over the years has become dramatically better, with huge benefits to health and the environment. Yet the path to progress has not always been perfect, and over the years improved scientific, engineering, and policy insights have revealed the need for improved standards, more cost-effective strategies, and revisions to improve the Act

itself. This report illustrates both progress and struggles in three major programs—tackling smog in Los Angeles, reducing emissions from motor vehicles, and addressing acid rain and particle pollution through cost-effective market-based programs.

Over the last half century, Clean Air Act programs have cut air pollution emissions by 74% while the economy has more than doubled. But the job of cleaning the air is not finished, and America and the world now face the enormous challenge of climate change.

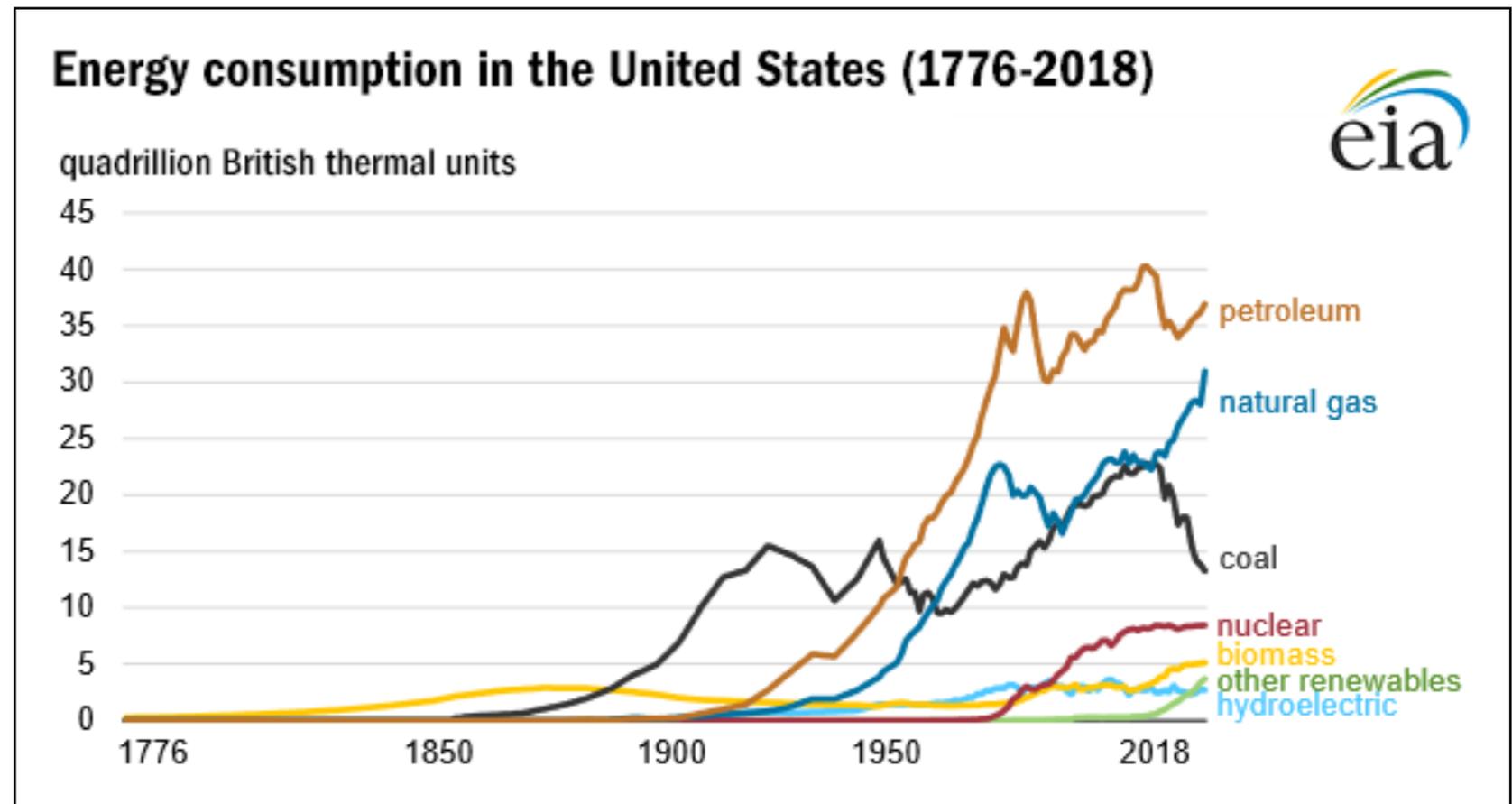


Air Pollution Chokes Northern India, December 10, 2018. A dense haze of fine particle pollution frequently extends over northern India, particularly in autumn and winter months. On this day, the air quality index in New Delhi, home to more than 20 million people, hit the "severe" category, as a stagnant weather pattern kept pollutants trapped over the region. India has been grappling with some of the world's worst air quality, with emissions from industry, traffic, biomass burning (from heating, cooking and agriculture), and dust. According to the World Health Organization, Delhi has the worst air pollution of any major city in the world. The other three Northern Indian cities shown are among 10 most polluted globally. *Photo:* [NOAA 20-Satellite](#).

1. A Look Back

The history of air pollution in the U.S. is linked with that of energy—beginning with the shift to coal power for the industrial revolution and residential heating and later the explosive expansion of automobile use and oil consumption—as well as the eventual shift to electric power for multiple industrial and domestic uses.^{1,2}

The industrial revolution caused major changes in the amount and kind of energy Americans used.²



Source: U.S. Energy Information Administration, [Monthly Energy Review](#)

It is hard to imagine the daily lives of people in heavily industrialized ‘smoky’ cities near the beginning of the 20th century. The horrific conditions led to efforts by reformers to reduce coal smoke, which at the time was largely considered a nuisance.³ Their incremental efforts produced some notable successes by the 1940s and 1950s, but new problems arose with the growing use of automobiles, petroleum, and even more coal. Progress in reducing air pollution in many areas had stalled by the early 1960s.¹ In addition, since the late 1940s evidence was increasing that different mixtures of air pollution particles and gases were having significant effects on public health (see next page).^{4,5}

Recurring air pollution episodes from coal combustion and factories in eastern cities were associated with measurable increases of deaths.^{1,6} In Los Angeles, increased automobile and other emissions combined with local meteorology, creating an atmospheric cauldron that produced a new kind of air pollution—a **photochemical smog**—that turned the sky brown and burned the eyes.⁷ Signs of this new kind of smog were beginning to be seen in the summertime in other parts of the country as well. And Federal researchers found elevated lead levels from gasoline in the air and in children. Air pollution was not just stagnating, it was getting worse.¹

The news of serious health effects from air pollution episodes and public perception of a worsening problem came at a time of major social and cultural change—as well as an increased



Pittsburgh 1905. Photo: Kingsley Association Records, 1894-1980, AIS.1970.05, Archives Service Center, University of Pittsburgh.

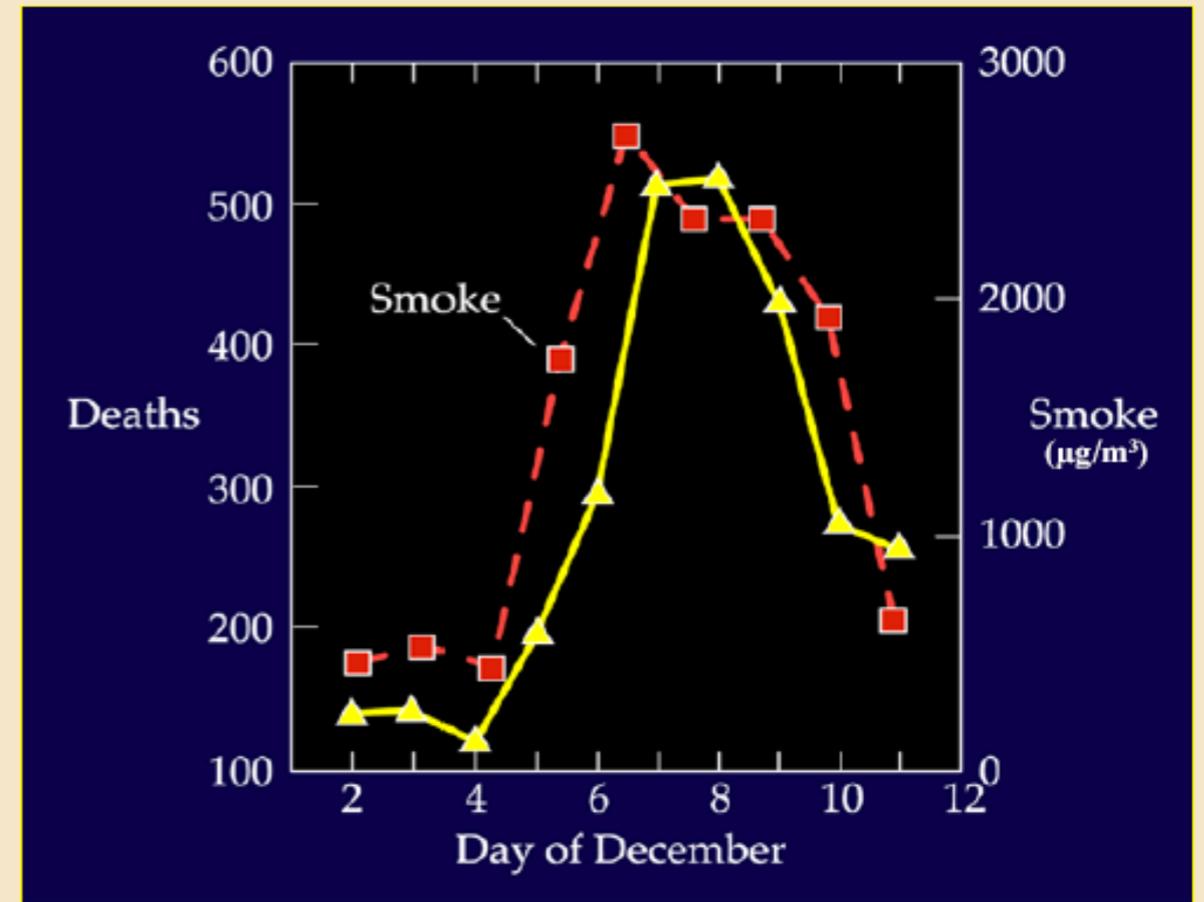
“Coal soot, for example, was particularly invidious, for it not only coated everything in the city with black dust... Soot found its way into cupboards and clothes, attics and cellars, and it colored the cheeks of the city’s children as they played in the street.”—D. Stradling³

national perception of environmental conditions as an important issue. In 1960, only six states had air pollution programs. The public demanded action and elected officials responded with an increasingly broad succession of national clean air legislative

Two Major Episodes that Established Air Pollution as a Significant Health Risk



Foggy conditions caused a four-day spike in air pollution in Donora, a small industrial town of 14,000 in Pennsylvania. During the episode, 20 people died and 6000 people suffered respiratory problems described as “a gasping for air and complaints of unbearable chest pains.”⁴ The Donora story made national headlines; one researcher said it showed “for the first time that air contamination in an industrial community can actually cause acute disabling diseases.”⁴⁹



On December 5-12, 1952, the worst air pollution disaster on record struck London, England.

Emissions from coal combustion built up in stagnation conditions causing a rapid rise in smoke particles (red) and gases including sulfur dioxide.⁵ Initially, the heavy smog obliterated visibility and cancelled events, but eventually official reports noted crowded hospitals and increased deaths (yellow). A report a year later estimated 4000 deaths during the episode, although a more recent reanalysis counting delayed responses estimated 12,000 premature deaths during and up to four months after the episode.



Earth Day Demonstration 1970. Photo: University of Michigan School for Environment and Sustainability, flickr photostream

requirements, research, and funding to develop state programs in 1963, 65, and 67.¹ Nevertheless, many viewed the progress made by government and industry as too slow. Pressure to do more about air pollution and environmental protection continued to mount, and by 1970 an estimated twenty million Americans attended one of many simultaneous ecological ‘teach-ins’ around the country on the first Earth Day.⁸ The overwhelming public interest led directly to the [creation of EPA in December](#) and bipartisan support as President Nixon signed the [landmark Clean Air Act](#) Amendments of 1970 into law on New Year’s Eve.¹



Impetus for the Clean Air Act of 1970

Video: Howard H. Baker Jr. Center for Public Policy, University of Tennessee

2. Overview of the 1970 Clean Air Act¹

The 1970 Clean Air Act Amendments were a significant strengthening and expansion of previous air legislation. The new law established a detailed science-based air quality management approach to addressing air pollution. It directed EPA to establish health and environmental based national air quality standards based on scientific criteria. The states were required to monitor levels of air pollution, identify those areas not meeting the national standards, and to develop and implement plans to meet them in 3 to 5 years. Given the scope of the problem in some areas, these deadlines were very tight. State air programs, many of which had been newly developed under the earlier federal legislation, had additional requirements for forecasting emissions and air quality, ensuring compliance with the emissions limits adopted in their state plans, and more. An important feature of air quality management was the requirement for using air quality monitoring to determine if plans were actually successful, and for additional measures to be applied if they were not.

To assist state programs and to address continuing growth in use of cars, the Act also included technology-forcing national emissions standards for new automobiles that required 90% reductions in hydrocarbons and carbon monoxide by 1975, and similar reductions for nitrogen oxides by 1976. The Act also required that EPA establish national technology-based



Signing the 1970 Clean Air Act. President Nixon, flanked by new EPA Administrator William Ruckelshaus and Council of Environmental Quality Chairman Russell Train. *Photo: Richard Nixon Library.*

standards for major new stationary sources, as well as minimum requirements for state air quality management programs.

The remainder of this report addresses three significant air pollution programs, including tackling smog in Los Angeles (Section 3), reducing emissions from motor vehicles (Section 4),

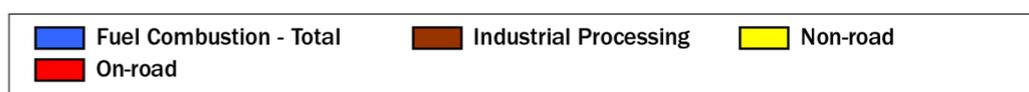
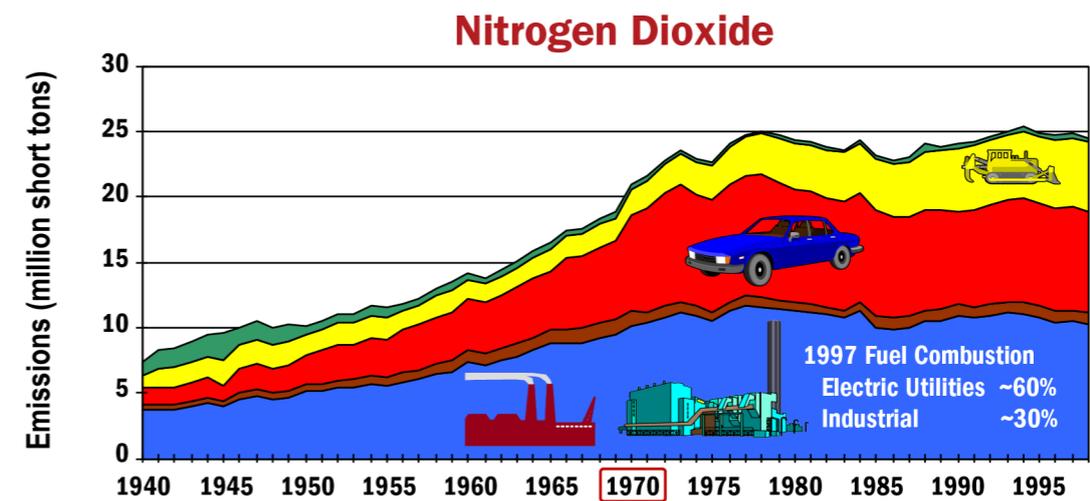
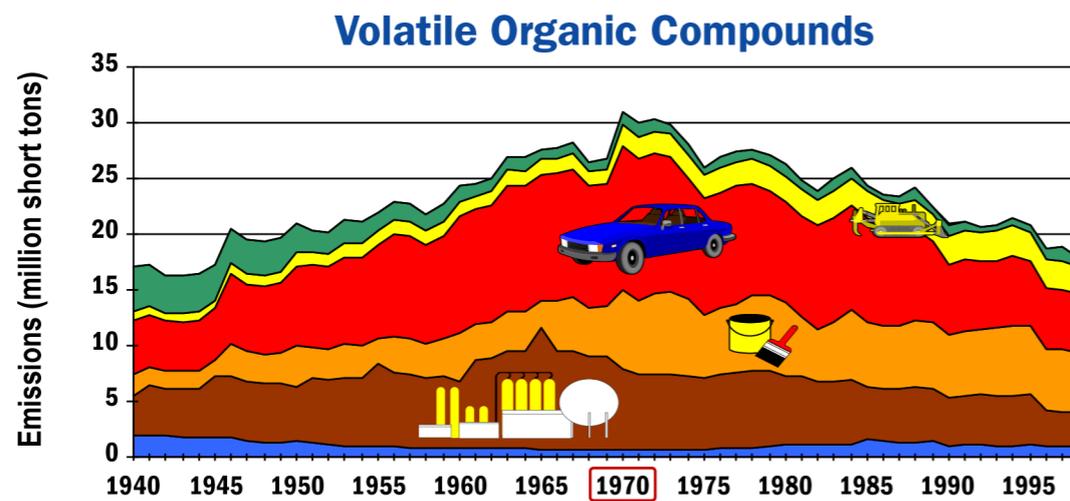
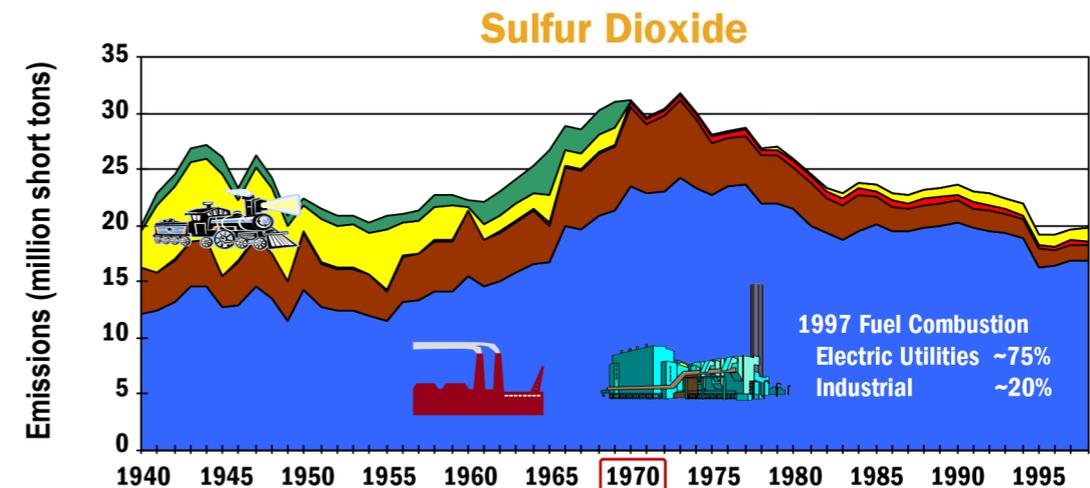
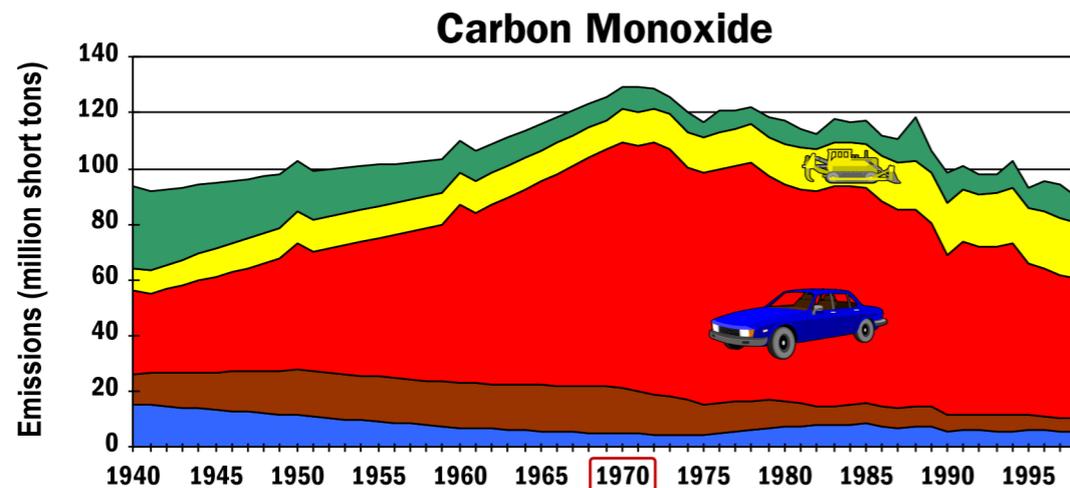
and addressing acid rain and particulate matter pollution ([Section 5](#)); documentation of the record of progress made by federal and state air programs under the Clean Air Act ([Section 6](#)); and future

threats and challenges in protecting these gains, and the need for continued improvements ([Section 7](#)).



Primary responsibility for implementing the Clean Air Act rests with the states, EPA, and affected sources. As illustrated on this chart, however, many other stakeholders have strong interests and roles in administration, oversight, judicial actions, and improving the process. Over the years, the Act and approaches to air quality management have evolved with new information.

Why Federal Intervention in Air Pollution Programs Was Necessary



Trends in U.S. emissions of four criteria air pollutants by sector (1940–1997).¹ Emissions for all major pollutants grew unchecked for decades (1940s–1970) with the rapid increase in automobiles and electricity production. These trends only began to change following passage of the 1970 Clean Air Act. As a result of federal legislation and funding in the 1960s, all 50 states had air quality programs by 1970, and were better prepared to implement the clean air programs. National automotive standards were a major cause of reductions in organic compounds (hydrocarbons) and carbon monoxide. They also helped stop the growth of total nitrogen oxide emissions. All three of these pollutants were the main cause of increased photochemical smog. After 1975, Clean Air Act policies and regulations, including Federal limits for new power plants and state plans to meet federal air quality standards, began to reduce sulfur dioxide emissions and limit nitrogen oxide increases from stationary sources. Growth in these emissions had increased fine particle concentrations and acid rain over broad regions in the eastern U.S. The sharp reductions of sulfur dioxide that began in the 1990s were the result of the market-based acid rain program mandated by the 1990 Clean Air Act amendments. As outlined later, emissions and air quality continued to improve after 2000.



3. Los Angeles Smog

California Leads the Way

The surprising appearance of a new kind of smog in the Los Angeles basin brought international notoriety to the area in the 1940s and 50s. It was not until 1952 that extensive research by Cal Tech scientist [Dr. Arie Haagen-Smit](#) found that the haze and irritant gases were *not* directly emitted from smokestacks or other sources, but were created in the atmosphere by reactions of hydrocarbon and nitrogen oxide emissions from automobiles, refineries, and other sources in the presence of sunlight.⁷

They called it photochemical smog. **Ozone**, a reactive form of oxygen (O₃), and other irritant gases and particles were the key components. The physical characteristics of the Los Angeles basin and abundant sunshine combined to trap the growing emissions and produce high levels of smog on many days of the year. In effect, some of the features that attracted people to California began to make it less desirable.⁷

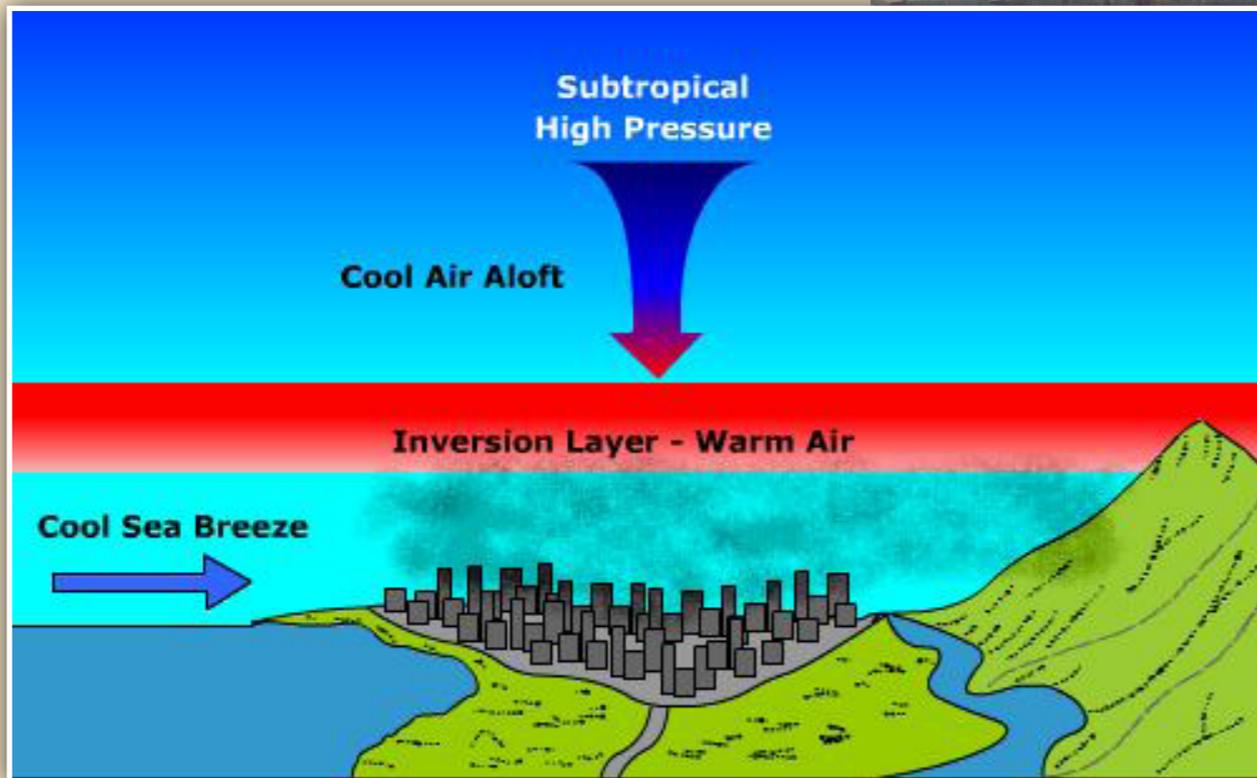
The implications of Haagen-Smit's unexpected findings were met with resistance from interests reluctant to regulate emissions from personal vehicles. But photochemical smog episodes continued to worsen, and in 1955 reached an all-time high of 0.68 parts per million (ppm) ozone—about nine times greater than EPA's 1971 health standard.⁹ In response to public concerns, Los Angeles authorities established guidelines to provide advice and

warnings about the severity of the episodes. They also began to lay the groundwork for reducing automotive emissions. In 1960, the California Legislature authorized creation of a board to test and certify automobile emissions controls; it also required that as of 1963, new vehicles had to be equipped with a special valve to reduce emissions.¹⁰ In 1966 California set first-in-the-nation auto tailpipe emissions standards for hydrocarbons and carbon monoxide. Congress included a waiver in the 1967 Air Quality Act that permitted California to continue to establish automobile emissions standards that were more protective than those required for the rest of the nation. After Governor Reagan named Haagen-Smit to head the new California Air Resources Board in 1968, the state added tailpipe standards for nitrogen oxides in 1971.

Although analyses could detect small improvements in some measures of ozone after 1963, by 1974 the levels in the Los Angeles Basin remained far higher than anywhere else in the country. In that year Los Angeles exceeded EPA's 2008 health-based air quality standard on 211 days. California continued to experience rapid growth in cars and population, while saddled with some of the most smog-promoting meteorological conditions in the world.

Making Smog

The weather and geography of the southern California basin are conducive to frequent [inversions](#), characterized by warm layers that act as a lid to trap air pollutants. Abundant sunlight promotes the formation of ozone, particles, and other photochemical products. The rapid growth of traffic and population added to the challenge of reducing the resulting air pollution.



View of the Port of Los Angeles and Long Beach, California. Photo: Nick C. Prior, CC.

The 1970 Clean Air Act and its Impact on Smog in the Los Angeles Region

The 1970 Clean Air Act Amendments, and their implementation at the local, state, and federal level, ultimately made a major contribution to reducing smog in the Los Angeles Region—the second largest metropolitan area in the U.S. Although Congress delayed adoption of tailpipe standards in 1974, by 1975 new cars were being equipped with catalytic converters to control hydrocarbons and carbon monoxide—and by 1981, they were upgraded to meet stricter limits for nitrogen oxides (see next section). As required by the Act, California submitted a plan to clean up the region’s smog problem in 1972. The reductions included in the plan were, however, inadequate to meet EPA’s new health standards for the Los Angeles Basin within the ambitious five-year schedule then allowed under the law. After litigation by a local public interest group,¹¹ EPA proposed a replacement plan that included transportation control measures to address pollutants emitted by motor vehicles as a supplement to controls on major industry and other stationary sources that had been adopted by local and state air quality agencies.¹ Some of these transportation measures were highly unpopular.

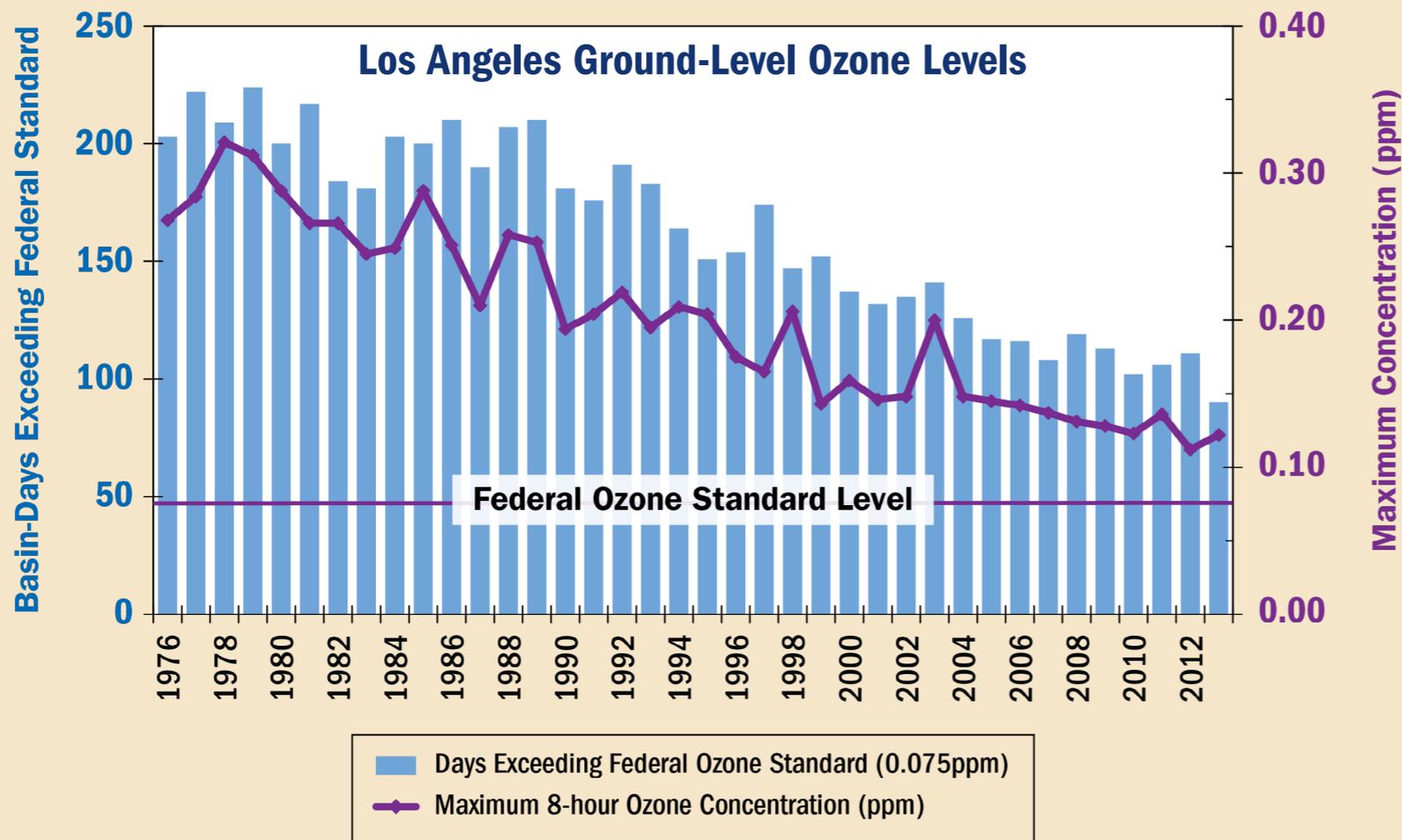
Because of the difficulties California and other state agencies faced in meeting the standards on time, Congress amended the Act in 1977 to permit more practical extended deadlines.¹ The Act also confirmed an EPA “offset” policy originally applied to Los Angeles in 1974. This policy permitted the use of emissions trading to accommodate economic growth while maintaining

progress toward attaining the national ambient air quality standards (NAAQS) under the Clean Air Act. In an effort to accelerate progress towards attainment, the amendments also required states not meeting the air quality standards to consider some of the measures in EPA’s plan for Los Angeles, including mandatory vehicle inspections. Transportation planning to reduce vehicle miles traveled, including programs such as high occupancy vehicle lanes and other incentives for car-pooling, became viable air pollution control strategies, continuing to this day. Public pressure on the auto industry to continue to improve auto emission controls, and on Congress to fund more mass transit, can be directly related to these initial transportation control plans.

The successful implementation of California’s plan for Los Angeles, as well as in much of the rest of California, led to definite signs of improved air quality beginning in the early 1980s. The 1977 Clean Air Act Amendments had added specific technology and progress requirements and greater penalties in the form of sanctions and construction bans for those areas failing to comply with the Act. Citizen groups continued to apply legal pressure on the EPA to meet deadlines and to propose federal implementation plans where state and local plans were not succeeding.¹² Throughout the 1980s, as pending deadlines from the 1977 Amendments came and went in parts of California, EPA worked closely with California’s air agencies to assure that every “reasonable, extra effort” was made to improve air quality.

These efforts ranged from approving actions under the “California waiver” to expedite more protective automotive emission standards to using EPA’s legal mandate to impose highway funding sanctions. Progressive state and local tailpipe, engine, and other emissions standards followed. In 1978, California required gas stations in many areas to install vapor recovery “boots” on gas nozzles to reduce ozone-forming gasoline emissions. The threat of sanctions convinced the California legislature to authorize a vehicle smog check program in 1984. In 1988, California enacted

a state clean air act that served as a model for some provisions adopted in the 1990 Amendments to the Federal Clean Air Act. Following a court order EPA again promulgated a federal backup plan. California responded with a new plan that EPA approved in 1996. Pursuant to the plan, the state implemented a new clean gasoline program that reduced emissions of smog-forming volatile organic chemicals by 300 tons/day, the equivalent of removing 3.5 million cars from the road.



Ozone Trends in California’s South Coast Basin, 1976-2012.¹³ Despite substantial growth in population and traffic and difficult weather that promoted smog formation, by 1978 harmful ground-level ozone levels in the Basin began to decline and the trend continued for decades. This chart depicts the 2008 Federal 8-hour standard. EPA strengthened the standard to 0.070 ppm in 2015.

The dramatic reduction in air pollution levels in California over the past four decades is an excellent example of how strong legislation, aggressive enforcement at the local/state/federal levels, and forcing technology for virtually every source of air pollution—from consumer products to changing the composition of gasoline—can successfully improve public health. EPA involvement played a major role in this success story. California’s state board and local agencies, often with larger staffs and with a longer historical record of innovative emissions control programs, adopted many advanced regulations to avoid having the Federal plan implemented in the State. These major technological and regulatory actions began with the 1970 Clean Air Act and demonstrated, at least in one state, that air pollution can be reduced by combined federal and state actions. Moreover, California programs have promoted electric vehicles, low pollutant-emitting paints, and other innovations that have become more widely adopted by others.

In summary, the actions taken by EPA, California, and Los Angeles area air pollution agencies have resulted in very significant improvements to air quality in Southern California since 1970.¹³ This is despite the combined growth in California’s population from 20 million in 1970 to nearly 39 million in 2012,¹⁴ and of registered motor vehicles from 12 million in 1970 to 27.7 million in 2012.¹⁵



Public electric vehicle charging at the South Coast Air Quality Management District Headquarters. The district is promoting the use of zero emission electric vehicles in its effort to continue smog reduction and to meet California climate targets. The SCAQMD charges its fleet of electric vehicles as well as providing free charging to the public. *Photo: South Coast Air Quality Management District*

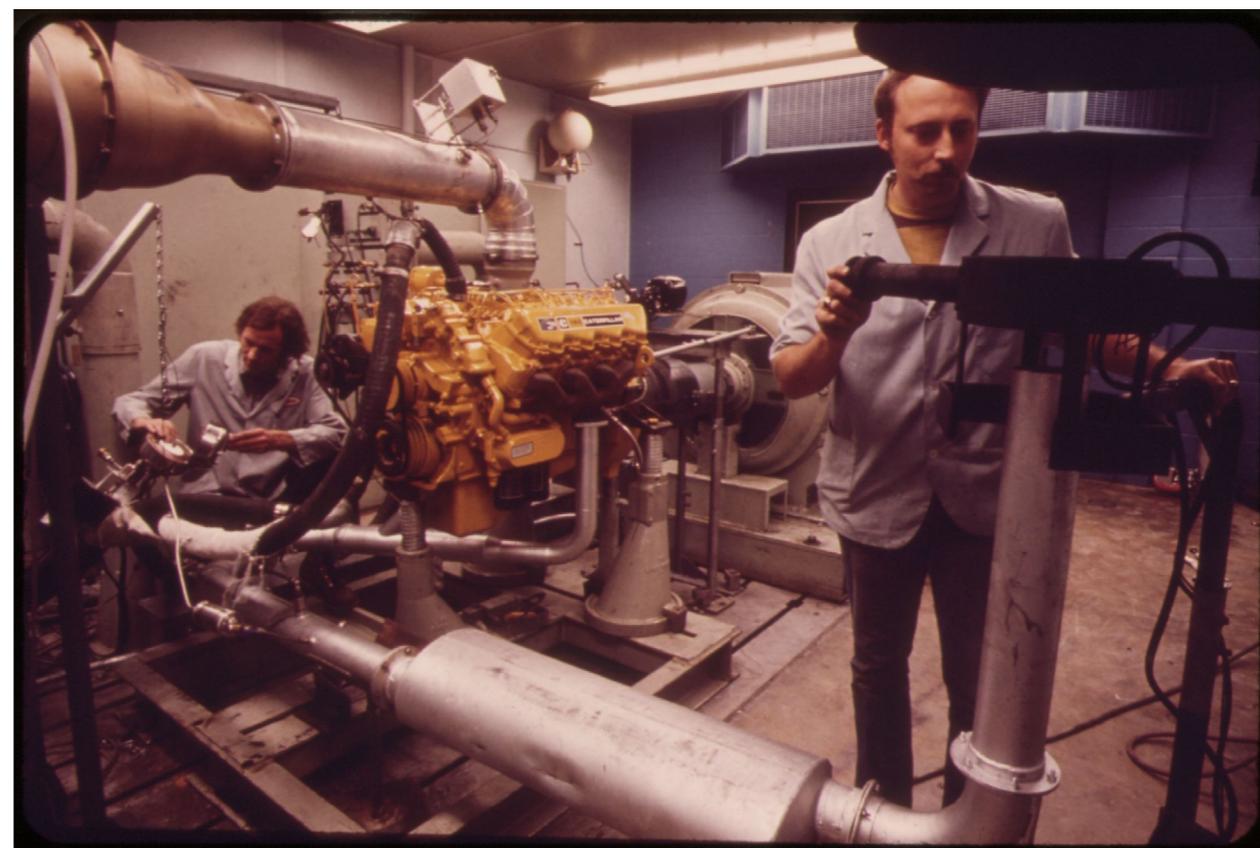
4. National Vehicle Emissions

Over the past two centuries, while the earth's population has increased seven times and global Gross Domestic Product (GDP) has increased 100 times, personal mobility has increased 1,000 times.¹⁶ The internal combustion engine was the most important technology in this transformational increase in personal mobility, particularly in America. But the benefits of personal mobility came with a huge cost. As outlined above, beginning in the 1940s, people in Los Angeles experienced waves of unexplained pollution that caused teary eyes, headaches, nausea, asthma attacks, and other reactions. In the 1950s school children were kept indoors during high-risk days. By the mid-1960s state and local agencies as well as the Federal government began to realize that smog from vehicle emissions had become a major contributor to air pollution throughout the country.¹

Over the past five decades under the Clean Air Act, the EPA has implemented a massive reduction of automobile emissions with new technologies and improved fuels. As required by the Act, the agency initially set tough automobile standards to clean up the air—a 90 percent reduction in hydrocarbons and carbon monoxide by 1975, with a similar reduction for nitrogen oxides by 1976.¹ But EPA's job wasn't easy. The Big Four automakers claimed a cleanup of tailpipe emissions risked a business catastrophe. "It is conceivable that the complete stoppage of the entire GM

production could occur," said General Motors in 1975, "with the obvious tremendous loss to the company, shareholders, employees, suppliers and communities."¹⁷ But EPA Administrator Ruckelshaus held firm and the regulations took effect.¹⁸

Two years later, the largest of what were then the Big Four automakers took out newspaper ads with a headline that happily read, "General Motors believes it has an answer to automotive air pollution problem...and the catalytic convertor has enabled



Technicians evaluating early catalysts in EPA's Ann Arbor Laboratory. Photo: Joe Clark, National Archives.

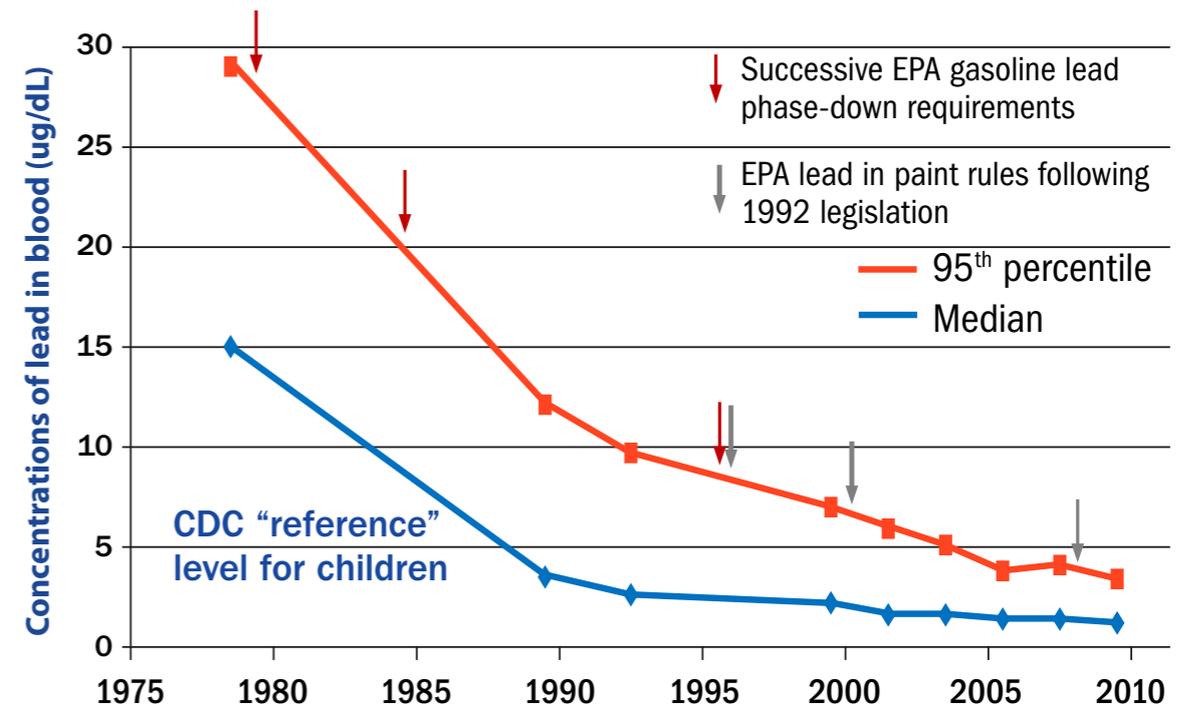
GM engineers to improve performance and to increase miles per gallon.”¹⁹ The ads went on to list the virtues of the new technology: the technology is safe, it is cleaner, it doesn’t reduce performance, and it improves efficiency. In a paid ad, GM refuted virtually every argument against the technology it had made earlier.

The introduction of the catalytic converter is a very successful example of the kind of revolutionary changes and technology-forcing actions that the EPA was capable of in the 1970s. Today it is hard to find any cars in the world without this feature. Ironically, the emissions standards that American automakers resisted so vehemently in the early 1970s made American businesses world leaders in clean emissions technology.

Once the catalyst technology had been developed, another problem cropped up. At the time, all gasoline contained a lead additive to increase octane and prevent engine knock. But lead also gummed up the chemical reactions that allowed catalytic converters to clean auto exhaust. After only about 10-15,000 miles, the catalytic converters would be nearly useless. For the new air-cleaning technology to work properly, the U.S. would have to get rid of leaded gas. Over the next two decades, leaded gas disappeared from America’s filling stations.

This reduction was also motivated by the recognition that removing lead from fuel came with significant additional public health benefits (see figure).²⁰ Lead causes numerous adverse human

Blood Lead Levels in Children, 1976–2010

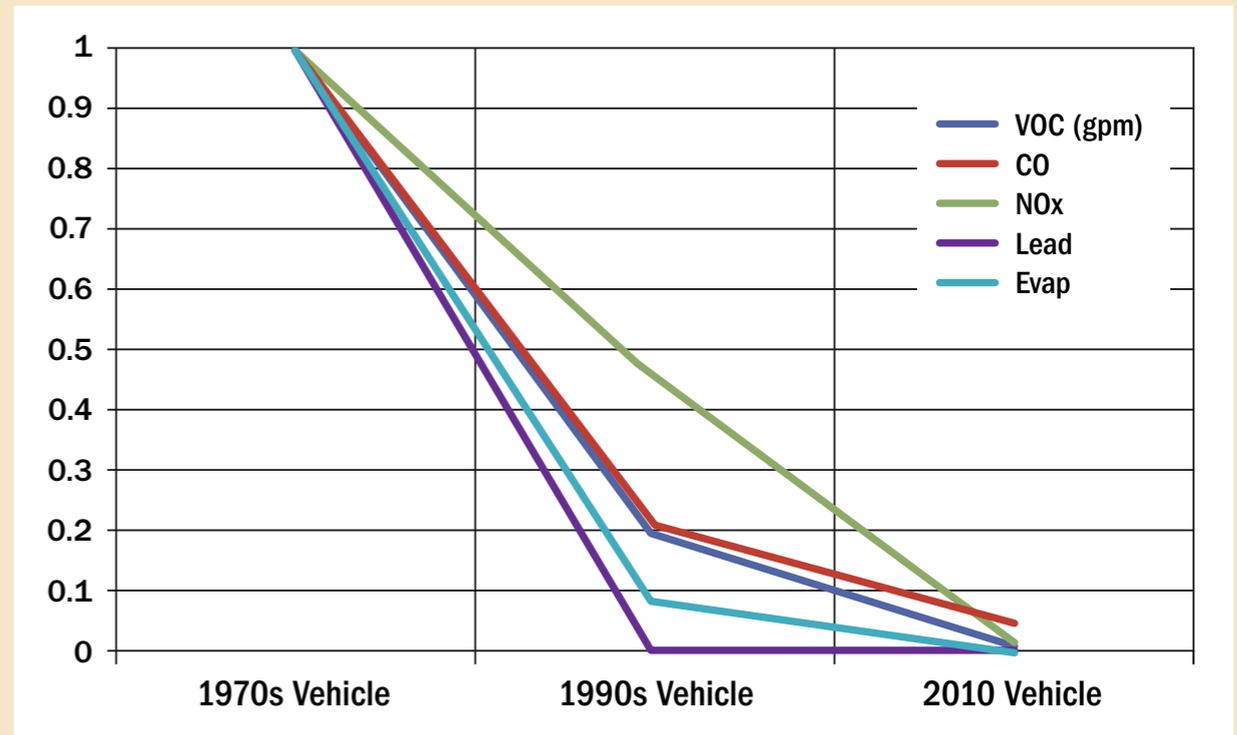


Harmful blood lead levels declined in average (median) and most affected (95th percentile) children in response to successive EPA requirements to remove lead in gasoline adopted in 1979, 1985, and 1996. Other programs, including reduced lead in paint, also contributed to lead level declines in the mid-1990s. The current Center for Disease Control (CDC) reference level for exposed children is 5 micrograms per deciliter.

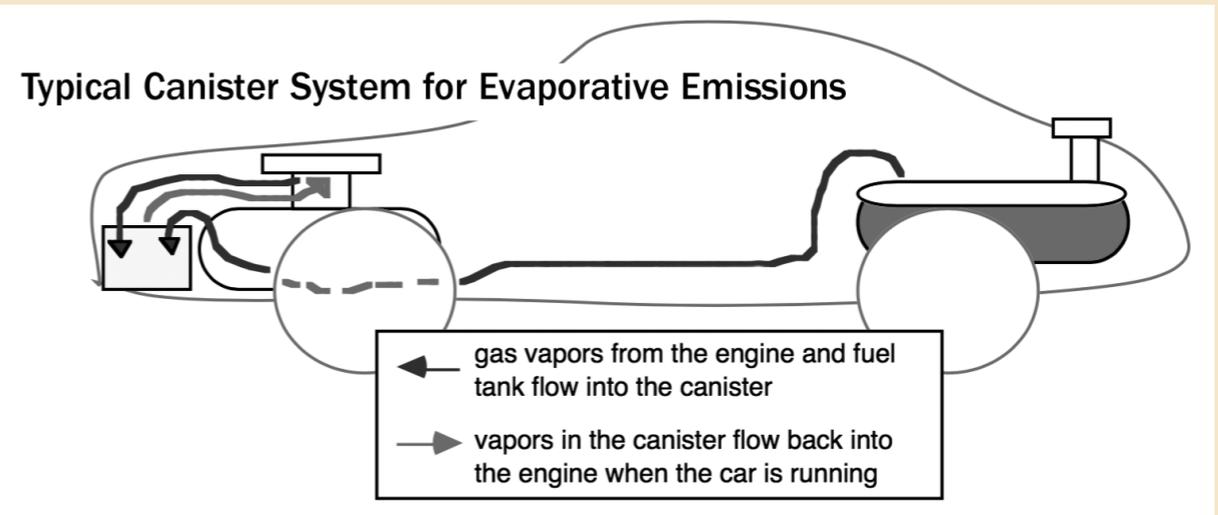
health effects, but is particularly detrimental to neurological development in children.²¹ Lead reductions are estimated to have prevented the cumulative loss of over 10 million IQ points in American children.²² The U.S. was the first country to eliminate lead. European nations and other countries followed, and today gasoline is almost lead-free across the planet.

EPA undertook similar programs to address emissions from other mobile sources including trucks, locomotives, marine engines, and agricultural and construction equipment. EPA also required improved formulations for cleaner burning gasoline and diesel fuels. Since the 1970s cars, trucks, buses, locomotives, marine engines, and other mobile sources have become up to 99 percent free of conventional pollutants like hydrocarbons, carbon monoxide, nitrogen oxides and particle emissions.²³ Sulfur in gasoline and diesel has been reduced by over 90 percent. Collectively, it is estimated that the mobile source emission rules established in the past 20 years will, when fully implemented, prevent an estimated 40,000 premature deaths, even larger numbers of cases of respiratory symptoms, and the loss of 4.7 million days of work lost due to pollution-related symptoms each year.²⁴ In monetary terms, the estimated health benefits of these rules are 20 times higher than their combined costs—an enormous positive outcome.

In conclusion, clearly the progress that EPA has made in regulating vehicles under the Clean Air Act has been a major factor in the reduction of air pollution levels throughout the nation since 1970.



Clean air act reductions of multiple pollutants from cars.²³ Since 1970, the allowable emissions from individual cars (in grams per mile—left vertical axis) have been reduced by over 90% for lead and three pollutants that contribute to photochemical smog—volatile organic chemicals (VOC), carbon monoxide(CO), and nitrogen oxides (NOx). As a result, U.S. national emissions of these pollutants have decreased despite an over 400% increase in total miles driven each year.



Controlling evaporative emissions. These controls prevent evaporation of gasoline (VOC), reducing pollution with a net cost savings.

5. Smoke, Fire, and Acid Rain

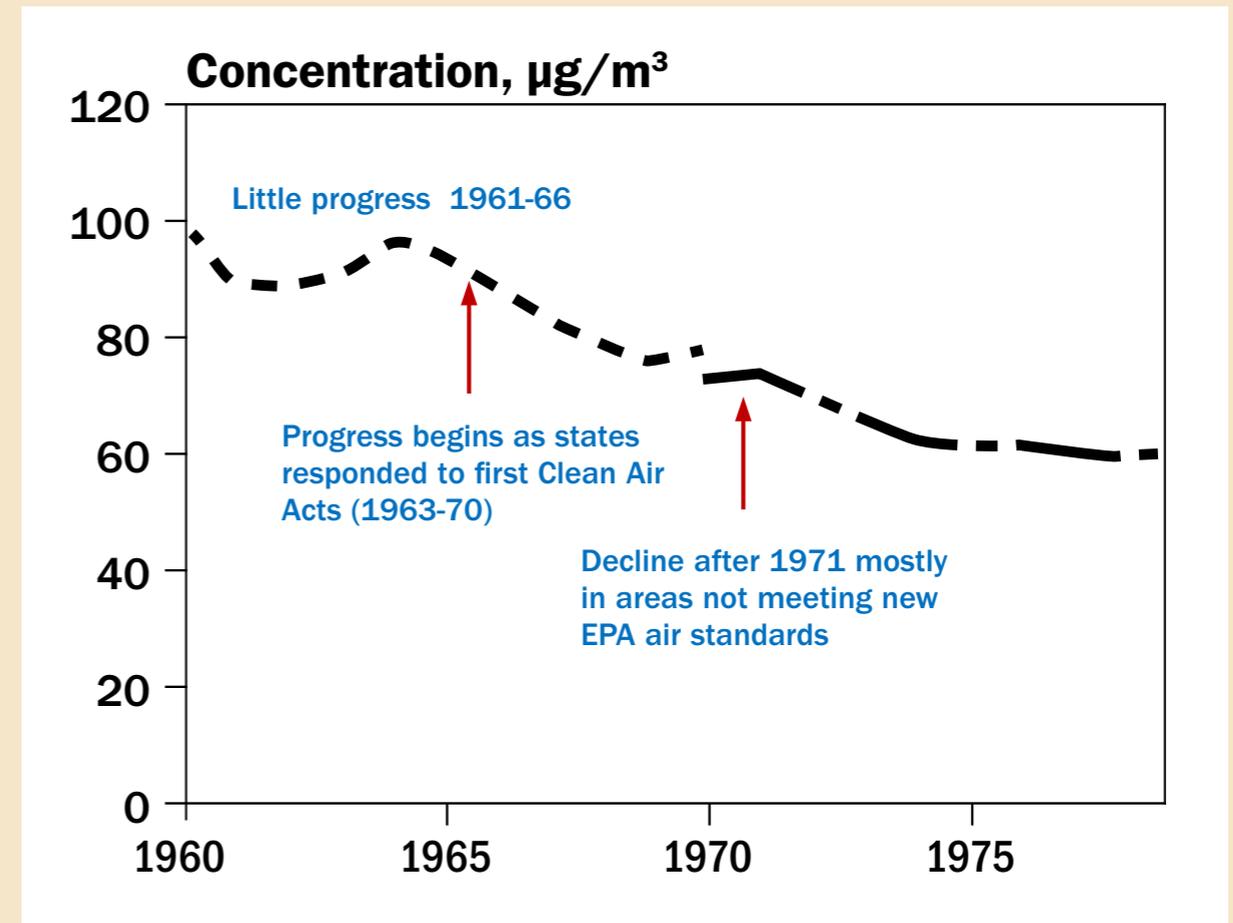
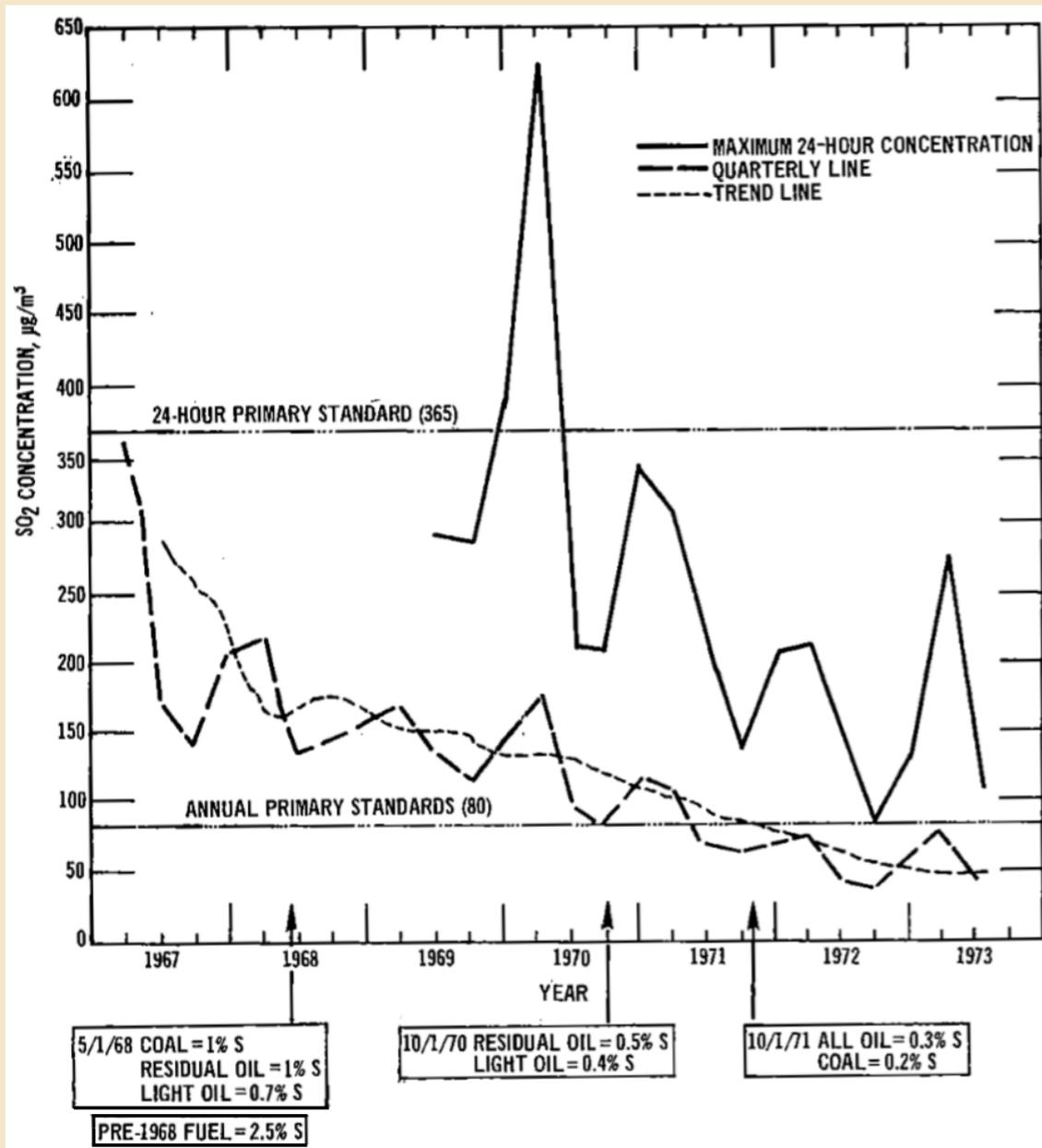
As noted above, by the mid-1960s the combination of particles and **sulfur oxides** from coal combustion in eastern urban areas had been implicated in air pollution-related deaths and illness during successive air pollution episodes. Accordingly, in much of the country, the new approaches established under the 1970 Clean Air Act initially focused on combustion sources that were the major contributors to unhealthy levels of sulfur dioxide and particle pollution then found in many cities. As shown in the actual measurements (see figures page 21), these early programs were highly successful in reducing both pollutants.^{1,25}

Despite these significant early successes, the Clean Air Act requirements for research and tracking air quality and emissions revealed some important limitations in the effectiveness of these programs, as well as new threats to public health and the environment. The air quality data showed that—as expected—sulfur dioxide and particle levels *decreased* in urban areas, but concentrations of both pollutants *increased* or stayed flat in many rural locations. The measurements also showed that acidic sulfate particles, a large portion of the smaller **fine particles** that originate from atmospheric transformations of sulfur dioxide, were *increasing* in the summertime throughout the Eastern U.S. Fine particles can travel hundreds of miles from sources. These factors accounted for the observed increase of particle pollution in rural areas.

A harder look at the trends in emissions over the period provided the explanation for the increase in sulfur dioxide gas and sulfate particles. As shown in the actual measurements (see next page), these early programs were highly successful in reducing both pollutants.^{1,25} But large sources of sulfur dioxide, such as coal-fired power plants, were growing in size and numbers. These large sources were able meet the ground-level sulfur dioxide standards by building tall stacks (which dilute the maximum levels reaching



Coal-fired plant, circa 1942. Photo: U.S. Library of Congress, Alfred Palmer.

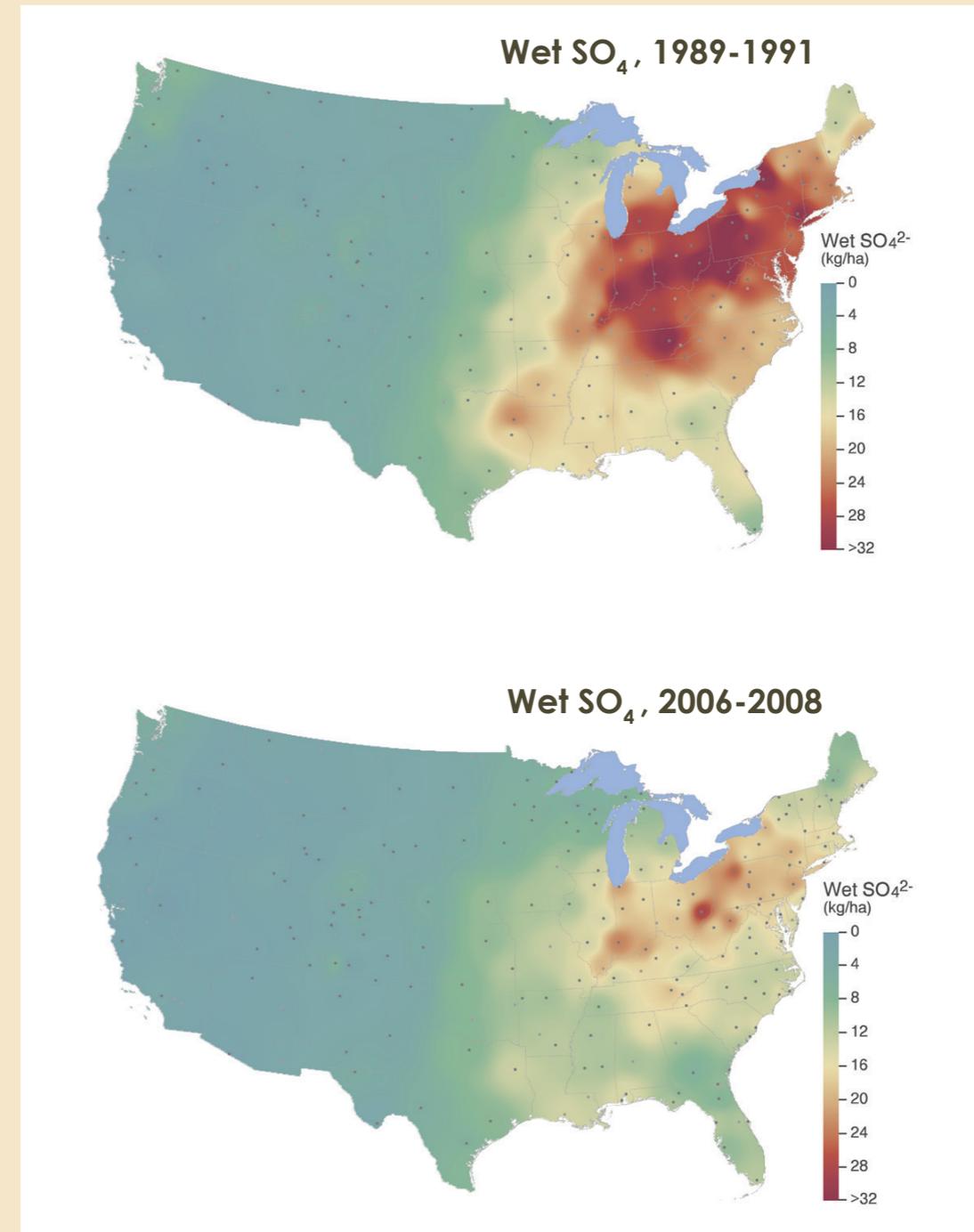


New clean air regulations greatly reduced the high urban levels of sulfur dioxide and particle pollution.^{1,25} **Left:** Sulfur dioxide levels declined in Bayonne, NJ following stronger state and local limits on combustion fuel sulfur content. The area met EPA's health standards by 1972-73. The peaks varied and were higher during the winter heating season. Sulfur limits drove shifts towards cleaner fuels, including low-sulfur oil and gas. Fuel sulfur limits were used in a number of other cities to meet the sulfur dioxide standards. **Right:** National trends in average total outdoor particle pollution measured at 122 mostly urban monitors (1960-70) and 1109 monitors (1970-79). The decline began with state, municipal, and federal actions in response to clean air act legislation in the 1960s. The continued decline in the average particle pollution levels in the larger number of areas required to monitor under the 1970 law mostly occurred in those cities that violated EPA's health-based particle standards. The switch to cleaner fuels reduced particle emissions as well as sulfur dioxide in cities; states and municipalities also added requirements for particle-capturing control technology on major sources.

the ground) and by locating new plants in rural areas away from urban restrictions. As seen in the [emissions trends chart](#) on page 11, the net result was a continuous increase in total sulfur dioxide emissions between 1955 and 1975.

In addition to the health concerns that were raised by the increased levels of fine acid-sulfate particles, a new issue emerged: widespread acid rain. Researchers found large regions were experiencing levels of rainfall acidity strong enough to harm fish and other aquatic life in geologically sensitive lakes and streams in the Eastern U.S. and Canada that lacked adequate capacity to neutralize the acids. Deposition of sulfuric and nitric acid from increased air emissions of sulfur and nitrogen oxides was determined to be the major cause.

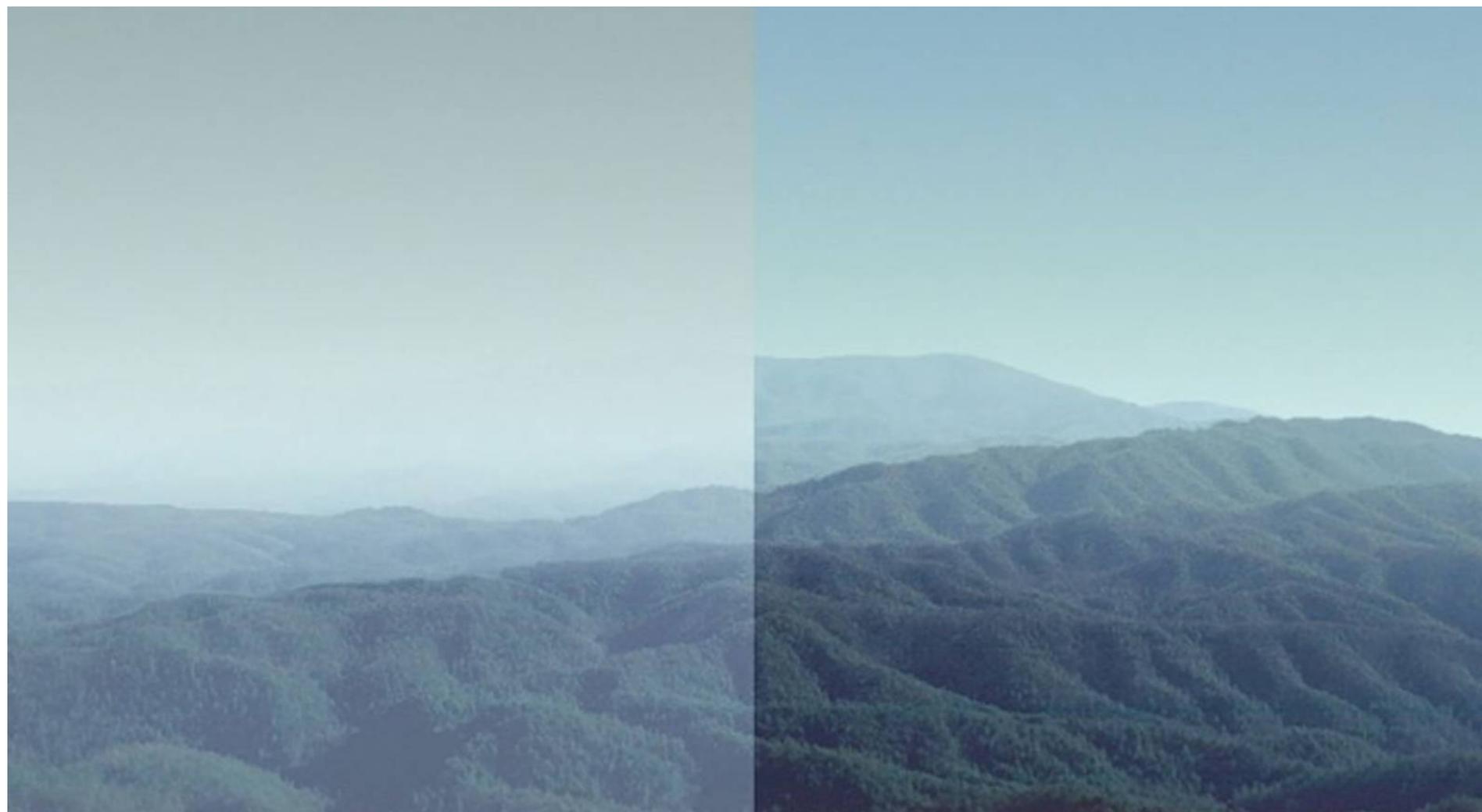
After 1975, EPA policies and regulations under the Clean Air Act halted increases of both sulfur and nitrogen oxide emissions, and prompted an initially slow but continuous reduction.¹ At the same time, research into the health effects of smaller “fine” particles, the environmental effects of these pollutants (e.g., acid rain), and the relationship between emissions and the observed effects was expanded during an extended period of national debate over the need for stronger reductions. Ultimately, Congress passed the 1990 Clean Air Act amendments, which mandated an innovative [market-based](#) program for cost effectively reducing sulfur oxide emissions from power plants. Sulfur oxide emissions were capped at a level that would achieve close to a 50% reduction. The 1990 amendments also mandated limits on nitrogen oxide emissions



Acid Rain Program Success.²⁶ Measurements of rain and snow before and after the acid rain and related programs show a dramatic reduction of acid sulfates deposited in precipitation. The regions of greatest sulfate reductions originally had the highest sulfur oxide emissions.

from power plants, as well as more protective mobile emissions standards for nitrogen oxide and other automotive pollutants discussed above.^{1,26} By the early 1990s new health effects studies found that fine particles were implicated in a significant increase in death rates at far lower levels than previously believed. EPA finally established the first standards for these fine particles in 1997. Other research found additional reductions in sulfur oxides emissions would be needed to meet them. The acid rain program and the additional programs to address fine particles and mercury from power plants and other sources produced dramatic

emissions reductions and benefits to health and the environment that are continuing today.²⁷ Regulatory analyses of three specific programs indicate that, when fully implemented, the sulfur and nitrogen oxide reductions from the acid rain, fine particle, and mercury regulations for power plants would prevent a combined 34,000 to 45,000 premature deaths and 4.3 million lost days of work per year.²⁷ Put in economic terms, the analyses indicate that the range of estimated cumulative health benefits of these three programs are 20 to 37 times larger than the societal costs.



A visible improvement in air quality in the Great Smoky Mountains.⁵⁶ A comparison simulating the haziest days observed in 1990 (left) with those observed in 2010 (right). Fine particle reductions are responsible for the improved visibility. These reductions are largely attributed to lower regional sulfur oxides emissions induced by Acid Rain program and subsequent Clean Air Act regulations. Photo/Simulation: Jenny Hand, Colorado State University.



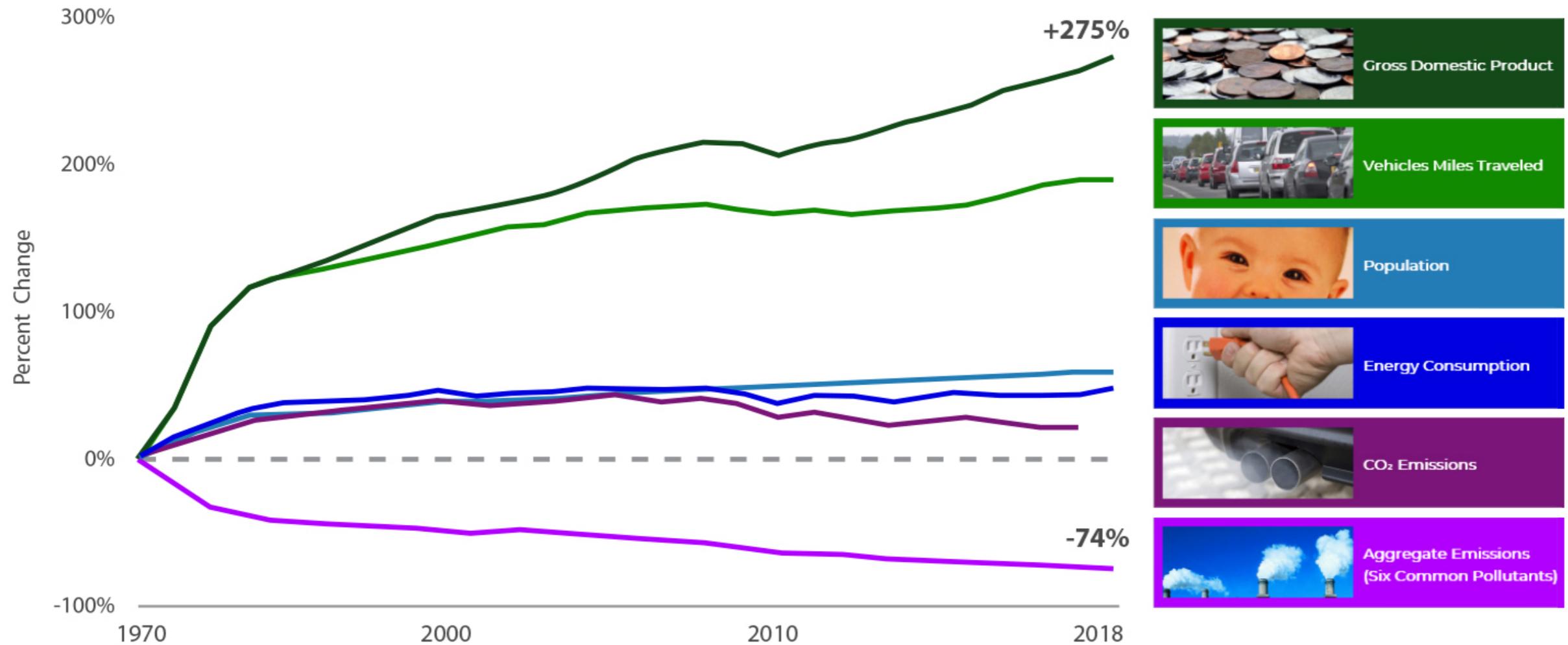
6. Summarizing the Progress Made under Clean Air Act Programs

Today, we have ample data to document the progress made under the Clean Air Act as amended in 1970, 1977, and 1990.²⁸ Indeed, measuring progress—or lack of it—is one of the most important requirements of these laws. The data include air quality trends from widespread air monitoring, emissions trends from state inventories and in-(smoke)stack monitors, and extensive analyses of the costs and benefits realized by implementing pollution reduction programs under the Act. The long-term data show that the U.S. has made tremendous progress in reducing both air pollutant emissions²⁹ and ambient concentrations of the major pollutants identified as having significant health and environmental effects (see figures on the next page). Until the Clean Air Act began to take hold in the early 1970s, national emissions of air pollutants had been steadily increasing for decades. The EPA, state, and local programs outlined above reduced emissions from vehicles as well as power plants and other stationary sources. These reductions have resulted in a continuing decline in human exposures to the major classes of key air pollutants for which EPA has established national standards.

Throughout the more than four decades of the Act, there have been repeated predictions that various air pollution regulations would damage the economy and increase unemployment. The record shows these forecasts were consistently overblown.^{30,31} As shown in the figure on the next page, the economy more than

doubled during this period. A number of analyses and studies have shown little to no overall effect on employment. Indeed, entire new industries have arisen that market innovative technologies to reduce air pollution. Moreover, EPA's first comprehensive peer-reviewed analysis of the Clean Air Act found that, between 1970–1990, the cumulative benefits to society ranged from about \$6 trillion to about \$50 trillion.³² These benefits generally represent the estimated value Americans place on avoiding the dire air quality conditions and dramatic increase in illness and premature death that would have prevailed without the clean air legislation and state/local programs. By comparison, the estimated compliance costs were about \$520 billion—the benefits were 12 to 96 times larger than costs. A recent major assessment of cumulative Clean Air Act benefits and costs realized or expected between 1990 and through 2020³³ found that the estimated benefits were 4 to 90 times greater than cost. A large fraction of the estimates in these studies is related to health effects, which are derived largely from valuations of decreased premature deaths due to fine particles and to a lesser extent ozone. These analyses project that clean air programs since 1990 will prevent 230,000 premature deaths per year as of 2020. Additional environmental benefits include better visibility; less damage to trees, crops and materials; and reduced ecosystem damage from acid rain. By all of these measures, the Clean Air Act has produced enormous

Comparison of Growth Areas and Declining Emissions 1970-2019

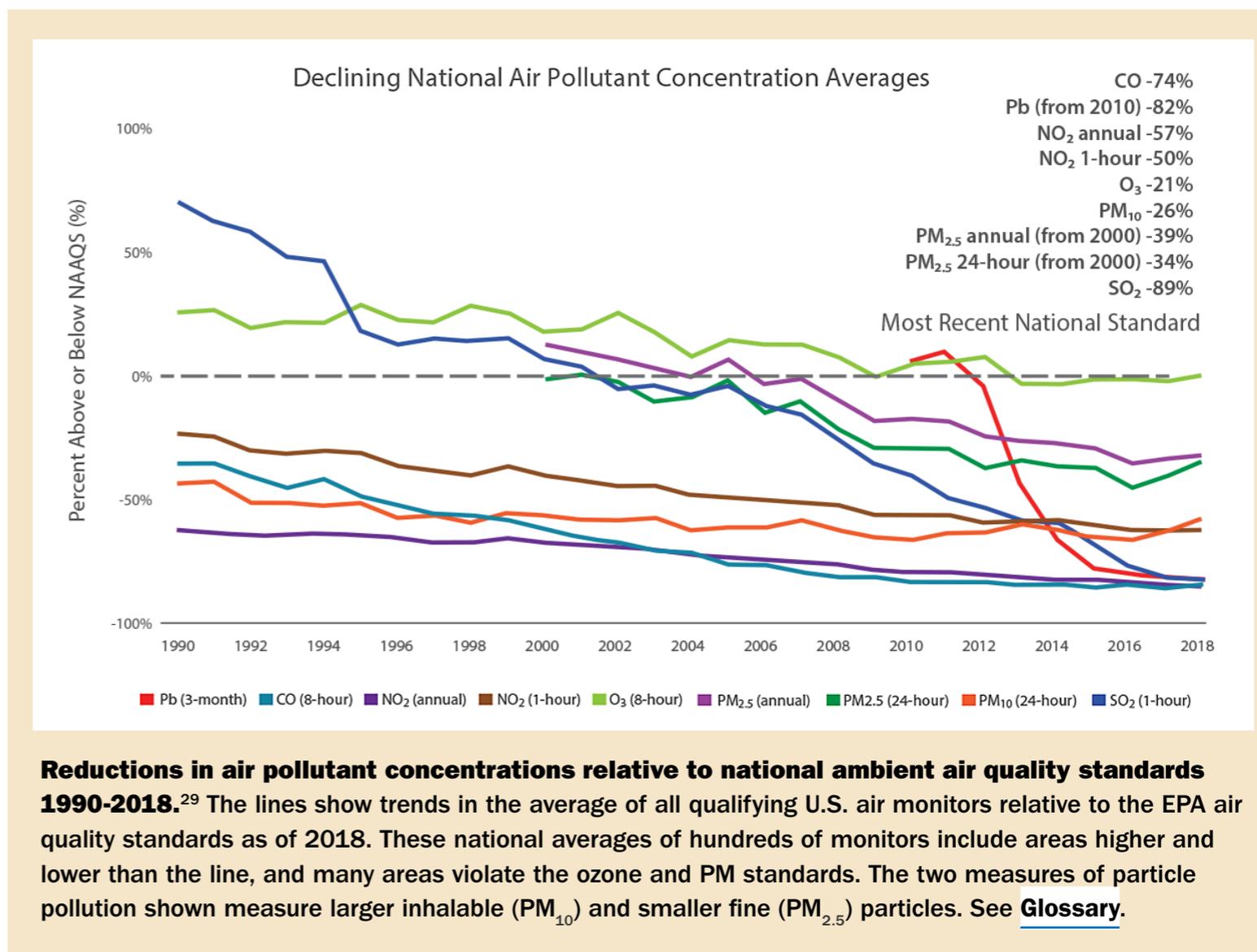


Clean Air Act programs reduced national emissions of regulated air pollutants despite growth in societal activities. This graph shows the percentage decrease in emissions of six air pollutants (74%) regulated under the 1970 Clean Air Act relative to their combined levels in 1970 (0% change), contrasted with the relative expansion of four societal/economic activities. Since 1970, emissions of regulated pollutants (bottom purple line) have steadily declined despite continued growth in population, energy consumption, traffic, and the economy. By contrast, carbon dioxide (CO₂), which was not targeted by these programs until 2012, has mainly tracked trends in energy consumption and traffic. The recent downturn in CO₂ emissions that began with the 2009 recession has continued due to several factors, including a leveling of total vehicle miles, a reduction in coal combustion for electric power generation as some power plants switched to natural gas, and a significant increase in power generation from renewable sources, particularly wind and solar.

progress, and has been an excellent investment towards the well-being of all Americans.

The progress made by the Clean Air Act is not limited to the programs aimed the six major air pollutants as summarized in the sections above. The 1990 Clean Air Act amendments also authorized new approaches for addressing particularly hazardous air pollutants and stratospheric ozone depletion.

Hazardous Air Pollutants (HAPs), also called “air toxics,” include carcinogens and substances capable of serious health effects (e.g. benzene, mercury and chloroprene) that often come from limited classes of stationary sources. Since 1990, EPA has issued emissions standards to control emissions of 187 HAPs from 174 categories of major stationary sources (e.g., chemical plants, oil refineries, aerospace manufacturing facilities, etc.), as well as from 68 categories of small “area” sources that represent 90 percent of the worst urban toxic pollutants. States have elected to administer or enforce many of these federal standards. These rules have reduced estimated major stationary air emissions of HAPs by 1.7 million tons per year, with additional reductions from other sources.



The regulations of vehicles to reduce smog discussed above have had the co-benefit of reducing many air toxic pollutants as well. Additional regulations targeted benzene and other HAPs in fuels that continued to pose health risks. Since 1990, these rules have reduced HAP emissions by about 1.5 million tons per year with further reductions expected as “Tier 3” vehicle and fuel regulations issued in 2014 are implemented.

The stratospheric ozone layer (about 10 to 50 km above earth’s surface) is critical to reducing part of the solar spectrum that

puts us at risk of skin cancer and cataracts. Chlorofluorocarbon (CFC) refrigerants, halons, and some other chemicals have in the past reduced this “good” ozone. Reversing the depletion of stratospheric ozone required international negotiations leading to the 1987 [Montreal protocol](#). The 1990 Clean Air Act Amendments provided EPA with the authority to develop and implement regulations to ban, phase out, or otherwise reduce these ozone-depleting chemicals. Collective global actions on reducing these chemicals are estimated to save millions of American lives from skin cancer and hundreds of millions from non-fatal skin cancers.



Thin line of Earth’s atmosphere and the setting sun. NASA

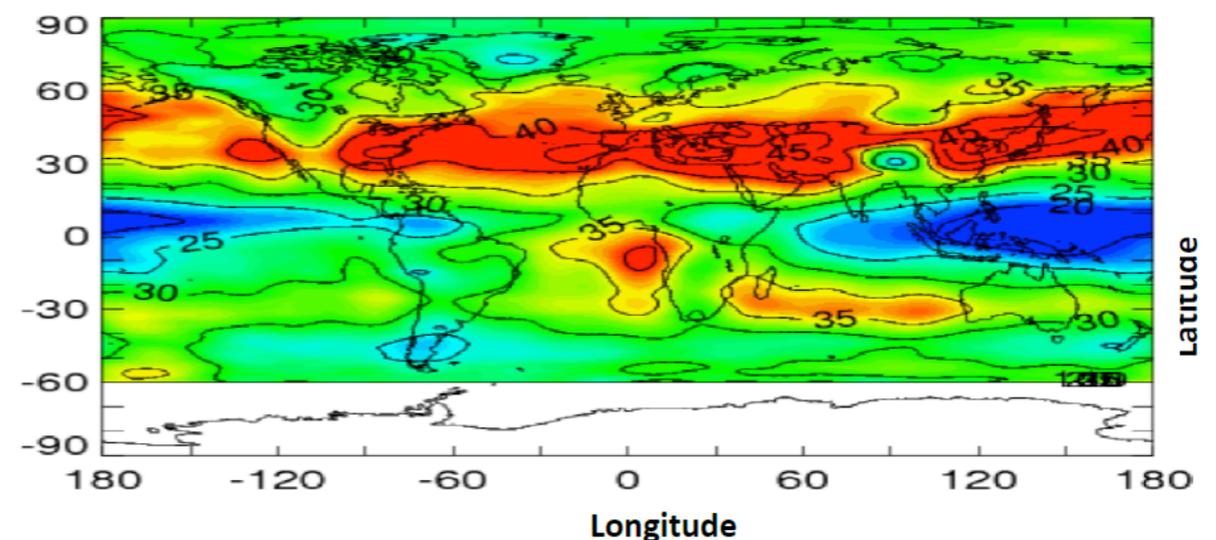
7. Future Challenges: Air Quality Management in a Changing World

Despite the overwhelming success of U.S. clean air programs since 1970, we are not finished with air quality management. While air quality is much improved nationwide, a number of U.S. cities still do not meet all of the current national ambient air quality standards (NAAQS). Based on recent assessments, it appears likely that fine particle and ground-level ozone pollution may remain responsible for tens of thousands of premature deaths and illness, even after new programs for vehicles and power generation are fully implemented.³⁴ New health research has been driving EPA's air standards to more stringent levels, making them more difficult to attain.

Expert groups have recommended improvements to air quality management approaches to increase their efficiency and effectiveness, including focusing on multiple pollutants when developing strategies, instead of addressing one pollutant class at a time.¹

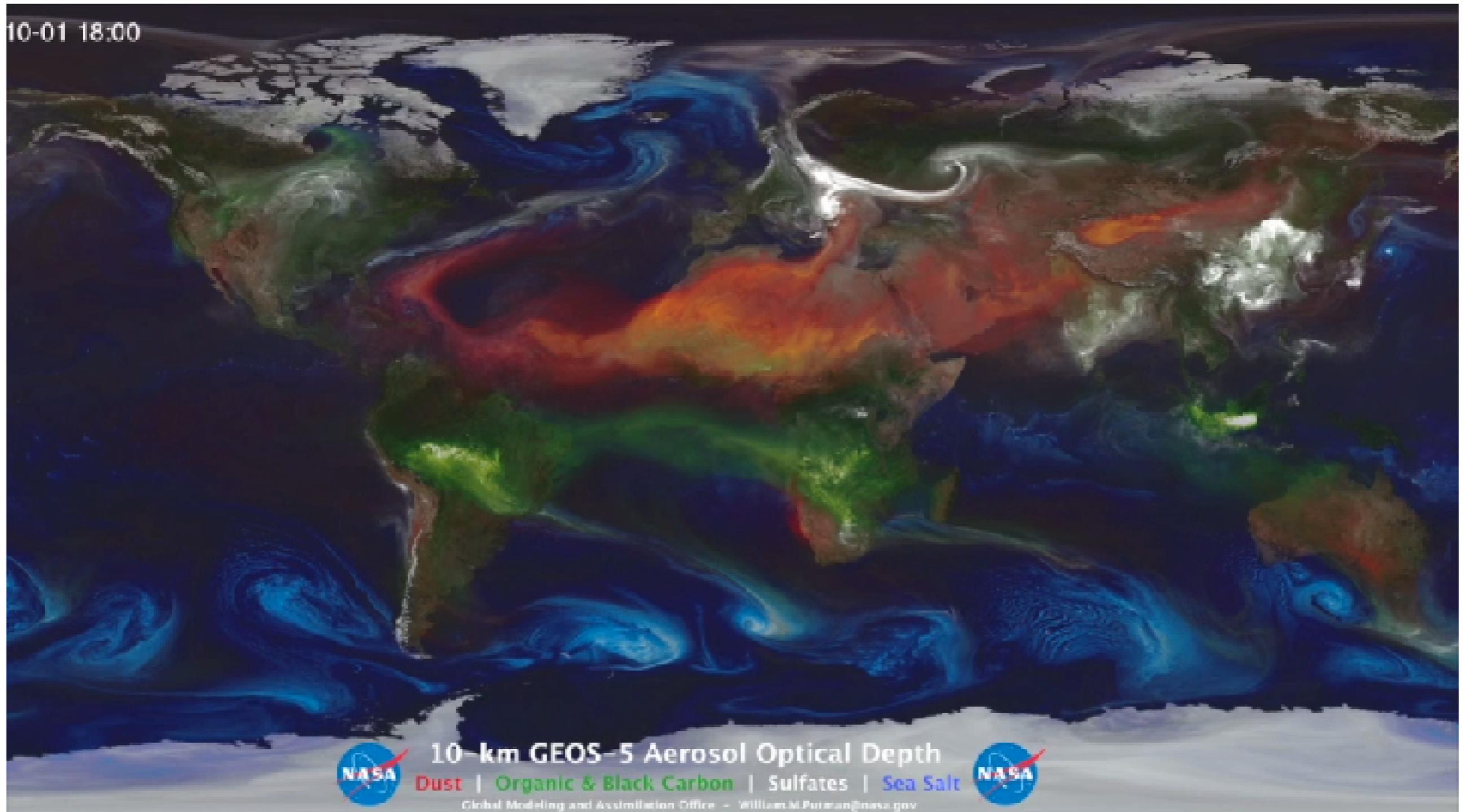
As U.S. standards for ozone and fine particles are strengthened, the relative importance of international transport of air pollution around the globe becomes more a more influential factor in attaining them.^{35,36,37} The air coming into the U.S. often contains relatively high background levels of air pollutants from upwind continents. Effective strategies for addressing background

pollution include working with countries and regions to build air quality management expertise and undertaking regional and global initiatives to reduce air pollution. The figure below shows intercontinental transport of ozone in the lower layers of the atmosphere (troposphere) from satellite data. Long range transport of different human and natural sources of particle pollution is also illustrated in video results from a [NASA global model](#).



Intercontinental ozone pollution transport from satellite data.³⁶ Multi-year average July satellite ozone measurements for the lower levels of the atmosphere (excluding stratospheric ozone). Warmer colors reflect higher concentrations, with dark red indicating the highest levels. International transport of ozone can contribute to increasing background in downwind areas making it harder to attain air quality standards. Because ozone is a greenhouse gas, it also affects climate.

10-01 18:00



Global Transport of Particles

This video from a [NASA model](#) shows four source types: Sulfates (white) from coal and oil combustion, organic and black carbon (smoke) from open burning of fields and forests and energy related combustion, as well as natural windblown dust from desert areas and sea salt. Note periodic transport of sulfates from the U.S. to Europe and from China to the U.S.

The global transport data illustrate why air pollution is a pressing public health problem in many parts of the world. While air quality has improved in America and much of Europe in recent decades, it has been getting much worse in many developing countries, notably in Asia and the Indian subcontinent (see photos pages 3-4). Based on the Global Burden of Disease project, the combination of outdoor and indoor household (e.g., cooking and heating with coal or wood) air pollution may be responsible for 4 to 9 million premature deaths in 2015.³⁷

EPA and experts from public and private sector organizations around the globe are working to help developing nations apply the engineering, science, and policy lessons learned from successful air pollution programs to the world's worst air pollution.

Management of conventional air pollutants in the U.S. and elsewhere also faces challenges from climate change.³⁸ Warmer, dryer conditions in summer can lead to increased air stagnation across broad regions in the U.S., making it even more difficult to attain ozone standards. Prolonged droughts in some regions are leading to increased wildfires, which have resulted in regionally high exposures to fine particles. These phenomena may be responsible for the recent uptick in average ozone and fine particles seen in the last two years in the [air trends figure](#) on page 26. Air quality planners need to account for these kinds of climate-related changes in meteorology and emissions that are, at present, uncertain and difficult to predict.

Indeed, climate change itself is widely regarded as the greatest environmental challenge of our times. The multiple threats and disruptions presented by climate change go far beyond its effects on air quality. Even a summary treatment of the issues, including the nature and timing of strategies needed to address—as well as cope with—the most serious long-term damages is beyond the scope of this report.

The solutions are complex and well beyond the U.S. or any single nation. Providing optimal and timely programs to address the range of actions needed to address climate just for the U.S. will be a daunting challenge. As illustrated in the figure on page 25, Clean Air Act programs over the last 50 years have had only a limited effect on CO₂ emissions, despite the obvious strong links to conventional air pollution sources. The fossil fuel burning cars, power plants and factories that have long been the subject of clean air programs are the largest sources of carbon dioxide, which is the most significant greenhouse gas. Notably, air pollution controls for these emission sources did not halt the continued growth in carbon dioxide from them, because it was not directly regulated.

In 2007, however, the Supreme Court ruled that greenhouse gases are pollutants that can be regulated under the Act.³⁹ As a result, EPA began to take steps that would at least begin some reductions in greenhouse gases from these sources.

In 2010 and 2012 EPA issued the first auto emissions standards for greenhouse gas emissions under the Clean Air Act. Fully implemented, these phased regulations would have cut greenhouse emissions from vehicles by half, double the fuel economy of passenger cars and light-duty trucks by 2025, and save over 4 billion barrels of oil and \$1.7 trillion for consumers.⁴⁰ In August 2019, however, EPA and the Department of Transportation proposed requirements that would weaken the stronger standards for new 2020-2025 models of cars and small trucks. In September 2019, they withdrew the waiver that had previously permitted California and other states to establish tighter state emissions standard for vehicles. These actions did not affect EPA's 2011 and 2016 rules that would provide substantial additional greenhouse gas emission reductions from medium and heavy-duty trucks.^{41,42}

In August 2015, EPA used its stationary source authorities under the Clean Air Act to issue the Clean Power Plan, which would reduce greenhouse gas emissions from electricity production by 32% from 2005 levels by 2030.⁴³ This program would have also further reduced other air pollutants, and the estimated benefits were far greater than costs. States could have allowed a wide range of cost-reducing alternatives, including flexible emissions-trading options, switching from coal to natural gas, encouraging more renewable energy sources like wind or solar, and increasing the efficiency of coal-fired plants.

Despite the benefits, the Clean Power Plan (CPP) was viewed as controversial, generating millions of comments from many groups, both opposing and supporting it in legal appeals. In the end, EPA decided to withdraw the CPP and in June 2019 replaced it with the Affordable Clean Energy Rule (ACE), which analyses suggest would result in far lower emissions reductions than the CPP. The estimated reductions and the ACE rule itself are also controversial and subject to litigation.

Traditional air pollution programs and climate change are also linked in other ways.³⁸ Some air pollutants, notably ozone and the soot particles emitted by diesel engines and some other sources (black carbon) also contribute to warming. The increased interest in international transport of ozone has revealed yet another link. The largest contributor to ozone on this global scale is methane, the major component of natural gas. Methane is a potent greenhouse gas that is second only to carbon dioxide in contributing to climate change. These air pollution-climate linkages present significant challenges as well as opportunities for designing more effective programs for both.

Unlike the domestic air pollution successes since 1970, however, the U.S. cannot unilaterally solve the multiple threats posed by a changing climate. Addressing climate change will require an extraordinary level of international cooperation. In December 2015, 196 nations formally recognized “that climate change represents an urgent and potentially irreversible threat to human

societies.”⁴⁴ The [Paris Agreement](#) set ambitious goals for limiting the increase in global temperatures and for continuous reductions in greenhouse gas emissions. In 2015, 184 countries, including the U.S. submitted plans for their intended reductions beyond 2020. Collectively, the submissions were insufficient to achieve the agreed upon limit in global temperature (2°C above pre-industrial levels), so countries were required to revise their submissions and increase their commitments every 5 years. In June 2017, however the President announced the U.S. would withdraw from the *Paris Agreement*. The recent EPA regulatory changes noted above make it unlikely the U.S. will meet its intended emissions reductions, much less the even more aggressive reductions in emissions and activities recommended to avoid the most significant effects of climate change forecast by a recent UN report.⁵⁷

As debate continues on the nature of potential Federal programs, some states and cities as well as some industries are developing their own programs to reduce greenhouse gas emissions, promote renewable energy sources, and cope with predicted weather extremes, such as increased flooding and fires. At an individual level, numerous sources provide varying estimates of a personal “[carbon footprint](#)” that examine how your choices for transportation, home energy use, and diet can affect the total, and how they may vary by [where you live](#).



EPA staff working with Indian air quality officials in New Dehli. EPA has developed partnership programs with other nations to help improve ambient air quality in mega-cities. *Photo: Dale Evarts, EPA.*



Teens shoot hoops at a public park in Port Arthur, TX. African Americans are 75% more likely to live in fence-line communities, e.g., areas near gas and oil facilities—than the average American, [NAACP-CATF](#). Photo: Karen Kasmauski/ILCP

Even as overall U.S. air quality has improved when viewed on-average, it is still the case that many individuals are exposed to concentrations higher than measured by typical air monitors. Some of the highest exposures to air pollution occur for communities who live near industries that produce or use hazardous chemicals, facilities with high diesel truck traffic, and heavily traveled roadways. Typically these highly exposed communities are people of color and/or lower socioeconomic status, many of whom lack access to health care. Health studies

of particle pollution have that found Black and Hispanic people are at significantly higher risks than the general population. As discussed more fully in our overview report in this series, Environmental Justice is an important issue across the board for all pollution sources, pathways, and exposure types. [EPA's goal](#) is “the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.”

[EPA's 2020 strategic plan](#) places special emphasis on meeting fine particle pollution standards in communities with poor air quality and low-income populations. It is a challenge for citizens in these communities to hold state and local air programs as well as EPA, to the promise of addressing these issues. In addition to the many air monitors managed by state and local air programs, EPA has an [Air Sensor Toolbox](#) site intended to provide guidance on the use of new lower cost air sensors that make it possible for “citizen scientists” to measure air quality in their own neighborhoods and communities, whether to assess potential concerns about nearby sources or for educational purposes. Air sensor loan programs have included collaborations with community groups, schools, and others.





Summary

The historical record and continuing analyses have shown that the Clean Air Act was both necessary and highly cost effective in reducing the substantial harmful effects of air pollution to public health and the environment. Without Federal intervention, the poor air quality and extreme episodes of the 1960s would have become far worse. Back then, the largely uncoordinated efforts of numerous municipalities and a few states were not working, and emissions were increasing steadily. National regulation of vehicle emissions and uniform national health and welfare targets made good policy sense then and now. Even in California, with the nation's most advanced state and municipal air programs, EPA involvement helped spur action, innovation and continued progress.

Federal and other research into the effects, causes, and management of air pollution spurred by national regulations helped identify the need for increased protection as well as the development of more efficient and cost-effective market-based solutions for addressing problems such as acid rain and

fine particles. Over the last half century, Clean Air Act related programs have cut air pollution by 70% while the economy has more than doubled.

Today, as in the past half century, efforts by EPA, state and local agencies, industry and the public to implement and support Clean Air Act goals continues to improve air quality and protect the health of American families and workers. Fewer premature deaths and illnesses mean Americans experience longer lives, better quality of life, lower medical expenses, fewer school absences, and better worker productivity. Yet the job is not finished. Air quality managers will need to continue to make progress on air pollution by coordinating innovative strategies for multiple emissions to help address the challenges presented by a changing climate and international transport. Ensuring that these air quality benefits reach all Americans, regardless of race or socioeconomic status, is a challenge that requires a continued commitment by air program officials as well as continued vigilance by the public.



Glossary

Carbon Monoxide

[Carbon monoxide](#) (CO) is a colorless, odorless gas emitted from inefficient combustion processes. Nationally and, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources. CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death. CO also contributes to the formation of ground level ozone.

Greenhouse Gas (GHG)

[Greenhouse gases](#) trap heat in the atmosphere, which makes the Earth warmer. Carbon dioxide (CO₂) from fossil fuel combustion is the most important greenhouse gas related to human activities. This is because of the large quantity of emissions and the long lifetime of CO₂ in the atmosphere. Other important greenhouse gases include methane (CH₄), the main component of natural gas, nitrous oxide (N₂O), and fluorinated gases.

Hazardous Air Pollutants (Air Toxics)

The 1970 Clean Air Act Amendments defined [hazardous air pollutants](#) as those for which no ambient air quality standard exists and that may cause serious health effects such as death and irreversible illnesses. EPA was required to establish

standards for significant stationary emission sources of such pollutants that would protect public health with an “ample margin of safety.” States were charged with ensuring the standards were implemented. EPA initially named beryllium, mercury, and asbestos as hazardous and issued standards for several source categories.¹ Between 1975 and 1989, EPA had difficulty in deciding on appropriate emissions standards for several carcinogenic pollutants, and actions were subject to repeated lawsuits. The 1990 Clean Air Act Amendments addressed these issues. It created an initial list of 189 hazardous air pollutants. EPA was required to define significant stationary source categories to be regulated and to establish technology-based standards as a first step, with a later assessment of residual risk. The Act also added provisions to study and regulate hazardous air pollutants from mobile sources.

Hydrocarbons¹ (Volatile Organic Chemicals)

[Hydrocarbons](#) (HC) represent a broad class of organic compounds consisting of carbon and hydrogen. While individual hydrocarbons can be directly harmful to health, EPA's 1971 national standard for HC were intended solely to address their contribution to the formation of photochemical oxidants (ground level ozone). EPA later rescinded the HC standard and has continued based

emissions and related regulations and guidance on those volatile organic compounds (VOC) that participate in atmospheric photochemical reactions. Major sources of VOCs from human activities include motor vehicle emissions; evaporative losses from gasoline, solvents, paints, cleaning agents; and petroleum production. Natural sources of biogenic VOC (e.g. trees, other vegetation) in summer months can dominate non-urban emissions of VOC across large portions of the U.S. In such areas, including the eastern U.S., emissions of nitrogen oxides from human activities are a major cause of periodic regionally high levels of ozone observed in the summer time.

Mercury

[Mercury](#) is a toxic air pollutant emitted by a number of manmade and natural sources. In the U.S., about half of manmade mercury is emitted by power plants. Atmospheric mercury becomes a problem after it is deposited or washed into lakes and streams. There it can be converted into methyl mercury by microorganisms. In this form, mercury becomes increasingly concentrated up the food chain from plants to fish. The most common way people in the U.S. are exposed to mercury is by eating fish containing methylmercury. Infants in the womb are at greatest risk to elevated methyl mercury. They are exposed when their mothers eat fish and shellfish that contain methyl-mercury. This exposure can adversely affect unborn infants' growing brains and nervous systems.

National Ambient Air Quality Standards and Criteria Air Pollutants¹

The Clean Air Act of 1970 mandated EPA set national standards for certain widespread air pollutants that have an adverse effect on public health and the environment and come from numerous or diverse sources. The Act called for *primary standards* to protect public health, including “sensitive” populations such as asthmatics, children, and the elderly. *Secondary standards* were to be set to protect public welfare against effects such as visibility impairment, effects on crops, materials damage, and ecosystem effects. The standards were to be based on *criteria* that reflected the latest scientific information on the effects of these pollutants.

In 1971, EPA established National Ambient Air Quality Standards (NAAQS) for six major pollutants based on criteria documents that were largely completed by the Public Health Service before EPA was formed. The criteria pollutants subject to NAAQS were: particulate matter (total suspended particulate matter), sulfur oxides (sulfur dioxide), photochemical oxidant (ozone), carbon monoxide, nitrogen oxides (nitrogen dioxide), and hydrocarbons.

Over the years EPA revised the criteria and standards. EPA dropped hydrocarbons because as a mixture it was mainly listed as a contributor to ozone formation. Lead was added. The other original five criteria pollutants remain, but the corresponding standards have been modified in various ways to reflect significant advances in scientific information. An EPA summary of the current standards is available [here](#).

Nitrogen Oxides

Nitrogen dioxide (NO₂) is one of a group of reactive gases known as nitrogen oxides (NO_x). The majority of NO_x from human activities is emitted as nitric oxide (NO), which is readily transformed into NO₂. Major sources combustion in cars, trucks and buses, power plants, and off-road equipment. NO₂ exposure linked with a number of adverse effects on the respiratory system. EPA has established standards protect public health, including the health of sensitive populations—people with asthma, children, and the elderly.

Nitrogen oxides also contribute to effects on health and the environment through the atmospheric formation of ground-level ozone, fine particle pollution, and acid rain.

Ozone (Smog Ozone)

Ground level or “bad” ozone is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NO_x) and volatile organic compounds (VOC) or hydrocarbons (HC) in the presence of sunlight. It is a major component of *photochemical smog*. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NO_x and VOC. Breathing ozone can trigger a variety of health problems, particularly for children, the elderly, and people of all ages who have lung diseases such as asthma. Ground level ozone can also have harmful effects on sensitive vegetation and ecosystems.

By contrast, naturally formed ozone in the stratosphere (stratospheric ozone) serves as a protective layer against the harmful effects of ultraviolet rays.

Particle Pollution (Particulate Matter)

Particle pollution, also known as particulate matter (PM), is a complex mixture of small particles of various sizes and compositions. Particle pollution is made up of a number of components, including acids droplets (such as nitrates and sulfates), soot, organic chemicals, metals, and soil or dust particles.

The size of particles is directly linked to their potential for causing health and environmental problems. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects, including increased mortality, hospital admissions, and aggravation of illness in sensitive populations.

The first EPA standards set in 1971 measured PM total suspended particles (TSP), which included particle of all sizes. Later revisions

to those standards grouped particle pollution into two size categories:

- *Inhalable coarse particles* (PM_{10-2.5}), such as those found near roadways and dusty industries, are larger than 2.5 micrometers and smaller than 10 micrometers in diameter.
- *Fine particles* (PM_{2.5}), such as those found in smoke and haze, are 2.5 micrometers in diameter and smaller, and can be mixtures of solids and liquid droplets. These particles can be directly emitted from sources such as open burning and diesel engines, or they can form in the atmosphere when gases emitted from power plants, industries and automobiles undergo chemical and physical transformations.

Sulfur Dioxide (Sulfur Oxides)

[Sulfur dioxide](#) (SO₂) is the major sulfur oxide gas in the atmosphere. The largest sources of SO₂ emissions are coal combustion in power plants and other industrial facilities, with smaller amounts from

industrial processes (e.g. metal smelting), and the burning of high sulfur containing fuels by locomotives, large ships, and non-road equipment.

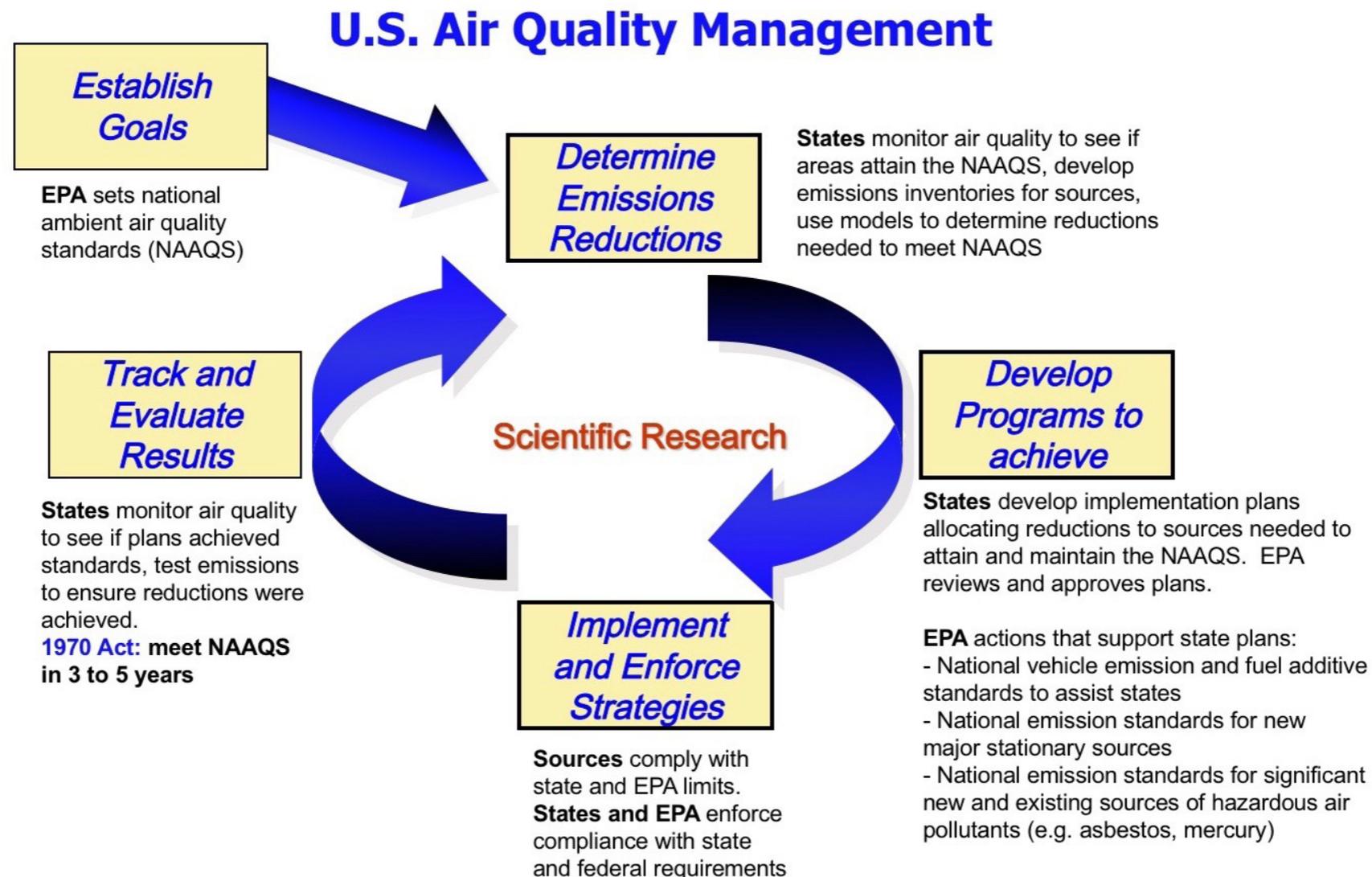
The first SO₂ standards were based on studies showing strong associations between high levels of SO₂ and particle pollution and increased mortality and illness, and damage to vegetation. Current scientific evidence links short-term exposures to SO₂, ranging from 5 minutes to 24 hours, with an array of adverse respiratory effects including airway tightening (bronchoconstriction) and increased asthma symptoms.

Sulfur oxides are transformed in the atmosphere into acid sulfate particles, which are a major component of fine particle pollution. Fine particles are associated with premature mortality and other serious health effects. Deposition of sulfur oxides and sulfates from the atmosphere is the largest contributor to acid rain in eastern North America.

Appendix. Major Approaches for Managing Air Pollution

Over the years, several systems have been advanced for addressing environmental pollution. These have included private “nuisance” lawsuits brought against individual polluters, direct “command and control” regulation of pollution sources, market-based systems such as fees and trading, and voluntary

incentives. The Clean Air Act Amendments of 1970 established a comprehensive air quality management (AQM) approach to addressing the multifaceted air pollution problems present across the country. The essence of AQM adopted in the 1970 law is illustrated in the diagram below.



Air Quality Management.¹ See figure on previous page. Under the 1970 Clean Air Act Amendments, the AQM system is driven by health and welfare-based NAAQS established by EPA. Congress gave most of the responsibility for the AQM process to the states, supported by federal rules for some sources and by federal grants. **Top:** Each state must determine its air quality relative to each of the NAAQS in all cities and areas and determine emissions reductions needed to attain and maintain the standards. **Right:** States evaluate a collection of national and state-based emissions measures and must submit a detailed, comprehensive, and legally binding plan to meet the NAAQS by a future date. **Bottom:** Controls and measures must be implemented and checked by compliance and enforcement oversight. **Left:** Finally, results of monitoring of the air or emissions are examined to see if the plan worked. If not, or if EPA strengthens the NAAQS based on new scientific information, the process is repeated. Over time, the U.S. AQM system has evolved through legislation and policy to deal with problems in achieving results, advances in scientific and technical understanding, changing socioeconomic and political conditions, and the development more efficient policy mechanisms.

What sets AQM apart from other systems is its reliance on ambient air quality standards based on evidence of undesirable effects. These standards govern whether, and to what extent, a particular jurisdiction needs to reduce emissions. Such standards require some understanding of the health and environmental effects of pollution and some judgment by policymakers. As

such, AQM fits in the category of “risk-based” environmental programs. A major strength of the AQM system is the continuous evaluation of how well plans for attaining standards achieve risk targets through monitoring of air quality. One limitation is that the entire process is time and resource consuming; it places heavy demands on improving the scientific and technical information needed to establish effects-based ambient standards, measure key pollutants, inventory sources and emissions, develop cost-effective control scenarios, and forecast and assess results.

Technology-based standards are a major alternative to risk-based programs.¹ The approach includes emissions or equipment standards that reflect a level of emission reductions from various source categories that is generally based on best available technology, considering feasibility and costs. While these standards reduce risk, the level does not depend on whether risk targets or met or exceeded. Technology based standards are a prime example of “command and control” regulations. In the 1960s, Congress debated proposals to adopt national emission standards for all sources, alone or in combination with an ambient AQM strategy. In the end, Congress chose to assist state implementation of AQM programs with technology-based standards for new sources of pollutants related to the national standards. National standards, instead of state, rules made obvious sense for new vehicles, although Congress allowed California to establish tighter tailpipe standards. Congress also required EPA to set national performance standards for new major stationary sources of NAAQS pollutants, but left decisions

on existing sources to the states. Requirements for major new stationary sources were later expanded and made more stringent, particularly for review of new sources locating in areas that had not attain the air quality standards. Congress codified location-specific new source review and prevention of significant deterioration provisions in the 1977 Clean Air Act Amendments.

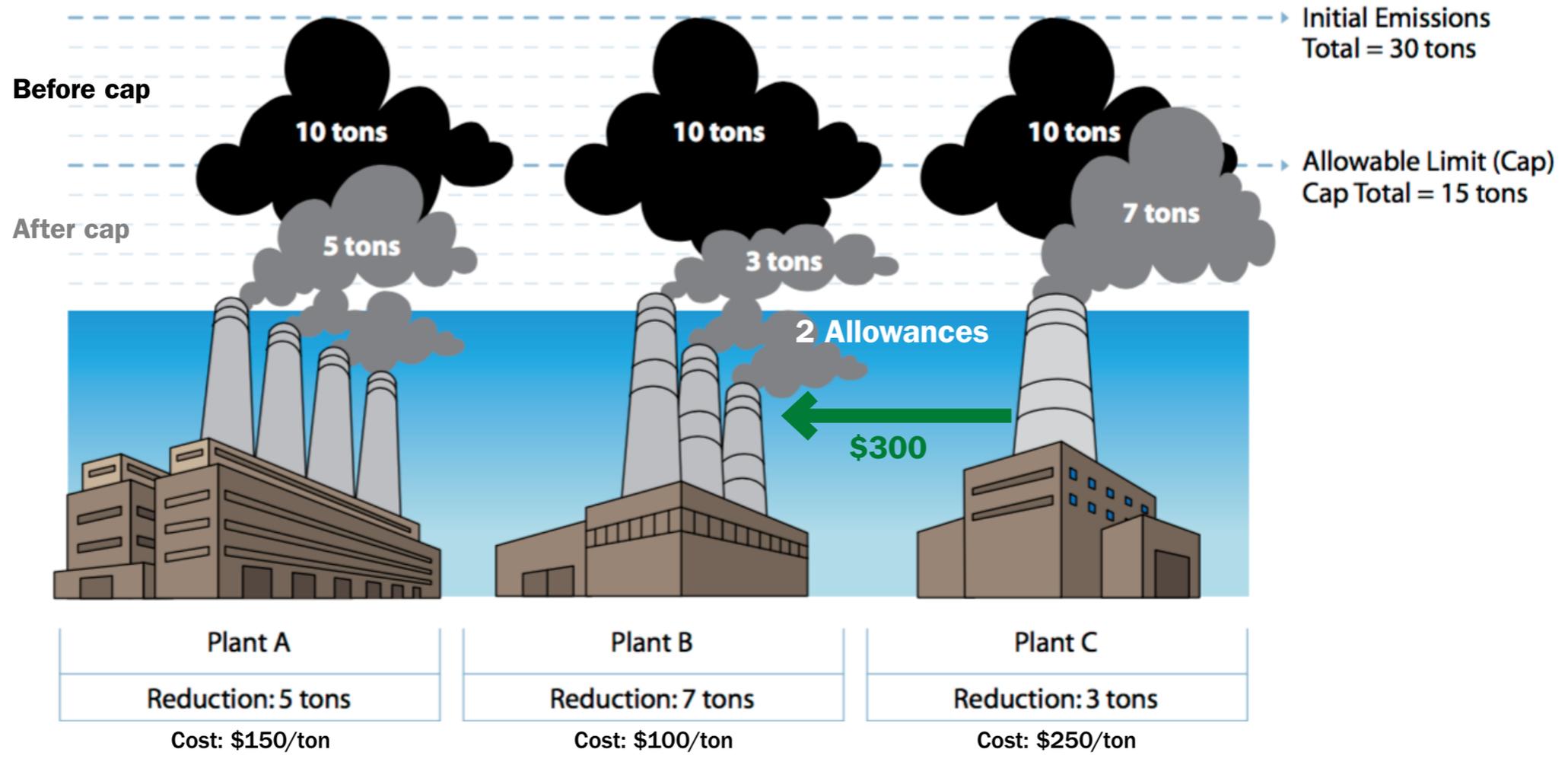
Congress decided on a separate scheme for new and existing stationary sources of hazardous air pollutants in the 1970 Amendments. The Act stated that emissions standards for sources of these particularly toxic pollutants should protect public health “with an ample margin of safety.” This risk-based approach became problematic—paralyzing, in fact—in the 1970s and 80s as EPA wrestled with determining what an acceptable level of risk would be for carcinogenic air pollutants.⁴⁵ The 1990 Amendments addressed this logjam by developing a presumptive list of pollutants and calling for technology-based emissions standards (maximum achievable control technology or MACT) as a first step in the process. After eight years, a second step required an evaluation of whether the residual risk that remained after MACT was acceptable.

Market-based or incentives programs provide direct and indirect monetary inducements that encourage sources to reduce harmful emissions. As a result, they create incentives for companies to incorporate pollution abatement into production or consumption decisions and to innovate in such a way as to continually search for the least costly method of abatement. This encourages further

innovation in pollution reduction methods. Command and control regulations in the 1970 Clean Air Act have been highly effective at reducing air pollution, from vehicles or large stationary sources.⁴⁶ Nevertheless, they also have been criticized because they do not provide such incentives to “go further” or “get equal reduction for less,” can cost more and be less flexible than necessary, and do not work as well for smaller dispersed sources.

Two major examples of market-based approaches are 1) fees on emissions (e.g. \$100 per ton), and 2) tradable permits or allowances that specify the total amount of pollution a source can release. EPA first adopted some aspects of trading in 1974 in a policy that permitted new sources to offset their emissions by purchasing extra (non-required) reductions from existing sources. As noted in Section 3, this “offset trading” policy was adopted in the 1977 Clean Air Act Amendments. In the 1980s trading was used to facilitate several programs, such as the phase-down of lead in gasoline and tighter tailpipe standards.⁴⁷

The 1990 Clean Air Act Amendments saw a major expansion of market-based programs, headlined by the acid rain program (see figure on the next page). The acid rain program is generally regarded as a significant success, with very high rates of compliance and costs much lower than a technology-based approach.^{48,49,50} EPA built on the acid rain program framework in developing emissions budget trading programs to help attain national particle and ozone standards in the eastern U.S.



Trading Basics. In this simplified example, each of these plants starts out emitting 10 tons of pollution (black clouds). A cap is set calling for a 50% reduction in total emissions. To meet this goal, each plant is given emissions “allowances” of just 5 tons. In this case, achieving the needed reductions costs more at plant C than at plant B or A. Plant A chooses to just meet its new allowance limit and reduces by 5 tons. Plant B reduces by 7 tons, creating a *surplus* allowance of 2 tons. Plant C reduces by 3 tons and purchases the surplus allowances from Plant B at a price lower than the cost of further controls at plant C (2 tons x \$150/ton= \$300). The net result is a total reduction (15 tons) that meets the cap at lower costs than if all 3 plants had to reduce by 50%. In the 1990 U.S. acid rain program, Congress established a phased cap and trade program, setting the final national cap affecting thousands of power plants at 8.95 million tons of sulfur dioxide, or about half of total sulfur dioxide emitted by affected plants in 1980. *Graphic: EPA.*

The success of the acid rain and related regional air pollution programs also rests on advances in scientific understanding of the effects and movement of air pollution, and on the development of sophisticated devices that monitor stack emissions on a continuous basis.^{46,50} Trading programs are most effective for regional pollution issues like acid rain and sulfate particles, as well as both regional and urban ozone. These are largely caused by many dispersed sources. Trading programs may be less protective in cases where individual sources are large enough to cause local health and environmental harm. In such cases, purchasing allowances from distant sources would not alleviate effects near the problem source.

The ability of advanced monitors to provide fast and accurate emissions data was important to facilitate trading among sources.⁵⁰ Those purchasing allowances need to have assurance that the emissions reductions were real and verifiable. Because sources are required to submit their emissions data electronically to EPA, the Agency can use them to track compliance of individual sources as well as closely follow the overall success of the program.

This level of monitoring works well for major power plants, but is expensive, and is not practical for all pollutants, source types and sizes. Alternative lower cost approaches to determining emissions for smaller sources using continuous operational data (predictive monitoring) have been approved for use in the acid rain program.⁵¹

Because greenhouse gas (GHG) emissions generally can be measured with sufficient accuracy using such methods (e.g., monitoring fuel consumption and carbon content), the European GHG program allows predictive emissions monitoring for large as well as smaller sources.⁵²

The U.S. acid rain program became a model for pollution abatement and GHG trading programs around the world. The largest of these is the multinational European Union Emissions Trading Scheme (2005) for GHG.⁵³ U.S. examples include a regional GHG program for Northeast States (2005), the California program (2006) and the EPA Clean Power Plan (2015). Nevertheless, while few “fee” programs have been implemented, debate continues among economists and policy makers over which market-based approaches would be best -allowance trading or a tax or fee on carbon emissions.^{54,55}

U.S. Air Quality Management: a hybrid approach. The Clean Air Act Amendments of 1970 were an example of a command and control regulatory program, in this case a mixture of risk based and technology-based approaches. The risk-based components included federal ambient air quality standards and emissions standards for major sources of hazardous air pollutants. The law also included technology-based standards for new vehicles and new stationary sources.

Despite suggestions that command and control programs are inherently inefficient, analyses of implementing the 1970

Clean Air Act through 1990 found substantial benefits that far exceeded costs (section 6 above).³¹ Some economists have noted that at the time, the evolving air quality management model adopted in the 1970 Act was likely *more* effective and efficient than would have been possible by trying to establish emissions fees or trading programs.⁴⁵ In 1970, many large sources were essentially uncontrolled for several major pollutants and the continuous monitoring and reporting technology and the scientific understanding needed to make such lower cost market based programs possible had not yet been developed.

Nevertheless, as outlined in sections 3-5 above, implementation of the Act was not without problems, delays, and inefficiencies.

Over time, EPA, states, sources, and Congress incorporated new insights from these experiences as well as advances in science and engineering prompted by the efforts improve air quality. The increasing adoption of market-based solutions culminating with the acid rain and subsequent trading programs are one example of how these advances ultimately worked their way into the Clean Air Act. Indeed, it is fair to characterize the current Clean Air Act as a philosophical “hybrid,” with a mixture of risk and technology based approaches combined with market-based mechanisms and voluntary incentives for implementation, compliance, and progress.

References

- ¹ Bachmann, J.D. 2007. Critical Review: Will the Circle Be Unbroken: A History of the U.S. National Ambient Air Quality Standards. *Journal of the Air & Waste Management Association* 57: 652-697.
- ² U.S. Energy Information Administration. 2019. Petroleum, natural gas, and coal continue to dominate U.S. energy consumption. <https://www.eia.gov/todayinenergy/detail.php?id=40013>
- ³ Stradling, D. 1999. *Smokestacks and Progressives: Environmentalists, Engineers, and Air Quality in America, 1881-1951*; Johns Hopkins University Press: Baltimore, MD.
- ⁴ Schrenk, H.H.; Heimann, H.; Clayton, G.D.; Gafafer, W.M.; Wexler, H. 1949. *Air Pollution in Donora PA, Epidemiology of the Unusual Smog Episode of October 1948*; Public Health Bull 306; U.S. Government Printing Office: Washington, DC.
- ⁵ Brimblecombe, P. 1987. *The Big Smoke: a History of Air Pollution in London since Medieval Times*; Methuen & Co. Ltd.: London, U.K.
- ⁶ Fensterstock, J.C.; Fankhauser, R.K. 1968. *Thanksgiving 1966 Air Pollution Episode in the Eastern United States*; U.S. Department of Health, Education, and Welfare: Durham, NC.
- ⁷ Dunsby, J. 2004. Localizing Smog: Transgressions in the Therapeutic Landscape; In DuPuis, E.M., Ed.; *Smoke and Mirrors: the Politics and Culture of Air Pollution*. NYU Press: New York, NY p 172.
- ⁸ Nelson, G. *Beyond Earth Day—Fulfilling the Promise*; University of Wisconsin Press: Madison, WI, 2002.
- ⁹ South Coast AQMD. May 1997. The Southland's War on Smog. <http://libraryarchives.metro.net/DPGTL/epa/1997-southlands-war-on-smog-aqmd.pdf>
- ¹⁰ California Environmental Protection Agency. California's Air Quality History-Key Events. <http://www.retailcra.org/RegGuidance/Lists/RNGList/Attachments/659016/GCA00046.pdf>
- ¹¹ City of Riverside vs. Ruckelshaus, Environmental Reporter Cases 1728 (C.D. Cal.1972)
- ¹² EPA Region 9 press release, February 15, 1994. EPA Environmental News. San Francisco, CA
- ¹³ Chang, E. 2014. 2016 Air Quality Management Plan. Presentation to Joint Energy, Water & Environmental Sustainability and Transportation & Goods Movement Councils. South Coast Air Management District. http://www.lachamber.com/clientuploads/EWE_committee/10.10.14_AQMD.pdf
- ¹⁴ CA Department of Finance, 2013. Total State Population Nears 39 Million. Sacramento, CA
- ¹⁵ USDOT, FHWA. 2012. *State Motor-Vehicle Registrations -2012*. Table MV-I. Washington, DC.

- ¹⁶ Nakicenovic, N. 2013. Global future energy perspectives with focus on sustainable energy for green economic growth. Keynote presentation. DTU International Energy Conference—Sustainable Energy for Green Economic Growth. Copenhagen. September 10-12, 2013.
- ¹⁷ Kenworthy, E.W. 1973. GM asks delay on '75 standards; says it can't meet limits on two auto pollutants. Ruckleshaus unsatisfied. *New York Times*, March 13.
- ¹⁸ Oge, M. 2015. *Driving the Future: Combating Climate Change with Cleaner, Smarter Cars*. Arcade. New York City.
- ¹⁹ *Post-Standard*, Syracuse New York. September 12, 1974. Page 9. <http://www.newspapers.com/newspage/36716361/>
- ²⁰ World Health Organization. 2019. Lead Poisoning and Health. <https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health>
- ²¹ EPA. 2013. *Americas Children and the Environment*. Third Edition. <http://www.epa.gov/ace/biomonitoring/lead.html>
- ²² EPA, 1997. *The Benefits and Costs of the CAA, 1970 to 1990*: Prepared for U.S. Congress by U.S. Environmental Protection Agency. Appendix G. <http://www.epa.gov/sites/production/files/2015-06/documents/contsetc.pdf>
- ²³ EPA. Milestones in Mobile Source Air Pollution Control and Regulations. <http://www3.epa.gov/otaq/consumer/milestones.htm>
- ²⁴ EPA. 2012. Total benefits and costs from EPA analyses of 5 major regulations. See: Benefits and Costs of Five Important Clean Air Rules in 2030. <https://www.epa.gov/sites/production/files/2015-05/documents/2030annualbenefits.pdf> Accessed March 2020.
- ²⁵ EPA. 1973. Monitoring and Air Quality Trends Report, 1972. EPA-450/1-73-004. http://www3.epa.gov/airtrends/pdfs/Trends_Report_1972.pdf
- ²⁶ EPA. 2010. Atmospheric Deposition in: *Our Nation's Air -Status and Trends through 2008*. <http://www.epa.gov/airtrends/2010/report/atmosphericdep.pdf>
- ²⁷ Total benefits and cost estimates from EPA analyses of three major regulations:
 1) [The 1993 Acid Rain Program](#) (ARP),
 2) [the 2005 Clean Air Interstate rule](#) (CAIR) and its successor, the [2011-14 Cross State Air Pollution Rule](#) (CSPAR), and
 3) [the 2011-15 Mercury and Air Toxics Standards](#) (MATS).
 The ARP is fully implemented, while CSPAR and MATS are near. These two programs have been affected by judicial reviews and recent EPA actions. See also [Combating acid rain, cleaner power plants, significant economic benefits](#).
- ²⁸ EPA. 2015. Progress Cleaning the Air and Improving People's Health. <http://www.epa.gov/air/caa/progress.html#cars>
- ²⁹ EPA. 2019 Air Quality Trends Show Clean Air Progress. https://gispub.epa.gov/air/trendsreport/2019/documentation/AirTrends_Flyer.pdf
- ³⁰ EPA. 2019. Economic Growth with Cleaner Air. https://gispub.epa.gov/air/trendsreport/2019/documentation/AirTrends_Flyer.pdf

- ³¹ Heintz, J., Garrett-Peltier, H., and B. Zipperer. 2011. *New Jobs – Cleaner Air: Employment Effects Under Planned Changes to the EPA’s Air Pollution Rules*. A Ceres Report. University of Massachusetts Political Economy Research Institute.
- ³² EPA. 1997. *The Benefits and Costs of the CAA, 1970 to 1990*. Report to Congress. <http://www.epa.gov/air/sect812/retro.html>.
- ³³ Benefits and Costs of the Clean Air Act. Second Prospective Study - 1990 to 2020. <http://www.epa.gov/cleanairactbenefits/prospective2.html>
- ³⁴ Anenberg, S. C., L. W. Horowitz, D. Q. Tong, and J. J. West. 2010. An estimate of the global burden of anthropogenic ozone and fine particulate matter on premature human mortality using atmospheric modeling. *Environ. Health Perspect.* 118:1189–95. doi:10.1289/ehp.0901220 <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2944076/>
- ³⁵ Fiore, A. M., F. J. Dentener, O. Wild, et al. 2009. Multimodel estimates of intercontinental source–receptor relationships for ozone pollution. *J. Geophys. Res.* 114(D4): D04301.
- ³⁶ NASA. Monthly Mean Climatology Maps of Tropospheric Column Ozone. NASA Goddard Homepage for Tropospheric Ozone. https://acd-ext.gsfc.nasa.gov/Data_services/cloud_slice/#nd
- ³⁷ Burnett et al, 2018. Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. Proceedings of the National Academy of Sciences September 2018, 115 (38) 9592-9597; DOI: 10.1073 <https://www.pnas.org/content/115/38/9592>
- ³⁸ Fiore, A.F., Naik, V. and E. M. Leibensperger. 2015. Critical Review: Connecting air quality and climate change. *J. Air Waste Manage. Assoc.* 65(6):645–685. doi:10.1080/10962247.2015.1040526
- ³⁹ EPA. 2009. EPA’s Endangerment Finding. <https://www.epa.gov/ghgemissions/endangerment-and-cause-or-contribute-findings-greenhouse-gases-under-section-202a-clean>
- ⁴⁰ EPA. 2012. EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017-2025 Cars and Light Trucks. <http://www3.epa.gov/otaq/climate/documents/420f12051.pdf>
- ⁴² EPA. 2015. Cutting Carbon Pollution, Improving Fuel Efficiency, Saving Money, and Supporting Innovation for Trucks. <http://www3.epa.gov/otaq/climate/documents/420f15900.pdf>
- ⁴³ EPA. 2015. Clean Power Plan for Existing Power Plants. <http://www2.epa.gov/cleanpowerplan>
- ⁴⁴ United Nations Framework Convention on Climate Change. Conference of the Parties, Paris, 12 December 2015. Final Agreement. <http://unfccc.int/resource/docs/2015/cop21/eng/109.pdf>
- ⁴⁵ Wichers II, W.A., Michael G. Cooke, M.G., Walter J. Kramarz, W.J., and B. H. Brandon. 1992. Regulation of Hazardous Air Pollutants Under the New Clean Air Act: Technology-Based Standards at Last. *Environmental Law Reporter*. 22 ELR 101717. <http://elr.info/sites/default/files/articles/22.10717.htm>

- ⁴⁶ Cole, Daniel H. and Grossman, Peter Z. 1999. When Is Command-and-Control Efficient? Institutions, Technology, and the Comparative Efficiency of Alternative Regulatory Regimes for Environmental Protection. Articles by Maurer Faculty. Paper 590. <http://www.repository.law.indiana.edu/facpub/590/>
- ⁴⁷ Michael H. Levin, 2016. Lessons from the Birth of Emissions Trading, Part I. *BioCycle Magazine*: 43-45. May; Part II: Is Nutrient Trading Poised for a Surge?: 48-50, June. <https://www.biocycle.net/2016/05/04/lessons-birth-emissions-trading/>
- ⁴⁸ EPA, 2005. Acid Rain Program Benefits Exceed Expectations. <https://www.epa.gov/sites/production/files/2015-08/documents/1999report.pdf>
- ⁴⁹ Burtraw, Dallas and Palmer, Karen. 2003. *The Paparazzi Take a Look at a Living Legend: The SO2 Cap-and-Trade Program for Power Plants United States*. Resources for the Future, Washington D.C. <http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-03-15.pdf>
- ⁵⁰ Napolitano, S., Schreifels J.; Stevens, G., Witt. M., LaCount, M., Forte, R. and K. Smith, (2007), The U.S. Acid Rain Program: Key Insights from the Design, Operation, and Assessment of a Cap-and-Trade Program, *The Electricity Journal*, 20, (7), 47-58
- ⁵¹ Roth, M. and P. Lawrence. "A cost-effective alternative to continuous emission monitoring systems." *Environmental Science & Engineering Magazine*. 23: 55-56. 2010.
- ⁵² Ellerman, A. D., Joskow, P., and Harrison," D., Jr. 2003. Emissions Trading in. US: Experience, Lessons, and Considerations for Greenhouse Gases. Washington, DC: PEW Center on Global Climate Change.
- ⁵³ Ellerman, A.D. and B.K. Buchner. The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results. *Review of Environmental Economics and Policy*. 1 (1). 2007. <https://academic.oup.com/reep/article-abstract/1/1/66/1548600>
- ⁵⁴ Lewis, B. and S. Twidale. 2015. Carbon tax or trade? Debate loses steam as world embraces both. *Reuters, U.S. Edition*. <http://www.reuters.com/article/eu-carbon-tax-idUSL5NOYFOHU20150527>
- ⁵⁵ Gollier, C. and J. Tirole. 2015. Making climate agreements work. *The Economist*. <http://www.economist.com/blogs/freexchange/2015/06/united-nations-climate-conference>
- ⁵⁶ Hand, J.L. 2015. Reduced haze in the Great Smoky National Park. Visibility simulation representative of the haziest 20% of days measured in 1990 and 2010. Air Resources Specialists, Colorado State University. Personal Communication.
- ⁵⁷ Intergovernmental Panel on Climate Change "Special Report: Global Warming of 1.5 °C", 2018. <https://www.ipcc.ch/sr15/>

Photo Credits:

Cover: Sunset seen through heavy smog in southern California, May 9, 1972. Gene Daniels. EPA Documerica. National Archives and Records 542679.

Section header: Los Angeles Smog, December 2005. David Iliff. License: CC-BY-SA-3.0.

EPA Alumni Authors

John Bachmann: EPA, 1974-2007. 1989-2007 Senior Science Advisor. Associate Director for Science/Policy and New Program Initiatives. Office of Air Quality Planning and Standards (OAQPS), Office of Air and Radiation (OAR) Research Triangle Park, RTP, NC.

David Calkins: EPA, 1970-1995, and with its predecessor agencies in the USPHS, 1963-1970. Served as Chief, Air Quality Control Region Designation Branch, Washington; Chief of Air & Water Planning Branch, Region 9; Director, Office of External Relations, Region 9; Chief, Institutional Analysis Division, NCAQ; Chief Air Programs, Region 9; and Environmental Scientist, World Health Organization, Geneva.

Margo Oge: EPA, 1980-2012. 1980-1986, Office of Toxic Substances (OTS), Air Quality; 1986-1994, Deputy Director, OTS; 1994-2012, Director Office of Transportation and Air Quality, OAR, Washington, DC.



EPA Alumni Association Members David Calkins, Margo Oge, and John Bachmann, primary authors of this report.

This update incorporates detailed comments, recommendations and edits by:

Dale Evarts: EPA 1988-2018, OAQPS, OAR, RTP. 2006-2018, Group leader of the Climate, International, and Multimedia Group and

Dan Costa: EPA 1984-2018. 1984-2003, Chief, Pulmonary and Toxicology Branch; 2003-2018, National Program Director, Air Climate and Energy Research Program, Office of Research and Development, RTP, NC.

Acknowledgement: The authors are grateful for comments from a number of EPA alumni and educators, but in particular would like to acknowledge Michael Levin for his extensive review and helpful suggestions.

This document was produced by the EPA Alumni Association, with graphic design and production support provided by Regina Scheibner (courtesy of Tetra Tech).