Cleaning the Air We Breathe: A Half Century of Progress

John Bachmann, David Calkins, and Margo Oge

EPA Alumni Association

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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 subject matter essays in support of its Half Century of Progress project. An integrated summary based on all of these essays, **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 and other members of the public about the major environmental problems and issues encountered in the United States in the latter half of the 20th century, as well as the actions taken and progress made in mitigating these problems. We hope that, besides summarizing the history of U.S. environmental programs, these essays 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 each of the essays. This document was reviewed by the EPA AA Board of Directors and members of the association. We welcome comments on this document, which you may email to **the EPA Alumni Association**.

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

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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 China were commonplace in many U.S. cities in the early to mid- 20th century. Both large and smaller industrial cities 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 were not enough – and nationwide, the emissions of harmful air pollutants were growing steadily.

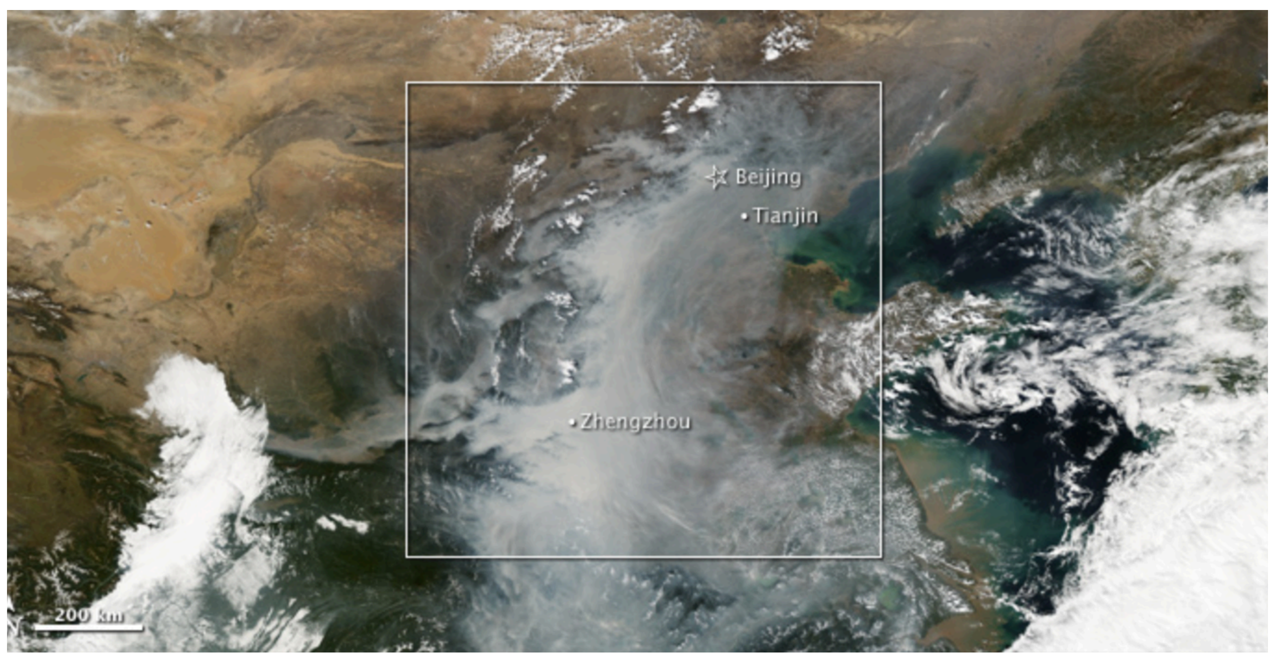
The initial response included successive federal laws that strengthened the capacity of federal and state air pollution programs and developed an increasingly broad and coherent national framework for regulation that culminated in the Clean Air Act Amendments of 1970. This law transformed America's approach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

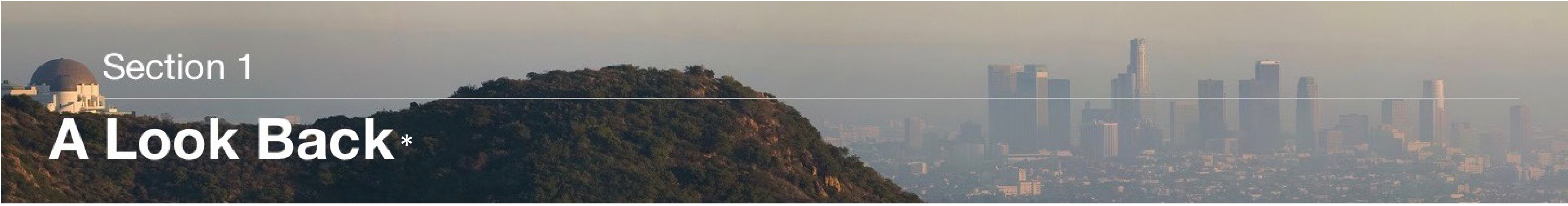
Beijing Smog. *Photo:* Daylight in Tiananmin Square. Michael Davis Burchat, Flickr. Creative commons.

The process was designed to result in continuing improvements over time, and it has: in terms of the pollutants the 1970 Clean Air Act addressed, U.S. air quality over the years is 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. Our essay 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 70% 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.

Smog over China, October, 2010. During this week-long episode, Chinese authorities declared air quality "poor" to "hazardous" around Beijing and 11 eastern provinces. Grayish areas in the middle are smoke and fog (smog) across a wide region; whitish areas are clouds. Satellite sensors suggest particle pollution from fires, industrial emissions, and vehicles were likely contributors. *Photo*: NASA Earth Observatory.



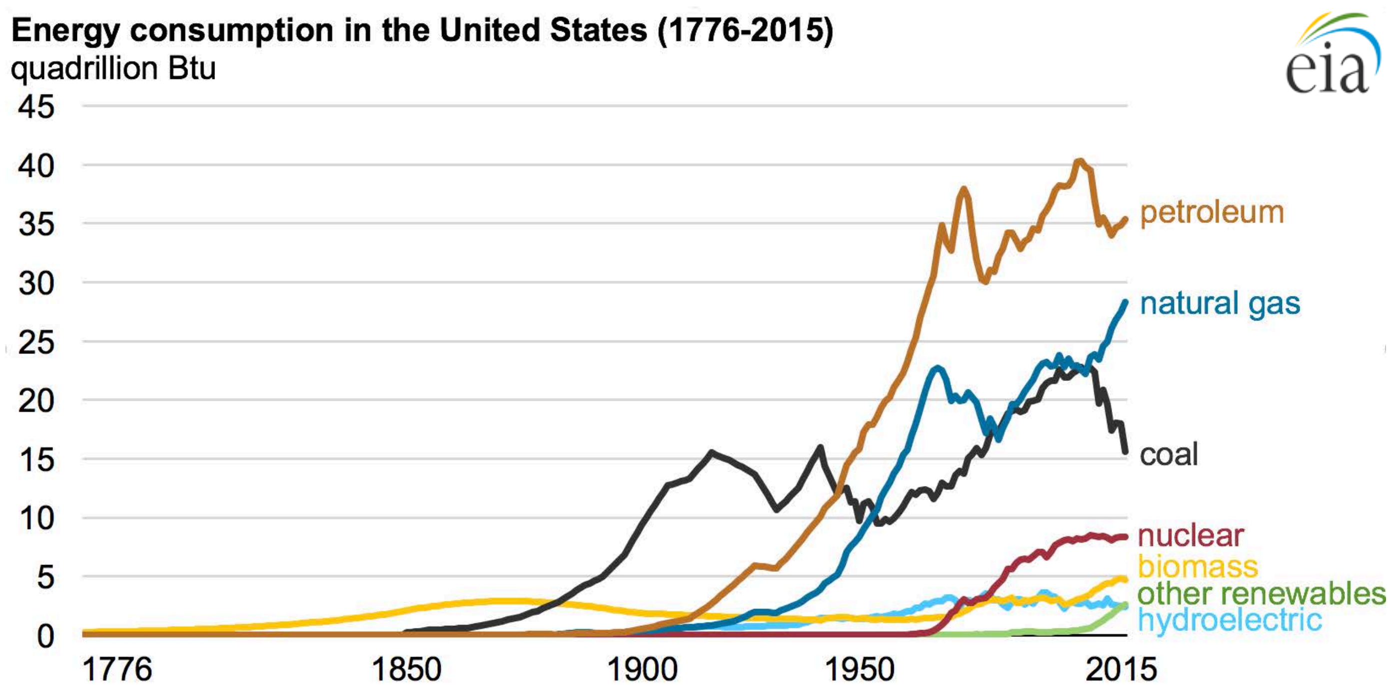


Section 1

A Look Back*

The history of air pollution in the U.S. is linked with that of energy – beginning with the shift to coal to power the industrial revolution and heat homes and apartments in increasingly large cities, and later the explosive expansion of automobile use and oil consumption, as well as the further shift to electricity for multiple industrial and domestic uses.[1,2]

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



"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. Stradling[3]

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

It is hard to imagine the daily lives of people living in several heavily industrialized 'smoky' cities near the beginning of the 20th century. These horrific conditions led to efforts by reformers and some cities to reduce coal smoke, which at the time was largely considered a nuisance.[3] These slow efforts produced some notable successes by the 1940s and 1950s, but new problems arose with the growing use of automobiles, petroleum, and 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 two episodes insert).[4.5]

Recurring air pollution episodes from combustion and factories in eastern cities were associated with measureable increases of deaths.[1,6] In Los Angeles, increased automobile and other emissions combined with local meteorology, creating a virtual 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]

Smog episodes increased health concerns in the 1960s

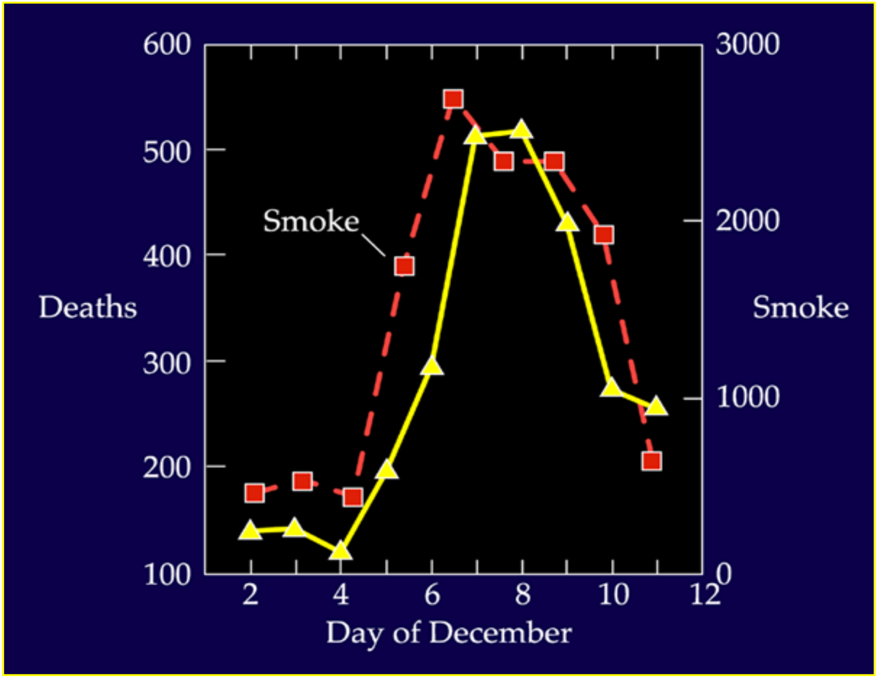
***Left*:** Widespread stagnation conditions in late November 1966 produced high levels of both visible and invisible air pollutants in a number of cities from New York (shown) to as far south as Birmingham, Alabama. New York city recorded 170 excess deaths during this Thanksgiving episode. Photo: Neal Boenzi, The NewYork Times/Redux.

***Right*:** By the mid 1950's the new *photochemical smog* in Los Angeles introduced a thick haze as well as ozone and other gases. The mixture aggregated respiratory conditions and burned the eyes.[7] *Photos*: Herald Examiner Collection/Los Angeles Public Library; *insert:* Smoggy Day, Los Angeles, 1964. (cropped). UCLA Library/Los Angeles Times Collection.

Two major episodes that established air pollution as a significant health threat

Right: Foggy conditions caused a four-day spike of air pollution in Donora, a small industrial town of 14,000. 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]" *Photo:* Pittsburgh Post Gazette.

Donora, Pennsylvania, at noon, 1948
Photo: Pittsburgh Post Gazette



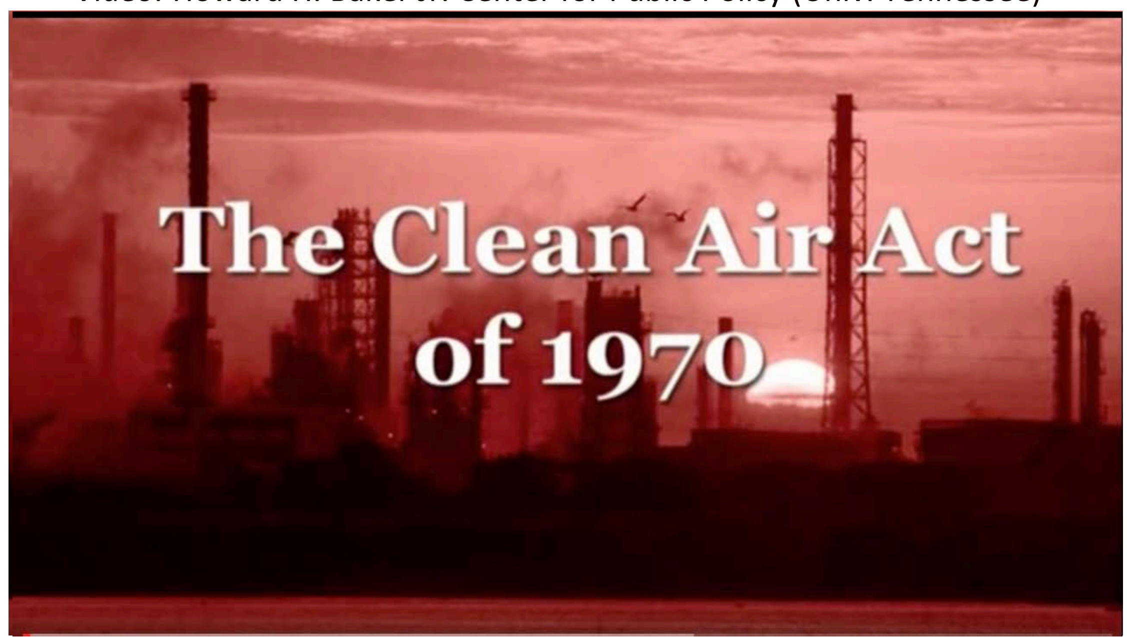
Left: On December 5-12, 1952, the worst air pollution disaster on record struck London, England. Emissions from coal combustion built up in stagnation conditions causing a rapid rise in smoke particles (red) and gases including **sulfur dioxide**.[5] Initially, the heavy smog obliterated visibility and 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.* U. of Michigan Rackham Graduate School Blog.

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 increased national perception of the environment as a whole as an important issue. In 1960, only six states had air pollution programs. The public demanded action and politicians responded with an increasingly broad succession of national clean air legislative requirements, research, and funding to develop state programs in 1963, 65, and 67.[1] Nevertheless, many viewed progress 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 '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 of 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 (Univ. Tennessee)



Overview of the 1970 Clean Air Act[1]

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 national 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.

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

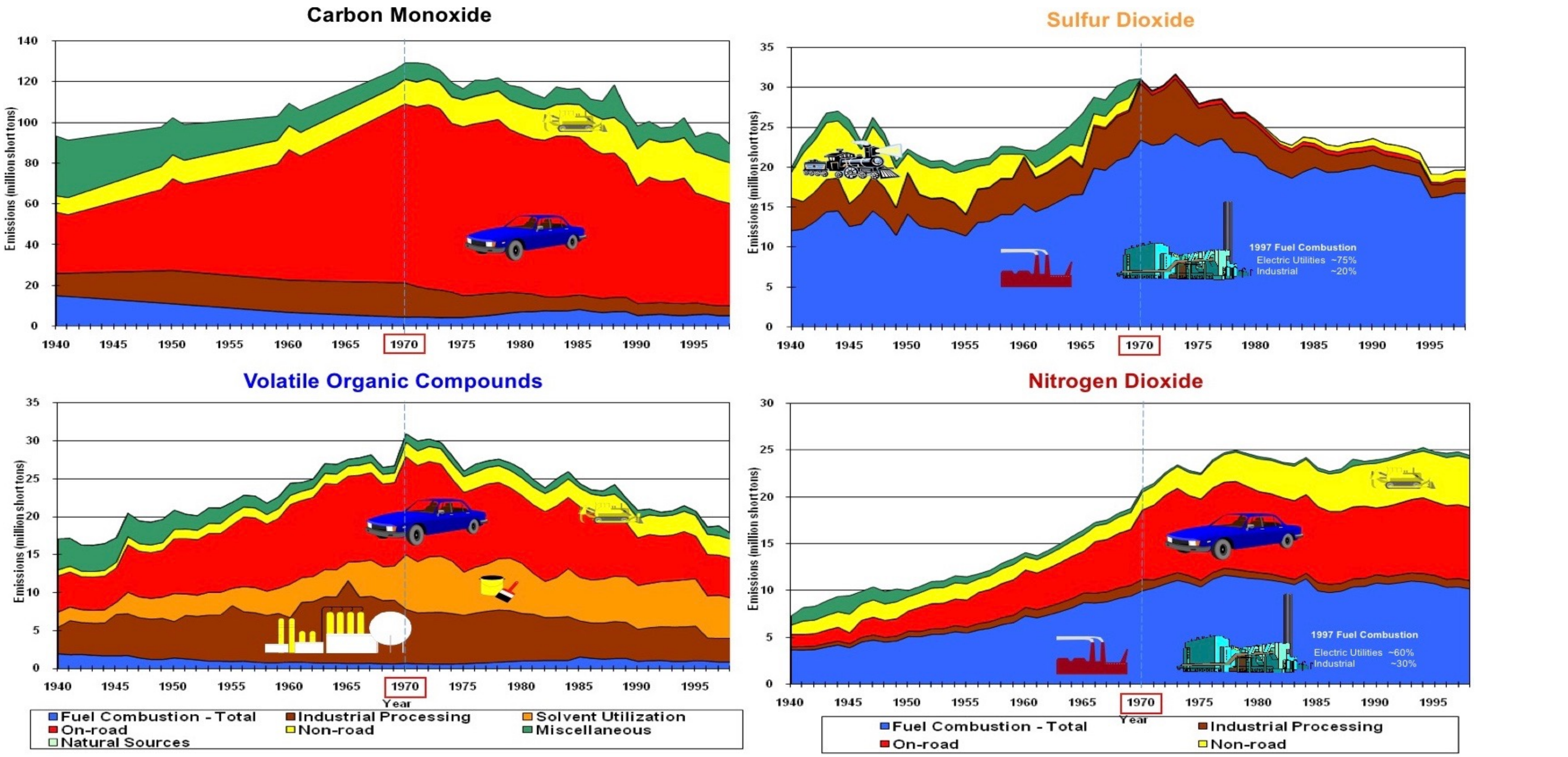
To assist state programs and to address continuing growth in use of cars, the Act also included **technology-forcing** national emissions standards for new automobiles that required 90% reductions in **hydrocarbons** and **carbon monoxide** by 1975, and similar reductions for **nitrogen oxides** by 1976.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

Act also required that EPA establish national **technology based standards** for major new stationary sources, as well as minimum requirements for state air quality management programs.

The remainder of this section on air quality addresses (1) three significant programs resulting from this legislation – tackling smog (ozone) in Los Angeles, reducing emissions from motor vehicles, and addressing acid rain and particulate matter pollution; (2) documentation of the record of progress made by federal and state air programs under the Clean Air Act; and (3) future threats and challenges to protecting these gains and continued improvements.

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



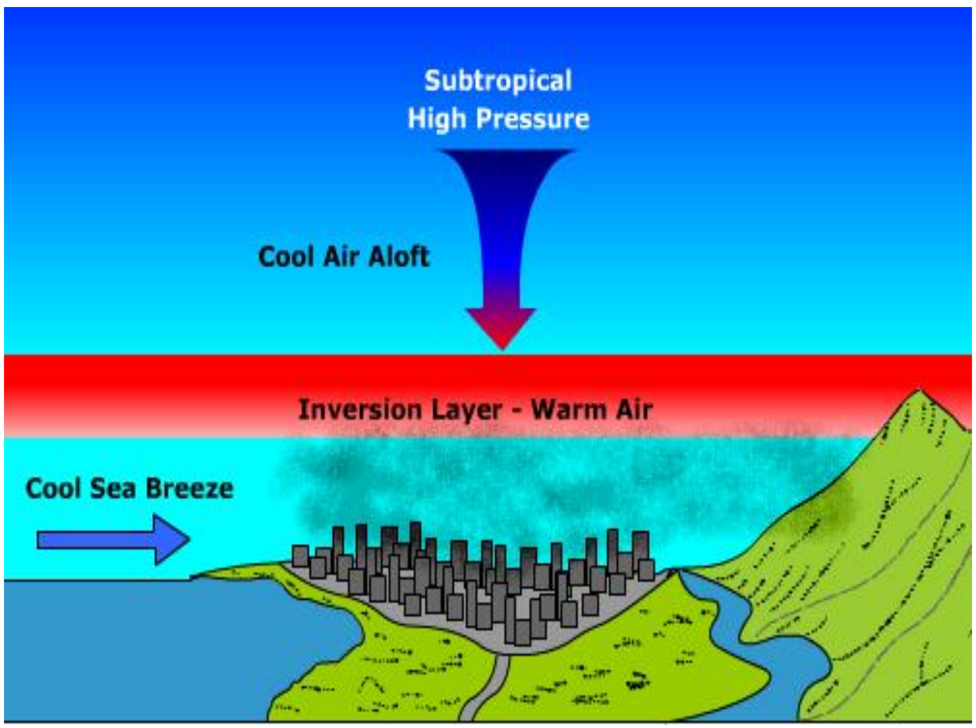
Trends in U.S. emissions of four *criteria air pollutants* by sector (1940–1997).[1] Emissions of all major pollutants, which had been growing for decades with the rapid increase in automobiles and electricity production, peaked following passage of the 1970 Act. As a result of federal legislation and funding in the 1960s, all 50 states had air programs by 1970, and were better prepared to move on implementing 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 in the 1990s were the result of the market-based acid rain program mandated by the 1990 Clean Air Act amendments.

California Leads the Way

The surprising appearance of a new kind of smog in the Los Angeles basin (see page 8 photo) 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 (O_3), 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 ppm ozone (nearly 9 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 wavier in the 1967 Air Quality Act that permitted California to continue to establish automobile emissions standards that were tighter 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 difficult smog-promoting meteorological conditions in the world.



Making Smog

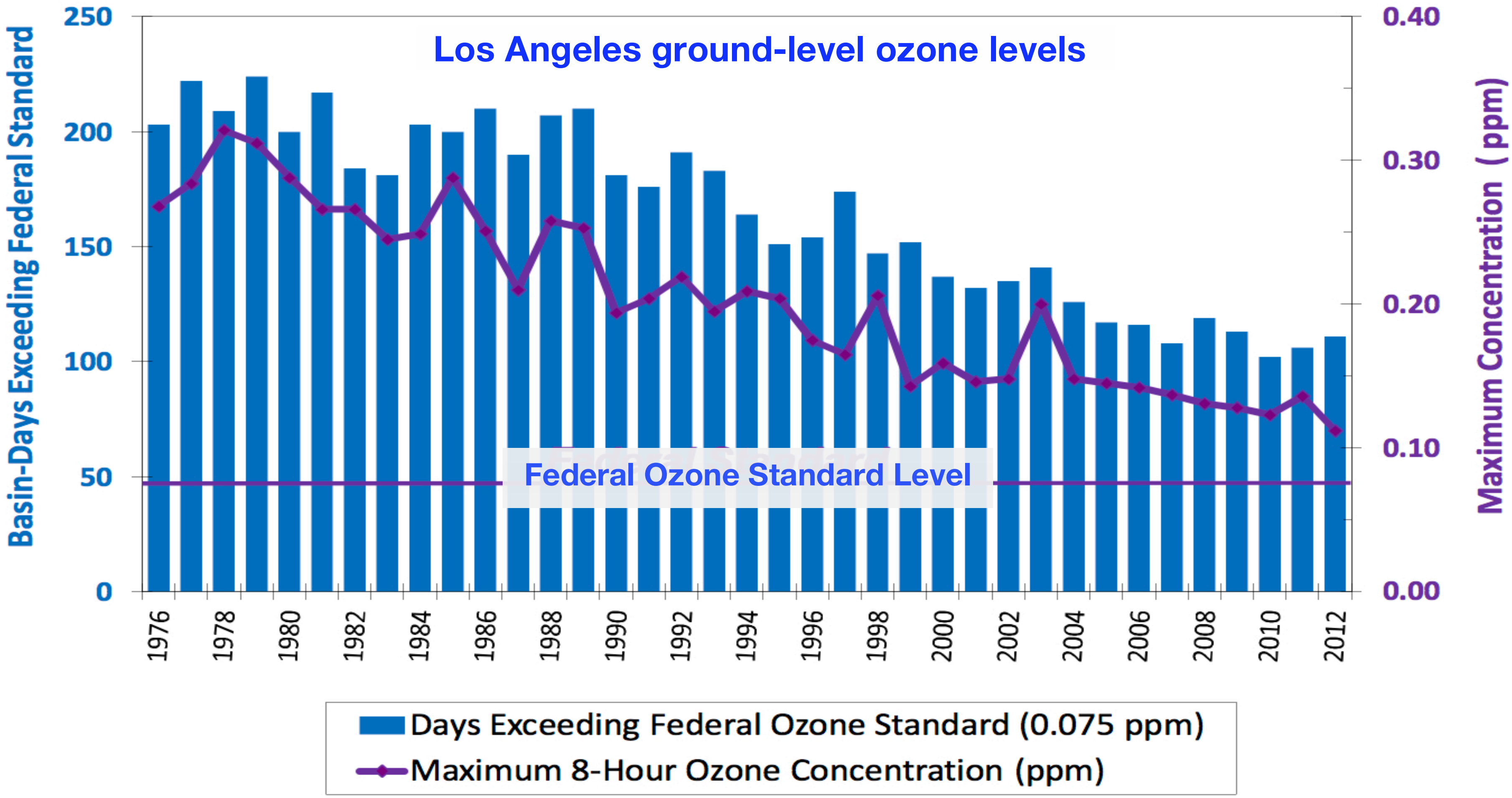
The weather and geography of the southern California basin are conducive to frequent inversions, warm layers that act as a lid to trap air pollutants. Abundant sunlight promotes formation of ozone, particles, and other photochemical products. The rapid growth of traffic and population added to the challenge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

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 tighter 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 in 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 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 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 subsequent plans in Los Angeles, as well as in much of the rest of California, began showing 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 tighter automotive emission standards to using EPA's legal mandate to impose highway funding sanctions. The threat of sanctions convinced the California legislature to authorize a vehicle smog check program in 1984. 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. 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.

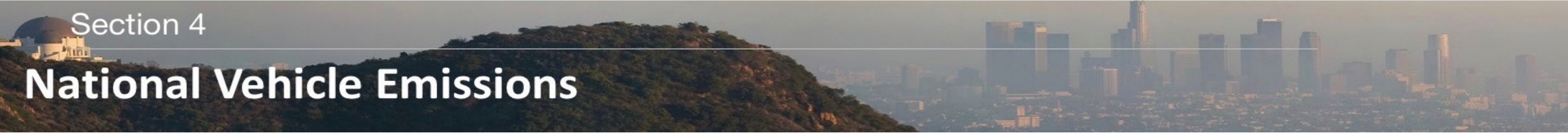


Ozone Trends in California's South Coast Basin, 1976-2012.[13] Despite substantial growth in population and traffic and difficult weather that promoted smog formation, since 1978 ground-level (bad) ozone levels in the Basin have continued to decline.

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, and 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.

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 Managment District

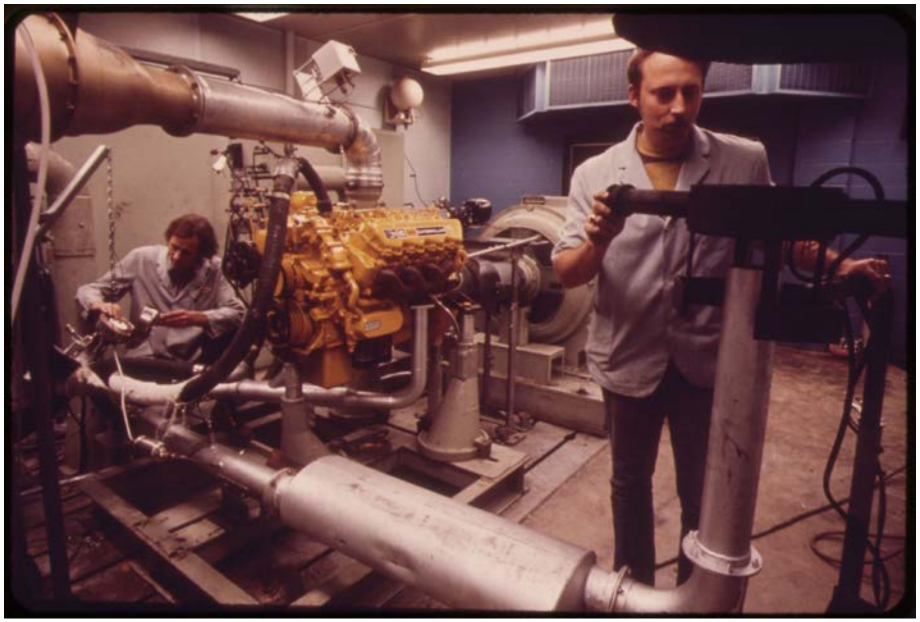


National Vehicle Emissions

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. But this success 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 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, the GM refuted virtually every argument against the technology it had made earlier.



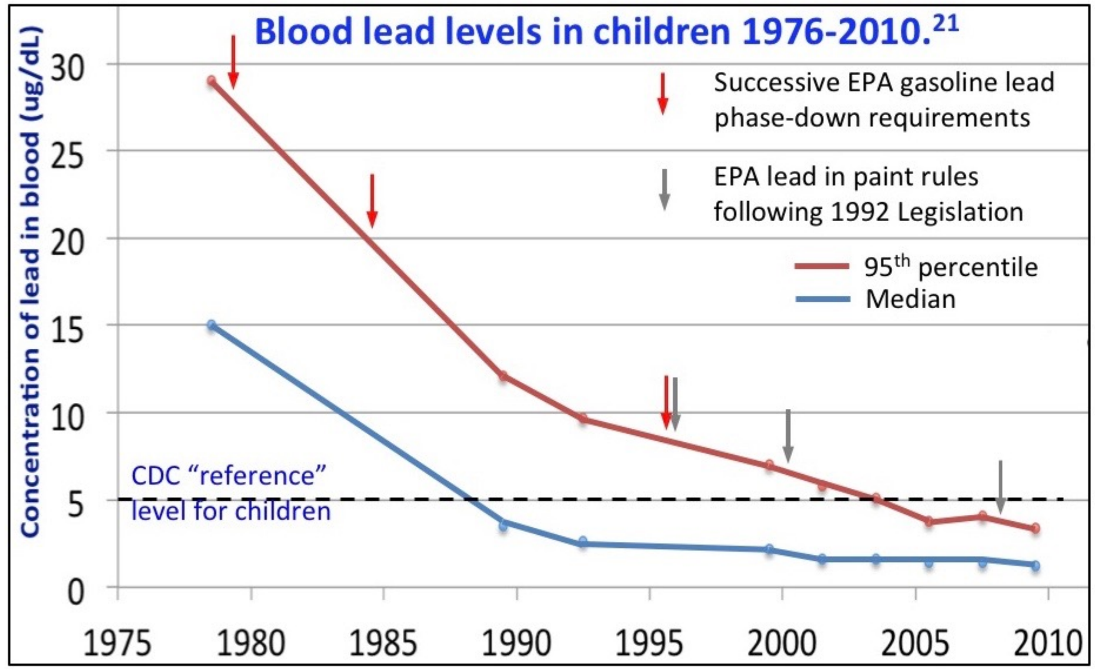
Technicians evaluating early catalysts in EPA's Ann Arbor Laboratory, 1973. *Photo:* Joe Clark, National Archives

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 catalysts. Ironically, those 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.

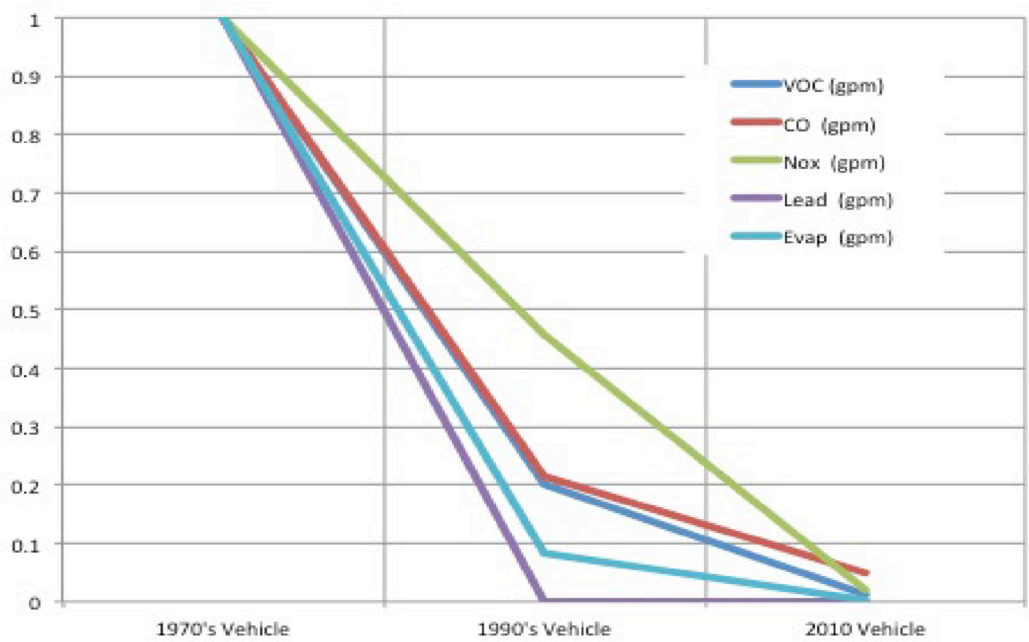
This reduction was also motivated by the recognition that removing lead from fuel came with significant additional public health benefits (see figure).[20] Lead causes numerous adverse human health effects, but is particularly detrimental to neurological development in children.[21] Lead reductions are estimated to have prevented the

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 in 1979, 1985, and 1996. Other programs, including reduced lead in paint, also contributed to the declines in the mid-1990s. The current Center for Disease Control (CDC) reference level for exposed children is 5 micrograms per deciliter.



cumulative loss of over 10 million IQ points in American children.[22] The US was the first country to eliminate lead. European nations and other countries followed, and today gasoline is almost lead-free across the planet.

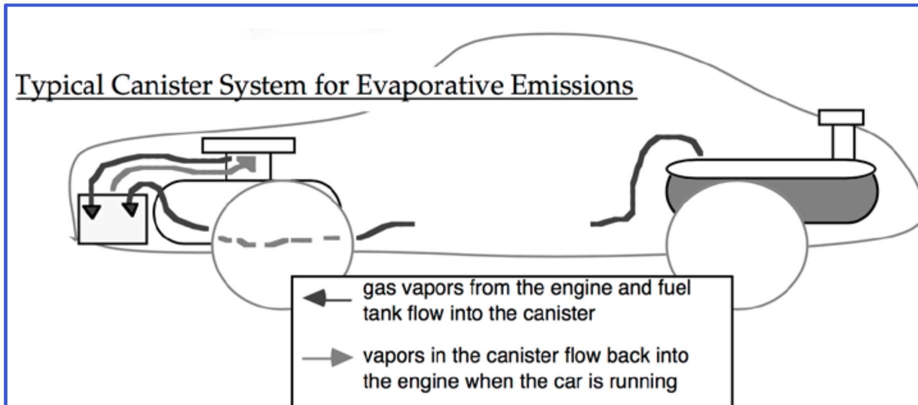
EPA undertook similar programs to address emissions from other mobile sources including trucks, locomotives, marine engines, and agricultural and construction equipment. EPA also required improved formulations for cleaner burning gasoline and diesel fuels. Since the 1970s cars, trucks, buses, locomotives and marine engines and other mobile sources have become up to 99 percent cleaner for conventional pollutants like hydrocarbons, carbon monoxide, nitrogen oxides and particle emissions.[23] Sulfur in gasoline and diesel have been reduced by over 90 percent. Collectively, it is estimated that the mobile source rules established in the past 20 years will, when fully implemented, prevent an estimated 40,000 premature deaths, even larger numbers of



Clean air act reductions of multiple pollutants from cars.[23] *Left:* Since 1970, the allowable emissions from individual cars (in grams per mile) 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.

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.

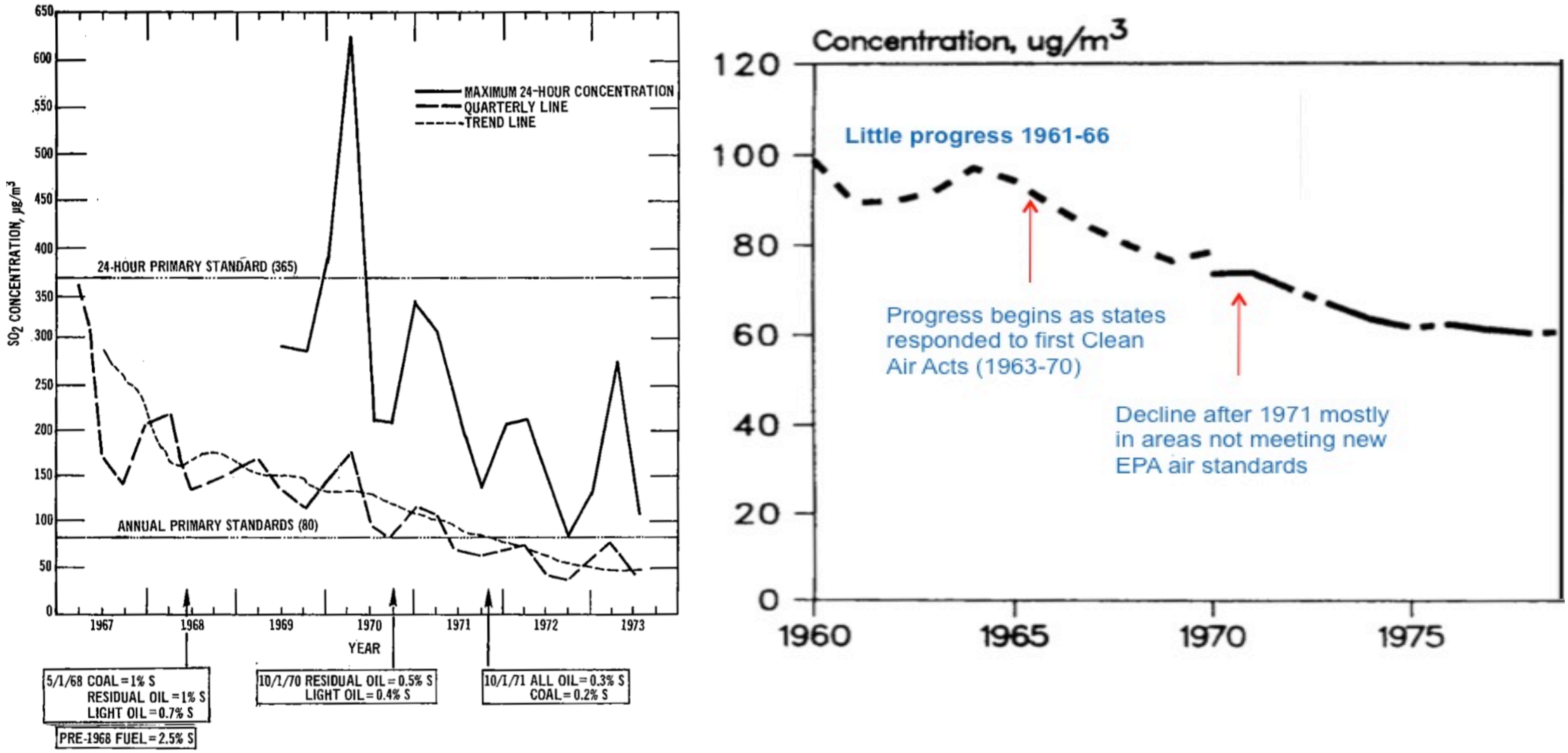


Controlling evaporative emissions. These controls prevent evaporation of gasoline (VOC), reducing pollution with a net cost savings.

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 observed in 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 below) 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.

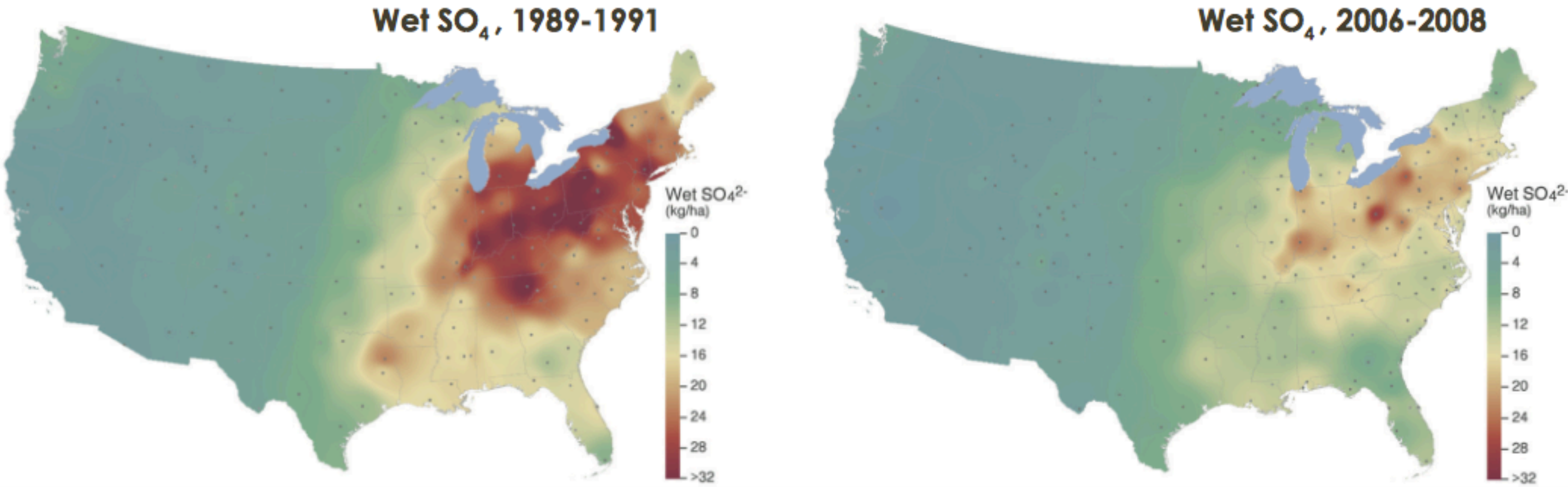


New clean air regulations greatly reduced the high urban levels of sulfur dioxide and particle pollution.[1,25] ***Left:*** Sulfur dioxide levels declined in Bayonne, NJ following stronger state and local limits on combustion fuel sulfur. The area met EPA's health standards by 1972-73. The peaks varied and were higher during the winter heating season. These sulfur limits drove shifts towards cleaner fuels including low-sulfur oil and gas. Fuel sulfur limits like these were used in a number of 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.

A harder look at the trends in emissions over the period provided the explanation for the increase in sulfur dioxide gas and sulfate particles. The state fuel sulfur requirements, such as those shown in the figure above, generally reduced sulfur dioxide emissions in urban areas. 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 the ground) and by locating new plants in rural areas away from urban restrictions. As seen in the emissions trends chart above, the net result was a continuous increase in total sulfur dioxide emissions between 1955 and 1975.

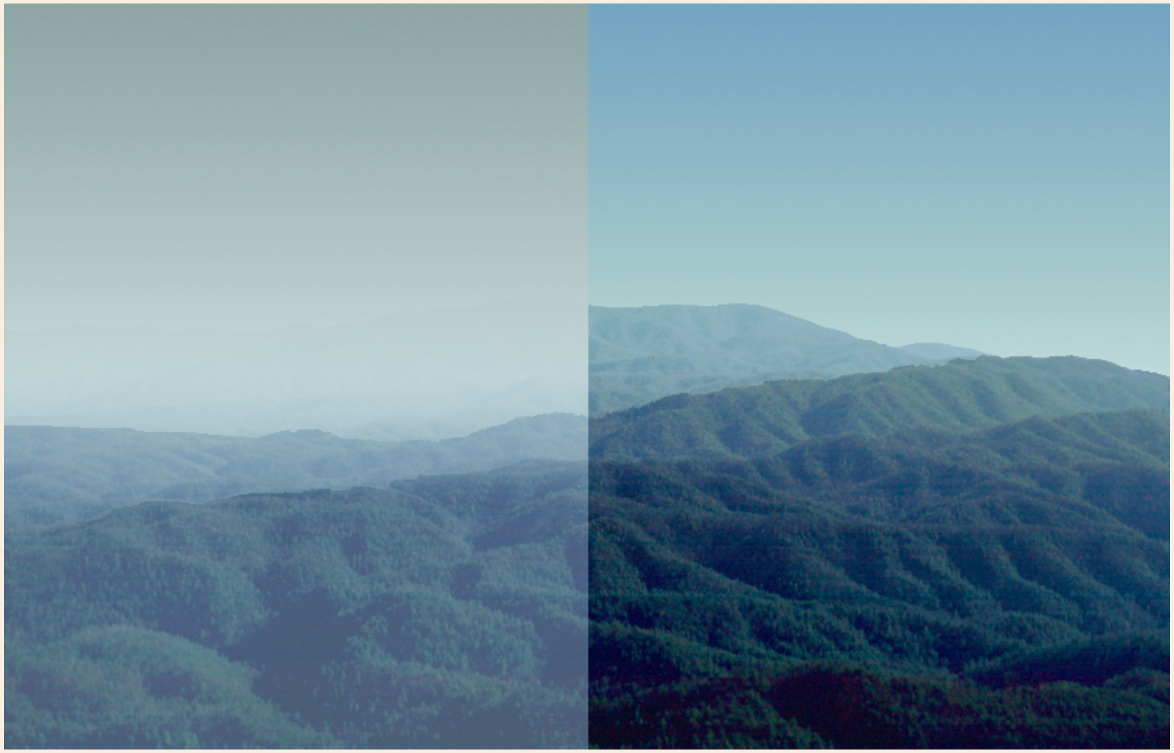
In addition to the health concerns that were raised by the increased levels of fine acid-sulfate particles, a new issue emerged, widespread acid rain. Researchers found large regions were experiencing levels of rainfall acidity strong enough to harm fish and other aquatic life in geologically sensitive 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 these increases of both sulfur and nitrogen oxide emissions and began a continuous but initially slow reduction.[1] At the same time, research into the health effects of smaller "fine" particles, environmental effects of these pollutants such as acid rain, and the relationship between emissions and these 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%



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.

reduction. The 1990 amendments also mandated limits on nitrogen oxide emissions from power plants, as well as tighter 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.



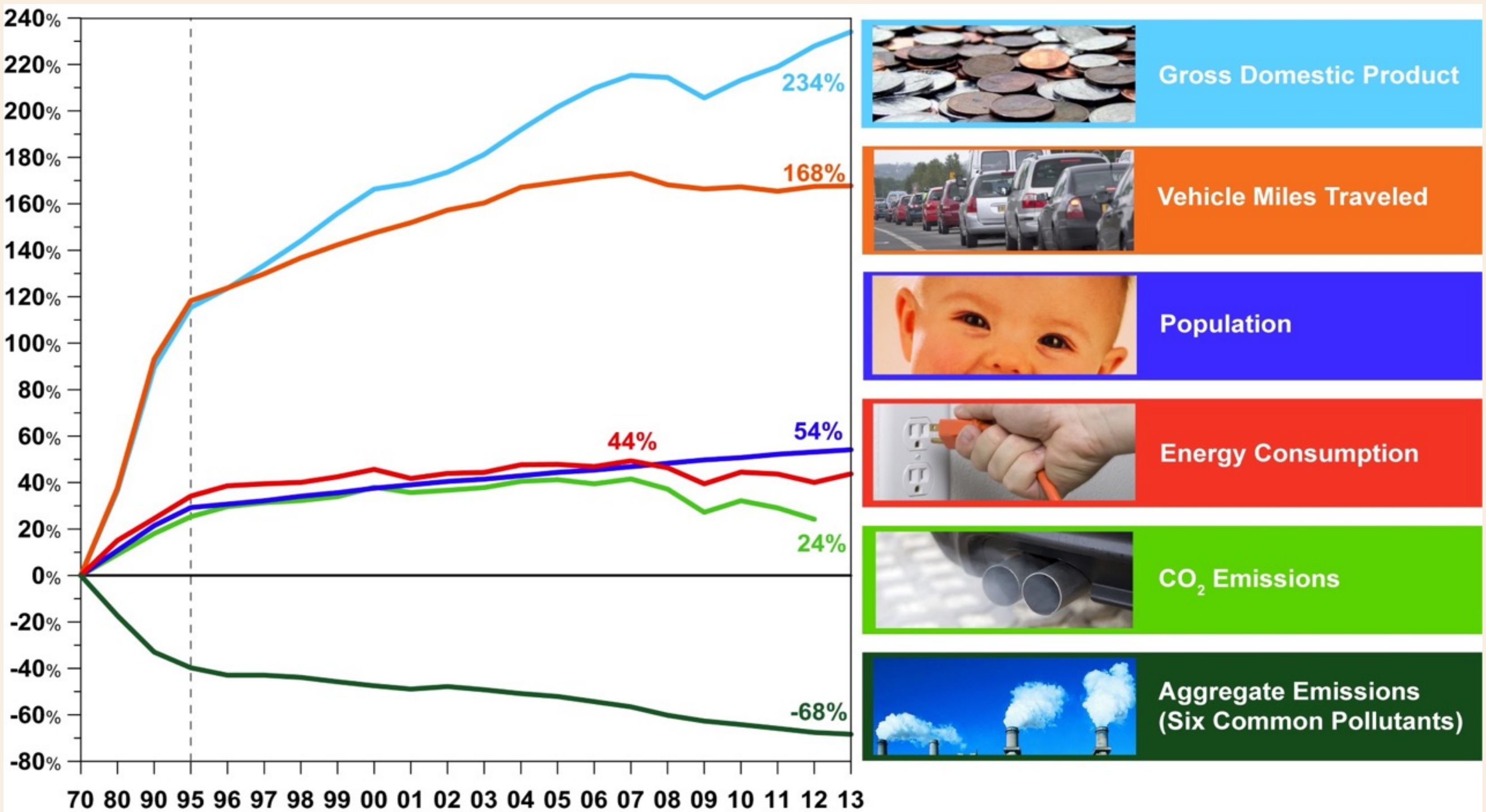
A visible improvement in air quality in the Great Smoky Mountains.[56]
A comparison simulating the haziest days observed in 1990 (left) with those observed in 2010 (right). Fine particle reductions are responsible for the improved visibility. These reductions are largely attributed to lower regional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

Section 6

Summarizing the progress made under Clean Air Act Programs

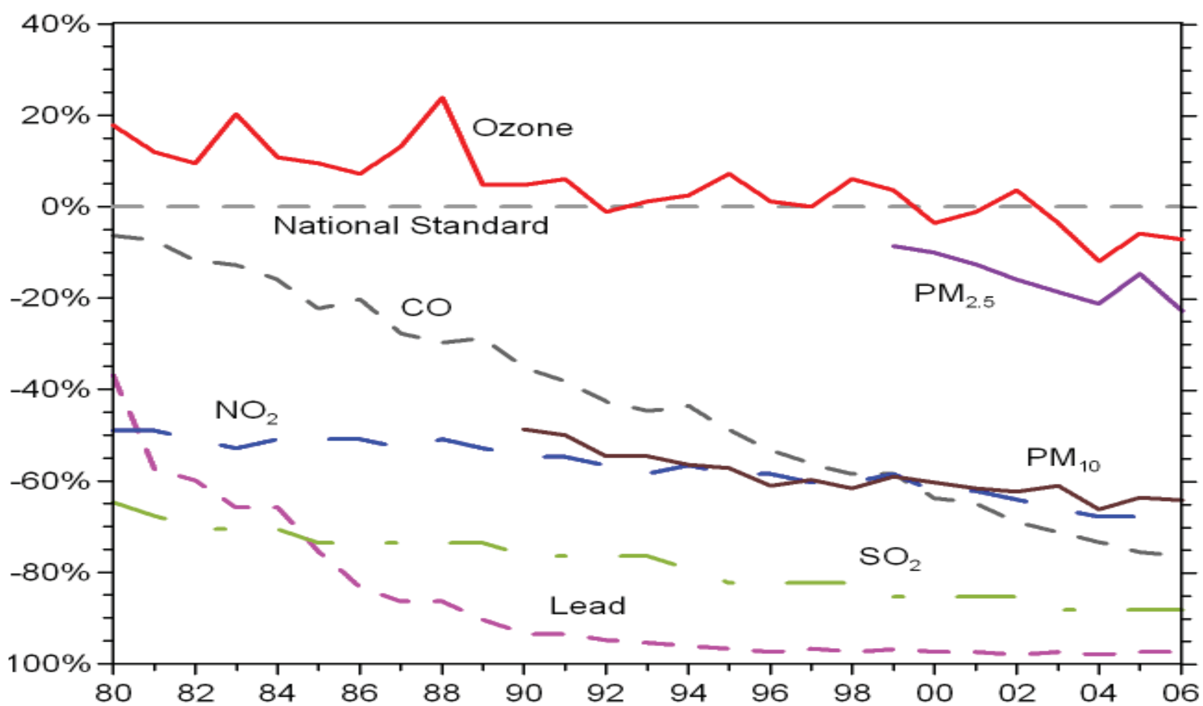
Today, we have ample data to document the progress made under the Clean Air Act as amended in 1970, 1977, and 1990.[28] Indeed, measuring progress – or lack of it - is one of the most important requirements of these laws. The data include air quality trends from widespread air monitoring, emissions trends from state inventories and in-stack monitors, and extensive analyses of the costs and benefits realized by implementing pollution reduction programs under the Act. These long-term data show that the U.S. has made tremendous progress in reducing air pollutant emissions[29] and concentrations of the major pollutants identified as having significant health and environmental effects (see figures below). Until the Clean Air Act began to take hold in the early 1970's, 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 production and other stationary sources. These reductions have resulted in a continuing decline in 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 below, 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



Clean Air Act programs reduced emissions of regulated air pollutants despite growth in societal activities.[29] Since 1970, emissions of regulated pollutants have steadily declined despite continued growth in population, energy consumption, traffic, and the economy. By contrast, carbon dioxide (CO_2), which was not targeted by these programs until 2012, has mainly tracked trends in energy consumption and traffic. The recent downturn in CO_2 emissions that continued after the 2008-10 recession is the result of several factors. These include a leveling of total vehicle miles traveled, a reduction in coal combustion for electric power generation as some plants switched to natural gas, and a significant increase in power generation from renewable sources, particularly wind and solar.

conditions and dramatic increase in illness and premature death that would have prevailed without the 1970 and 1977 Clean Air Act and its associated state and local programs. By comparison, the estimated compliance costs were about $520 billion. The benefits were 12 to 96 times larger than costs. The most recent major assessment addressed the cumulative Clean Air Act benefits and costs realized or expected between 1990 and through 2020.[33] 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 progress, and has been an excellent investment towards the well being of all Americans.



U.S. trends in key air pollutant concentrations improve relative to national ambient air quality standards 1980-2006.[1] The trends show a continuous reduction in the average of all qualifying air monitors relative to the EPA air quality standards as of 2007. See EPA updated trends and standards here (page 4). The two measures of particle pollution shown measure larger inhalable (PM_{10}) and smaller fine ($PM_{2.5}$) particles. See Glossary.

Future Challenges: Air quality management in a changing world

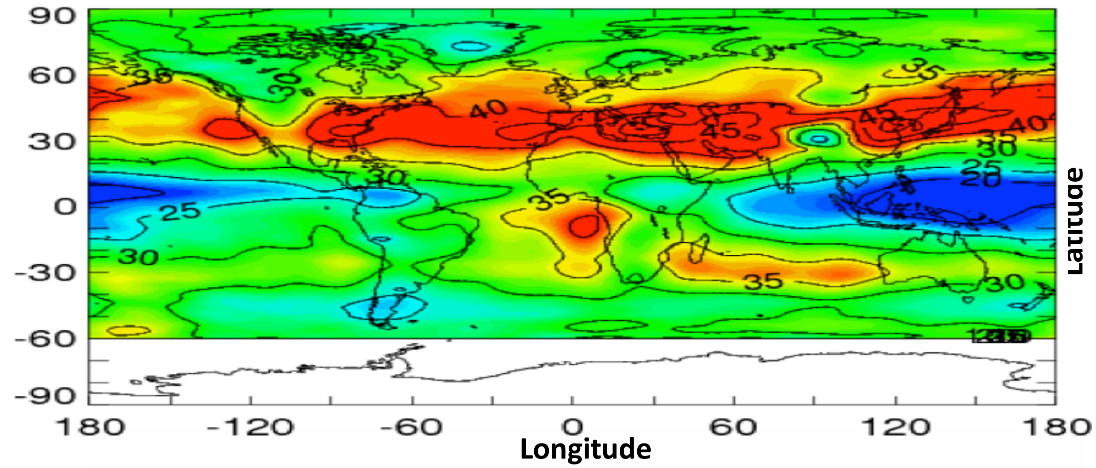
Despite the overwhelming success of U.S. clean air programs since 1970, we are not finished with air quality management. While air quality is much improved nationwide, a number of U.S. cities still do not meet all of the current national ambient air quality standards. Based on recent assessments, it appears likely that fine particle and ground-level ozone pollution may remain responsible for tens of thousands of premature deaths, 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 influential in attaining them.[35,36,37] The air coming into the U.S. often contains relatively high background levels of these pollutants from upwind countries. The most effective strategies may need to include negotiating additional reductions from nations that contribute to U.S. pollution, as well as addressing U.S. emissions that affect other countries. 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.

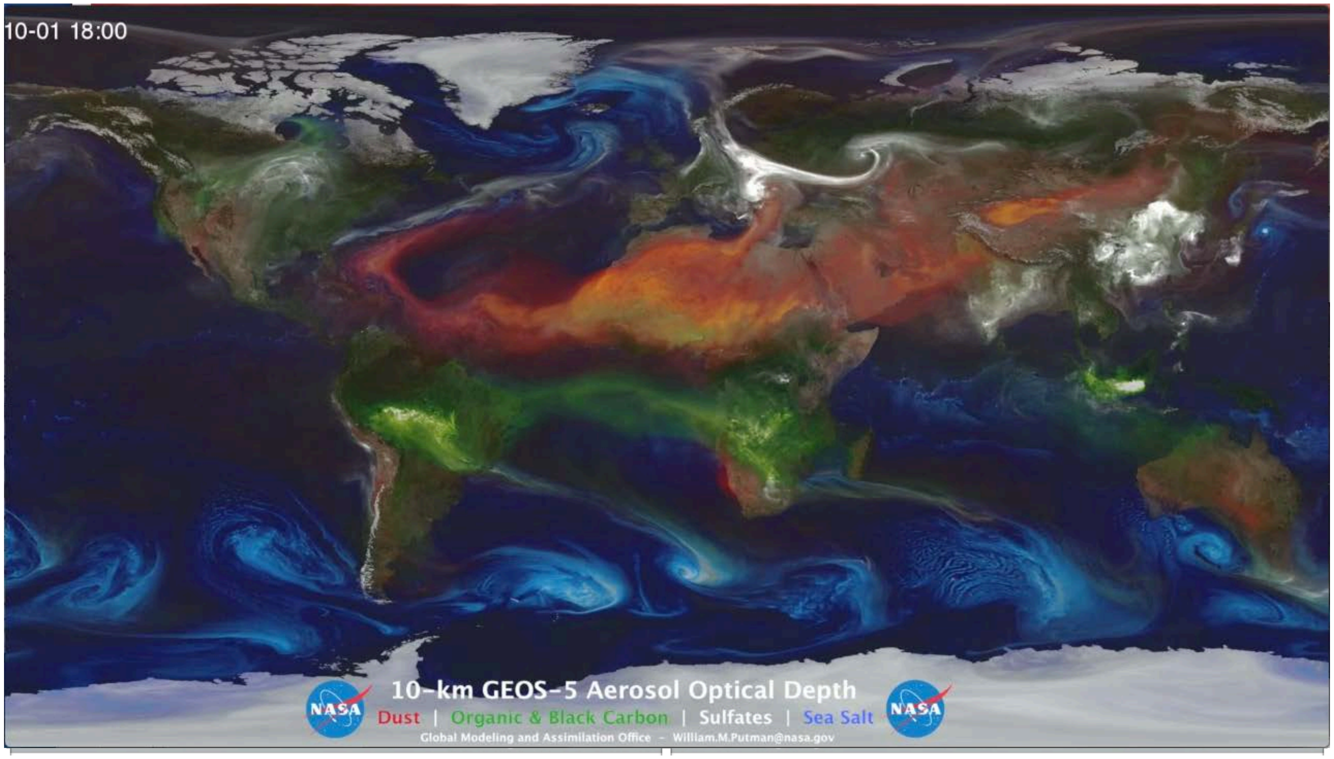
The global transport data illustrate why air pollution is a pressing public health problem in many parts of the world. While air quality has improved in America and Europe in recent decades, it has been getting much worse in many developing countries, notably in Asia and the Indian subcontinent (see Beijing photo above). Based on preliminary estimates by the World Health Organization, the combination of outdoor and indoor household (e.g., cooking and heating with coal or wood) air pollution may be responsible for up to 7 million premature deaths in 2012.[37]

EPA as well as experts from both public and private sector organizations around the world 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.

Air quality 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 episodes across broad regions in the U.S., making it even more difficult to attain ozone standards. Prolonged droughts in some regions may lead to increased wildfires, which would result in regionally high levels of fine particles. Air quality planners will need to account for these kinds of potentially significant changes in meteorology and emissions that are, at present, uncertain and difficult to predict.



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. 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.



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.

Indeed, climate change is widely regarded as the biggest environmental challenge of our times, with strong links to air pollution programs. The fossil fuel burning cars, power plants and factories that have long been the subject of clean air programs are also the largest sources of carbon dioxide, the most important **greenhouse gas** contributing to climate change. Yet as illustrated in the emissions trends chart above, Clean Air Act programs that greatly reduced conventional pollutants did not affect the continued growth in carbon dioxide, which was not regulated by these programs.

In 2007, however, the Supreme Court determined that greenhouse gases are pollutants that can be regulated under the Act.[39] In 2010 and 2012 EPA issued the first auto emissions standards for greenhouse gas emissions under Clean Air Act authority. These regulations will cut greenhouse emissions from these 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 2011 and 2015 EPA issued and proposed a two phase program to reduce greenhouse gas emissions for medium and heavy duty trucks and buses[41,42] with substantial additional reductions.

In August 2015, EPA used its stationary source authorities under the 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 also further reduce other air pollutants and the estimated benefits are far greater than costs. Implementing states may allow or adopt a wide range of cost-reducing alternatives to "source-specific" control mandates., including flexible emissions-trading options, switching to from coal to natural gas, encouraging more renewable energy sources like wind or solar, and increasing the efficiency of coal-fired plants.

Like many major EPA actions, the Clean Power Plan has been controversial, generating millions of comments and participation by many groups, both opposing and supporting it in court appeals. The rules face policy and political as well as legal challenges before they can be fully implemented.

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 diesels and some other sources (black carbon) also contribute to warming. The increased interest in international transport of ozone has revealed 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, the U.S. cannot unilaterally solve the multiple threats posed by a changing climate, and some challenge the need for taking action. 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] They set ambitious goals for limiting the increase in global temperatures and for continuous reductions in greenhouse gas emissions. As of the end of 2015, 187 countries, including the U.S., had submitted their intended reductions beyond 2020. Collectively reductions expected for EPA greenhouse gas programs summarized above make up a major portion of the U.S. commitment for 2025, but more will be needed.

In the end, the lessons learned and expertise developed by EPA, the states, and industry over the last half-century will provide a strong foundation for the continued development of more innovative and integrated approaches that will be needed to the meet the many domestic and international challenges that remain.

EPA staff working with Indian air quality officials. Under a 2015 agreement on climate and clean energy, EPA is implementing partnership programs including AIRNOW indices to help improve ambient air quality in megacities like New Dehli. *Photo:* Dale Evarts, EPA.

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. 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, the Clean Air Act 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.

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 (CO_2) 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 CO_2 in the atmosphere. Other important greenhouse gases include methane (CH_4), the main component of natural gas, nitrous oxide (N_20), 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.

Hydrocarbons[1] (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 US, 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 pollutants[1]

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 (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 was 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 significant advances in scientific information. An EPA summary of the current standards is available here.

Nitrogen oxides

Nitrogen dioxide (NO_2) is one of a group of reactive gases known as nitrogen oxides (NOx). The majority of NOx from human activities is emitted as nitric oxide (NO), which is readily transformed into NO_2. Major sources combustion in cars, trucks and buses, power plants, and off-road equipment. NO_2 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 (NOx) 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 NOx 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)

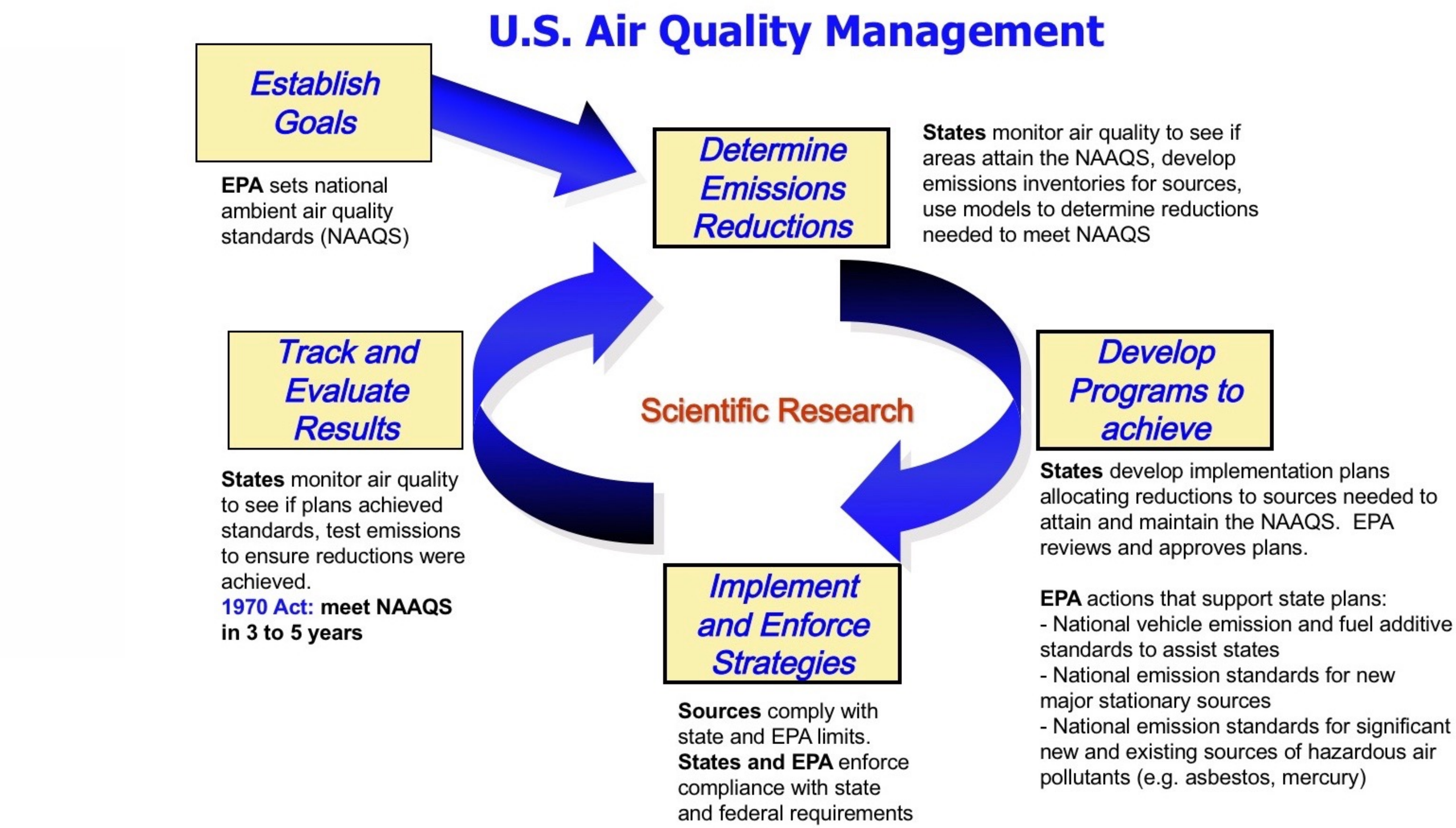
Sulfur dioxide (SO_2) is the major sulfur oxide gas in the atmosphere. The largest sources of SO_2 emissions are coal combustion in power plants and other industrial facilities, with smaller amounts from industrial processes (e.g. metal smelting), and the burning of high sulfur containing fuels by locomotives, large ships, and non-road equipment.

The first SO_2 standards were based on studies showing strong associations between high levels of SO_2 and particle pollution and increased mortality and illness, and damage to vegetation. Current scientific evidence links short-term exposures to SO_2, 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 above.* 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 adopting 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—in fact, paralyzing-- 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 log-jam 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 1980's trading was used to facilitate several programs, such as the phase-down of lead in gasoline and tighter tailpipe standards.[47]

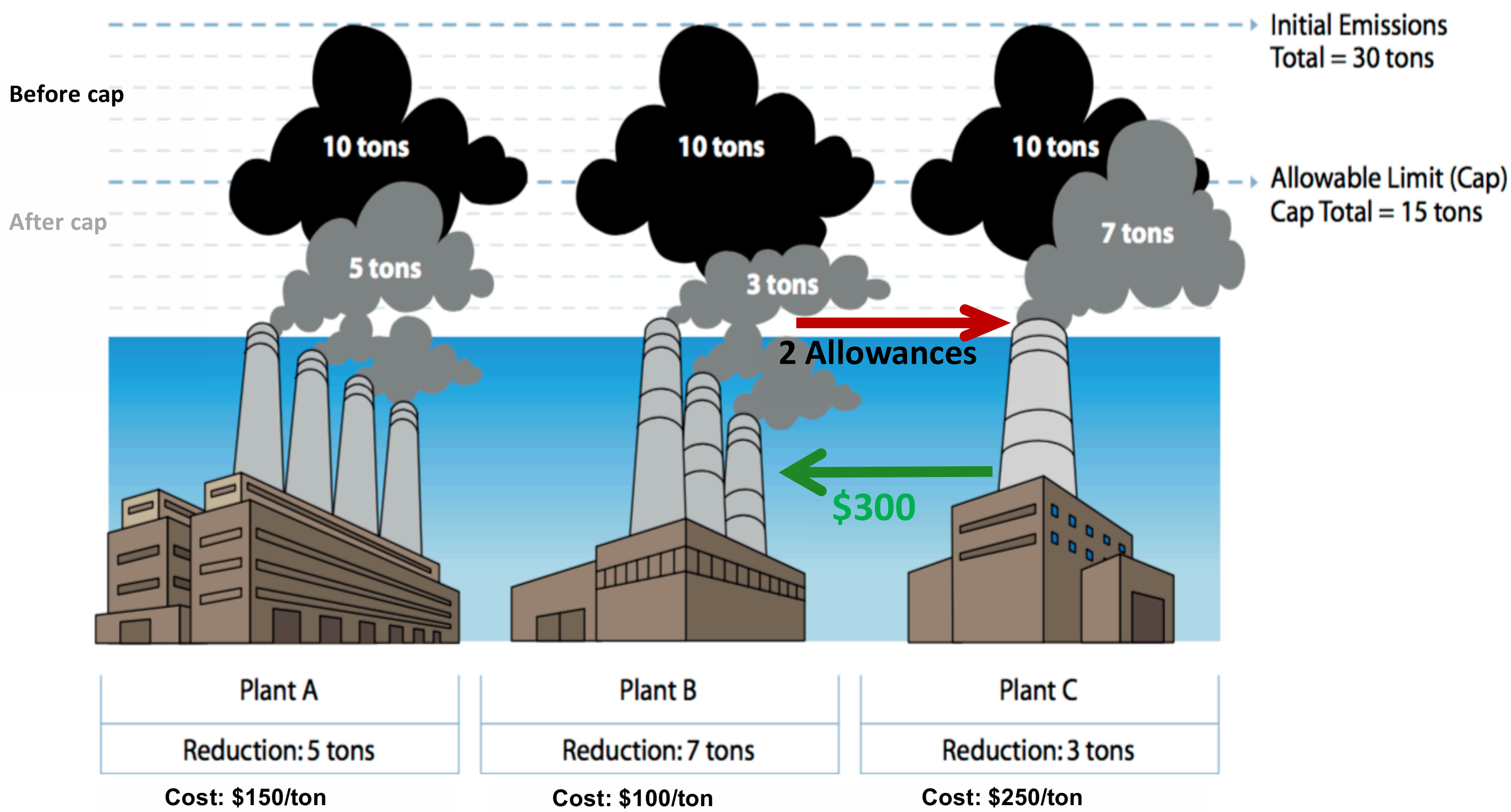
The 1990 Clean Air Act Act Amendments saw a major expansion of market based programs, headlined by the acid rain program (see figure below). The acid rain program is generally regarded as a significant success, with very high rates of compliance and costs much lower than a technology-based approach.[48,49,50] 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.

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]



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.

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.

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EPA Alumni Authors

John Bachmann: EPA, 1974-2007. Senior Science Advisor. Associate Director for Science/Policy and New Program Initiatives. Office of Air Quality Planning and Standards.

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 office of Air and Radiation; 1986-1994, Deputy Director, OTS; 1994-2012, Director Office of Transportation, Washington, DC.

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