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To cite this article: John Bachmann (2007) Will the Circle Be Unbroken: A History of the U.S. National Ambient Air Quality Standards, Journal of the Air & Waste Management Association, 57:6, 652-697

To link to this article: <http://dx.doi.org/10.3155/1047-3289.57.6.652>



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Published online: 24 Feb 2012.



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Will the Circle Be Unbroken: A History of the U.S. National Ambient Air Quality Standards

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ABSTRACT

In celebration of the 100th anniversary of the Air & Waste Management Association, this review examines the history of air quality management (AQM) in the United States over the last century, with an emphasis on the ambient standards programs established by the landmark 1970 Clean Air Act (CAA) Amendments. The current CAA system is a hybrid of several distinct air pollution control philosophies, including the recursive or circular system driven by ambient standards. Although this evolving system has resulted in tremendous improvements in air quality, it has been far from perfect in terms of timeliness and effectiveness. The paper looks at several periods in the history of the U.S. program, including: (1) 1900–1970, spanning the early smoke abatement and smog control programs, the first federal involvement, and the development of a hybrid AQM approach in the 1970 CAA; (2) 1971–1976, when the first National Ambient Air Quality Standards (NAAQS) were set and implemented; (3) 1977–1993, a period of the first revisions to the standards, new CAA Amendments, delays in implementation and decision-making, and key science/policy/legislative developments that would alter both the focus and scale of air pollution programs and how they are implemented; and (4) 1993–2006, the second and third wave of NAAQS revisions and their implementation in the context of the 1990 CAA. This discussion examines where NAAQS have helped drive implementation programs and how improvements in both effects and air quality/control sciences influenced policy and legislation to enhance the effectiveness of the system over time. The review concludes with a look toward the future of AQM, emphasizing challenges and ways to meet them. The most significant of these is the need to make more efficient progress toward air quality goals, while adjusting the system to address the growing intersections between air quality management and climate change.

INTRODUCTION

The celebration of the 100th anniversary of the Air & Waste Management Association occurs at an important juncture for U.S. air pollution programs. The year 2006 marked the 35th anniversary of the National Ambient Air Quality Standards (NAAQS).¹ The year before that was the 35th anniversary of the formation of the U.S. Environmental Protection Agency (EPA)² and the passage of the landmark 1970 Clean Air Act (CAA) Amendments.³ This law established the air quality management (AQM) framework that is in use today. Although much has changed

since then, the fundamental approach of the 1970 CAA was to formalize the broad outlines that define the respective roles and responsibilities of the major participants. The process was designed to result in continuing improvements over time, and it has: in terms of the pollutants the 1970 CAA addressed, U.S. air quality over the years is demonstrably and markedly improved (e.g., Figure 1). On the other hand, the process has been far from perfect in timeliness and effectiveness, and a number of important air quality related challenges remain.⁴ Furthermore, EPA recently announced changes to the approach used over the last 25 yr to review and revise the NAAQS⁵ and an Agency advisory panel has just completed work on a series of recommendations for improving AQM.^{6,7} This is a good time to look at the history of U.S. AQM.

SCOPE OF THIS REVIEW

This review examines the evolution of AQM in the United States, with particular emphasis on the NAAQS. Although this excludes a number of important topics in U.S. air pollution law and practice, it is broader than most topics that have been addressed in prior reviews. The review summarizes the antecedents and practice of AQM across several historical periods, including (1) 1900–1970, spanning the early smoke abatement and photochemical smog control programs led by cities and states, the first federal involvement, and the development of the AQM approach embodied in the CAA Amendments of 1970 (2) 1971–1975, the beginning of the modern era, in which the first NAAQS were set and implemented; (3) 1976–1992, a period of the first revisions to the standards as well as substantial science/policy/legislative developments that would alter the focus and scale of air pollution programs and their implementation; and (4) 1993–2006, the second and third wave of NAAQS revisions and implementation measures responding to the 1990 CAA Amendments. The review concludes with lessons learned from the U.S. experience to date, discusses some of the key issues and challenges for future AQM, and outlines some improvements and alternative approaches that might be considered.

AQM, American Style: Is This the Only Approach?

AQM is one of several overarching strategies that can be employed in an organized program to reduce air pollution.⁸ Sometimes referred to as “air resource management,”^{9,10} the essence of AQM is shown in Figure 2.^{4,6}

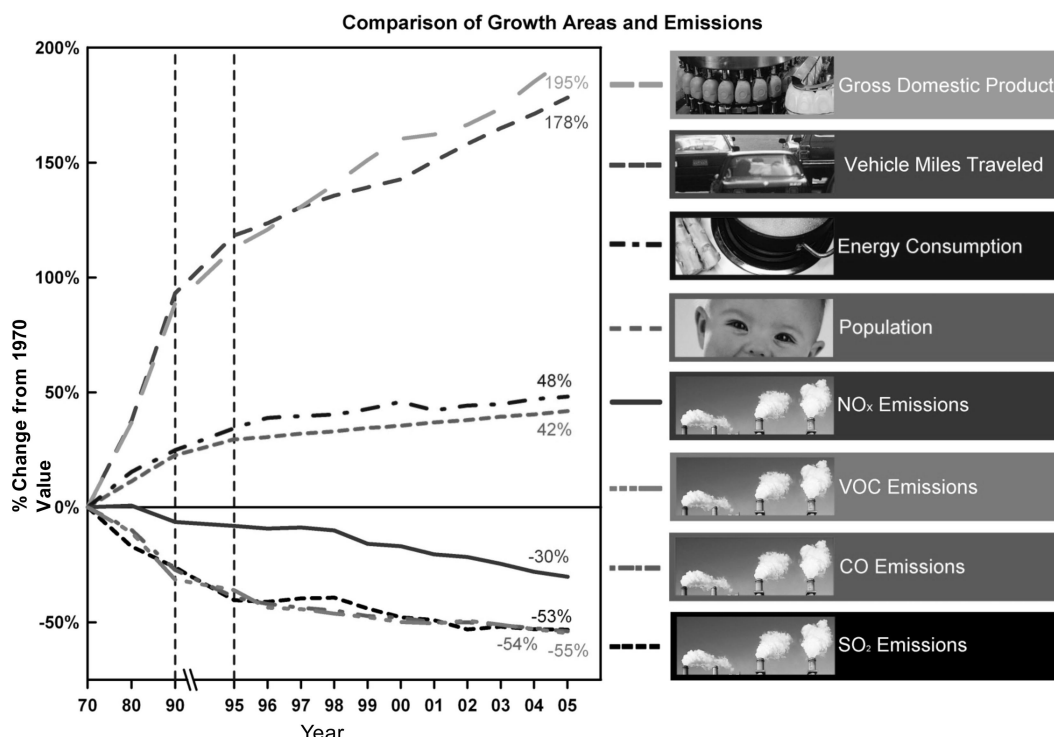


Figure 1. Progress in NAAQS pollution emissions continues while societal “drivers” grow.²⁴¹ Since 1970, emissions of regulated pollutants have steadily declined despite continued growth in population, energy consumption, traffic, and the economy. The benefits to society of the CAA can be estimated against 1970, as can what “might have been” without such efforts. A peer-reviewed EPA retrospective analysis estimated the range of cumulative benefits for 1970–1990 of about \$6 trillion to about \$50 trillion as compared with compliance costs of \$520 billion. Although such estimates are highly uncertain, it is reasonable to conclude that the benefits of all CAA programs combined substantially exceed the costs.²⁴²

This approach has a conceptual appeal for scientists and engineers. In practice, however, it can be daunting to execute, owing to the extraordinary level of technical and scientific information needed to establish effects-based ambient targets, measure key pollutants, inventory sources and emissions, develop and estimate costs for alternative control scenarios, and forecast and assess results. Each of these technical steps in the process is subject to large uncertainties. Additional skills are needed to develop necessary regulations and incentives, get them approved through state and Federal processes, and implement and enforce the plans on a sometimes litigious and unwilling set of emitters, including the general population (e.g., car inspections). From the 1960s to the present, those involved in or reviewing the process have repeatedly called for improved information and tools for all of the technical aspects, and have frequently sought resources, and technical, regulatory, and legislative assistance. The effectiveness of AQM depends on the nature and scale of the air pollutant problem as well as the level of understanding, skill, and commitment in multiple disciplines.

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, it

falls into the category of “risk-based” environmental programs.^{11,12} A major alternative strategy relies on emissions standards that require controls on various source categories based on best available technology (BAT), considering feasibility and costs. The BAT emissions standards approach is also an example of “command and control.”

The concept of adopting national emission standards, alone or in combination with an ambient AQM strategy, was the subject of considerable Congressional debate in the 1960s. The “risk versus technology” debate has continued among scholars for all environmental media. Many take issue with the whole notion of establishing “safe” levels of pollutants as being inconsistent with science and time consuming^{11,13–16}; some have championed BAT as more effective.^{11,17} Those who favor BAT note that it avoids many inherent difficulties in establishing and implementing risk-based targets and can therefore be implemented more quickly.^{9,11} It also provides a readily enforceable and equitable solution with some certainty for affected sources. A major argument of those favoring the risk or standards approach is that, without some normative goal, BAT would over-control in some areas and under-control in others.

National emissions and ambient standards are, of course, not mutually exclusive. Emission limits are needed to attain NAAQS, but required reductions may be lower than those achievable by BAT. In fact, the schemes established by CAAs of 1970, 1977, and 1990 adapted

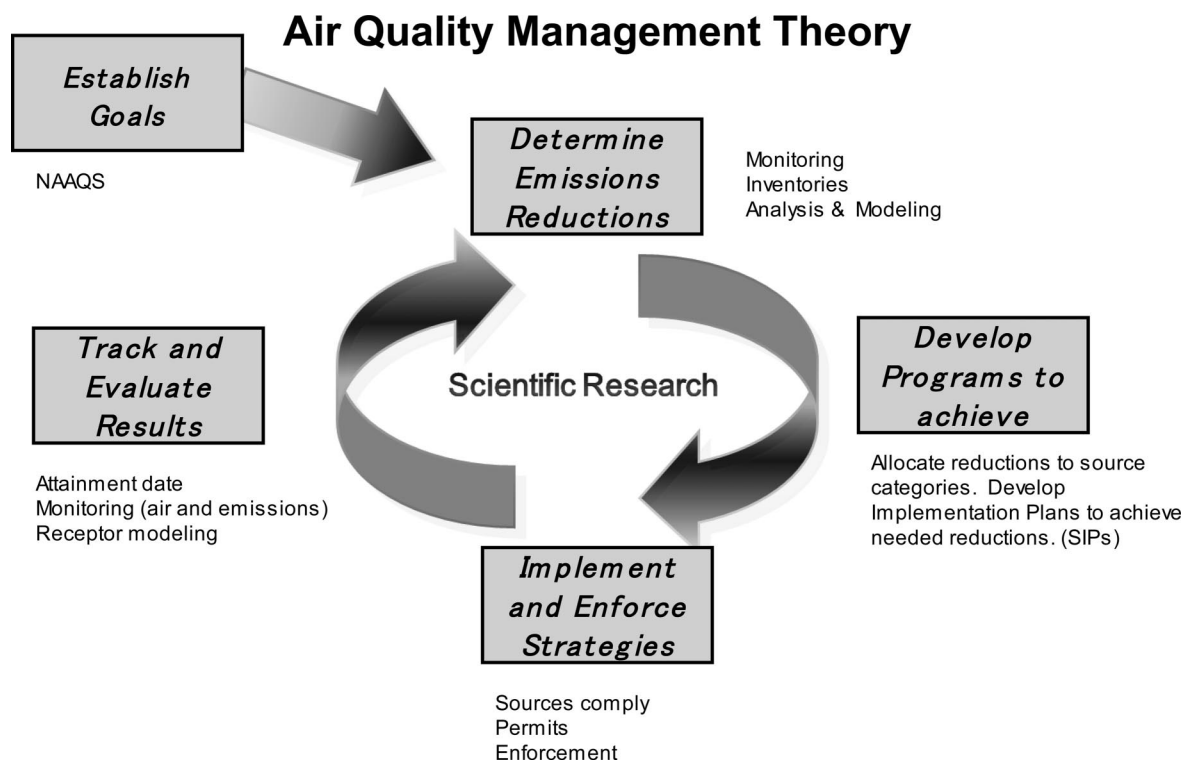


Figure 2. A conceptual model of AQM theory. This version is often referred to as the AQM “wheel” or “circle” and serves as the central focus and metaphor for this review. Under the 1970 CAA Amendments, the system is driven by NAAQS established by EPA. Congress gave most of the responsibility for the AQM process to the states, supported by federal rules for some sources and by federal grants. 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. States evaluate a collection of national and state based emissions reductions and must submit a detailed, comprehensive, and legally binding SIP to meet the NAAQS by a future date. Controls and measures must be implemented and checked by compliance and enforcement oversight. Finally, monitoring of the air or emissions is used to see if the plan worked. If not, or if the standards are strengthened, the process must be repeated. In practice, AQM in the United States does not fully conform to this theoretical model, and is better understood as a hybrid system. Over time, the system itself has evolved through legislation and policy to address problems in achieving results, advances in scientific and technical understanding, and changing socioeconomic and political conditions.

elements of both approaches, making it a philosophical “hybrid.” Although these CAA Amendments did establish and retain an ambient standards-based AQM system, they supplemented this approach with a growing number of national and area-specific emissions requirements.

By 1976, Stern’s classic compendium recognized at least two additional strategies for reducing air pollution.^{8,18} One approach was classified as “financial incentives,” such as taxes on fuels, tax deductions for controls, fines, fees, effluent charges, and subsidies. Another approach “seeks to maximize cost effectiveness” but was called the “cost-benefit” strategy. Today, we would classify the “financial” approach as a subset of “market-based” strategies. The successful market-based “cap-and-trade” programs to address acid rain and ozone (O₃) attainment¹⁹ have incorporated elements of both these categories.

An overview of U.S. AQM would not be complete without mention of the key participants. EPA has a major role in developing scientific criteria and establishing NAAQS as well as providing support to state and local programs through grants, guidance and rules, national emissions standards for stationary and mobile sources, and enforcement. As part of the executive branch, EPA coordinates and submits major rules for review by federal agencies, including the Office of Management and Budget

(OMB) and the Council on Environmental Quality (CEQ). EPA and many of these agencies sponsor research to advance the process. Congress provides budget and oversight for EPA’s activities as well as passing legislation. The judiciary resolves issues regarding NAAQS, implementation rules, national emissions standards, and enforcement. The states have the primary responsibility for implementing the NAAQS, beyond those federal controls mandated under the CAA, including monitoring, developing control programs, and formalizing State Implementation Plan (SIP) regulations. Some states conduct and sponsor scientific research related to effects and implementation. Under the CAA, states may also impose their own air quality standards that are stricter than federal NAAQS (e.g., www.arb.ca.gov/homepage.htm).

Public and private stakeholders, scientists and engineers, news media, and the public at large also play important roles in multiple stages of AQM. Major industry sectors such as transportation, petroleum, power generation, metals, mining, chemicals, and large-scale agribusiness take steps to meet various state and federal requirements, and also develop new approaches to reduce emissions. Some industries and coalitions sponsor research and analyze relevance to aspects of the process (e.g., Electric Power Research Institute [EPRI; my.epri.com/portal/]; and the joint Agency-Industry funded

Health Effects Institute [HEI; www.healtheffects.org/index.html]). Some stakeholders are advocates in the review and revision of the NAAQS, implementation policy, standard setting, and guidance. This may involve meeting with Agency policymakers, lobbying the Congress, petitions, and lawsuits. Examples of stakeholder organizations include state and local air agencies (e.g., the National Association of Clean Air Agencies, Western States Air Resources Council), industry associations (e.g., American Petroleum Institute [API], Edison Electric Institute, Motor Vehicle Manufacturers Association, American Iron and Steel Institute [AIS], National Mining Association), and environmental and public health groups (e.g., Environmental Defense, Natural Resources Defense Council [NRDC], American Lung Association). Scientists and engineers not only conduct research, but also play important roles in developing science assessments and reviewing Agency assessments and policies, recommending additional research and, in some cases, policy approaches (e.g., National Research Council [NRC]/National Academy of Sciences [NAS] panels, the Clean Air Scientific Advisory Committee [CASAC], NARSTO).

Even a cursory look at the history of the NAAQS and air pollution shows that developments are subject to what is sometimes called big “P” (i.e., partisan) and little “p” (e.g., interagency or office) politics and all of the changing societal, economic, cultural, and other influences related to a particular time and place. Although the state of scientific and technical developments of a given era shape the nature and effectiveness of societal responses to air pollution, such developments depend on the relative priority society places on the issue. Although air pollution is the focus of our profession and this review, it is infrequently at the center of national or local attention; it competes with many other issues in the modern world.

20TH CENTURY AIR POLLUTION BEFORE THE 1970 CAA AMENDMENTS

Part I: Up in Smoke (1900–1950)

“One of these days when the mischief is fully done, when our once pellucid and crystalline atmosphere is transformed into Chicago reek, and Pittsburgh smoke and London fog, men will begin to realize what they have lost, and will hold conventions, and pass resolutions, and enact laws, and spend great sums of money for the undoing of the mischief and the restoration of our atmosphere to its original state.” Editorial, New York Tribune, May 11, 1899²⁰

By the turn of the nineteenth century, the industrial revolution had transformed much of American life, creating new “industrial cities” such as Pittsburgh, Cleveland, and Milwaukee, and changing the character of many older cities built on commerce, such as New York, Boston, and Philadelphia, which acquired major industries as well.²¹ The rapid growth (urban population doubled between 1880 and 1900) and vast economic prosperity of the

nineteenth century cities came at the price of “. . . overcrowded tenements, congested traffic, critical health problems, smoky skies, mounds of putrefying wastes, polluted waterways, and unbearable noise levels. . . .”²¹ Inevitably, these conditions led to an increasing environmental awareness for urban and suburban dwellers. Individuals and groups, largely drawn from the middle and upper classes that benefited most from the economic advantages of urban life, began to protest, sue, and press local governments for remedies to specific pollution-related “nuisances,” usually on a local level.²¹ These early environmental reformers generally shared the outlook of the larger Progressive movement (1890–1920s). They did not seek a return to nature, but to preserve the economic benefits of the industrial system while working toward a better urban environment.²⁰

Despite repeated protests that were often led by local women’s clubs, nuisance lawsuits, and city ordinances, thick clouds of black smoke from the combustion of high volatility bituminous coal remained a persistent feature of the industrial urban landscape. Indeed, the story of U.S. air pollution in the first half of the twentieth century was largely driven by the growing amount, character, and geographical distribution of coal use (Figure 3). Pittsburgh, Chicago, Cleveland, Cincinnati, Milwaukee, and St. Louis relied on nearby supplies of the more plentiful bituminous coal to fuel factories and dwellings, whereas notably cleaner New York, Boston, and Philadelphia usually had access to the less plentiful high-solid anthracite from eastern Pennsylvania. San Francisco relied on natural gas.²² At the time, the most effective smoke mitigation options—switching to anthracite or natural gas—were limited by local availability and cost. Other useful, but less effective, options such as improved firing technologies, taller stacks, attention to operation, and mechanical collection, were not in wide use, partially because of cost and lack of information.

Smoky days in these cities were characterized by a combination of coarse soot and dust fall with fine carbonaceous and acidic particles and gases from industrial and domestic sources. Limited data suggest ambient particle

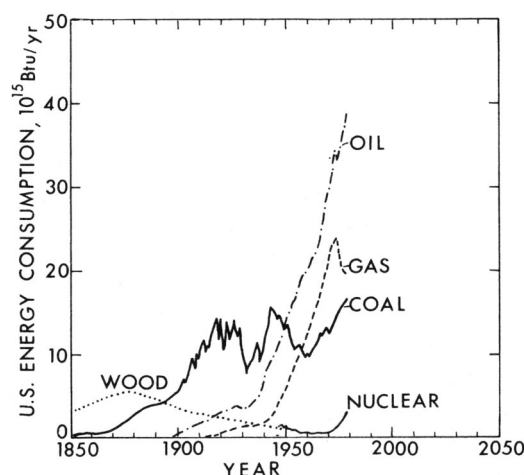


Figure 3. Trends of fuel consumption in the United States.³³ Between 1900 and 1950, coal was the dominant source of energy. The dip in consumption marks the Great Depression, and the following peaks mark the economic recovery leading into World War II, followed by increased coal use for electric power generation.

levels in Chicago, Cleveland, and Pittsburgh in the 1910s were on the order of 1000–10,000 $\mu\text{g}/\text{m}^3$, with dust fall levels in Pittsburgh of 1000 t/mi^2 .²³ Episodes would frequently blot out the sun, requiring gaslights at midday in Pittsburgh, which contemporaries noted was “a smoky dismal city at her best.”²⁴ But smoke’s effects were not limited to obscuring the sun.

*Coal soot, for example, was particularly invidious, for it not only coated everything in the city with black dust, it also had an oily quality, which helped it cling to clothing, curtains, furniture, and other items. . . Soot could stick to exposed skin, collect in nostrils, lungs, eyes, and stomachs. . . 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 dusty streets.*²⁰

Although most agreed that smoke was a nuisance, questions persisted in the popular culture about how serious a health menace it presented. An increasing scientific and medical consensus was that smoke was harmful, but the evidence was thin.^{20,22,24} A mid-19th century suggestion that smoke had at least some beneficial properties, for example as a germicide, persisted.^{11,24} Still, reformers such as the Pittsburgh’s Ladies Health Protective Association and the St. Louis Wednesday Club argued that smoke abatement was a public health necessity, in addition to their position that cleanliness was a moral value and an attractive environment was an economic good.^{20,22,24} The counter argument was that a smoky atmosphere was the index of prosperity, that economically viable alternatives did not exist, and that smoke was not harmful to health.^{11,20,22,24} Tolerating this esthetic nuisance was just a necessary evil for the good of the community.

The early 1900s saw a number of protests, failed attempts at municipal regulation, and interventions against regulations by the courts. A controversial transition from prosecution to a technical and cooperative approach to smoke management emerged with the introduction of the Ringelmann Chart and the smoke inspector.²² The founding of the International Association for the Prevention of Smoke (forerunner of A&WMA) in 1907 was emblematic, as was the growing number of municipal smoke regulation authorities and statutes (Table 1). Most ordinances prohibited smoke emissions of greater than no. 3 on the Ringelmann chart (60% opacity) from larger sources, but exempted most domestic combustion.²⁵ Programs began using trained engineers to check violations and to educate business and industry on improved firing methods and alternative equipment. Engineers and reformers created what Stradling²⁰ termed a “conservationist movement” to increase efficiency and economy by decreasing the waste associated with unburned fuel (smoke and carbon monoxide [CO]) going up the stack.

Also emblematic of the era was a proliferation of special studies on control approaches and surveys of smoke related pollution in St. Louis, Chicago, and other areas. The most far reaching of these was the nine-volume Mellon Institute Study in Pittsburgh (1912–1914),²⁶ which addressed air pollution levels, effects, economic

Table 1. Development of principal American municipal smoke abatement legislation before 1930.²⁵

Decade	Cities
1880–1890	Chicago, IL; Cincinnati, OH
1890–1900	St. Paul, MN; Cleveland, OH; Pittsburgh, PA
1900–1910	Los Angeles, CA; Minneapolis, MN; St. Louis, MO; Milwaukee, WI; Indianapolis, IN; Dayton, OH; Detroit, MI; Akron, OH; Buffalo, NY; Rochester, NY; Syracuse, NY; Washington, DC; Baltimore, MD; Philadelphia, PA; Newark, NJ; Springfield, MA; New York, NY; Boston, MA
1910–1920	Portland, OR; Denver, CO; Kansas City, MO; Des Moines, IA; Duluth, MN; Nashville, TN; Birmingham, AL; Louisville, KY; Flint, MI; Toledo, OH; Atlanta, GA; Columbus, OH; Richmond, VA; Albany County, NY; Jersey City, NJ; Hartford, CT; Providence, RI; Lowell, MA
1920–1930	San Francisco, CA; Seattle, WA; Salt Lake City, UT; Sioux City, IA; Omaha, NE; Cedar Rapids, IA; Grand Rapids, MI; Lansing, MI; East Cleveland, OH; Wheeling, WV; Erie County, NY; Harrisburg, PA

damages, and controls. Pittsburgh adopted Ordinance No. 257 based on recommendations in this report in 1914. On the other hand, the 1915 Chicago Association of Commerce study²⁷ of the costs and benefits of railroad electrification took 5 yr to complete and delayed implementation in Chicago by well over a decade.²⁰ Inspired by New York’s early regulations, Chicago women’s groups had advocated rail electrification there as early as 1908.²⁰

Between 1906 and the U.S. entry into World War I in 1917, smoke programs appeared to progress in several cities at the same time that coal utilization increased. Milwaukee limited the number of smoky days.²² A 1912 report claimed Chicago reduced smoke by 75% in the central city.²⁸ Improvements were also noted in Philadelphia and Rochester, NY.²⁰ By 1915, Pittsburgh smoke was noticeably improved despite coal use having more than doubled (Figure 4).²³ Although smoke abatement efforts were halted during the increased industrial production stimulated by the war, Figure 4 indicates that smoke levels in Pittsburgh did not return to their former peaks. In the postwar era, advocates and inspectors in smoky cities again worked to improve the problem. The combustion strategies they employed reduced soot as measured by opacity, but increased cinder and fly ash emissions. By the 1930s, municipal regulations began to add requirements for total particle mass emissions.²⁵

The dearth of ambient measurements does not permit verification of the extent to which the air improved, worsened, or stayed the same in most cities between World War I and World War II, though accounts suggest that due to strikes and supply problems with anthracite coal, New Yorkers had more problems with smoky coal in the 1920s than in 1899.²⁰ By April 1928, the *New York Times* proclaimed that a new study had surveyed cities from the Atlantic Seaboard to St. Louis and found “More soot here than in Pittsburgh.”²⁹ Figure 3 indicates that U.S. total coal use peaked in the 1920s and declined after the start of the Great Depression (1929), only to ramp up again with the economy as the United States prepared for war (1939–1941). Figure 4 shows that the occurrence of heavy smoke in Pittsburgh followed this pattern, with

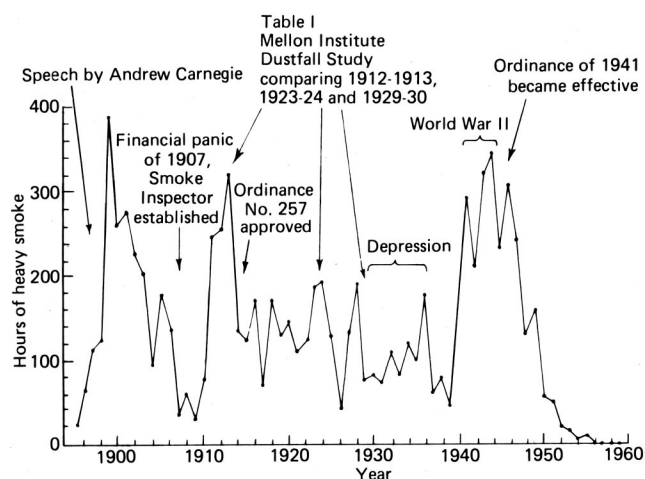


Figure 4. Number of hours each year during which heavy smoke was recorded in Pittsburgh, 1895–1960.²³ The low levels before 1898 were at the end of a 5-yr period in which Pittsburgh had switched to homes and industry to natural gas. The “return to coal” brought back the smoke, but the hiatus and return apparently changed the public perception and tolerance of the nuisance.^{24,44} Reductions and increases thereafter are related to economic conditions that affected output and the influence of smoke control programs.

conditions in the 1920s and 1930s apparently improved over peaks observed in 1900 and 1912–1914.

In the 1930s, the *New York Times* periodically reported smoke data in tons per cubic mile from an Owens automated smoke sampler in Central Park. Between 1930 and 1931, the annual average at the site fell by more than 50%, from 3.97 to 1.84 t/mi³ (860 µg/m³ to 400 µg/m³).³⁰ The meteorologist taking the measurements attributed the drop to greatly reduced economic activity (evidenced by lower amounts of bituminous coal mined), actions by health groups to control smoke, and differences in weather. By the last full year reported (1936), annual levels had fallen to 290 µg/m³.³⁰ The highest of two months reported in 1939 was 170 µg/m³. Whatever the relationship was to actual mass, these data indicate that smoke continued to decline throughout the Depression.

The major breakthrough in smoke management resulted from the work of Raymond Tucker, a mechanical engineering professor from Washington University of St. Louis. With an assignment to “clarify the air” in St. Louis, he worked between 1934 and 1940 on the alternative strategy of regulating the fuel instead of the smoke. Initial “coal washing” rules reduced ash and sulfur but resulted in modest improvements in smoke.²⁰ Tucker recognized that residential smoky coal, not just industry, was an important part of the problem, and he advocated eliminating the use of bituminous coal.²⁰ He also recognized that the shift would reduce sulfur dioxide (SO₂) as well. Aided by a 2-week newspaper campaign in November 1939 and one of the worst smoke episodes in St. Louis history on November 28, 1939 (midnight at noon and near zero visibility³¹), Tucker and a committee developed a regulation that would require consumers of high-volatility coal to use mechanical stokers or switch to smokeless fuel. After the regulation was passed in 1940, the next winter brought a sharp contrast between the clean air of

St. Louis and smoke across the river in Illinois.²⁰ Impressed by this achievement, citizenry and community leaders in Pittsburgh united against increasing smoke from rising steel production (Figure 4) and passed a similar ordinance in 1941.³² Although implementation was delayed by the war, civic leaders, the press, and industry worked to develop a program that took effect in 1946–1947.³² Figure 4 illustrates the dramatic improvement from the late 1940s on, putting an end to two centuries of misery in the Smoky City. Other cities, such as Cincinnati and Milwaukee, eventually followed suit, but they had to overcome organized opposition from the coal industry.²⁰

The viability of these regulations was enhanced by pipelines that increased access to affordable natural gas, and most consumers preferred gas to coal. Air in other cities, like Kansas City, benefited from ongoing consumer and economic choices to switch fuels.²² Other energy shifts also reduced urban smoke. Through the mid-1940s, a substantial amount of coal was used for transport in steam locomotives and water traffic. Electrification of urban railroads in some urban areas and increasing use of diesel- and gasoline-powered vehicles greatly decreased coal smoke emissions from transport to negligible amounts by 1955.³³ Urban industry, elevator operators, and others also increasingly switched from direct coal use to more convenient and locally clean electric power, or to oil or natural gas. All of these shifts, which largely occurred at ground level, should have been particularly effective in reducing urban population exposures to smoke (and sulfur oxides [SO_x]) emissions. Coal was increasingly used in power plants with efficient combustors and control devices, minimizing direct particle emissions with higher release points that further reduced local exposures. Some of these shifts were for efficiency and economic reasons,²⁸ but others were driven by concern over smoke emissions.

Several essays and books have been written about the legal, policy, societal, cultural, and technical aspects of the crusade against smoke in the United States and abroad.^{11,20,22,24,32,34–38} The following science and policy observations on this period are based on their findings in light of current knowledge.

- (1) Several authors^{11,22} concluded that the smoke abatement movement was a failure, as evidenced by the lingering problems through the 1940s. But as Stradling²⁰ points out, the evidence suggests that early smoke programs brought some reductions or held things in check, with the notable exception of World War I. Yet bituminous coal use grew from 111 million t in 1890 to 556 million t by 1918, a 500% increase. The pressure from the early advocates and the efforts of the smoke inspectors may have averted a more pressing environmental disaster.²⁰ In Pittsburgh, overall dust fall did not decrease between 1912 and 1923, but the tar content was reduced. This is consistent with the increasing application of improved combustion approaches, which would be expected to reduce the organic fraction of PM. This fraction contains polycyclic organics and other combustion products generally considered to be more toxic than carbon cinders or ash.

Although not measured, improved combustion should also have reduced CO.

- (2) The fact that the United States failed to address the pervasive smoke problem for decades is worth exploring. Morag-Levine¹¹ addresses the failure of nuisance law and the courts. The burden of proof in winning a nuisance suit is high enough with a single source; when the nuisance consists of many emitters in an industrial city, it is difficult to show how a single entity adds detectable amounts. The courts long shared the prevailing attitude of many municipal governmental authorities that the smoke nuisance was the unavoidable consequence of progress. This attitude was evidenced in a Depression era decision against a request to enjoin mounds of burning mine wastes:

*"Much of our economic distress is because of the fact that there is not enough smoke in Pittsburgh . . . The metropolis that earned the sobriquet of the "smoky city" has not been living up to those vaporous laurels."*³⁹

Although largely ignored in early smoke programs, SO₂ damage to vegetation from isolated smelters sparked both study and "successful" nuisance lawsuits,¹² including the notorious case of the Ducktown, TN, copper smelter. After the smelter built tall stacks to avoid damage payments to local farmers, substantial quantities of SO₂ crossed state lines into Georgia, damaging crops and forests. Georgia brought suit in a case ultimately decided by the U.S. Supreme Court in 1907 (*Georgia vs. Tennessee Copper*, 1907).

- (3) The failure of municipalities to respond to the citizenry regarding pervasive smoke is notable when contrasted with their response to contaminated drinking water and sewage waste, which were addressed between 1850 and 1930.^{40,41} These programs cost municipalities substantial sums. In this case, evidence linking contamination of these amenities and the spread of diseases, such as cholera and dysentery, in crowded cities was apparent to both the citizenry and governments. It was clear that the lack of these services limited the economic vitality of the industrial city, prompting leaders to respond quickly.

This was not the case for smoke. Despite the prevailing medical opinion and the claims of activists, the case for health effects of smoke rested on limited research and conjecture. Efforts by the Mellon study group^{26,42} to examine health effects, for example between "smoky" and "non-smoky" cities, produced equivocal results, as did the accompanying review of the literature.^{24,43} Mellon study director John O'Connor wrote a letter to the editor of the *Pittsburgh Sun* that noted "indirect effects" on health and agreed with the *Sun* editorial that stated:

*" . . . those who favor smoke abatement do not need the bugaboo of health to bolster up their case. The fact that Pittsburgh is taxed \$10,000,000 a year because of the smoke nuisance is sufficient argument."*²⁴

Municipalities were less likely to take the costly steps needed to address what could be characterized as a largely esthetic issue, however severe.

Given what we now know about the health effects of high concentrations of suspended particles and SO_x in London and New York, it is surprising that U.S. research efforts through the 1930s were unable to reach more definitive conclusions about adverse health effects. Two factors likely contributed:

- With no reliable routine measure of population exposure to smoke, much less to other air pollutants, it was not possible to make realistic linkages between air pollutants and health either across cities or from day to day. The Mellon review⁴³ did find reports of associations between urban fogs (e.g., London) and increased deaths, as well as higher death rates in cities compared with non-urban areas, but this did not conclusively implicate air pollution.⁴⁴
- The likely signal-to-noise ratio of air pollution effects was low. Death rates in the 1900s were much higher than today, and the leading cause was infectious disease, especially pneumonia and tuberculosis.⁴⁵ Because fewer Americans smoked in 1900 and life expectancy was low, the cohort of people at highest risk of mortality from particles (>65 yr with cardiovascular disease) was one-third of its present fraction of the population.⁴⁶ It would take a rare, extreme event to detect an air pollution effect.
- (4) The lack of routine air quality monitoring also made it difficult to provide objective evidence about the effectiveness of emissions reductions, both within and between cities. This slowed the transfer of information about what worked and what did not. The lack of research and normative objectives allowed opponents to challenge concerns that the "nuisance" was also a pressing public health menace. Battles over these issues were repeated in different cities and times. Morag-Levine¹¹ suggests that the very nature of American law and governance prevented the "feasible technology" approach that she argues (without comparative measurements)⁴⁷ improved air quality in German industrial cities long before improvements in the United States.
- (5) It is regrettable that the federal government played no significant role, although the federal lead on air pollution (Bureau of Mines) did some useful research on improved coal combustion and the Public Health Service and others sponsored some air pollution survey work. The Bureau of Mines, however, also dismissed prematurely the risks of adding lead (Pb) to gasoline based on

preliminary results of animal research in 1926.³⁸ The disparate and underfunded municipal smoke abatement programs could not be expected to independently to develop and implement coordinated strategies that might have accelerated the move to cleaner fuels and alternative uses of coal such as electricity and gasification. (The latter was seriously explored in Pittsburgh after a brief period in 1887–1892, during which natural gas was the major fuel.)²⁴ From its inception, the Smoke Prevention Association (A&WMA predecessor) enhanced information sharing and standardization among municipal smoke engineers, thereby contributing to faster dissemination of improved combustion and dust control technologies.²⁰ However, Stradling²⁰ argues that the organization's increasing focus on technical aspects of improving coal combustion and dust control reinforced the presumption that the use of bituminous coal as a primary fuel must continue. This precluded an early, active consideration of the strategies—electrification and alternative fuels—that provided a lasting solution to smoke only decades later.

- (6) Additional research might also have explored and expanded the evidence that led Mellon Institute air pollution director Herbert Meller to conclude that much more attention should be paid to invisible gaseous pollutants such as SO₂ and CO.²⁴ As noted above, improved combustion did little to reduce SO₂ emissions. Meller²⁴ developed a research agenda on the concept of “hygienically pure air” analogous to goals for drinking water or food. He believed that protective ambient limits could be set for various air contaminants. But Mellon funds were drying up during the Depression, and he was unable persuade the U.S. Public Health Service (PHS) or others to support his vision. Uekoetter³⁸ notes how the prevailing attitudes of the era tended to “legitimate the lethargy” of researchers and public officials regarding air pollution.
- (7) The smoke experience also provides several examples that support the suggestion by Brimblecome³⁵ and Davidson²³ that an increase in public awareness and concern often accompanies a sudden and perceptible degradation of air quality. As Gugliotta²⁴ and Davidson²³ suggest, this was certainly the case for Pittsburgh after the end of the brief period of clean skies (1884–1992), during which the city was fueled by a local natural gas field. In the minds of the townspeople, that period broke the necessary connection between smoke and industry.²⁴

Citizens and the press in both St. Louis and Pittsburgh were motivated by perceptible increases in smoke just before World War II. Their increased concern undoubtedly helped spur the adoption of effective rules. Other examples of community responses to notable changes in air pollution that

spurred action came just a few years later, as summarized in the following section.

More than Meets the Eye: a New Sense of Urgency. Toward the end of the 1900–1950s era, two unrelated developments changed the course of air pollution control in the United States. In 1948, as Pittsburgh was enjoying dramatic improvements from its smoke program, just 29 km away the small industrial community of Donora experienced an air pollution disaster that could not be ascribed solely to smoke. An unusual meteorological inversion resulted in a 4-day buildup of fog, PM, and SO_x from steel and zinc smelters and sulfuric acid plant emissions. During the episode, 20 people died, and 6000 people (approximately 43% of the total Donora population) suffered respiratory problems described as “a gasping for air and complaints of unbearable chest pains.”⁴⁸ The Donora story made national headlines, as did a study of the episode by PHS.⁴⁹ As the first *New York Times* story on Donora noted, this episode appeared similar to an incident in the industrial Meuse Valley of Belgium in 1930, in which 68 deaths were attributed to air pollution.^{48,50}

The *New York Times* article on the PHS Donora report began: “Air pollution as a major national health problem was made the subject today of a 173 page report by the Public Health Service.”⁴⁸ A PHS spokesman said the Donora report proved “for the first time that air contamination in an industrial community can actually cause acute disabling diseases.” The U.S. Surgeon General “said there should be immediate research both into air pollution *per se* and the effect of polluted air in shutting out healthful rays of the sun. He reported that he was asking Congress today for \$250,000 as an added appropriation for this work.”⁴⁸ The article accurately conveyed the report's finding that no single pollutant was responsible, with the “smog cases” likely attributed to a combination of contaminants. Nevertheless, “sulfur dioxide was listed as the chief culprit.”⁴⁸ The report itself estimated that SO₂ and particulate matter (PM) levels likely reached 1800 µg/m³ and 5300 µg/m³ respectively.⁴⁹

The times were indeed changing. Not only did the word “smoke” not appear in the story, but one of the pollutant gases was prominently featured. The federal involvement was immediate and prominent, and the PHS was established as the lead federal agency. Most significantly, the message that air pollution was a national public health problem was now clear. Whereas Stern²⁵ noted that people soon forgot the episode, such a convincing demonstration of a link between air quality and severe health effects on American soil helped to galvanize national support for long-range efforts needed to address not just “smoke”, but “air pollution.”

The second transforming development was the unexplained occurrence of eye-burning smog events beginning in 1943 in Los Angeles, one of the major urban areas that used virtually no coal. Although it is called smog, it consisted neither of smoke nor fog, and it turned out to be a new form of air pollution that appeared as widespread haze that burned the eyes. Analyses of Los Angeles International Airport visibility data suggested that although eye irritation became noticeable in 1943, the haze in the basin had been worsening for some time. Even in the

1930s, visual ranges above 20 km were rare in the summer and early fall,⁵¹ which we now recognize as the peak season for smog formation.

Seeking expert advice, in 1946 the *Los Angeles Times* hired Raymond Tucker, recognized for his work in St. Louis, to study the problem and recommend solutions. Tucker's recommendations^{20,52} focused on banning obvious sources of PM and SO_x emissions such as incinerators and fires at waste dumps, monitoring industrial emissions, and penalizing diesel truck drivers with smoky emissions. In 1947, California passed the first statewide legislation authorizing county air pollution regulations for anything other than smoke, and Los Angeles County immediately formed an Air Pollution Control District. But there was no "silver bullet" strategy, as was the case for smoke in St. Louis. When the kinds of sensible measures Tucker recommended^{20,52} were later adopted, dust fall was reduced, but the controls failed to address the main sources of the smog problem. In addition to initial regulatory activities, the city, industry, and the state mounted research and monitoring programs to better understand the nature, sources, and effects of smog. In this case, officials perceived the sudden and growing eye-stinging smog episodes as an economic threat to an area whose growth in part depended on the attraction of its warm, sunny skies to health seekers.⁵²

Both the Donora disaster and Los Angeles smog problems gave national attention to the seriousness of air pollution. In late 1949, acting on a request led by the Bureau of Mines, President Truman asked the Secretary of the Interior to head a federal committee to organize the First U.S. Technical Conference on Air Pollution, which was held in Washington, DC, in May 1950.²⁵ The letter, however, stressed that any federal efforts were to be limited to assessment and resources "since the responsibilities for corrective action and the benefits are primarily local in character".⁵³ It would be more than a decade before federal involvement moved beyond community support and research.

Part II: Building the Foundations of AQM (1950–1960)

In 1950, reflecting the new priorities in the field, the Smoke Prevention Association changed its name to the Air Pollution and Smoke Prevention Association. In 1952, it became the Air Pollution Control Association. This was an eventful year for air pollution. After moderate progress in New York City and continuing newspaper stories and citizen complaints critical of the city's Smoke Bureau, New York created a new Department of Air Pollution Control, with a director who had medical instead of combustion engineering credentials.⁵⁴ With the influence of coal smoke waning and new concerns over public health and invisible pollutants, the transition in New York, in other cities, and at the federal level elevated the importance of health professionals in air pollution control programs.²⁰

By 1950, Professor Arie Haagen-Smit of the California Institute of Technology had identified O₃ as a major component of the smog that caused respiratory problems and damaged vegetation and rubber.⁵⁵ In 1952, his smog chamber studies found the source of the problem—by injecting and irradiating samples of refinery emissions

and auto exhaust, Haagen-Smit could produce high levels of O₃.⁵⁶ Mixing O₃ with gasoline fumes produced aldehydes and other compounds that were responsible for eye irritation. The emergence of smog in California could now be related to the rapid growth of population, vehicle miles traveled,⁵⁷ and stationary sources of invisible fumes, all in a basin where the prevailing meteorology was conducive to trapping and transforming the emissions in the abundant California sunshine. It would be some time, however, before a consensus was reached on controlling automotive emissions.

Near the end of 1952, (December 5–12), the worst air pollution disaster on record occurred in London, England. Initially, heavy fog obliterated visibility, causing traffic accidents and canceling events, but eventually official reports noted crowded hospitals and increased mortality.^{58,59} A year later, a report set the number of deaths at approximately 4000 (today estimates of the totals are as much as three times higher). This not only cemented the relationship between pollution and health, but also resulted in a substantial increase in research and monitoring, both in the United States and in Europe. The results of the British research, in particular, would form much of the basis for the first U.S. NAAQS for PM and SO₂ in 1971.^{60,61}

In 1954, responding to a request from Senators Thomas Kuchel (California) and Homer Capehart (Indiana), President Eisenhower asked the Secretary of Health, Education, and Welfare (HEW) to lead an interdepartmental committee on Community Air Pollution.⁵³ The committee recommended a federal program of research and technical assistance that was later enacted as the Air Pollution Control Act of 1955.²⁵ The one-and-a-half-page law authorized the Secretary of HEW to fund federal research and to assist states and educational institutions in training personnel and carrying out research. The effort was to be led by the research-oriented PHS, which had already begun sponsoring such activities. In addition to recognizing the dangers of air pollution, the law stated the policy of Congress to "preserve and protect the primary responsibility and rights of the states and local governments in controlling air pollution. . . ." The bill authorized \$5 million/yr for 5 yr, but only \$16.5 million of the authorized \$25 million was actually appropriated during the period.⁵³ The law was extended in 1959, and in 1962 a directive to study motor vehicle exhaust was included.²⁵

Meanwhile, regulation and control of air pollution was continued by municipalities and the State of California. In the East, the continuing transition to cleaner fuels and power, aided by continuing municipal programs to regulate stationary sources, resulted in reductions in both PM and SO_x in the central portions of formerly smoky cities. The PHS National Air Sampling Network (NASN), with the help of local authorities, began measuring particles and chemical components in 1953 with high-volume samplers in 17 communities.⁶² Later reconfigured and expanded to additional locations and to include gases, NASN began to provide objective information about trends in these air pollutants. The Los Angeles Air Pollution Control District (LAPCD) began to act on the Haagen-Smit findings, starting with controlling hydrocarbon emissions from industrial gasoline storage tanks in 1953.⁶³ At the

Table 2. Alert stages for toxic air pollutants in Los Angeles (1955).⁶⁶

Gas	In ppm of air		
	First Alert ^a	Second Alert ^b	Third Alert ^c
CO	100/hr 200/0.5 hr 300/10 min	100/2 hr 200/hr 300/20 min	— 200/2 hr 300/hr
NO _x	3	5	10
SO _x	3	5	10
O ₃	0.5	1	1.5

Notes: ^aStill safe but approaching level where preventative action is required. ^bA health menace exists at a preliminary stage. ^cA dangerous health menace exists.

end of the decade, the LAPCD limited the amount of reactive olefins in gasoline.⁶⁴

In 1954, Los Angeles experienced several severe photochemical smog episodes, which prompted concerns about possible serious health consequences, particularly in light of the recent Donora and London disasters.^{65,66} In 1955, LAPCD established an ambient monitoring-based alert system with three graduated levels (Table 2): (1) an initial warning, (2) curtailment of certain emissions sources, and (3) emergency actions.⁶⁶ At the time the alert levels were developed, the scientific literature contained several published occupational studies of O₃ and some animal toxicology, but very little else,⁶⁷ forcing policy choices with limited information. The emergency episode alert and management system approach was an important innovation that was later made part of the CAA and remains in use today. Ironically, the initial year marked the highest level of O₃ ever recorded in Los Angeles (0.68 ppm). In 1956, the network expanded to 15 sites, and researchers used the information to develop the first community health studies of photochemical air pollution. The results of their research formed much of the basis for the first national photochemical oxidant standards in 1971.⁶⁷

Setting episode criteria levels to prevent significant harm begs the question for both policymakers and the public at large of what levels might represent clean air. The industrial hygiene community was familiar with the use of the so-called “threshold limit values” and “maximum allowable concentrations” for various substances in occupational settings.⁶⁶ As California State Department of Public Health researcher John Goldsmith wrote, such limits “are neither really thresholds, nor allowable.”^{65,66} Their origin and purpose (a guide to limit exposures for most healthy adult workers) make them ill-suited for the application of protecting the general population from ambient air pollution. Nevertheless, as Meller had realized in 1933,^{24,68} California policy makers and health officials concluded that establishing limits for ambient air would provide a useful target for air pollution control programs. In 1959, then-California Governor Edmund “Pat” Brown took the position that such standards must be set before control programs for automobiles were established.⁶⁹ In that same year, the legislature passed a law instructing the California Department of Health (CDH) “to develop and

Table 3. Table of Standards for Ambient Air Quality in California (1959) (after Stern, 1962, Table XVII).⁶⁶

Pollutant	“Adverse” Level (level at which there will be sensory irritation, damage to vegetation, reduction in visibility, or similar effects)
Oxidant	“Oxidant Index”: 0.15 ppm/hr by the potassium iodide method (eye irritation, plant damage, and visibility impact)
O ₃	
NO ₂	
HC	
Photochemical aerosols	
Carcinogens	Not applicable
SO ₂	1 ppm/hr, or 0.3 ppm/8 h (plant damage) ^a
Sulfuric acid	Footnote references to toxicology results
CO	Not applicable ^b
Pb	Not applicable
Ethylene	Footnote indicates standard expected in 1 yr
PM	Sufficient to reduce visibility to less than approximately 4.82 km when relative humidity is less than 70%

Notes: ^aSerious level: 5 ppm for 1 h (bronchoconstriction in human subjects). Emergency level: 10 ppm for 1 h (severe distress in human subjects). ^bSerious level: 30 ppm for 8 h or 120 ppm for 1 h (interference with oxygen transport by blood).

publish” standards for the quality of California’s air, and the department followed with the first state ambient air quality standards for several pollutants. Separate legislation required the CDH to establish maximum allowable standards for motor vehicle emissions.

The CDH, unlike with later ambient standards, did not define a protective level, but instead concentrations it judged to be associated with three standards of harm—adverse, serious, and emergency (see Table 3 summary), following the approach but not the conclusions of the LAPCD. The CDH listing of standards⁶⁶ included brief summaries of the studies that provided their basis, or in the case of pollutants for which they judged sufficient evidence was not available, a mention of suggestive evidence or evidence of absence. Plant damage and/or visibility featured prominently as the basis for adverse levels. The “basis” summary listed only two O₃ health studies, and CDH found no direct health basis for standards. Yet several additional occupational and other studies existed at that time.⁶⁷ One might understand if the more aggressive LAPCD, which had set alert levels for O₃ as well as nitrogen dioxide (NO₂), felt undercut by the state experts. The CDH also moved on its mandate to develop automobile exhaust emissions standards, using roll-back modeling of projected air quality in 1970 to estimate what automotive reductions might be needed to meet tighter air quality standards.⁶⁶

California and some members of Congress wanted to push the auto industry to develop and install emission controls. After more aggressive legislation was defeated, in part because of PHS objections to national regulations, Congress in 1960 enacted legislation requiring the PHS to report to Congress on motor vehicles, air pollution, and health.⁵³ Although reorganizing to form a Division of Air Pollution in 1960, the PHS saw itself as a resource and

research organization and “neither sought nor wanted” authority to control pollution.⁵³

Part III: The Race to the Top (1961–1970)

The 1960s were a time of major social, political, and cultural change in America. These societal developments also had a profound influence on public perception of environmental issues, specifically air pollution, as growing problems. At the beginning of the decade, federal involvement was limited to a modest contribution to research, monitoring, and state assistance, whereas municipalities had the primary responsibility for controlling air pollution. The combined response was limited and uneven. The Division of Air Pollution in the PHS had 251 employees and a budget of about \$4 million in 1960.⁷⁰ Close to 60% of the \$10 million spent by all state and local air programs was in California. By the end of the decade, federal legislation and a new agency would set the agenda, with national regulations for air quality, mobile sources, and some stationary sources. The primary responsibility for implementing this agenda would shift from municipalities to the states: 84 municipalities but only 8 states had authorized air pollution programs in 1960.²⁵ By 1970, all 50 states had programs.

Federal Legislation—Round 1. In 1962, national awareness about the environment was raised by Rachel Carson’s *Silent Spring*,⁷¹ which was the subject of a CBS special report the following year. In December, the Second National Conference on Air Pollution²⁵ garnered some attention for the issue in the United States, just as another air pollution episode was under way in London. Although British programs had reduced coal smoke, an estimated 850 people died in this event.⁶¹

President Johnson agreed to support the HEW’s advocacy of an expanded federal role in air pollution. Senator Edmund Muskie (Maine) and Congressman Kenneth Roberts (Alabama) worked closely during hearings and into conference to craft the final legislation, which was signed by President Johnson in December as “The Clean Air Act of 1963” (Table 4). The key innovation, termed the “Abatement Conference,” was a complex multistage process that maintained the primacy of state and local authority over air pollution control. It contained no ambient or emissions standard requirements, and generally made HEW participation contingent on a request from the state, with the exception of interstate air pollution.

The law’s use of “criteria” to mean a summary of the relationship between air pollutant levels and effects on the “health or welfare of persons” was not widespread at the time. As noted above, the CDH called its science summary “the basis” for the California ambient standards. Stern later cited the 1961 CDH report, which contained a 53-item cause and effect tabulation for SO_x , as an example of air pollution criteria.⁶⁶ The difference between what is meant by “air quality criteria” and “air quality standards” apparently led to confusion in the PHS and later in Congressional hearings. With no deadlines or specific mandates, the PHS produced only one set of criteria pursuant to the 1963 CAA, for SO_x in 1967. It included 79 cause-and-effect statements, but also contained

a table of alternatives with ranges of concentrations that “can be collectively utilized as criteria of acceptable air quality.”⁶⁶ Today, this table looks more like modern EPA staff paper (SP) recommendations for air quality standards rather than air quality criteria. For example, the summary table listed 24-hr SO_2 ranges of 0.05–0.08 ppm maximum and 1 hr of 0.04–0.06 ppm. As a comparison, the current 24-hr SO_2 NAAQS is 0.14 ppm, second maximum. It is not surprising that Congress heard substantial criticism of the first PHS criteria document (CD).⁷²

The omission of federal regulations or authority to address mobile sources seems glaring. California had already adopted two sets of standards (positive crankcase ventilation [PCV] beginning with 1963 models cars and tailpipe limits with 1966 models sold in California). Auto manufacturers began including PCV devices on a voluntary basis nationwide by 1963.⁷³ Congress held multiple public hearings on the issue and in 1965 passed the Motor Vehicle Air Pollution Control Act (Table 4). It allowed the HEW Secretary to set emissions limits for new motor vehicles, but with no deadlines.²⁵

Meanwhile, states and municipalities showed little enthusiasm for the abatement procedure authorized under the 1963 law.²⁵ By late 1967, HEW had no requests for intrastate pollution abatement and only three requests for federal intervention in interstate pollution abatement. Stern²⁵ concludes that “very little air pollution abatement was actually accomplished by these procedures.” By 1966, 53 cities had limits on PM emissions from combustion, 15 cities regulated PM from sources other than combustion, and only 6 cities had regulations on the sulfur content of fuel. Ten states had set air quality standards for one (usually total suspended particles [TSP]) or more substances. Advocates in Congress and the Administration began to conclude that something stronger was needed.

By the mid-1960s, there was sufficient nationwide ambient air quality data to evaluate ambient concentrations and trends. TSPs had dropped from the mid-1950s,⁶² but composite averages (95 sites) remained approximately 100 $\mu\text{g}/\text{m}^3$ annual geometric mean for 1960–1965 with individual city averages ranging up to approximately 200 $\mu\text{g}/\text{m}^3$.⁶⁰ SO_2 levels began to decline, with composite annual averages (32 sites) near 0.02 ppm in 1965.⁶¹ But peak 24-hr values ranged between 0.18 and 0.74 ppm in five eastern cities. Annual NO_2 levels were between 0.03 and 0.04 ppm in six eastern urban areas and 0.05 ppm in Los Angeles.⁷⁴ The ninth-percentile 8-hr CO levels (1962–1967) ranged from 18 to 27 ppm for five eastern cities and were 27 and 29 ppm for Los Angeles and Denver, respectively.⁷⁵ The number of days with at least 1 hr above 0.10 ppm oxidant (buffered KI method) ranged between approximately 10 and 52 in five eastern cities and approximately half of all days with measurements in two Southern California sites.⁶⁶ Growing levels of CO and NO_2 led some states in the Northeast to consider whether to follow California’s lead on automotive standards.⁷⁶

Unless one lived in an area with established air quality norms, it may have been hard to grasp the meaning of these ambient numbers. People depended in part on their own senses, and in part on accounts in the press relaying announcements of periodic alerts, as in Los Angeles. New York experienced periodic episodes of highly visible smog

Table 4. Key federal legislation.^{25,53,82}

Title	Overview of Major Provisions	Key Provisions Related to Air Quality Standards
The Clean Air Act of 1963	Authorized the DHEW (PHS) to expand its research program, provide grants to states and local air control agencies covering over half the cost of developing or improving programs, and to conduct studies on air problems of interstate or nationwide significance. Section 5 established a Federal role in control actions whereby the HEW Secretary—on his own or at the request of state or local officials—could initiate a conference procedure to abate interstate pollution. Authorized \$65 million over 3 yr. Required semiannual reports on motor vehicle emissions and established a technical committee to evaluate progress.	Section 103 Authorized DHEW/PHS to “compile and publish criteria” on the effects of problem air pollutants.
The Motor Vehicle Control Act (1965)	Authorized DHEW to set “practicable” emissions standards for new motor vehicles, but established no deadlines. Added provisions for abatement of international pollution between the United States and Canada and Mexico, and authorized additional research for SO ₂ and motor vehicle emissions	None
The Clean Air Act Amendments of 1966	Extended the 1963 law. Added authority for grants to maintain (not just develop) state and local programs. Authorized \$55.5 million for 2 yr	None
The Air Quality Act of 1967	Established an AQM approach, with required actions by states and increased Federal role in establishing AQCRs, criteria for ambient state standards, review of state standards and control plans, and authority to step in if states failed to develop standards or plans or failed to enforce violations. HEW also given authority to seek immediate court action to stop emissions in episodes where there is “imminent and substantial endangerment” to the health. Abatement conference process was maintained until new AQM approach was implemented. Authorized HEW to establish a fuel additive registration program and grants to states for motor vehicle inspection programs. Preempted state regulation of new automobile emissions except for California.	Required HEW to develop air quality criteria for particular pollutants that describe the effects on health and welfare of varying concentrations of each pollutant or combinations. They must be reviewed by other agencies and advisory committees required by the law. More specifically, the law required reconsideration of the 1967 HEW SO _x criteria.
The Clean Air Act Amendments of 1970	Established the fundamental structure of current U.S. air quality management (see Figure 2). EPA establishes NAAQS, provides guidance to states on implementation; States have primary responsibility to develop SIPs to attain and maintain the standards by specified dates, (3–5 yr from NAAQS), EPA reviews SIPs, sanctions for failure to plan or submit an adequate plan. EPA has two authorities to regulate stationary sources directly: (1) Section 111—technology-based standards for new sources of “criteria” pollutants; states apply such technologies to existing sources for designated non-criteria pollutants; and (2) Section 112—risk-based standards for hazardous air pollutants. New technology forcing mobile source emissions standards set in legislation at 90% reduction from 1970 models for HC and CO (1975 model year) and less restrictive NO _x limit (1976 model year); procedure to extend deadlines if needed. Language indicates need to prevent significant deterioration with no explicit requirements. Provisions for judicial review of actions under the law.	S. 108 expanded definition of scientific criteria. S. 109 requires primary (health based) and secondary (welfare based) NAAQS. Requires NAAQS within 4 months for five pollutants for which criteria existed at enactment; established process for subsequent criteria and NAAQS and requires periodic review of established criteria and NAAQS.

in 1962 and 1963. State officials in New York and New Jersey developed and expanded the episode alert and mitigation system adopted in Los Angeles. In 1965, the New York State Air Pollution Control Board required that the New York City agency expand the network to five locations. A warning

system was in place for one of the more remarkable episodes of the decade during Thanksgiving 1966.⁷⁷

Because of widespread stagnation conditions in the East during late November 1966, high PM, CO, SO₂, and NO₂ levels were recorded in New York and other cities on

the eastern seaboard, and as far south and west as Chattanooga, TN, and Birmingham, AL. The New York-New Jersey area called alerts based on peak levels of PM (measured by a tape transmittance sampler and CO, but not SO₂). Warmer temperatures (reduced heating) and switching of electric generators from residual oil to natural gas were credited with lower SO₂ levels than during previous episodes. Later analyses of health information estimated approximately 170 excess deaths in New York City alone. With wide reporting of continuing smog alerts in Los Angeles, and levels in the East high enough to raise mortality, it was easy for the public to conclude that the country had an air pollution problem.

Federal Regulation—Round 2, an Opportunity Missed. The third National Conference on Air Pollution was held in December 1966, in part to build public interest and support for a stronger federal role in air pollution controls.⁷⁸ Vice President Hubert Humphrey, who opened the conference, spoke of the need for a regional approach with nationally uniform emissions standards. HEW Secretary John Gardner summary of the Administration's proposals made clear what lessons had been taken from the experience of the 1963 Act:

*"Lack of uniform air quality and emission standards serves as a deterrent both to states and communities and to industry. Until standards are devised, many communities will be reluctant to make the investments necessary to control air pollution. And unless the communities within a regional airshed require identical controls from the sources of pollution, their efforts are likely to be piecemeal and only partly effective."*⁷⁹

At the close of the conference, however, it was clear the Administration had not coordinated with Senator Muskie, who said:

*"With the exception of moving sources of pollution (for example, automobiles), I do not favor fixed national emission standards for individual sources of pollution. We do need national ambient air quality criteria, applied as standards on a regional basis. The Federal Government is the logical entity to develop the criteria, with the cooperation of public and private groups."*⁸⁰

The story of why the Administration believed it could overcome the opposition of the most powerful environmental voice in the Congress is outlined by Jones.⁵³

Given the attention academics have paid to the advantages of an emission- or technology-based approach over a risk-based air management system,^{11,12} it is surprising not to find more discussion about the point in history at which these two approaches were openly debated in the legislative process. The Johnson Administration argued that national standards for major stationary sources would avoid placing some industries at a competitive

disadvantage, with less emphasis on the speed of technology-based standards over those produced under an AQM approach. Whatever the merits of national emission standards, alone or in combination with ambient standards, Muskie remained opposed.⁵³ He believed variations in local conditions would make national limits impossible, without over- or under-controlling in particular areas. The final legislation did not include such a provision.

Here, it appears that the fatal policy flaw was the presumption by both sides that national emission standards needed to be set at levels to achieve ambient standards everywhere. That conception of emission standards is not consistent with the core of the "best feasible technology" ideal. As long as the Administration clung to the idea of regional ambient standards as targets to be met in particular areas, uniform emission standards would have to be unreasonably stringent to work in every location. Apparently, the thought of a uniform national technology-based approach, supplemented by more stringent local or state limits, was not acceptable to the Administration because one of its policy goals was to ensure that industry in cleaner areas did not have an advantage over those in dirtier areas.

Other factors also contributed to the defeat of uniform stationary source limits. Many had doubts as to whether even the expanded PHS National Center for Air Pollution Control (888 employees and \$40 million appropriation) was up to the task of setting industrial emission standards for so many sources.⁵³ Many were disturbed by the problem of federalism, in this case with the national government reaching too far into the roles and responsibilities of state and local agencies. Finally, industry certainly had varying opinions on the idea of nationally uniform standards. In the end, Congress consigned the concept to a provision requiring a 2-yr study exploring national emissions standards for moving and stationary sources.⁸¹

President Johnson signed the Air Quality Act of 1967 in November.²⁵ It established a formal AQM process (Table 4) patterned after the Water Quality Act of 1965.⁸² It required actions by HEW that triggered responses by the states with tight deadlines, but it provided no penalties for states that failed to comply. It also required the development of national criteria by HEW and regional specific air quality standards set by the states that could vary according local conditions and policy. The legislative history of the Act contains a colloquy between NACPA chairman John Middleton and Senator Muskie on the distinction between criteria and standards. Middleton noted that "air quality standards are essentially an expression of public policy rather than scientific findings." Muskie, apparently still unclear, summarized by saying "criteria are the targets" and "standards are the timetable for meeting them."⁸³

Federal Legislation—Third Time's the Charm—or Strike Three? By this time, the 1960s, were in full swing. The civil rights movement was winding down and mass anti-war protests escalated along with the war in Vietnam. Hair hit Broadway with a song called "Air." In April 1968, the *New Yorker* published an in-depth article summarizing both the expanding results and practice of air pollution

research in the United States and Great Britain.⁸⁴ The article ends with a quote from a National Air Pollution Control Administration (NAPCA) epidemiologist: "What we do know is that people get killed by air pollution, and I don't see any excuse for there being enough air pollution to kill people. Do you?"⁸⁴ In 1969, Stewart Brand published an edition of *the Whole Earth Catalog* featuring a photograph, taken by astronauts on their way to the moon, of a fragile Earth from space.⁸⁵ Concern for the environment was escalating. Polls were showing a substantial increase in public concern over environmental issues, with air pollution beginning to appear high on the lists of national issues.⁵³ Politicians, always attuned to such shifts, began to take serious notice. Senator Gaylord Nelson saw a linkage in both the audience and the methods of the student protests against the Vietnam war. He conceived the idea of a national teach-in on the environment that eventually turned into a coordinated series of events held across the country on Earth Day in 1970.⁸⁶ The nascent environmental movement was so successful that some activists became concerned that it would drain energy from the anti-war effort and other causes.⁵³

President Nixon saw the rising concern about the environment as an opportunity, and in 1969 the Administration developed a broad agenda, beginning with the creation of the CEQ in January 1970. That year, Nixon made the environment the theme for the domestic portion of his State of the Union Address. He accompanied his rhetoric with a package of 37 proposals, including legislation and administrative moves, relating to multiple aspects of the environment.^{25,53} One of these led to the formation of EPA late in the year. Another set of proposals would revise numerous aspects of the less than 3-yr-old CAA, furthering increasing the role of the federal government. On the day the proposals were submitted, the president also announced that HEW was issuing more stringent motor vehicle emission standards under its existing authority.²⁵

With the president calling for fundamental change, the 1967 CAA was officially declared dead before it could be implemented. But structural problems in the approach began to appear. Neither the federal government nor the states were equipped to implement the requirements according to schedule. An obvious problem was that control actions could be triggered only after HEW issued criteria, and the states, many of which had little experience or expertise in this area, established ambient standards. HEW was to issue criteria "as soon as possible." It was nearly a year later that HEW released the first two—revised criteria for SO_x and a new document for PM. The next three criteria (CO, O₃, and hydrocarbons [HC]) were not scheduled until April 1970, with five more in the following year.^{60,61,67,74,75,87}

As is the case today at EPA, HEW prepared CDs using in-house experts and outside consultants. The process was managed by the Bureau of Criteria and standards of NAPCA, headed by Dr. Delbert Barth. The Bureau contracted with various experts, including some with experience in the CDH standards process. The 1967 CAA required review and coordination with other agencies through a federal committee as well as a panel of technical experts. The bureau convened the National Air Quality

Criteria Advisory Committee (NAQCAC), a panel consisting of experts from academe, industry, and states. The federal review was handled through a group of 17 agency liaisons. Both the development of criteria and establishment and execution of the mandated review process took time.

The other federal "trigger" for state action, specification of air quality control regions (AQCRs), also was not moving quickly. By the end of 1969, only 25 AQCRs had been designated, and an additional 57 were yet to be completed; accordingly, by the same date, states had submitted regional air quality standards for only 6 AQCRs. Congressional hearings that month highlighted the delays and problems, and representative Rogers pressed NAPCA to speed up the process. Chairman John Staggers (West Virginia) later summed up the factors contributing to the lack of progress as follows:

*"First, cumbersome and time-consuming procedures called for under the 1967 act; second, inadequate funding on Federal, State, and local levels; third, scarcity of skilled personnel to enforce control measures; fourth, inadequacy of available test and control technologies; fifth, organizational problems on the Federal level where air pollution control has not been accorded a sufficiently high priority, and sixth, last but not least, failure on the part of the National Air Pollution Control Administration to demonstrate sufficient aggressiveness in implementing present law."*⁸⁸

Later commentary by state and local air officials would be even more pointed about the flaws in the framework. Victor Sussman, then air director of Pennsylvania, later called the exercise of defining air basins or AQCRs a "pointless charade" that should "soon be forgotten."¹⁰ He also believed that inadequate emission inventories and limitations in modeling capability precluded their use in developing the kind of location-specific source emissions limits tied to just attaining state standards. He also viewed this approach as time consuming and unnecessary, favoring the approach of adopting best available control technology (BACT) in areas that violated the standards. His recommendation to apply such uniform limits, later called "reasonably available control technology" (RACT), in nonattainment areas before modeling, eventually formed the basis of U.S. policy and law.

Denver air director John O'Fallon believed Congress made a serious mistake in delaying controls by imposing the resource management process before BAT controls. He argued that the Act should have called for:

*... an immediate and direct frontal attack on the air pollution problem by demanding a reduction of industrial emissions at the source as soon as possible. National industrial emission standards should precede ambient air standards as a logical and necessary prerequisite to their attainment."*⁹

O'Fallon noted two arguments for national emission standards. In addition to ensuring equity of control requirements across areas, he noted that air pollutants travel long distances, and eventually emissions in clean areas could affect problem areas. He also believed Congress erred in shifting the focus of air pollution control from the municipalities to the states noting that, in 1967, the cities had far more expertise in the issues.⁹ The need to create new programs and expertise in the majority of states contributed to delays in implementation.

Whether for sound policy reasons or political ones, by 1970 a consensus was developing that the CAA needed to be substantially strengthened. Ironically, Senator Muskie had introduced a more incremental approach to reauthorizing the CAA, until the president's proposals and a blistering critique of the senator's environmental credentials by Ralph Nader's group in *Vanishing Air*, which was released in May 1970.⁸⁹ The book states that following the signature of the 1967 act:

*An enlightened, liberal press paid dutiful homage to the handiwork of the Senator from Maine, calling the Air Quality Act a victory for Muskie and a blueprint for the nation. American industry, on the other hand, breathed a collective sigh of relief. . . .*⁸⁹

Jones⁵³ presents an amusing analysis of the progress of the various versions of clean air legislation in 1970, terming it "speculative augmentation in Washington." Given the intensity of environmental issues, particularly after Earth Day, politicians found themselves in a race to the top. Each new piece of proposed clean air legislation introduced that year—from Administration to House to Senate—became "more environmental" than the last.⁵³ No one wanted to appear on the wrong side of this issue. Some legislators, for example Senator Thomas Eagleton (Missouri),⁸⁸ clearly favored a return to the concept of uniform national emission standards for stationary sources. The HEW report on the issue⁸¹ recommended NAAQS, with national emissions standards only for new sources and for certain toxic and hazardous air pollutants (HAPs). Congress appeared satisfied with this approach. Support for federal issuance of national, as opposed to regional, ambient air quality standards seemed universal.

The legislative history indicates the most intense discussions were related to automotive emission standards. One intriguing footnote to the development of those standards indicated that even these "technology" provisions appear to be at least partially based on a consideration of impacts relative to ambient health targets. The legislative history points to an analysis of the issue by the aforementioned Del Barth and NAPCA staff that was presented at the 1970 Air Pollution Control Association (APCA) meeting.⁹⁰ These authors used the same forecast and rollback approach followed by the CDH to recommend tailpipe emissions limits, beginning with their own assessment of "desirable" air quality goals based on the CDs, which were 9 ppm for 8-hr CO, 0.06 ppm for 1-hr O₃, and 0.1 ppm for 1-hr NO₂. This also foreshadowed a possible NAPCA position on what standards for these pollutants might be. The rollbacks needed to meet these

standards in 1980 resulted in estimated automotive emissions reductions of between 80% and 90% from the recently proposed 1970 emissions standards. This is in the range adopted in the final legislation.

After resolving differences between the Senate and House versions, a process that went well into December, the landmark CAA Amendments were passed, and signed into law on New Year's Eve. At that point, EPA was about 4 weeks old. The bill covers 63 pages in the conference report and is well over double the length of the 1967 Act. Of most importance for this review are the criteria and NAAQS requirements, and aspects of their development.

Specifics of the NAAQS Requirements in the 1970 CAA Amendments. Sections 108 and 109 of the amendments govern the criteria and NAAQS development and review process. Section 108 specifies development of scientific criteria, with much of the language drawn from the previous CAA, but with clarification of the process and the characteristics of the kinds of pollutants that should be considered. It specifies that the administrator publish a list for pollutants: (1) which have an adverse effect on public health or welfare; (2) which are derived from numerous or diverse mobile or stationary sources; and (3) for which criteria had not already been issued before enactment. As before,

*"the criteria shall accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on public health and welfare which may be expected from the presence of the pollutant in the ambient air, in varying quantities."*³

The 1970 amendments eliminated requirements for consultation with advisory committees and federal departments for criteria, but not for the associated control techniques. It called for periodic review and reissuing of the criteria and issuance of new or revised criteria and control techniques to be announced in the *Federal Register* with copies for the general public.

Section 109 specified that the EPA administrator propose NAAQS within 30 days of enactment for each pollutant for which air quality criteria had been issued before enactment. After a reasonable period for submission of written public comments (not longer than 90 days), the administrator was required to promulgate each standard, making such modifications as appropriate. At the time of enactment, criteria had been issued for five pollutants: PM, SO_x, oxidants, HC, and CO. Section 109 specified that when criteria are issued for additional pollutants, the administrator simultaneously must propose NAAQS and follow the same procedures for existing criteria pollutants.

The 1970 CAA specifies two kinds of standards:

- Primary NAAQS, "which in the judgment of the Administrator, based on such criteria and allowing an adequate margin of safety, are requisite to protect the public health."
- Secondary NAAQS shall specify a level that "in the judgment of the Administrator, based on such criteria, is requisite to protect the public welfare from any known or anticipated adverse

effects associated with the presence of such pollutant in the ambient air."

Perhaps no aspect of this language has drawn more confusion, criticism, and commentary than the phrases "margin of safety" and "protect public health." The original Senate proposal called for national standards "which are necessary to protect the health of persons" and national goals, "to protect the public health and welfare from any known or anticipated adverse effect." Health was therefore covered by both standards and goals. The proposal then listed a variety of effects that, in the final legislation, were included in Section 302(h) as the definition of public welfare. The commentary on the Senate proposal indicates that the standards should consider not only the science in the air quality criteria, but also the need for margins of safety to provide "a reasonable degree of protection" against "hazards which research has not yet identified." This concept was transferred from similar phrasing that appeared at the very end of the original CDs. This "margin of safety" requirement was apparently important enough to put in the statutory language in the final version.

The Senate legislative history indicates that "reference should be made to a representative sample of persons comprising the sensitive group rather than to a single person in such a group."⁹¹ It adds that protection is sufficient when there is an absence of adverse effects on the health of a statistically related sample of persons in sensitive groups, which essentially means the number of people needed to detect an effect. The Manufacturing Chemists Association commented on the statutory language⁹¹ and suggested that the phrase "health of persons" be changed to "public health" in the standards section and that "public" be inserted before health and welfare in the criteria section. They agreed with the concept of protecting sensitive populations but wanted to avoid the impractical idea of protecting the most sensitive individual. They also suggested the insertion of "adverse" before "effects on public health and welfare" in the goal provision. All of these changes are consistent with the language incorporated in the final statute.

The language and history do not provide any indication that by using the phrase "margin of safety" Congress believed in an effects "threshold" (a term not used in the statute or legislative history summarized above), as opposed to the "lowest observed level of effects"⁸⁸ that formed the basis of the original criteria. As used in engineering, a margin of safety does not imply "zero risk," as some⁹² have argued. The original Senate concept of having a two-stage approach to protecting health through "standards" and "goals" suggests that lawmakers did not expect the standards to provide complete safety against all effects or to be risk free. The clarifying additions of "adverse" and "public" in the final statute suggest that Congress neither wanted to address trivial (nonadverse) effects, nor that standards would protect all Americans, no matter how sensitive. Statements later made by Congressional figures in the development of the 1977 CAA Amendments imply that these leaders understood that the standards would not provide absolute safety, and that their recollection of the terminology used in their 1970 legislative history was a bit fuzzy.

Finally, in conference, the Senate dropped the standards and goals in favor of primary and secondary standards for public health and public welfare, respectively. A distinction between the two was maintained by setting attainment deadlines for primary standards, but none for secondary standards.

Section 107 places primary responsibility for AQM with the states. Although it grandfathered prior AQCRs, it made all non-AQCR areas within a state an AQCR, so that the entire state was covered by the NAAQS. The current approach of designating "nonattainment areas" was not added until the 1977 CAA Amendments. Section 110 sets forth requirements for the development, submission, review, and approval of the SIPs. SIPs, which were to be submitted within 9 months of NAAQS promulgation, were required to provide for attainment and maintenance of the NAAQS, and enforcement of emissions standards and other measures. Attainment of primary NAAQS was required within 3 yr after EPA approval of the SIP, and for secondary NAAQS within a "reasonable time."

Part IV—Evaluating the Pre-NAAQS Era (1900–1970)

In keeping with the spirit of the AQM circle (Figure 2), it is important to provide some evaluation of what was happening in the atmosphere from 1900 to 1970. The data available for this purpose are limited in scope and resolution, and subject to substantial uncertainties. A sampling of the information, however, may provide enough of a mosaic to get a "big picture" of where and when progress was made over the period.

The earliest periodic measurements were for PM as dust fall, smoke shade, or TSP. We have seen the long-term trend for smoke in Pittsburgh (Figure 4). Figure 5 shows available long-term trends for PM by two methods for New York. Although it took decades for both cities to improve, it is clear that Pittsburgh, which started out with a far more serious problem, acted sooner and more decisively. Figure 6 depicts TSP trends for 1960–1970 for a composite of 122 urban areas (mostly center city). As in New York, the average began to improve in the latter half of the decade. The composite SO₂ maxima for 32 NASN sites suggest that urban SO₂ levels began to decline after 1966, at an average rate much slower than in New York.

Trends information for metals⁹³ and benzene soluble organics (BSO)⁹⁴ show that reduction of PM and SO₂ emissions had some additional benefits for urban areas. Between 1960 and 1970, particulate BSO (which contains polycyclic organics among other combustion products) was reduced by 55% at 32 urban sites, with 27 showing statistically significant trends. The decline was strongly correlated with declines in residential coal use. Striking reductions in northeastern vanadium and, to a lesser extent, nickel between 1969 and 1972 were concurrent with, and attributable to, reduced fuel sulfur regulations. Fuel oil desulfurization also reduces the content of these metals. Urban PM reductions were concurrent with reductions in cadmium, iron, and manganese, but titanium levels increased. Composite Pb, associated with auto emissions, increased between 1965 and 1968 but by 1973 returned to the 1965 levels.

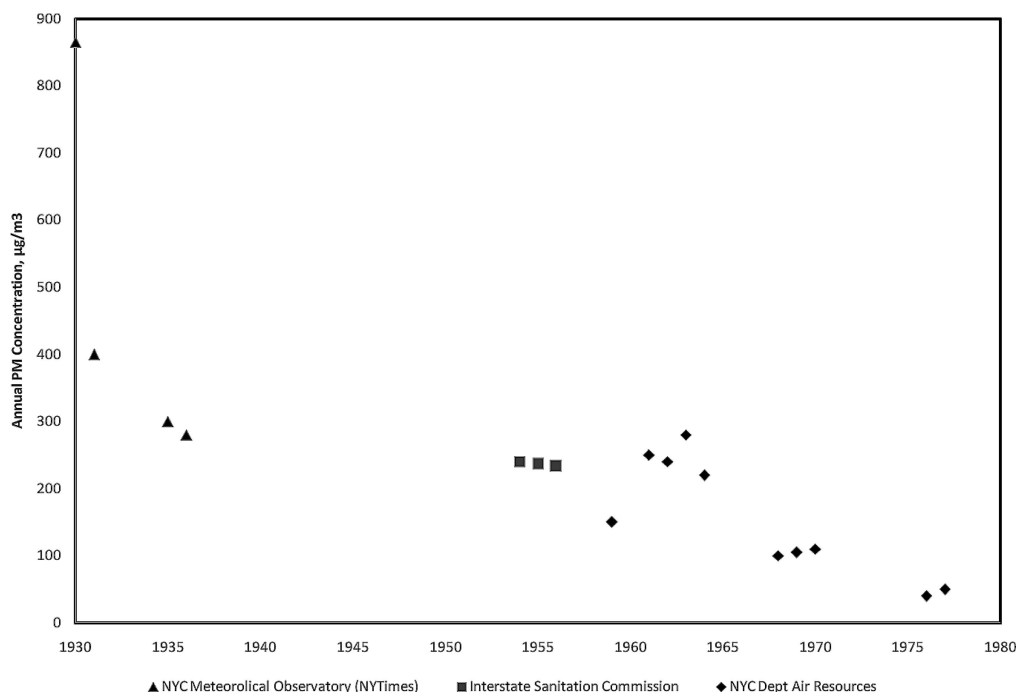


Figure 5. Trends in particulate matter in New York City (1930–1976).^{30,243} New York was described in 1899 as relatively smoke free but developed smoky coal problems by the 1920s. A precipitous drop in PM followed the Depression, but the air in the 1950s was apparently not much improved over the 1930s. The levels did not begin to improve until after 1965 and continued thereafter. SO₂ levels for 1954–1976 (not shown) actually increased through a peak in 1964, with a citywide annual average of 0.24 ppm.²⁴³ After that, SO₂ levels declined rapidly through 1972 and more gradually thereafter.

Data for the remaining criteria pollutants for this period outside of California are limited to several cities from the HEW “CAMP” network for 1962–1972.⁹⁵ These limited measurements are of uneven quality and show a mixture of trends in four eastern cities and Denver. Nitrogen oxides (NO_x) levels increased in all areas, with NO₂ flat to increasing. CO (five cities) declined, partly enhanced by a method change, and oxidant (three cities) increased in Chicago and decreased in Philadelphia and Cincinnati.

The highest oxidant/O₃ levels were in California. Whereas maximum oxidant levels in Los Angeles fluctuated with no clear trend between 1955 and 1972, more

robust statistics began to show a response to control measures in 1960. Box and Tiao⁶³ used intervention analyses to examine the combined impact of the 1960 reduction of olefin content in gasoline and the opening of a freeway. Using 1955–1972 data, their model found a statistically significant reduction in the monthly average of peak O₃ hourly values after the intervention. They also detected a small but significant benefit of the more gradual reductions after the 1966 California tailpipe standards. The control strategies based on Arie Haagen-Smit’s smog chamber research apparently worked in the real world. More generally, in the Los Angeles basin between 1962 and 1971, NO₂ trended upward, whereas CO levels declined.⁹⁶

From a national perspective, the air quality measurements summarized above are limited in time and space. Most reflect urban center concentrations. Although this is important in terms of peak exposures, many people live some distance from the center of the city or suburbs, and substantial gradients in concentrations are likely. Furthermore, the most abundant indicator, TSP, does not provide a clear distinction between distributions of fine and coarse particles. Recognizing the strong relationship between PM_{2.5} and light extinction, EPA and others began to use airport visual range data as an indicator of long-term fine particle trends in the 1970s.⁹⁷ Despite some limitations, seasonal visibility trends in various regions of the East still provide semiquantitative perspectives on air pollution patterns and trends beginning in 1948 that are not available from ambient PM measurements.³³

Visibility trends for the eastern seaboard suggest that wintertime suburban/regional fine particle levels decreased between 1948 and 1972, as early particle control

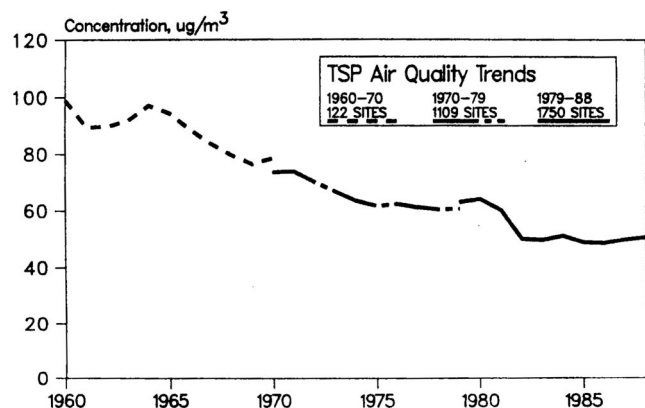


Figure 6. Historical trends in TSP concentrations, 1960–1988.²⁴⁴ Urban TSP began a long decline between 1965 and 1982. The pattern between 1979 and 1982 is affected by a measurement artifact relating to the filter media.²⁴⁵ Little progress is apparent after 1982.

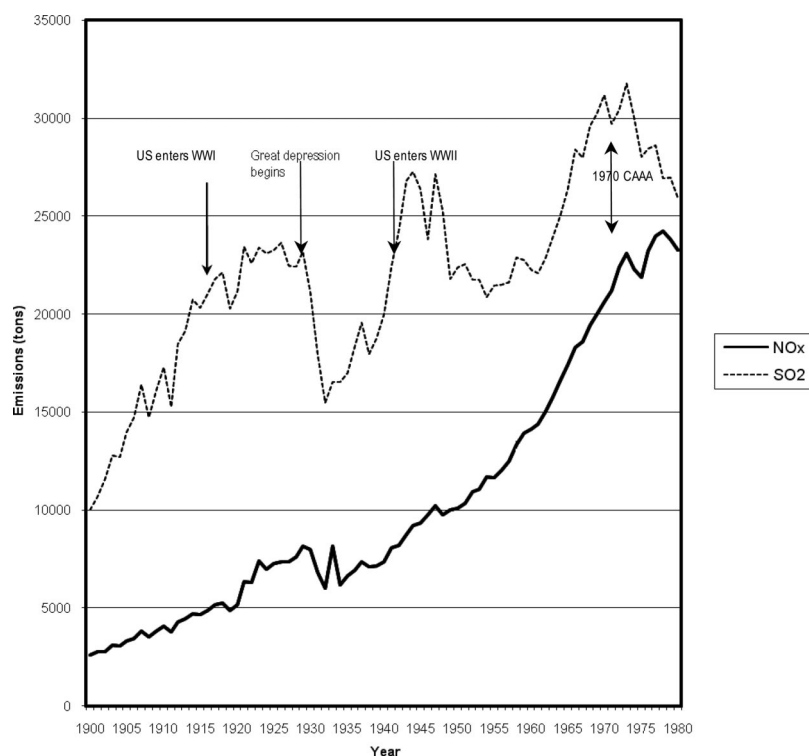


Figure 7. Long-term trends in national SO_x and NO_x emissions.²⁴⁶ Trends in SO_x are largely driven by coal combustion, and are qualitatively consistent with the coal use data in Figure 4. Other significant sources included smelters and residual oil. The largely monotonic increase in NO_x is related to total fossil fuel combustion, including coal in the early period with the increasing addition of automotive emissions. Emissions of both pollutants peaked in the mid-1970s.

programs were put in place and residential coal combustion declined. The rate of improvement was smaller for the Ohio River valley region with no apparent trend in the Midwest. But the most striking aspect is the consistent increase in warm-season fine particles suggested by the decrease in summer visual range found in all eastern regions during this period. This important and apparently broad increase in population exposures to fine particles and reduced visibility are not readily apparent in the overall center city trends. Trends in seasonal coal use patterns provide a strong hint as to the cause. In 1951, consumption clearly peaked in the winter with residential and railroad use, and power generation comprised approximately 25% of the total. By 1974, overall coal consumption had increased, but with much less seasonality and a small summer peak; the power sector consumed more than 60%.³³ Another hint was in a limited dataset from urban and nonurban areas, suggesting the sulfate (SO₄²⁻) fraction of TSP was increasing in the 1960s.⁹⁸

We now know that the reductions in summertime visibility across the East were strongly related to the increased emissions of SO_x. The change in national emissions of criteria pollutants and their precursors is another way of evaluating what was happening in U.S. air pollution. The longest period of record exists for SO_x and NO_x, estimated from fuel use information for 1900 to 1980 (Figure 7). The trends have been broken down by major source sectors beginning in 1940 (Figure 8). A number of substantial uncertainties exist in the development of these estimates from gross national statistics, but the general patterns are almost certainly meaningful. The early

record, combined with Figure 3, shows the influence of overall economic activity and coal use on SO_x and NO_x. Volatile organic compound (VOC), NO_x, and CO emissions from mobile sources increased, with the power sector responsible for increases in SO_x after the early 1950s. The increase in all of these gaseous pollutants in the 1960s is also striking.

Although data do not exist for regional air quality before 1970, the visibility patterns and current information permit some inferences with regard to the 1960s. Fine particle concentrations apparently increased throughout the East, particularly during the summer. Increase in SO₄²⁻ and perhaps secondary organics must have been at least partly responsible for the lack of consistent TSP trends in nonurban areas.⁹⁵ Wintertime decreases in primary emissions of any particle size in urban areas would be partially offset by increases in summertime secondary fine particles. Whereas the summer increase was largely because of increased emissions, other factors likely contributed. Tall stacks reduced local peaks, but as was known to Georgia farmers at the turn of the century, dispersed SO₂ over a wider area. New electricity generation units were increasingly located in nonurban areas.

The higher SO₄²⁻ and poorer visibility noted in the summer late in this period appear disproportionate to the more uniform emissions expected between summer and winter based on seasonal fuel use.³³ This suggests photochemical conversion processes were important in the region by the 1960s. By then, regional NO_x emissions in the East reached levels that, in combination with biogenic and anthropogenic VOC, could have produced the kind

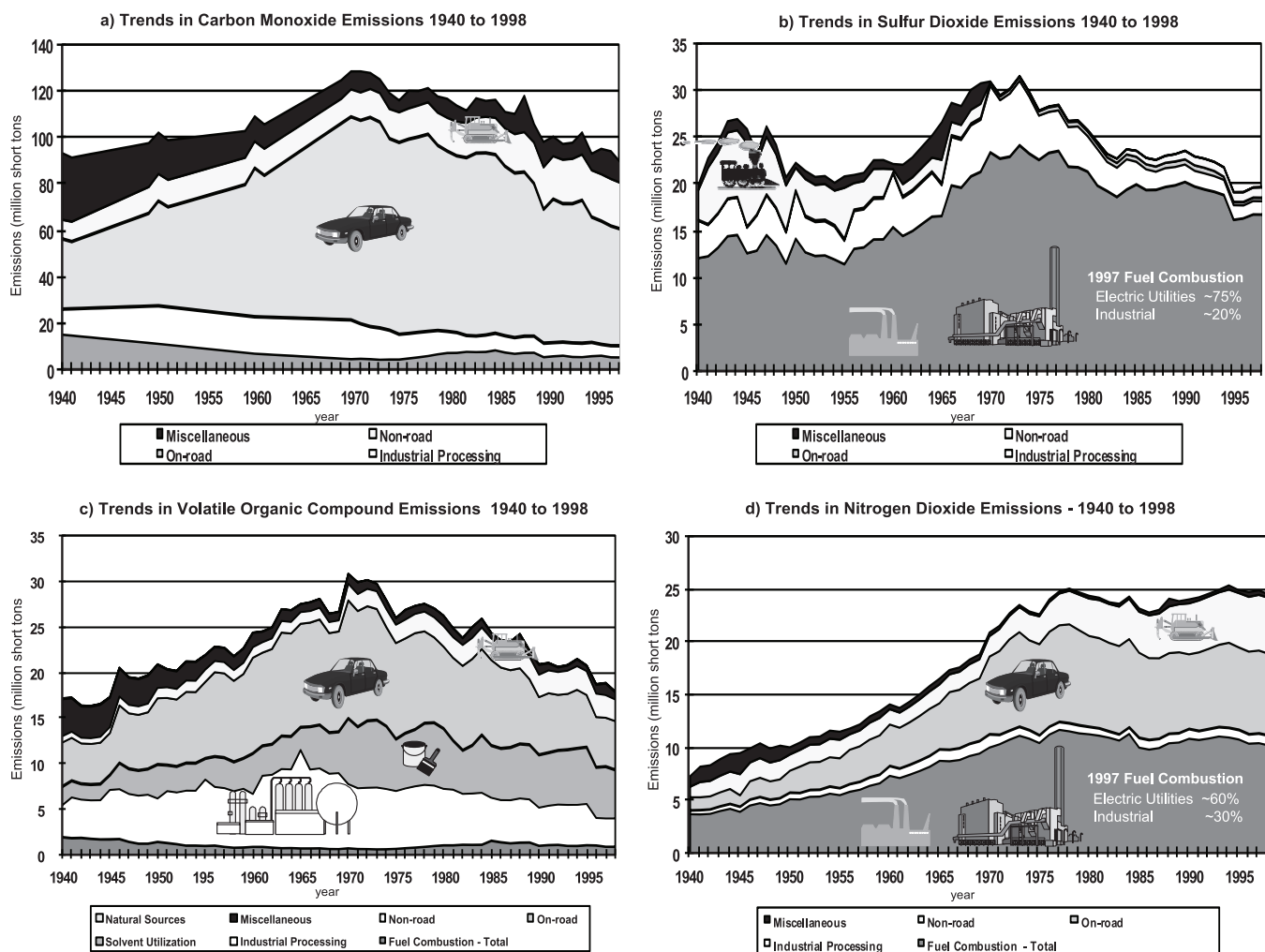


Figure 8. Trends in emissions of key criteria pollutants by sector (1940–1997).²⁴⁷ Emissions of all pollutants peaked following passage of the 1970 CAA. Requirements for reduced automotive emissions was a major cause of reductions in (c) VOC and (a) CO and the leveling of total NO_x emissions. Reductions or limits in growth of (b) SO_2 and (d) NO_x came from industrial and power generation sectors. VOC reductions occurred in industrial sectors.

of regional scale O_3 episodes observed in the 1980s. Unfortunately, regional monitoring of O_3 was limited until 1977.⁹⁹ As noted above, oxidant levels did exceed the 1971 1-hr standard in several eastern cities. As documented later, SO_x and NO_x emissions during this period also were responsible for adverse effects on aquatic and terrestrial ecosystems related to acid deposition, nutrient loadings, and O_3 damage.^{100–104}

It has become fashionable in some circles^{14,28,105,106} to claim that air pollution in the United States used to be much worse than today and that air contaminants have been declining ever since we learned how to measure them. Furthermore, it is claimed that state and local programs as well as societal shifts were already addressing the important air quality problems before the unnecessary and burdensome intrusion of the federal government into the process.¹⁰⁷ Whereas some of the specifics of these claims are true, they are half-truths; the environmental record through 1970 does not support either their fundamental premise or their main conclusions.

The PM and visibility trends show that the combined efforts of municipal and state pollution control programs and the beneficial changes in societal patterns of energy use and transportation reduced urban smoke through the 1950s. But these factors did not counter the collective emission pressures related to a growing population, a growing economy, and other societal changes (e.g., the spread of suburbs and the replacement of urban mass transit with personal automobiles). The fact that the nation was unaware of these developments and growing problems is largely because of the low priority assigned to what was termed a nuisance until 1949. Once the problem had been defined as a serious threat to health and a worsening eye-burning smog problem emerged to frighten southern Californians, increased federal and state resources stimulated the research and monitoring needed to understand the issues on a national level.

The growth in understanding and air pollution expertise in many municipalities and states between 1955 and 1970 was facilitated and later required by federal

grants, education, and training programs. The increased state and local regulatory activities on a national level that resulted in marked declines in urban SO₂ and TSP from 1965 through 1972 were stimulated in part by federal requirements in the 1963 and 1967 legislation. None of this is meant to denigrate the leadership, initiative, or efforts and results delivered by the dedicated air pollution experts in these agencies. The progress municipalities and some states made in smoke, PM, SO₂, and O₃ through the early 1960s came without direct involvement from a federal government that saw its role limited to research and support. They, along with air pollution professionals in and leaders in relevant industries, are what make U.S. AQM the obvious success it is today.

From the perspective of the 1960s, California and Los Angeles had the ability and the popular support to address the nation's most difficult air quality problems, but even they, through both state and Congressional representatives, sought a federal role in air pollution control and enforcement. Despite programs that improved the air of many cities and apparently ended the overt "killer smog" episodes, on a national level air pollution was a growing problem. From what we know now, it was more widespread and multidimensional than was generally realized at the time. Federal regulation of growing automobile emissions was an obvious policy choice. In the late 1960s, the societal forces (e.g., increased affluence, increased awareness, improved technology) that some argue would have dealt with air pollution without a federal presence, resulted in the public demanding a strong national assault on air pollution. They got it.

THE NAAQS (1971–2007)

Part I: EPA Meets Statutory Deadlines for Setting NAAQS, Implementation Guidance (1971–1975)

Despite the fact that the EPA was less than a month old when the CAA passed on December 31, 1970, the proposed standards for the original six NAAQS pollutants appeared in the *Federal Register* on January 30, 1971; the final standards and monitoring guidance were published on April 30, 1971, meeting the 120-day statutory schedule (Table 5). It can be done, but perhaps only during a much simpler era than today.

Supplemental Tables 1 through 7 (http://www.awma.org/journals/pdfs/2007/6/10.3155-1047-3289.57.6.652_supplmaterial.pdf) present a detailed chronology and commentary on the development of criteria and establishing, reviewing, and revising the NAAQS for each of the seven pollutants (i.e., PM, SO_x, CO, O₃, HC, NO_x, and Pb) that were listed and regulated under Sections 108 and 109 between 1971 and 2006. These tables constitute the core of this NAAQS history. Whereas the chronology tables are organized by pollutant, the discussion here looks across multiple pollutants to examine how NAAQS have been set and reviewed over the years (Table 6), with some discussion of the role of the NAAQS and scientific information in implementing improved AQM programs.

The original 1971 primary and secondary standards (for TSP, SO₂, CO, O₃, HC, and NO₂) are summarized in Table 5). The four NAAQS components are as follows: (1) indicator—the specific pollutant to be measured (the indicator is *not* necessarily the same as the criteria pollutant class, e.g., TSP for PM, or SO₂ for SO_x); (2) level—the concentration (μg/m³ or ppm); (3) averaging time—the time period (e.g., annual, 8 hr) associated with the specific

Table 5. 1971 U.S. Primary and secondary NAAQS.^a

Pollutant (indicator) ^b	Level	Averaging Time	Form ^b
PM (TSP)	75 μg/m ³	Annual	Geometric mean
	260 μg/m ³	24 h	Not to be exceeded more than once per year
TSP secondary standard	150 μg/m ³	24 h	Not to be exceeded more than once per year
SO ₂	0.03 ppm	Annual	Arithmetic mean
	0.14 ppm	24 h	Not to be exceeded more than once per year
SO ₂ secondary standards	60 μg/m ³	Annual	Arithmetic mean
	(0.02 ppm)		
	1300 μg/m ³	3 h	Not to be exceeded more than once per year
	(0.5 ppm)		
CO	10 μg/m ³	8 h	Not to be exceeded more than once per year
	(9 ppm)		
	40 μg/m ³	1 h	Not to be exceeded more than once per year
	(35 ppm)		
Photochemical oxidants (as O ₃)	200 μg/m ³	1 h	Not to be exceeded more than once per year
	(0.08 ppm)		
HC	160 μg/m ³	3 h, 6–9 a.m.	Not to be exceeded more than once per year
	(0.24 ppm)		
NO ₂	100 μg/m ³	Annual	Arithmetic mean
	(0.053 ppm)		

Notes: ^aWith the exception of PM and SO₂, secondary NAAQS set identical to the primary standards. ^bThe terms "indicator" and "form" were not used in the 1971 notice.

level; and (4) form—aspects of statistical measures to be applied to the level and averaging time. The 1971 standards used a deterministic form, which applies to a particular year as an average or a level not to be exceeded more than once. Later standards adopted statistical forms such as expected annual mean or 98th percentile 24-hr concentration averaged over 3 yr. Whereas most attention in standard setting is focused on the level, the relative protection or stringency of the NAAQS depends on each of the four components. NAAQS also must be accompanied by a Federal Reference Method, which details the acceptable approaches for monitoring and data handling to determine compliance. Because the original NAAQS were expressed in mass/volume terms, in 1971 all data were required to be adjusted to standard temperature (25 °C) and sea-level pressure (760 mm Hg).¹

The terse *Federal Register* proposals^{108,109} provided no rationale for the administrator's provisional decisions on specific NAAQS or a clear articulation of how they were linked to the scientific evidence. The final notice¹ provided only a brief response to comments that identified key studies and effects for CO and oxidants. Supplemental Tables 1–7 illustrate how specific statements in the CDs for the pollutants appear to be linked to the averaging times and levels chosen for the respective standards, but except for CO and O₃, that is the only guide to the bases for the decisions.

Even more elusive is the decision-making process itself. We know key staff involved included Bern Steigerwald, then head of the EPA air pollution office in Durham, NC, which later became the Office of Air Quality Planning and Standards (OAQPS); Del Barth, formerly head of the NAPCA criteria development group; and Ed Tuerk, a former deputy to NAPCA commissioner John Middleton. In the month-old agency, the kinds of formal internal procedures such as project initiation, steering committees, policy office reviews, and clearance requirements that characterized all subsequent NAAQS actions were not yet established. After some initial options work, a group met in Washington to discuss specifics for the proposal. The proposed CO and oxidant standards were identical to those Del Barth had recommended in his 1970 APCA paper,⁹⁰ but in place of a 1-hr NO₂ standard, there was a 24-hr standard and annual standards for NO₂. Staff prepared a draft package on the standards for the administrator, who was briefed on them, as well as the just completed CD and associated listing decision for NO_x, in late January.¹¹⁰ Ruckelshaus¹¹¹ later recollected that the discussion at the briefing was relatively short and the materials limited.

EPA received relatively few comments on the proposed standards and did not hold a public hearing on them, something that had been required under the 1967 CAA for the state standards. Public comment critical of the standards resulted a few notable changes. The final oxidant standard was increased from 125 µg/m³ (0.06 ppm) to 160 µg/m³ (0.08 ppm).¹ Based on the presumed relationship between HC and oxidant, this required a corresponding increase in the HC standard. EPA declined to revise the 8-hr CO standard, but agreed that the evidence was uncertain. The proposed 1-hr level was, however, raised from 15 to 40 mg/m³, which was more in line

with the levels in the relevant study in the criteria. The proposed 24-hr NO₂ and SO₂ standards were dropped because of lack of evidence for that averaging time. Public records indicate that John Middleton briefed Ruckelshaus on the NAAQS decision on April 14, 1971.¹¹⁰ The final standards, together with necessary FRMs, were issued on April 30, 1971, accompanied by a press release that included a synopsis of the administrator's views.

"These are tough standards," Ruckelshaus said. "They are based on investigations conducted at the outer limits of our capability to measure connections between levels of pollution and effects on man. In the case of CO, one of the most important automobile pollutants, we have set a standard to protect against effects reported by investigations that prompt arguments even among our own scientists. In the case of photochemical oxidants, also largely contributed to by automobiles, our standards approach levels that occur fairly commonly in nature."

*"The legislative history of the CAA makes it plain," he added, "that when we talk about protecting the "public health" against polluted air, we are talking about protecting those citizens who are particularly sensitive to it—in other words, those citizens already afflicted with cardio-respiratory problems. If we have erred at all in setting these standards, we have erred on the side of public health."*¹¹²

Although EPA lacked the time or capacity for regulatory impact analysis, the administrator was aware that these standards would have important consequences. The press release also summarized the difficulties in meeting these standards in various areas around the country, noting the importance of the vehicle emission standards and admitting a dearth of information critical to meeting the oxidant standards, and limitations in the state of current control technologies for NO_x and SO_x. In the case of PM and SO₂, Administrator Ruckelshaus suggested an aggressive version of the strategy Raymond Tucker had implemented in St. Louis:

*"He [Ruckelshaus] said seven metropolitan areas might have serious trouble meeting the sulfur oxides and particulate standards. . . 'We estimate that to bring air pollution levels down to the standard for particulates in New York will require a 300% increase in natural gas usage in the city. The only encouraging feature in the prognosis is that curing the particulate problem with natural gas will also take care of the sulfur oxides problem.' He forecast somewhat less serious difficulties for Chicago, St. Louis, Baltimore, Hartford, Buffalo, and Philadelphia."*¹¹²

The Consequences of a Hurried Process. Given the importance of the NAAQS, it is surprising that neither industry nor environmental stakeholders were more aggressive in commenting or in pursuing the issue in litigation.

Table 6. Chronology of Criteria Review and NAAQS Decisions, 1969–2007.

Year	PM	SOx	O ₃ /Oxidant	CO	HC	NOx	Pb
-	CD	CD					
1970							
-	P,F	P,F	CD P,F	CD P,F	CD P,F	CD,P,F	
-		CD, P, <u>F-</u> <u>revoke 2°</u>					
1975							
-	EPA decision to review all six criteria and NAAQS;				DC Circuit orders		
-							Pb NAAQS
-							CD, P
-							F
1980		CD, SP	CD,P <u>F</u> DC Cir.Ct.	CD, 1 st SP P	Rev. Paper P	CD SP	DC Cir.Ct.
-	CD, SP						
-	P	Decision		CDA,SPA	<u>F, Revoked</u>	P	
1985				F, <u>revoke 2°</u>		F	
-	CDA, SPA	CDA,SPA	CD				CD, CDA
-	<u>F PM10,</u>						
-	ANPR PM _{2.5}	P					
-			CDA,SP				
1990							CDA, SP
-				CD			
-				SP			
-		F, 2°	P			CD	
-		CDA,SPA,P	F	F, no P			
1995			CD,SP1°			SP,P	
-	CD, SP, P	F	SP2° ,P			F	
-	<u>F,PM_{2.5}</u>		<u>F, 8-hr</u>				
-		DC Cir.Ct.					
-	DCCir.Ct		DCCir.Ct				
2000				CD			
-	Supreme Ct.		Supreme Ct.				
-			UVb P				
-			UVb F				
-	CD						
2005	SP						
-	P, <u>F</u>		CD				CD
-			SP, P				SP

Notes: CD = Final Criteria Document; SP = Final OAQPS Staff Paper; CDA,SPA = addenda updating CD, SP; P = proposed; F = promulgation of final decision (F = major revision). Court Actions = Major review and decisions by the D.C. Circuit Court of Appeals, Supreme Court. UVb P,F = EPA's response to remand to reconsider O₃ NAAQS for "protective effect" of ground level O₃ against UVb radiation. 1°, 2° = primary, secondary standards. Only TSP (1971–1987) and SO₂ (1971–2007) have secondary standards that differ from primary.

These interests may not have understood the potential impacts, and industry may have been distracted by several major enforcement actions the EPA was pursuing under various statutes.¹¹³ In early 1972, however, Kennecott Copper Corp. used the Act's provisions for citizen suits and judicial review to challenge the scientific basis for the annual secondary SO₂ standard. This case changed the regulatory process for all subsequent NAAQS decisions. Given the short deadlines, EPA used

an "informal rulemaking process" to propose and promulgate the standards. The D.C. Circuit Court of appeals found that the rulemaking record did not give it a sufficient basis to complete its review. It remanded the standard back to the agency, calling for a more complete explanation of its basis. EPA quickly recognized it had erred in ascribing the vegetation damage observed in a study with high peaks to the long-term average. EPA updated the criteria for SO₂ effects on vegetation, and

after consultation with other federal agencies, ultimately withdrew the annual secondary standard and reaffirmed the 3-hr standard. This embarrassment led to the adoption of more formal regulation development procedures within the agency, as well as stricter administrative procedures.^{110,114} Internally, the process added review of recommended rules by a steering committee, consisting of representatives from a number of headquarters media, policy, and research offices as well as EPA regional offices. Steering committee approval was required before bringing a decision to the administrator. In the case of the SO₂ secondary standard review, the recommended proposal appeared before the steering committee no fewer than three times and the administrator was briefed twice.¹¹⁰ The proposal also underwent review by OMB.

Under the expanded administrative procedures¹¹⁴: (1) EPA was to make available to the public the information and technical methodologies it relied upon by the time of proposal; (2) the preambles to proposal and final rules were to provide a detailed explanation of EPA's decision; (3) EPA was required to respond to all "significant" comments on the proposal by the time it issues its final rule; and (4) all of the above documents, analyses, preambles, and responses constituted the record that the court would examine in reviewing the final standard decision. Objections not raised in the record could not be raised in court. The halcyon days of a speedy NAAQS process were over.

Whatever Happened to the Other Ambient Standards? In a 1970 response to questions from Muskie's committee, Middleton provided a schedule for the development of air quality criteria beyond the five that had been issued.^{88,115} The schedule listed 24 elements, compounds and mixtures over a 5-yr period, beginning with, in 1971, fluorides, Pb, NO_x, and polynuclear organics. Senate sponsors expected NAAQS for at least five more pollutants. A few states had ambient standards for some of these pollutants.²⁵ Yet, after the passage of the amendments, EPA listed and issued criteria for only one additional pollutant, NO_x/NO₂, which was included in the original 1971 standards.

NAPCA and later EPA commissioned the NAS to prepare reports on a number of the pollutants it was evaluating as potentially requiring criteria. These reports came out over a period of years,¹¹⁶⁻¹²⁴ and were used by agency staff, but not for developing criteria. EPA management realized that the level of effort required to establish, monitor, implement, and enforce NAAQS represented a large resource burden, for state and local agencies, EPA, and industry. With the ongoing effort to implement and enforce NAAQS affecting every major source category of air pollution, the EPA set a high hurdle for adding new criteria pollutants.

As EPA management and staff considered the evidence for a particular pollutant, they would determine whether the problems it presented would be handled adequately by implementing existing NAAQS, or faster and more effectively by one of the other regulatory mechanisms provided by the new amendments. For example, if

a pollutant came from one or only a few source categories, it might be better regulated under the Section 111 or 112 stationary source mechanisms. The existing NAAQS included particles and five of the most prevalent gases. Advanced particle controls were effective for a number of the metals and trace elements on the list, and stationary and mobile hydrocarbon limits would cover many additional substances. The exceptions included the more volatile elements such as mercury, those emitted from poorly controlled residual oil or gasoline combustion (e.g., nickel, vanadium, and Pb) and problematic inorganic gases from industrial processes such as hydrogen fluoride and hydrogen sulfide. These more source specific issues could be addressed with a more targeted and less intensive process than the NAAQS.

Pb was one of the first priorities on the 1970 list of upcoming criteria. Early on, EPA decided it would use the CAA fuel additive authority to reduce the Pb content in gasoline—which was necessary to ensure the effectiveness of automotive catalysts as well as to reduce direct health effects. These reductions would address the most pervasive source of Pb exposure, and if needed, stationary source standards could address more isolated problems such as Pb smelters. The essence of this alternative approach was communicated to the administrator in a memo on January 21, 1971.¹³ EPA decided that an ambient Pb standard was not necessary. An alternative rationale was used to dismiss odors. According to Bern Steigerwald,¹²⁵ he and others in management viewed odors as a fairly complex and location-specific nuisance problem that was best left to local and state authorities. The agency did move under Section 111(d) of CAA to regulate both new and existing sources of a class of odors, reduced sulfur compounds. Morag-Levine¹¹ is strongly critical of the U.S. regulatory approach to localized problems, particularly odors.

By January 1971, EPA management had decided to regulate beryllium, mercury, and asbestos under the first Section 112 National Emissions Standards for Hazardous Pollutant (NESHAP), which were promulgated a month before the NAAQS.¹²⁶ Later, analysts in the OAQPS Pollutant Strategies Branch applied a "preferred standard path analysis" to each pollutant that was the subject of successive NAS or other authoritative reports. Staff used pollutant-specific information to make recommendations, recognizing that the NAAQS should be considered as a last resort. My first experience was with vanadium, where the external science advisors (NAQCAC) and the agency concurred that the SO₂ controls would be more than adequate to preclude a NAAQS or other direct regulation. In the early 1970s, one-by-one EPA assigned the pollutants that NAPCA had slated for criteria and NAAQS to alternative approaches, including no additional regulation. Between 1975 and 1980, EPA promulgated NESHAPS for major sources of vinyl chloride, benzene, radionuclides, and inorganic arsenic.¹²⁶ Several source categories emitting fluorides, reduced sulfur compounds, and sulfuric acid mist were regulated under Section 111(d).¹²⁷ But until EPA was sued, there would be no new NAAQS.

Implementation in Transition

"... even though air resource management is a crooked wheel, it is the only wheel in town and therefore we have to gamble against it." Victor Sussman, Director of Air Pollution Control in Pennsylvania, January 1972

The 1970 CAA Amendments set tight deadlines for SIP development, review, and approval (15 months after the final NAAQS). Although not specifically required, EPA developed regulations and guidance for SIP development and submission that were proposed in March and promulgated in August 1971, just over 5 months from the deadline for SIP submission.¹²⁸ The proposal garnered more than 400 written public comments, considerably more than the NAAQS. Besides deadlines for submission and attainment drawn from the CAA, features in the final guidance included: (1) "regions" in the state were classified into three priority categories according to the severity of the ambient violation, with more stringent requirements for priority I areas; (2) control plans approved for "example" regions would be automatically approved if applied to equal or lower priority regions; (3) requirements for public hearings; (4) provisions encouraging states to consider the socioeconomic impacts and relative costs and benefits of various emissions control strategies; emissions fees or other economic incentives authorized; (5) requirements for legally enforceable compliance schedules; and (6) approaches for considering the reductions expected from the federal mobile source rules. SIPs needed to achieve attainment 3 yr after plan approval (generally 1975), unless granted an extension of up to 2 yr.

Neither the amount of specific requirements nor the lateness in issuing them was welcome to the states. Although some recognized that the procedures imposed a useful rigor, they also consisted of requirements and details that were burdensome to understaffed agencies. States that had developed plans under the 1967 CAA had to repackage what had already been done to conform to EPA requirements. Moreover, with new faces in EPA regional offices, and perpetual reorganizations of NAPCA/EPA air offices, relationships needed to be re-established.⁵³

States developed and submitted plans, and EPA moved to review and approve them. It soon became clear that many states could not meet the 1975 attainment deadlines for all NAAQS, particularly the four related to automotive emissions. Even if the CAA's requirements for motor vehicles could have been met by 1975, only approximately 10% of the fleet would be controlled. EPA determined that available data were not sufficient for states to develop transportation control strategies or to predict the outcome on air quality. In May 1972, the agency granted a 2-yr extension to 17 states for meeting the CO and oxidant standards.⁵³ As a result of a lawsuit on the action in January 1973, the D.C. Circuit Court ordered EPA to rescind the extensions. The administrator wired the governors of these states that each would be required to submit revised plans by April that showed to attainment with the standards by mid-1975.⁵³ Under another

court order, in January 1973 EPA established a Federal Implementation Plan to attain NAAQS in southern California, including draconian measures such as gas rationing that prompted press and public outrage there.

In the end, the measures were not implemented, the administrator did not go to jail, and it was clear CAA would need some fixes. These early problems and confrontations in implementation, along with the 1973 energy crisis, clearly affected thinking about the nature of AQM. In 1971, the administrator's strategy had been to push hard to make all of the deadlines for standard setting, plan development, and implementation. Faced with the impracticality of attaining these goals on schedule, growing concerns that air pollution regulations were aggravating energy dependency, and forcing unpopular measures, either the standards or the deadlines needed to change. The passage of the Energy Supply and Environmental Coordination Act of 1974, in particular, marked a significant change in the overall enthusiasm for air pollution control. EPA was directed to promote the use of coal under the Orwellian heading of "clean fuels policy." On the positive side, energy conservation stimulated by high prices slowed the growth in demand. It was not until the 1977 CAA Amendments that Congress addressed the underlying issues in AQM. Meanwhile, the agency and the states soldiered on.

The good news during this period was that some indicators of air pollution continued to improve. A look at air quality, emissions, and even visibility figures discussed earlier demonstrates this. The "flattening" of SO_x emissions growth was accompanied by a stabilization of visibility trends in the eastern United States.³³ Reductions in PM and SO₂ emissions were directly related to implementation of state and municipal regulatory programs developed in part under the 1967 program but continuing under the new mandates. An analysis that separated trends in counties above and below the TSP NAAQS found "that the entire decline in TSP during the early 1970s occurred in nonattainment counties and that two-thirds of the 1971–1974 decline in these counties occurred between 1971 and 1972, the first year that the 1970 CAA was in force."¹²⁹ Nevertheless, by 1976, EPA sent letters to 45 states indicating that their SIPs were deficient for one or more of the NAAQS.

New NAAQS Science—Two Steps Forward and One Step Back. The supplemental chronology tables highlight some of the more important scientific and technical developments that eventually reshaped the NAAQS. The new CAA had funded and generated national interest in a large variety of projects related to health and welfare effects, atmospheric sciences, and control technologies. Two are notable. First is the recognition of the multimodal size distribution for PM in 1972.¹³⁰ This concept was clearly critical in framing subsequent research¹³¹ and ultimately policy and control choices for PM. Second is the increase in attention to aerosol composition and transport that arose from the early results of the EPA Community Health and Environmental Surveillance System (CHESS) program.¹³² These results suggested health effects at levels below the NAAQS, and that transformations of SO_x might be more important than the gas itself.

Unfortunately, clear problems in some aspects of monitoring and quality control, as well as an overly aggressive marketing of the results,¹³³ led to the demise of the EPA's air pollution epidemiology program, and legislative restrictions on its use for policy in 1977.¹³⁴ It is important to recognize the numerous problems with aspects of the CHES program. Nevertheless, a substantial amount of information on air quality, particle size and composition, and health was collected that likely would have been useful if checked and reanalyzed. The results might have accelerated some of the changes that were not made until two decades later. The agency lost substantial expertise in a core discipline for years. Yet preliminary CHES implications led some, including the National Institute of Environmental Sciences, to sponsor improved programs,¹³⁵ and caused others to examine the atmospheric and multimedia impacts of regional-scale transport and chemistry of air pollution.^{136,137} In the long run, the research and analyses in these areas would have a profound impact on the development of standards and implementation of regional strategies for PM, visibility impairment, acid rain, and O₃.

Part II: Revisionist History (1976–1993)

For essentially the same reasons that no new pollutants were listed under Section 108, EPA had little interest in revising the NAAQS in the first 5 yr. Internal reviews of the NAAQS conducted by health experts in the Office of Research and Development (ORD), as well as a 1974 review by the NAS done as part of a Congressionally mandated report on the automobile standards,¹³⁸ came to essentially the same conclusions:

*"In general, the evidence that has accumulated since the promulgation of the Federal ambient air quality standards by the EPA Administrator on April 30, 1971, supports those standards. Hence, on balance, the panels found no substantial basis for changing the standards."*¹³⁸

The NAS panel called for more research, emphasizing fine particles, NO₂, and oxidants in particular. Between 1971 and 1975, neither internal nor external forces pushed EPA to re-examine the original suite of standards.

The hiatus ended in 1976 with two events. First, NRDC sued EPA in 1975 to list Pb as a criteria pollutant and to set standards. The agency argued it had the discretion to follow the more effective risk management approach for Pb outlined above. The D.C. Circuit Court disagreed and on March 1, 1976, ordered EPA to begin the process. The agency listed Pb at the end of the month. Second, during 1976 the NAQCAC began surveying the existing criteria and, by June, was drafting a final report that recommended a complete review and revision of all of the existing CDs.¹³⁹ In September 1976, the recently created EPA Science Advisory Board (SAB) disbanded NAQCAC as a part of its restructuring of advisory panels.

On August 16, 1976, Bern Steigerwald and OAQPS staff met with Del Barth of ORD. They decided it was time to begin the review process and discussed alternative rationales for determining the sequence of the reviews. From Steigerwald's policy perspective, it would be best to

begin with the pollutants for which specific implementation measures were least advanced, and the science was most limited and then move on to SO_x and PM, for which implementation measures were more advanced. OAQPS was aware of questions being raised by API, states, and others on whether a few hours above the oxidant standards were worth the effort to develop disruptive transportation control plans.^{13,140} This made oxidants the logical choice to undergo review first. By the fall, EPA provided the following schedule in a response to NAQCAC:

- Photochemical oxidants (and related HC)—August 1977
- NO_x—February 1978
- CO—August 1978
- SO_x (and associated particulates)—August 1979
- PM—August 1979

The response indicated that formal publication of the documents would occur between 3 and 15 months later than those dates depending upon whether it would be necessary to develop new or revised standards as a result.¹⁴¹ EPA followed this order but did not meet these deadlines (Table 6). The last two (SO_x and PM) were combined into a single document, which was actually issued in August 1982.¹⁴²

Mislead. Work started on the Pb document even before the anticipated court decision. The overlapping O₃ review began in September 1976. Because no major CDs had been developed since 1970, the criteria review function had been transferred to the Criteria and Special Studies Office (CSSO), a small group located in the health effects laboratory in Research Triangle Park, NC. The fact that this organization was not ready for "prime time" became apparent after the release of the first external review draft in October 1976 and the reaction of the special lead criteria review subcommittee of the SAB. OAQPS was surprised when the draft CD recommended a specific Pb standard, inconsistent with the separation of criteria and standards in the statute. They were even less satisfied with the high level of 5 µg/m³. SAB panel members strongly criticized the poor quality of the effort, as well as the weakness of the recommendation.¹³

Melnick's review¹³ asserts that "EPA's scientists" recommended 5 µg/m³ and that the agency did an "about face" when it later proposed a much lower level of 1.5 µg/m³. Furthermore, he repeats Pb industry suggestions that this "reversal" might have been influenced by Assistant Administrator for Air David Hawkins, who came to the EPA from NRDC in 1977. These suggestions are dismissed by those closest to the project and contradicted by the comments of the independent SAB; this is apparent even in Melnick's account.¹³ The draft CSSO recommendation was inconsistent with a 1972 EPA Pb report that suggested 2 µg/m³ as a level of concern to health.¹³ Their inappropriate NAAQS recommendation cannot be construed as representing the mainstream views of agency scientists.

The ultimate result of this embarrassing experience was a reorganization that created a separate Environmental Criteria Assessment Office (ECAO). An academic expert from the University of North Carolina who had been

brought in to complete the final drafts of the Pb document, Lester Grant, became acting and later permanent director of ECAO in October 1978. EPA would accord higher priority to the criteria program through the remainder of the scheduled reviews.

Because this was the first major NAAQS action since 1971, the OAQPS staff who developed the recommendations and analyses were the first to go through the greatly expanded internal review and administrative review procedures. As detailed in the chronology, Pb represented a challenge because of the multiple exposure routes, and the fact that, like CO, the best indicator of exposure was a blood concentration. The OAQPS staff developed an inventive approach and analysis that: (1) established a target blood Pb level that would protect 99.5% of children, based on the recommendations of the Centers for Disease Control; (2) estimated a baseline level from non-air sources; (3) used limited data to set an assumed air Pb/blood Pb ratio; and (4) calculated the air concentration that would keep the total baseline plus air Pb below the target level. As the preamble¹⁴³ and reviewers¹³ noted, these analyses were subject to multiple uncertainties, and were sensitive to the selection of many of the parameters estimated. Whereas the staff methodology was reviewed by internal scientists, policymakers, and the public, it was not submitted to the SAB for review.

As for all NAAQS decisions, the final choice on the standard was constrained and informed by the scientific information, but ultimately based on the policy judgment of a politically responsible decision-maker, the EPA administrator. After consideration of and reaction to public comments, and review and discussion on the final package by OMB, the administrator promulgated a Pb standard of 1.5 $\mu\text{g}/\text{m}^3$ quarterly average in TSP.¹⁴⁴ The exposition of the rationale and response to comments in the proposal and final preambles for the Pb NAAQS set the tone for later NAAQS and bear little resemblance to the 1971 Notices.

In 1979, the Lead Industries Association sued EPA on several aspects of the decision. The final ruling (*Lead Industries Assoc., Inc. vs. EPA*, 647 F. 2d 1130, cert. den. 449 U.S. 1042 [1980]), set precedents that guided the agency's decision-making in future reviews. The major conclusions reached by the court include:

- The text of the CAA and legislative history indicated that EPA could not consider economic and technological factors in setting NAAQS under Section 109.
- The margin of safety was designed to address health effects that had not yet been uncovered by research and effects for which medical significance was a matter of disagreement. Requiring the agency to wait until it could conclusively demonstrate that a particular effect is adverse was inconsistent with the CAA's precautionary and preventive orientation.
- The Pb industries as petitioners argued that EPA was required to set a safe level and then adjust for an adequate margin of safety. The court held that the administrator was not limited to this approach but had the discretion to determine the appropriate approach to best fulfill the goals of CAA in the margin of safety. This is the kind of

policy choice the CAA leaves to the administrator's judgment.

- With respect to the specific technical basis for the standards, the court found adequate evidence in the record to support EPA's findings regarding the first adverse health effects level for Pb exposure as well as more serious effects of anemia and central nervous system detriments at increasingly higher levels. The agency was not arbitrary or capricious in determining other factors used in its analysis that led to the standard level.
- The court also praised EPA's execution of the expanded administrative procedures it had earlier required. It cited "the rigorous scientific and public review which permitted a thorough ventilation of the complex scientific and technical issues presented by this rulemaking proceeding."

O₃, a Risky Business—But First Some Words from Our Sponsors. The review of criteria and NAAQS for oxidants lagged the Pb process, with a period of substantial overlap. At the outset, it was decided that the indicator for the standard would be formally changed to O₃, and the CD referred to "ozone and other photochemical oxidants." Although initiating the review on its own, EPA was again subject to a court-ordered schedule filed by the API. The process was late enough to be affected by legislative developments, particularly the CAA Amendments of 1977.

These amendments addressed a number of issues that had arisen since 1970, including the attainment deadlines for the NAAQS, vehicle emission standards, prevention of significant deteriorations (PSDs), as well as newer concerns, such as visibility in National Parks. They made several changes that affected the NAAQS process:

- The CAA required that EPA review all of the existing criteria and standards by 1980 and every 5 yr thereafter.
- It established a scientific committee (later named CASAC) to review the existing criteria and standards and to make recommendations to the administrator regarding any new standards or revision of existing criteria and standards as appropriate, and on the same 5-yr schedule. The seven-member committee had to include at least one physician, a member of the NAS, and a representative from state or local air agencies.
- It required that, within 1 yr after enactment, EPA establish a short-term primary standard for NO₂ unless the administrator found it unnecessary based on the scientific criteria.
- Section 307(d) required public hearings of proposals and mandated the administrative procedures summarized above, including identification of all ex parte correspondence and meetings regarding NAAQS decisions. (This included any discussion or paper related to the decision with outside parties, generally between proposal and promulgation.)
- Minor changes in the wording of Section 108 were made to clarify the precautionary approach.

Other legislation passed in 1978, the Environmental Research Development Demonstration Authorization

Act,¹⁴⁵ required that EPA submit NAAQS proposals to the SAB for review.

Supplemental Table 4 provides an overview of the O₃ criteria and standards review process as well as the key developments and issues raised. Given a reinterpretation of the original study upon which the standard was based and the limited new evidence of effects at levels above 0.15 ppm, EPA proposed to relax the level of the standard to 0.10 ppm.¹⁴⁶ The proposal preamble presents the agency's thinking at the time about a number of the general issues critical to standard setting. In particular, it indicates that EPA was aware of criticism that the fundamental premise of the standards was built on a scientific fallacy; namely, the illusory concept of a "threshold" for health effects. The preamble quoted the 1974 NAS report to support the notion that "in no case is there evidence that the threshold levels have clear physiological meaning."¹⁴⁷ It also cited the legislative history of the 1977 CAA Amendments. The relevant House committee observed that the concepts of threshold and adequate margin of safety were "necessary simplifications to permit the Administrator to set standards."¹⁴⁸ That is, Congress reconsidered the issue in light of the scientific information, and decided that a change to the statute was not needed.

The preamble addresses EPA's view of the situation for O₃, noting that the science suggests no clear threshold for the health effects:

*"Rather there is a continuum consisting of ozone levels at which health effects are certain, through levels at which scientist(s) can generally agree that health effects have been clearly demonstrated, and down to levels at which the indications of health effects are less certain and harder to identify. Selecting a standard from this continuum is a judgment of prudent public health practice, and does not imply some discrete or fixed margin of safety that is appended to a known 'threshold.'"*¹⁴⁷

This treatment of the issue was the product of the efforts by staff in the OAQPS's Pollutant Strategies Branch, who began gearing up shortly after the decision to review the O₃ standard. After reviewing how the margin of safety concept was applied in engineering and federal occupational and food safety regulations, they developed a more formal approach consistent with the prevailing scientific information and decision analysis theory.^{149,150} This risk framework was used on a trial basis and results were presented in the proposal as preliminary. It was not used in the final decision. Nevertheless, the terminology and concepts that were developed and discussed by the staff during that period guided future analytical work on risk and exposure and clarified the approach to developing and arraying information for decision makers.

Rejecting the illusion that ambient standards could provide absolute safety through the threshold-safety factor approach, OAQPS staff began with the following premise: an adequate margin of safety exists, by definition, when risks associated with a particular standard are judged to be acceptable.¹⁵¹ Here, risk means a probability applied strictly to particular adverse events occurring in a given period of time based on the state of information at

the time of decision-making. From this point, it becomes critical to identify the major uncertainties that give rise to the risk in question. Some of these include uncertainties about the concentration or exposure-effects relationship for sensitive groups that are the focus of NAAQS decisions, and uncertainty about the existence of an effect in humans that has been demonstrated only in animals. Another important uncertainty was that associated with the temporal and spatial distribution of air pollutant concentrations and exposure when the standard is barely attained. Analyses of this uncertainty were also developed for O₃. One of the results was the move to a more robust statistical form (expected exceedance) in the specification of standards.

Of particular concern to the O₃ NAAQS was uncertainty about the point at which observed responses in sensitive groups are understood to be "adverse." For some air pollution effects observed in epidemiology studies (e.g., mortality, hospital admissions), there is little question about "adversity." But it is a continuing issue for pollutants such as O₃ and CO that rely substantially on controlled human studies. Ethics do not permit human testing to present a substantial risk of permanent harm, so the studies often cannot use the most sensitive individuals or investigate the most serious effects. In the case of O₃, EPA needed to consider the evidence from controlled human studies that found reversible changes in certain lung function tests, as well as some symptoms. No objective criteria existed for interpreting the significance of the various responses. OAQPS staff therefore consulted with health experts to determine at the point at which such changes become "adverse" to health. The experts generally concluded a range of between 5% and 15% drop in the particular lung function test used. This was used in the O₃ decisions. In later years, the American Thoracic Society produced guidelines¹⁵² for interpreting the adversity of the effects of air pollution for controlled human and epidemiological studies.

The risk assessment framework also helped staff define the respective roles of science and risk assessment, as well as their responsibilities in assessing and presenting information to decision makers. Although not always successful, the staff aspired to the standard articulated by Granger Morgan that the objective of good policy analysis "is to evaluate, order, and structure incomplete knowledge so as to allow decisions to be made with as complete an understanding as possible of the current state of knowledge, its limitations, and its implications."¹⁵³

In part, this meant that, unlike the approach often followed in developing risk assessments for carcinogens, risk and exposure assessments developed for the NAAQS would focus on the central tendency of the estimates, and not on ninety-fifth percentile risk numbers or risk benchmarks that included hidden safety factors. It also meant examining all of the information, from the most robust replicated studies in humans, to more uncertain results from single studies with suggestive, but not conclusive evidence. Although it was important to place greatest weight on the best information, the decisions should not rely wholly on the evidence from a single conclusive study, but also be influenced by less certain evidence of risk at lower levels.

Yet, if the agency were to concede that no clear thresholds exist for a pollutant such as O₃, what would stop the administrator from deciding on a level of zero? The O₃ preambles also give EPA's first statement on the fundamental issue of why the agency believed the CAA requirements for safety and restrictions against considering costs did not require levels approaching zero:

"The decision is made more difficult by the fact that the Clean Air Act. . . does not permit him to take factors such as cost or attainability into account in setting the standard; it is to be a standard which will adequately protect public health. The Administrator recognizes, however, that controlling ozone to very low levels is a task that will have significant impact on economic and social activity. It is thus important that the standard not be any more stringent than protection of public health demands."^{146,147}

Subsequent articulations of this view would stress the actual wording of Section 109 that standards must be "requisite" (i.e., no more than necessary) to protect public health with an adequate margin of safety. The question of whether a more explicit consideration of available cost estimates would have materially improved the 1979 O₃ decision is debatable. Melnick¹³ cites the President's Council on Wage and Price Stability Regulatory Analysis Review Group (COWPS/RARG) analysis as a possible rationale for a standard. RARG found the "costs per person-hour of unhealthy exposure" went up dramatically for standards below 0.16 ppm. The uncertainties inherent in this analysis were large, given the problems of estimating implementation control costs with inadequate emission inventories and limitations in O₃ modeling capability. It is hard to believe that the location of the "knee in the curve" for cost-benefits for O₃ would have been any less sensitive to changes in assumptions than the Pb analysis that Melnick¹³ earlier criticized. Later research would suggest EPA's assessment of the health effects at levels less than 0.15 ppm were likely much closer to the mark than the RARG assessment of costs. At the time, OAQPS characterized this alternative approach as follows:

*"The RARG methodology is keyed to economic efficiency and resource allocation. This approach focuses on aggregate health impacts and not on the health of sensitive individuals. The RARG model avoids complex judgments regarding medical evidence by arbitrarily assigning no value to less conclusive indications of health risk associated with low levels of exposure. The RARG approach selects only the most conclusive studies for use in the cost model and assigns no value to uncertain risks at lower levels."*¹⁵⁴

OAQPS staff clearly found the "risk-benefit" portion of the analysis lacking with respect to their principles for risk assessment, and the cost portion was inconsistent with EPA's Office of General Council interpretation of the statute.

On January 9, 1979, David Hawkins and Administrator Douglas Costle met at the White House with Charles Schultze (Council of Economic Advisers) and other top officials to discuss the final decision.¹⁵¹ Although the meeting later became the source of some controversy, such meetings have repeatedly taken place on major NAAQS decisions. The final primary and secondary standards were set at identical 1-hr levels of 0.12 ppm and published in February 1979.

API and others, including NRDC, sued on a number of grounds and in 1980 the D.C. Circuit Court again ruled in favor of EPA in *American Petroleum Institute vs. EPA*, 665 F.2d 1176 (D.C. Circuit Court, 1981), cert. den. 455 U.S. 1034 (1982). Key aspects include:

- The court again rejected an API argument that feasibility of attainment and consideration of costs and benefits were required, citing its own precedent in the Pb case. It also rejected a claim by Houston that the levels were too close to natural background to be feasible.
- API argued that the standards were not supported by substantial evidence because no adverse health effects were proven below 0.25 ppm over 2 h. The court held that the administrator recognized the uncertainty of the issue and made a rational judgment based on the studies in the record.
- The Court rejected NRDC's objections that EPA had failed to set standards for other photochemical oxidants. The agency decided to regulate the oxidant which, in the administrator's judgment, presented a predictable danger. The court held this was reasonable in light of the uncertain information about the class of photochemical oxidants as a whole.
- The Court rejected NRDC's argument that EPA did not allow an adequate margin of safety because the standard failed to protect sensitive individuals against easily predicted risks. The administrator considered the range of the probable level of adverse effect (0.15–0.25 ppm), and properly considered evidence related to the less predictable risk below that level. The administrator's basis for selecting 0.12 ppm took into consideration several factors and was rational.

In 1981, the multi-stakeholder National Commission on Air Quality (NCAQ), charged by the 1977 CAA to analyze air pollution programs, recommended that the statutory requirements and process for establishing and reviewing primary NAAQS remain unchanged.¹⁵⁵

CO, NO_x, and HC Reviews—Process Is Our Most Important Product. CO, NO_x, and HC were the first NAAQS reviews to follow the procedures that evolved after the 1977 CAA Amendments, most importantly, the oversight of both criteria and standards reviews by CASAC (see Figure 9). CASAC quickly discovered that the voluminous CDs were not directly useful to their task of making recommendations on the NAAQS. The CDs had expanded exponentially with the increase in scientific information, the new review procedures, CASAC recommendations, and legal concerns following the remand of the SO₂ secondary

standard—all of which prompted inclusion of as much information as possible. The entire set of the six original HEW CDs is not as thick as the 1979 O₃ document.

What evolved from early discussions with CASAC was the development of the OAQPS SP.^{156,157} This became an integrated assessment of the most critical policy-relevant information that was intended to bridge the gap between the CD and decisions required of the administrator. OAQPS science/policy staff integrated science and analyses from multiple disciplines to inform choices on the indicator, averaging time, form, and level of the NAAQS. By 1981, SPs included recommendations for all of these NAAQS attributes, including a range of alternative levels that were supported by the science. The SP also provided a vehicle to summarize the implications of associated air quality, exposure, and/or risk analyses. OAQPS staff organized the science assessment component as a series of critical elements to be addressed in the NAAQS; for example, mechanisms of toxicity, effects of concern, sensitive populations, and concentration-response information. Drafts of the SP were evaluated by CASAC and the public, helping to inform the process and sharpen the focus on what would be the most important issues. The papers also provided a foil the CASAC could use in making its own recommendations to the administrator. Ultimately, portions of the final SP would form the basis for portions of the preamble language in *Federal Register* notices.

CASAC played an important role in the NAAQS process after 1978. As Greenbaum et al.¹⁵⁸ noted, the panel has served as a form of “referee,” reviewing the general

contributions of the scientific community and the specific contributions of advocate-supported investigators, and helping the EPA distinguish between the significant number of useful contributions from the advocates and the smaller number of more purely “attack” analyses. They provide advice at every stage in the process, from initiation to development of CDs and SPs, recommendations on NAAQS, development of research agenda following reviews, and in several cases, commenting on the proposed decisions. Although it is generally accepted that CASAC’s inclusion in the process has increased the quality of the materials in the NAAQS review, it is also clear that the process itself has taken longer, despite repeated attempts by the committee and EPA to shorten it.⁷

The chronology (Table 6) and specific aspects of interest in the CO, NO₂, and HC reviews is detailed in Supplemental Tables 3, 5, and 6. The first two reviews reaffirmed the original 1971 standards, whereas the third delisted HC as a criteria pollutant and revoked the HC NAAQS. What is notable for all is the time taken between development of the CD, SP, proposal and final decision. Each of the actions began in 1977–1978. The final decisions were published in 1983 for HC and in 1985 for CO and NO₂. One cause for the delays was the long interregnum between administrators after the presidential election in 1980, followed by two more changes in administrators between 1983 and 1985. Little progress could be made on major actions until new management arrived and was brought up to speed. CO, which had been proposed in 1980, was further delayed by a reopening of the

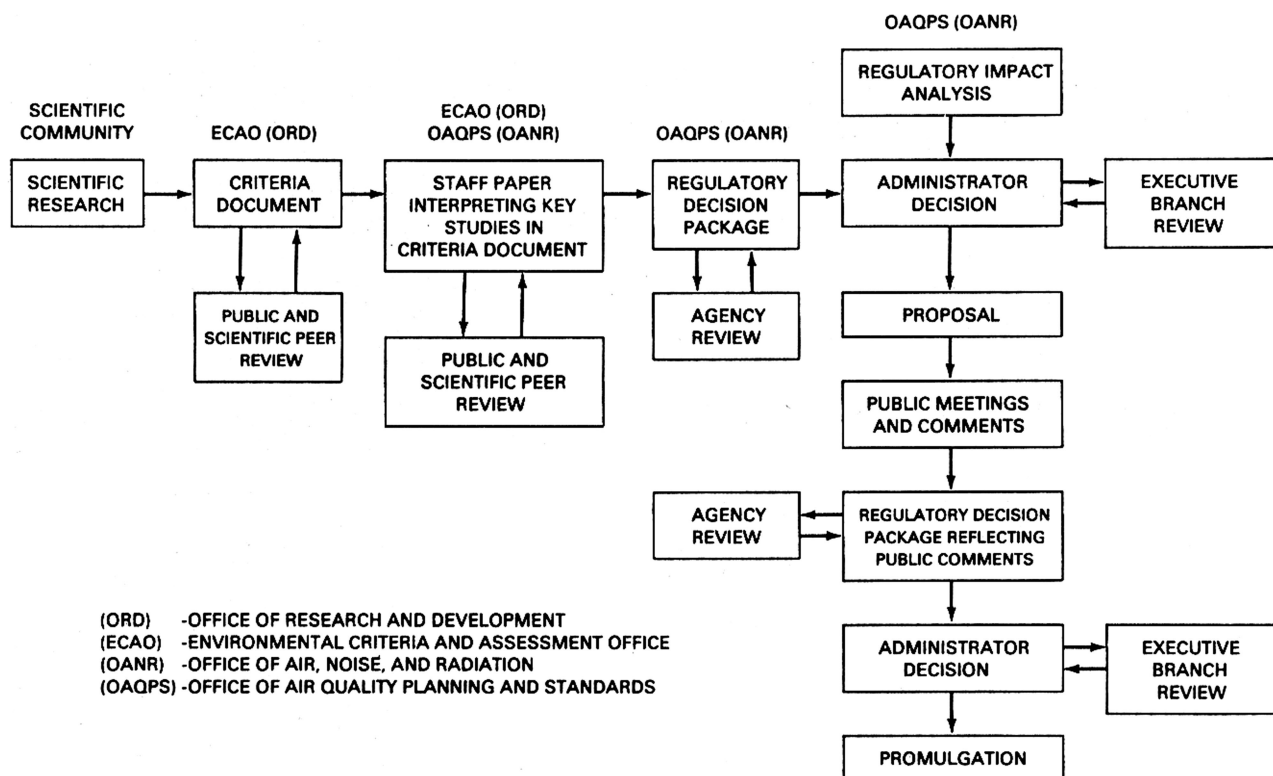


Figure 9. Overview of the criteria and NAAQS Review Process (1979–2006).²⁴⁸ Details of the process changed over time, but the major steps shown here remained essentially the same. Scientific peer reviews included workshops and formal meetings and comments by the CASAC. In some cases, CASAC also provided comments on the proposal. ECAO later became the National Center for Environmental Assessment (NCEA). OANR later became the Office of Air and Radiation (OAR).

public comment period and then by the discovery of potential problems that affected a number of key studies (Supplemental Table 3).

As noted above, the 1977 CAA Amendments called for a short-term NO₂ standard, based in part on the suggestion by the 1974 NAS report¹³⁸ recommendations. Initial review suggested this might not be appropriate, but after holding a public meeting in the summer of 1978, EPA moved on to a full criteria review without taking formal action. ORD began studies of short-term exposures to evaluate preliminary results from earlier short-term studies. After 1981, the process was further delayed by internal agency disagreements on whether a short-term standard should be proposed and a second change in the EPA administrator in 1983. By then, the agency needed to examine newer research not included in the 1982 CD.

In contrast, the revocation of the HC standard went smoothly. As noted earlier, the only basis for this standard was to help with O₃ attainment, and states never planned to meet it beyond the controls they developed for O₃. There was little disagreement with retaining the CO and NO₂ standards, but some concern about the need for the short-term standard. The articulation of key policy relevant studies and issues led to research recommendations, with work targeted to them sponsored by EPA, HEI, and others.

This illustrates one of the continuing and less appreciated benefits of the NAAQS. The intense science and policy interaction enables EPA and others to sharpen the most important scientific and analytical questions that need to be addressed for future reviews. The continued focus on remaining air pollution problems and the need for future reviews means such research strategies can reasonably be forecast over multiple years. This reduces, but does not fully eliminate, the "pollutant of the month" syndrome where research priorities shift from one concern to the next. In the case of the NAAQS, sometimes research funding is like a roller coaster, but it usually stays on the tracks.

PM and SO_x.

"The interest in air pollution is inversely proportional to its concentration." Sir Patrick Lawther, circa 1981.

The PM and SO_x reviews were the last to start and the last to finish. They were also among the most contentious, fraught with intrusive litigation, dueling expert panels, and a little intrigue. Key aspects of the history are summarized in Supplemental Tables 1 and 2 and also in a recent paper.¹⁵⁸ This summary will deal more with the process and some personal reflections than with the most critical aspects of the decision.

The late start and subsequent delays in these reviews permitted some opportunities to suggest research and monitoring efforts that would assist with critical issues before the nearly decade-long process was completed. Two NAS panels had published major reports on SO_x¹⁵⁹ and airborne particles.¹⁶⁰ Comparing the summary of controlled human studies of SO₂ with ambient data suggested that peak SO₂ concentrations near large point

sources might produce effects of concern, but very little work had been done on asthmatics. This was important because the original standards had been based on epidemiology studies where both SO₂ and PM were high. OAQPS communicated this as a research priority to ORD, which was eventually able to produce results that, together with those from other studies, were critical in the final stages of the review.¹⁶¹

OAQPS staff also worked with health and atmospheric scientists before the review to consider the science and policy basis for an indicator for the PM standard. All agreed that TSP was not the best indicator for PM. TSP contained substantial amounts of large particles that did not penetrate to the lung. Accordingly, because the TSP standards were often exceeded in dusty rural locations, OAQPS had developed a "rural fugitive dust policy" that placed low priority on such violations.¹⁶² Given the recommendations of the 1974 NAS report,¹⁵⁹ many assumed EPA would move to a fine or respirable particle (<3.5 μm) standard, or perhaps a standard for SO₄²⁻. The key policy question was what range of particle sizes might be of concern to the most sensitive individuals. The health experts concluded that inhalable particles as large as 10–15 μm in aerodynamic diameter could reach sensitive regions of the lung.¹³⁴ Atmospheric scientists recognized that the differences in formation mechanisms and chemical composition between fine and coarse particles might support another useful breakpoint. Miller et al.¹³⁴ provided a technical basis to develop new monitoring approaches and EPA established a temporary Inhalable Particle Network (IPN) to measure both fine and inhalable particles (i.e., PM₁₅) at more than 100 locations.¹⁶³ The results from the IPN in the early 1980s not only proved important in the final standards, but also formed the first basis for later epidemiological studies, including the American Chemical Society (ACS) prospective cohort study.¹⁶⁴

AISI represented an industry that was being hard hit by foreign competition as well as by the TSP standards. They sued EPA in 1978 in part to ensure that the results of the agency's CHESS studies were not used in the review. At one point, AISI lawyers got a temporary restraining order from a Pittsburgh judge that resulted in shutting down a closed expert workshop on early drafts. All subsequent workshops were open to the public. (I recall spending about 10 hr in depositions being questioned on various aspects of my role in the process, and my personal notebooks had to be turned over and were copied during discovery.) More productively, AISI also contracted with several pioneering British epidemiologists, whose studies had been cited in the 1969 CD to interpret their work in the context of standards.¹⁶⁵ Not to be outdone, ECAO countered by hiring a group of epidemiologists from the Harvard School of Public Health to provide an alternative view.¹⁶⁶ In 1981, new management came to EPA, bringing a different style and atmosphere. As Bill Ruckelshaus later saw it:

"... it was a nightmare... I mean it was really awful... In one of the offices they had compiled a 'hit list' of career appointees, drawn up in colored ink on charts. They were targeted for dismissal because of alleged disloyalty to

the administration. And the whole staff was aware of such things! . . . Very clear signals went out to the people of the agency which said, we don't trust you. We don't trust you to do what we want done. It generated enormous employee morale problems."¹⁶⁷ (emphasis in original)

Before the PM/SO₂ review process was over, I was to end up giving briefings on the PM and SO_x standards to four different administrators. Such briefings were often crowded with various aides and representatives of interested offices. A number of months after the CASAC closed on the SP and made their final recommendations on the standards (January 1982), I received a phone call from a high level EPA political appointee with some instructions for an immediate special briefing limited to this official, Administrator Ann Gorsuch, and me. In this after-hours session, I reviewed the scientific and policy bases for the decision. In response to a question at the end, I noted the results of the then draft PM Regulatory Impacts Analysis (RIA)¹⁶⁸ were not included because they had not been reviewed and contained cost information that could not be considered in the decision. I then summarized the key finding, which though preliminary and uncertain, suggested that the estimated benefits of the PM₁₀ standards exceeded the costs even at the lowest end of the ranges of the two standards combined. The administrator was furious. She could not believe that the air office would develop material that would undercut her choice for the PM standards. Almost certainly because of that exchange, we received no official guidance for the proposal before she left the agency, and PM was caught in limbo. This is the only case in which I know that an RIA had a direct influence on an administrator's nondecision regarding the NAAQS.

Bill Ruckelshaus returned for his second term as EPA administrator in May 1983, and within months took up the NAAQS reviews. After a number of briefings, he instructed us to propose a decision that would highlight the difficulty and importance of the decision, state that it could not be made solely on science, and asked if under the statute "is there room to consider other, non-scientific factors in making the major social policy judgment of picking a precise number from a range of scientifically justified values." He proposed the CASAC and staff ranges, with an inclination to the lower end, which was published in March 1984.¹⁶⁹

Despite the combined criteria, OAQPS prepared separate SPs for PM and SO₂, because the evidence suggested maintaining separate standards for both. The SO₂ paper lagged PM by about 6 months, and we briefed Ruckelshaus a number of times on this decision. The alternative staff and CASAC recommendations were: (1) keep the original standards, or (2) add a short-term standard based on the new chamber studies. He decided not to revise the original standards. At the time, Management believed that the decision did not need to be formally announced in the *Federal Register*. Soon after, Ruckelshaus left EPA.

The accumulated delays in the process meant that the 1982 SO_x/PM CD was aging by 1985, when we began discussions with the new EPA Administrator Lee Thomas

on what to do about final decisions for PM and SO₂. Moreover, the early portions of the review had stimulated a fair amount of new research and reanalyses of old data for both pollutants. The agency decided it would be best to take advantage of these new findings by developing "addenda" to update the CDs as well as SPs. In response to the growing number of new PM studies, agency staff started review and evaluation, with the assistance of two analysts brought in to work on statistical issues in epidemiology, including a reanalyses of the London mortality data.¹⁷⁰

After the updates and another round of reviews and briefings, Administrator Thomas signed the final rule for the PM₁₀ standards in July 1987, deferring a decision on a PM_{2.5} standard to protect visibility.¹⁷¹ Because the addenda included SO₂ as well as PM, another decision was required on whether the new studies on short-term effects and expanded exposure analyses would change the prior decision. In April 1988, EPA proposed not to revise the SO₂ standards, but solicited comment on an alternative of adding a 1-hr primary standard of 0.4 ppm.¹⁷² There would be no more NAAQS proposals or promulgation notices for the next 4 yr.

Some Additional Reflections. From one perspective, the 1971 NAAQS survived the first wave of revisions fairly well, with three of them unchanged (CO, NO₂, SO₂); one relaxed (O₃); one deemed unnecessary (HC); one new pollutant added (Pb); and one that was partly relaxed (TSP) and slightly tightened (PM₁₀). The new process was far more thorough and resulted in much greater stakeholder participation and the key premises and concepts were sharpened and tested. The effort also stimulated a substantial amount of new research on all of the pollutants. Overall, however, these first NAAQS reviews were cumbersome and beset with delays attributable to the process and to numerous transitions and problems in upper management. They also exemplify what Sunstein calls "the tyranny of the status quo."¹⁷³ Even small changes to the NAAQS could reopen the process of designations and SIPs. Accordingly, EPA was reluctant to make modest improvements to some NAAQS (e.g., to statistical forms, more appropriate averaging times) without compelling evidence of the need to revise, as was the case for O₃ and PM. EPA also missed some important opportunities and deferred decisions in cases where the science appeared to support actions that policymakers were simply not ready to take.

One of the most important of these was related to protecting public welfare, an issue that the 2004 NRC AQM Committee⁴ highlights as a continuing challenge. Most notorious was acid rain. It was clear that if the executive branch did not want to move either on a targeted approach (suggested by Ruckelshaus in 1983–1984) or more general legislation (recommended by the NCAQ in 1981¹⁵⁵), EPA was not going to be able to sustain secondary standards either. Accordingly, the agency found it necessary to defer action on deposition-related issues repeatedly in NO_x, SO₂, and PM notices. The effects of O₃ on vegetation also received "secondary" priority. The 1978 O₃ proposal developed a rationale for maintaining the original 1-hr secondary standard of 0.08 ppm. In

the final notice, the primary standard level became the level for the secondary standards. To justify this, EPA changed the criterion it had proposed for determining adverse effects on welfare.¹⁴⁸

EPA also missed an opportunity in the 1987 deferral of a decision on a secondary fine particle standard based on a solid link to visibility. Such a standard would have resulted in a national PM_{2.5} monitoring network up to a decade before one was finally put into place. That would have accelerated the specificity of studies on health effects, exposures, and source-receptor relationships. Of course, it would have been better to set separate primary standards for fine and coarse particles in 1987. But the available epidemiology information, in which aerometry did not clearly separate the two, could not be used to support two PM indicators.^{174,175} Things might have been different if reanalysis of the useful portions of the effects information and particle size and composition data collected in EPA's CHES program had been possible. But Congressional and legal actions precluded a dispassionate re-examination of the evidence on its own merits.

A subsequent Administration and Congress soon delivered a legislative program to address acid rain and regional haze in the form of Title IV and Section 169B of the CAA Amendments of 1990. These programs represented a more efficient approach to these issues than the NAAQS process could at that time. The 1990 CAA Amendments show that the nation's leaders were sometimes willing to address both ecosystem damage and esthetic effects of air pollution. But they also appeared to be sensitive to regional differences in the need for protection. In fact, aspects of the Section 169 visibility program suggested an alternative to improve the utility and effectiveness of future secondary standards. The specific visibility goals could change depending upon the context of a particular national park or wilderness area, and strategies to protect visibility in them also varied.¹⁷⁶

The concept of critical levels and loads^{4,177} that change with the sensitivity of affected ecosystems is similar to what appears to be working for regional haze programs and could be used in AQM. By contrast, the regional ambient standards approach in the 1967 CAA did not make sense, in part because of the lack of a uniform level of health protection for people across locations. The same is not the case for terrestrial and aquatic ecosystems, which vary in sensitivity with location. It would also be helpful if such goals could be expressed in a way that combined multiple stressors, instead of focusing on single pollutants. Unlike the CDH in 1959, it has been difficult for EPA administrators to set tougher standards for public welfare than they do for health. As illustrated by the timing of key decisions on secondary standards in several of the chronology tables, this has been the case across administrations and across parties. It might be easier to support if the goals could be targeted to the most sensitive locations.

A secondary fine particle standard would have helped with another generally unaddressed issue in these first revisions: that is the tendency to consider criteria pollutants one at a time. The SO₂-PM link to the contrary, each of the NAAQS decisions tended to focus on a specific

pollutant, when many nonspecific responses to air pollution must be the result of combinations of them.¹⁷⁸ PM, however, is itself a multiple pollutant. The use of a fine particle indicator prompts control strategists to consider multiple primary particles and several gaseous precursors and photochemical reactions that link PM with O₃, NO_x, SO_x, VOC, and ammonia (NH₃) emissions.¹⁷⁹ Although EPA began to adopt a "one atmosphere" perspective in implementing regulations after combining the PM and O₃ NAAQS reviews in 1997, the process would have come sooner with a secondary fine particle standard in 1987.

The implementation history of the SO₂ and PM standards also highlights the limitations of NAAQS for addressing SO_x on different geographic scales. As noted above, by the early to mid 1970s, EPA realized that some strategies to meet the SO₂ standards, notably tall stacks and intermittent controls, increased the spread of acidic sulfates that were of potential concern to health, visibility, and acid rain.^{98,180} As a result, EPA and later Congress attempted, through complex policies and modeling guidance, to limit or proscribe such approaches and use the SIP process to minimize SO₂ emissions from major sources such as power generators and smelters.^{88,181} But with increasing energy concerns, it was harder to justify the designations and limits EPA originally required for Ohio power plants based on conservative point source modeling when local monitors were not violating the SO₂ standards. Controversy over modeling details and limits for various plants continued into the 1980s, and the end result was an increase in allowable emission rates for large point sources. From the standpoint of the attaining the SO₂ or TSP standards, the results were acceptable. But the reluctance to adopt appropriate NAAQS prolonged the regional problems associated with SO₂. The continuing modeling battles also illustrates how AQM can break down, even for primary pollutants, without appropriate ground rules.

Another way to evaluate the performance of the NAAQS, as well as other components of the U.S. AQM system, regarding regional loadings of SO_x is to compare it with that of other developed countries for the same period. Between 1975 and 1990, the combined SO_x emission totals for the United Kingdom, Germany, and France declined by approximately 55%, as compared with an 18% reduction for the United States.¹⁸² Despite the fact that these countries emitted less than half of U.S. emissions, the absolute reductions they achieved were about the same as for the United States. The theory under the 1970 CAA was that clean new plants meeting New Source Performance Standards (NSPS) would eventually replace older high-emitting plants. In practice, however, the large capital expenditures needed to construct new facilities, slower growth because of energy conservation, as well as the additional costs of NSPS and BACT controls, all contributed to decisions to prolong the life span of existing uncontrolled coal-fired power plants (some more than 50–60 yr old).^{4,183} The theory was flawed. Clearly, America had some catching up to do.

At the other end of the scale, the decision not to add a short-term SO₂ standard meant that a large number of localized peak excursions could continue to present risks to asthmatics in such areas. Whereas EPA may have been

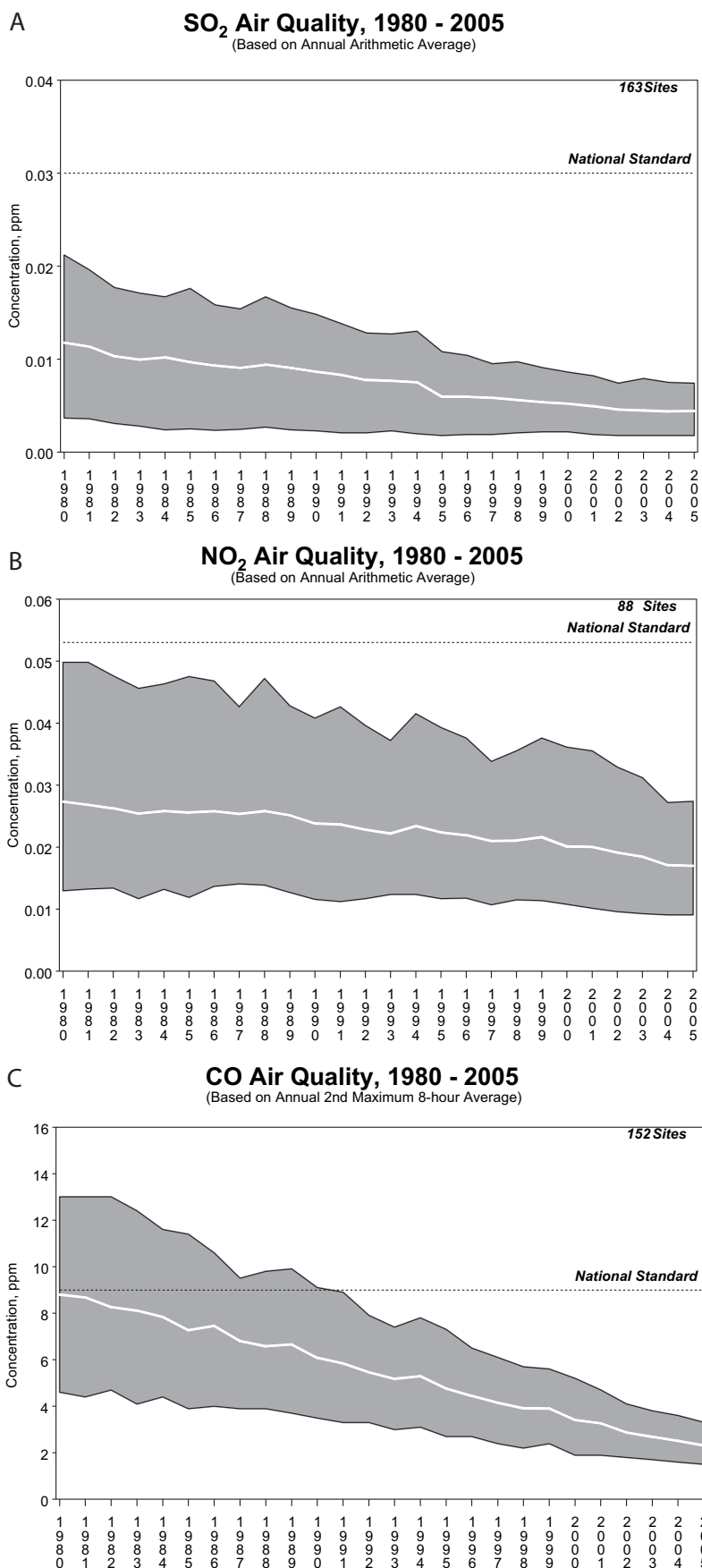


Figure 10. Long-term trends in NAAQS pollutant concentrations, 1980–2005: (A) SO₂, (B) NO₂, (C) CO, (D) Pb, (E) 1-hr O₃, and (F) PM_{10-2.5}. Shaded area depicts values for 10th–90th percentile for all U.S. monitoring sites. White line is average of all sites.

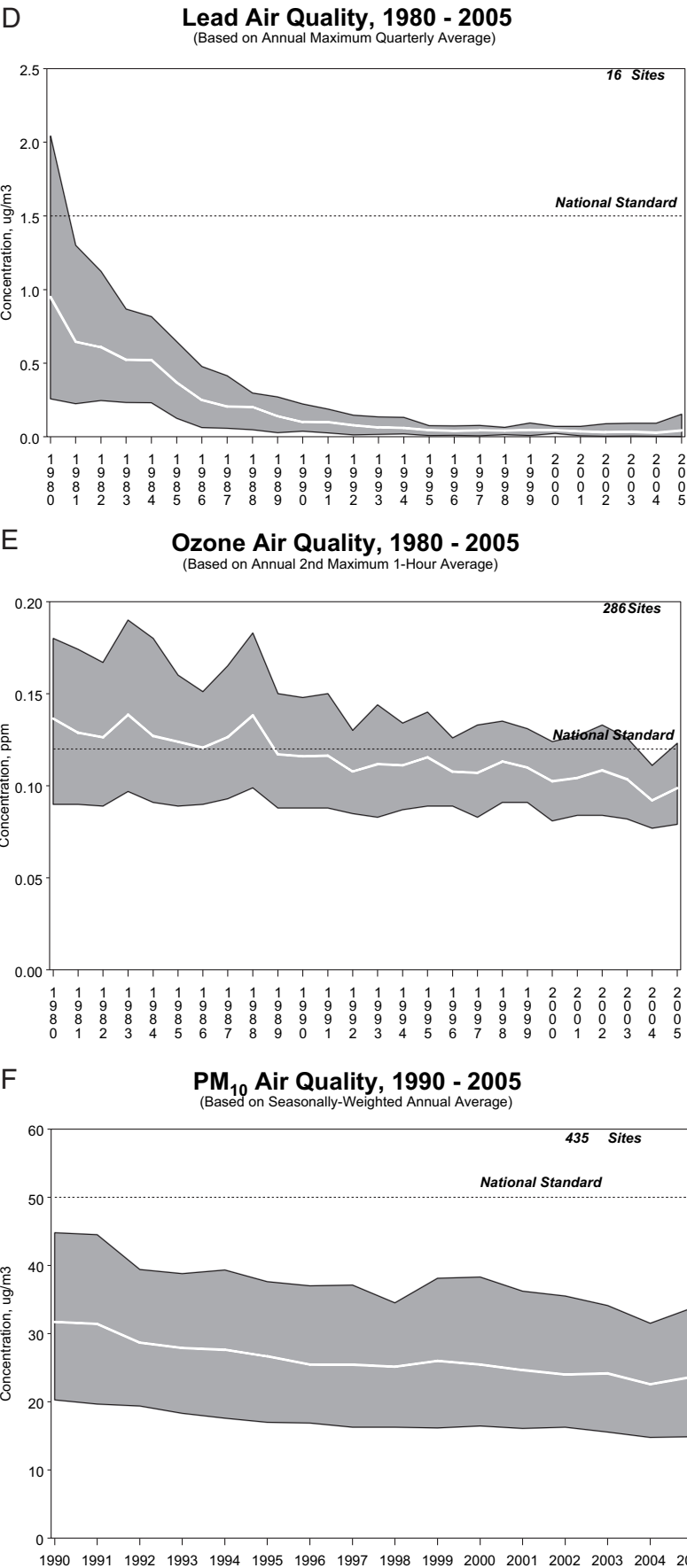


Figure 10. Cont.

correct in handling this issue through its 1998 state-based intervention level proposal, the process thus far supports Morag-Levine's¹¹ contention that the risk-based approach of the CAA can fail to address localized exposures to air pollution. If NAAQS are not the right mechanism, what alternative approach would move more quickly to address localized issues for criteria and for that matter, toxic pollutants? By the 1980s, the risk-based approach to HAPs in Section 112 of the 1970 CAAs had clearly failed when confronted with the issue of carcinogens, and Section 111 actions mostly concentrated on new sources of criteria pollutants. The 1990 CAA Amendments finally broke the HAPs stalemate with the Title III technology-based program.

Air Quality 1980–1990. Figure 10, A–F, depicts U.S. air quality trends for 1980–2005. By 1990, SO₂ and NO₂ were becoming less of a problem, at least in terms of the original standards, and Pb levels had been reduced, not only in air but also in children's blood.¹⁸⁴ CO levels continued to be violate the NAAQS in a number of cities, as was the case for the new PM₁₀ standards. The delays in the much anticipated replacement of the TSP NAAQS were matched by a lack of progress in TSP air quality for 1982–1988 (Figure 6). As Steigerwald¹²⁵ had observed for O₃ in 1976, a widespread lack of confidence in the NAAQS reduced the effort to implement them. Still, the biggest national problem from a SIP standpoint was O₃, where a slow improvement ended with a peak in the hot summer of 1988. A meteorologically adjusted regional analysis of 1980–1998 1-hr O₃ found significant declines for Los Angeles, the Northeast corridor, and the western bank of Lake Michigan, with isolated increases in the Southeast.¹⁸⁵ The multistate regional episodes of high O₃ in the eastern U.S. brought attention to the causes of a phenomenon that had been well recognized in scientific circles.

The emerging scientific consensus resulted in a major shift in policy and control strategies for O₃. Until the 1990s, with the exception of California, SIP strategies for O₃ control focused exclusively on controlling VOC emissions. Although biogenic VOC emissions were known to be large, early regional modeling found that removing them made little difference to O₃ levels. Only in later regional runs did analysts discover that removing anthropogenic VOC produced a similar result. The insights provided by field and modeling research studies^{186–188} and EPA regional simulations suggested that reducing regional O₃ in the East required major reductions of NO_x emissions from anthropogenic sources, and that NO_x controls could be beneficial in urban areas as well.¹⁸⁹ An NRC report¹⁸⁹ helped advance both science and policy in this area, eventually facilitating legislation, multistate regional coordination such as the Ozone Transport Assessment Group, and the Ozone Transport Commission, and funding for public-private research partnerships including NARSTO and the Southern Oxidants Study.

The O₃ problems were not solely related to regional transport or chemistry. Many areas in the country failed to meet the 1987 deadlines that had been extended by the 1977 CAA for attaining O₃, and in some cases CO, standards. Congress and industry commissioned studies to examine why more progress was not being made.^{190,191} These studies found a number of factors contributed,

from inadequate assumptions regarding “rule effectiveness” and poor enforcement, to the development of “cheater SIPs” that were encouraged by unreasonable deadlines. The combination of rising concerns about acid rain and failure to attain the O₃ standards coincided with the arrival of a new president, George W. Bush, who had pledged to address these issues. This created another one of those special “moments,” as in 1970, when a consensus emerged that something significant had to be done. The result was the CAA Amendments of 1990.¹⁹²

The development of these amendments is not covered in this review. Although these far-reaching changes represented a major development in U.S. AQM, they did not tinker directly with the NAAQS process. Figure 11 illustrates how each of the major amendments to the CAA in 1970, 1977, and 1990 increasingly tweaked each of the major steps in the evolving U.S. AQM system.

Part III: Riding the Waves (1993–2006)

As detailed in the chronology tables, the “third wave” of NAAQS development (second for Pb) actually began as early as 1983 for O₃ and as late as 1987 for CO. But whether standards were ready for decision-making or not, no formal rulemaking occurred after mid-1988 until 1992. This was actually a strategic choice by EPA management who, between 1989 and late 1990, were focusing on the 1990 CAA Amendments. Analysts in OAQPS and other air offices were also preoccupied by the amendment effort. The NAAQS represented a distraction both in terms of public communication and in-house effort. Apparently, other stakeholders were also distracted, for the period was unusually quiet with respect to litigation. That began to change in 1991–1993, when environmental groups filed a series of deadline suits to force completion of the O₃ and SO₂ reviews and to begin the next review of the PM standards. Given the 1977 5-yr review requirements, EPA had no defense. EPA's response to suits requiring completion of ongoing reviews was to issue decisions not to revise the particular standards.

Some of these lawsuits were motivated by the awareness of increasing scientific evidence that health effects of O₃ and PM occurred at levels below the standards.¹⁹³ The information on O₃ came from controlled human studies by EPA and others, as well as some epidemiology and panel studies. These suggested that prolonged exposures (6–7 hr) to O₃ produced effects at lower levels. Joel Schwartz published an increasing body of PM time-series epidemiological studies for U.S. cities using TSP and the new PM₁₀ data, with new long-term results from the Harvard Six-City and ACS studies.^{164,194,195} Although details of other reviews are summarized in the supplemental tables, the main NAAQS action in the 1990s was about O₃ and PM.

As the deadline for the lawsuits was approaching, the 1992 elections brought yet another transition at the top of EPA. EPA Administrator William Reilly signed the proposed decision not to revise the O₃ standard, and incoming Administrator Carol Browner issued the final. The deadline suit left little choice. A number of the newer studies had not been reviewed in the 1989 CD update. Browner agreed that it would be better to issue the final decision and then begin a forced march to revise the

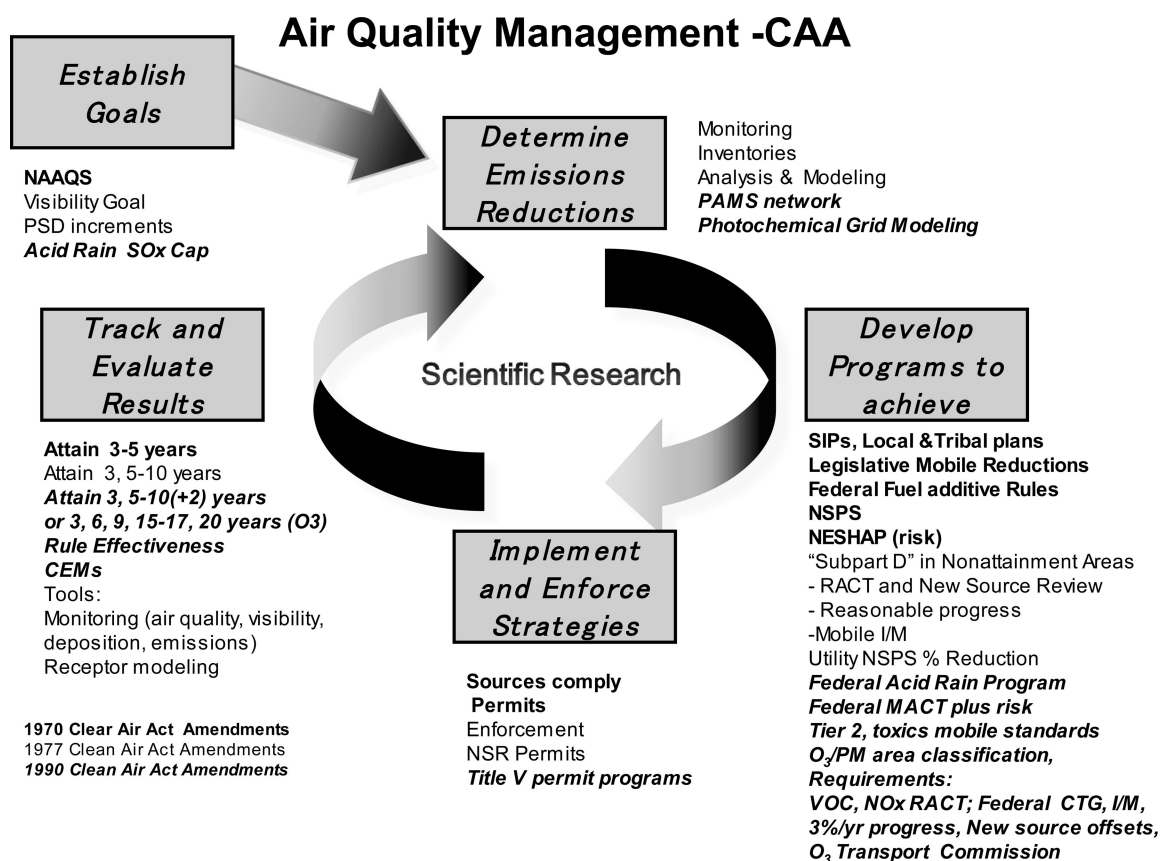


Figure 11. Evolution of the U.S. AQM hybrid approach. The 1970 amendments established NAAQS-driven AQM requirements but added national rules for new mobile and stationary sources. To address failure to attain, new scientific knowledge, and gaps in protection, major amendments in 1977 and 1990 added: (1) extended attainment deadlines; (2) increasingly prescriptive requirements for SIPs; (3) incremental revisions to address interstate transport; and (4) new national goals for clean air areas (1977) and acid deposition (1990), and provisions for implementation by the states (PSD, visibility) or the EPA (acid rain trading program) and more.

criteria and review the NAAQS on that basis. She also made a review of the criteria and standards for PM a high priority.

As shown in Supplemental Tables 1 and 4, the completion of these reviews eventually took on a different character from those of the past. Initially, criteria and SPs took 2 yr to reach a point for staff to brief management. Unlike the second-term Ruckelshaus and Lee Thomas, Administrator Browner relied more heavily on the Air Assistant Administrator Mary Nichols to wade through the details of the scientific assessments. She was briefed on the key issues, findings and staff recommendations, and agreed with her assistants and staff that both standards needed to be revised.

From that point on, Browner focused on strategic considerations regarding how such revisions might successfully be negotiated over executive and legislative opposition. This desire and the technical linkages between O₃ and PM resulted in a decision to arrange the review schedules so as to link the formal regulatory proposal and promulgation actions together for the two pollutants. Public communications and dealing with Congressional committee staff became a high priority for EPA management. As a result of these concerted efforts, press coverage and public participation in the process were unprecedented.¹⁹⁶ The three simultaneous 2-day public hearings were packed and EPA received some 70,000 public comments,

a large majority of which favored tighter standards. The extent of this strong sentiment partially blunted strong opposition to the standards, in the manner that Earth Day encouraged the 1970 CAA Amendments.

The Greenbaum et al.¹⁵⁸ review of the process noted the difference in interest group involvement pre- and post-proposal. In the pre-proposal period, such groups tried to influence the scientific basis for EPA's decisions. These efforts include providing comments to EPA and CASAC on draft CDs and SPs, as well as participating in CASAC meetings. Industry presented analyses finding weaker statistical strength or negative associations between PM and adverse health effects.^{197,198} NRDC's report¹⁹⁹ finding 40,000 deaths/yr from PM was released just before the CASAC meeting on the standards. During the post-proposal period, the emphasis shifted to providing Congress, local elected officials, the media, and the public with "spin" on the science.^{200,201} The emphasis on discussion of peer-reviewed science was often replaced by discussion of commissioned analyses with results distilled to the "sound bite."

Nuance and uncertainty were also lacking in EPA's public communications after proposal. The agency's sound bite was that the science demanded the revisions. Although it was true that EPA's assessment of the science found a need to tighten the standards, the *particular* standards proposed were obviously not wholly determined by science. The SP

and *Federal Register* notices aired the key issues and uncertainties in the data, the wide disagreement among CASAC members on the levels, particularly for $PM_{2.5}$, and the results of quantitative risk assessments for both pollutants. The final rule summarized and provided EPA's responses to all major comments and criticisms. The notion that the specific decisions were a policy choice based on consideration of the science and risks was clearly expressed. The agency also released an RIA that showed an estimated range of benefits associated with partial attainment of the $PM_{2.5}$ standards expected by 2010 exceeded projected costs by a factor of 2–10 and that the costs and benefits for O_3 were comparable with each other.²⁰²

The O_3 and PM decisions presented an interesting contrast in terms of the strength and nature of the underlying evidence as well as the severity of the effects. These were the first NAAQS revisions in which quantitative risk assessments played a major role. Although the PM assessment was judged too uncertain to be used to select particular levels, it supported the need to revise the standard and in deciding to make the annual standard the more stringent (controlling) standard relative to the daily. For PM, the epidemiological evidence for effects at particular levels was uncertain, but the reported effects were serious, with a large number of individuals at risk. The O_3 risk assessment was based largely on lung function and symptoms from controlled human studies, and applied to assess alternative standards in multiple cities, with a smaller analysis based on hospital admission studies. CASAC found this assessment useful in making its own recommendations on the O_3 standards.²⁰³ Here, the effects were much more certain than for PM, but much less severe. The ranges of risk estimated in different cities for alternative standards partially overlapped, which misled some into thinking the risk assessment had showed no differences among them. The differences were often small, but significant in terms of total numbers.

Congress held several hearings on the NAAQS, and Browner was steadfast in her support of both standards against some harsh questioning. In May, she had a 1-hr meeting with President Clinton; she reported that the president quickly accepted her decision and spent much of the time discussing how to reduce unnecessary burdens in the implementation process. This resulted in some of us writing the first draft of a letter that was later sent by Clinton to EPA directing implementation be carried out so as to "maximize common sense, flexibility, and cost effectiveness."²⁰⁴ The letter called for the agency to complete the next review of the standards in the statutory time frames (i.e., by July 2002) and noted that the need to establish a monitoring network and collect 3 yr of data would result in the next PM review being completed before the new $PM_{2.5}$ standards could be implemented.

The final decisions announced by Clinton in June 1997²⁰⁵ were generally similar to what was proposed, with the long-awaited addition of $PM_{2.5}$ standards, as well as more stringent standards for O_3 . Again, primary standards were set equal to secondary standards for both pollutants. Congress chose not to exercise its new authority under the 1996 Congressional Review Act to overturn the standards. In due course, petitions for review were filed by a

large number of parties, addressing a broad range of issues. The outcome would hinge not on the voluminous briefs petitioners filed challenging EPA's interpretation of the science, but would instead focus on the more general issue so many academic reviews had raised over the years. That is, given a wide range of scientific opinion and no clear thresholds, what criteria do EPA use for making the ultimate normative choice on the standards.

In May 1999, a three-judge panel of the D.C. Circuit Court issued an initial ruling holding that "the growing empirical evidence demonstrating a relationship between fine particle pollution and adverse health effects amply justifies establishment of new fine particle standards." (*American Trucking Associations vs. EPA*, D.C. Circuit Court, 1999). The panel also found "ample support" for EPA's decision to regulate coarse particle pollution, but vacated the 1997 PM_{10} standards, concluding in part that PM_{10} is a "poorly matched indicator for coarse particulate pollution" because it includes fine particles. EPA removed the vacated 1997 PM_{10} standards. The pre-existing 1987 PM_{10} standards remained in place.

The three-judge panel, however, also held (two to one) that EPA's approach to establishing the level of the PM and O_3 standards promulgated in 1997 effected "an unconstitutional delegation of legislative authority." Although the panel stated that "the factors EPA uses in determining the degree of public health concern associated with different levels of ozone and PM are reasonable," it remanded the rule to EPA, stating that when the agency considers these factors for potential nonthreshold pollutants "what EPA lacks is any determinate criterion for drawing lines" to determine where the standards should be set. It also required EPA to consider the possible "beneficent" effects of ground level O_3 in terms of protecting against UV_b from the sun. The panel again found that the administrator is not permitted to consider the cost of implementing those standards in setting them.

Both sides filed cross appeals on these issues to the U.S. Supreme Court. In February 2001, the Supreme Court issued a unanimous decision upholding EPA's position on both the constitutional and cost issues (*Whitman vs. American Trucking Associations*, 531 U.S. 457, 464, 475–476). On the constitutional issue, the court held that the statutory requirement that NAAQS be "requisite" to protect public health with an adequate margin of safety sufficiently guided EPA's discretion, affirming EPA's approach of setting standards that are neither more nor less stringent than necessary. The Supreme Court remanded the case to the D.C. Circuit Court of Appeals for resolution of any remaining issues that had not been addressed in that court's earlier rulings (*Id.* at 475–476). In March 2002, the Court of Appeals rejected all remaining challenges to the standards, holding that EPA's $PM_{2.5}$ standards were reasonably supported by the administrative record and were not "arbitrary and capricious" (*American Trucking Associations vs. EPA*, 283 F.3d 355, 369–372, D.C. Circuit Court). EPA subsequently concluded that small but unquantifiable benefit of smog- O_3 , if any, could not offset the larger known harms and left the standards as originally promulgated.²⁰⁶

Some advocates for alternative approaches^{173,207} criticized the Supreme Court's ruling. Schoenbrod²⁰⁷ suggests

the court rejected his “non-delegation” argument for “political problems” it might create for the court, and not based on a sound reading of constitutional law. Ironically, this highlights a problem for Schoenbrod,²⁰⁷ Melnick,¹³ and others who criticize EPA’s NAAQS decisions as being based on factors not openly discussed. No matter how detailed the written record supporting a policy or judgment, it is always possible to suspect other motivations. We might, for example, speculate that the court realized that if it had accepted Schoenbrod’s position,²⁰⁷ the result would have delayed the standards by years at the possible cost of tens of thousands of additional premature deaths. Was it politics or precaution?

In terms of air quality, the most important effect of these standards was the establishment of major multistate control programs in 1998 and 2005, the “NO_x SIP call” and the Clean Air Interstate Rule (CAIR).²⁰⁸ Each of these programs is based on adapting the highly cost-effective acid rain-style cap-and-trade programs to implementing the ambient standards.²⁰⁹ Such programs are a good match for reducing the regional component of O₃ and fine particles. Preliminary air quality data suggests that that the NO_x SIP call produced the kinds of O₃ reductions expected in the first 2 yr of the program.^{210,211} In the next decade, the CAIR rule will result in further significant reductions in fine particles, easing the implementation burden in areas throughout the eastern U.S., with estimated costs of \$2.6 billion to \$3.1 billion and benefits of \$86 billion to \$100 billion/yr by 2015.²¹² The new O₃ and PM_{2.5} NAAQS also helped to secure support for tighter emissions standards and lower fuel sulfur regulations promulgated after 1999 for several categories of on- and non-road gasoline and diesel powered mobile sources.⁴

Both standards have also had the expected effect of increasing monitoring for PM_{2.5} and components, and research on the most crucial issues identified in the review.^{213–215} As Schoor²¹⁶ noted recently, subsequent research on exposure, controlled human studies and new and reanalyzed epidemiology for PM support Browner’s decision to establish the new standards in the face of uncertainties. Reanalysis of the key long-term health effects studies¹⁶⁴ disproved the notion that they were “junk science” based on problematic “hidden data.” As summarized in Supplemental Table 1, the most recent PM review²¹⁷ resulted in a tightening of the 24-hr PM_{2.5} standard, something Carol Browner said would “not happen in our lifetime.” One guide to the reduction in uncertainty for fine particle health effects over the years is the change in the range of levels CASAC recommended for the 24-hr standards. In 1986, the range of recommended 24-hr standards for PM₁₀ was 140–250 µg/m³.²¹⁸ In 1996, the range among various panelists for 24-hr PM_{2.5} went from 20 to over 65 µg/m³.²⁰³ But in 2006, the nearly unanimous consensus of the panel ranged between 30 and 35 µg/m³ for 24-hr PM_{2.5}.²¹⁹ Furthermore, in this review the panel believed the EPA staff risk assessment could be used in deciding the levels of the standards. Administrator Stephen Johnson chose not to accept this advice, and based his decision on an assessment of the strength of the underlying studies.

Obviously, important issues and uncertainties remain, notably related to particle composition, the role of

the gas and particle mixtures, and for that matter, what the D.C. Circuit will have to say in response to promised litigation. Another set of issues for particle pollution is developing improved information on the concentration, composition, and health effects relationships for coarse particles. The most recent review of this issue was contentious because of the limited nature of the effects information, particularly with respect to coarse particles found in more rural communities.

The current O₃ review is far along enough to conclude that the 1997 NAAQS are unlikely to be relaxed. Both EPA staff and CASAC have concluded that the increased evidence from controlled human studies and epidemiology studies suggest the need for more stringent O₃ standards.²²⁰ It will be interesting to see whether and how the quantitative risk assessment is used in the decisions on the standard, and also what judgments are made as to the nature of the effects associated with O₃.

THE END OF HISTORY?

The Last SPs—A New Process

In late 2005 as the NAAQS team was preparing the PM *Federal Register* proposal notice for signature, they got an early Christmas present when EPA Deputy Administrator Marcus Peacock⁵ requested a hard look at the process for reviewing the criteria and standards, and for recommendations to improve the strength and increase the speed of the process. Staff held discussions with stakeholders, including CASAC, and reviewed the results and recommendations of past efforts to improve the process. The final agency workgroup report⁵ released in 2006 contains a number of recommendations to modernize and improve the efficiency of the process. Scientific assessment would become more continuous and make better use of current information technology. The “compendium” of all studies would be kept separate from a trimmed down “Integrated Science Assessment,”⁵ which would combine features of recent CDs with the integrated effects portions of the SP. The SP would be replaced with a “Policy Assessment Document” that retained the portions of the SP that translated the integrated science and the results of separate staff analysis of risk and exposure into a range of policy alternatives.

As a participant in the workgroup, I believe that, if well staffed and implemented, these suggestions would result in more relevant and timely products. The deputy administrator largely accepted these recommendations, and also decided that future policy assessment materials would reflect the input of EPA management, and not only staff views. He also decided that the policy alternatives would be released in the form of a final “Advanced Notice of Proposed Rulemaking” that would be published in the *Federal Register* and not as a separate policy document reviewed in advance by CASAC. I am much less enamored of this last decision, both because it reduces the ability of CASAC to provide early insights on the presentation, and because the nature of *Federal Register* notices might not permit the kind of technical depth, illustration, and rigor that can be attained in a separate document that did not have the additional costs per page of a notice. In any event, the new process is already being put into place as appropriate in the ongoing and planned NAAQS reviews

for Pb, NO₂, SO₂, CO, and PM. The O₃ and Pb SPs are likely the last of their kind.

New Challenges—Back to the Future

The remarkable progress made over the last 40 yr of AQM in the United States has led some to suggest that it is time to stop worrying about air pollution and move on to other matters.¹⁰⁶ Certainly, conventional air pollution is not the national priority today that it was at the time of the passage of the 1970 CAA Amendments. Few areas do not meet the SO₂, NO₂, CO, and Pb NAAQS. Yet, we still have a significant number of areas that do not meet the O₃ and PM_{2.5} standards, we are decades from approaching the national visibility goal, and acid and nutrient deposition is still a concern for some ecosystems.⁴ We are well on the way to significant new improvements in all of these areas, but the end is not fully in sight. Moreover, whereas risks from air pollution are, on average, modest, it is still reasonable to expect that the cumulative effect may number in tens of thousands of early deaths nationwide. The “end of air pollution history” advocates find it necessary to dismiss the recent literature on the health effects of PM and O₃ as “junk science”, but mainstream experts believe the risks remain significant.^{219–221}

The NRC committee on AQM⁴ views air pollution as a continuing problem. Their 2004 Report⁴ lists several major challenges that air quality managers will need to contend with in the upcoming decades together with recommendations and actions to reshape the AQM process so that it is better able to meet these challenges. The following briefly discusses some key challenges, highlighting issues most related to NAAQS review and implementation.

Meeting NAAQS for O₃ and PM_{2.5} and Reducing Regional Haze. As noted above, EPA and the states are already implementing the kind of multipollutant, multistate control strategies recommended by the NRC to address these goals through the “NO_x SIP call” and the CAIR “cap-and-trade” programs. But more will be needed, particularly in California and other western areas that are not part of these programs. Post-CAIR nonattainment forecasts for O₃ and the 2006 PM_{2.5} NAAQS^{208,222} suggest post-CAIR attainment strategies will need to focus on subregional and urban scale sources. A focus on urban sources of primary PM is also consistent with a robust strategy to reduce all of the major components of PM_{2.5}. The 2002 review addresses other visibility strategy issues.^{176,223}

Controlling HAPs and Ensuring Environmental Justice. As illustrated in this history, NAAQS and hazardous air pollutant programs have had little overlap. We noted how decision makers relied on NAAQS implementation in reducing some toxic pollutants. The NRC is calling for a more coordinated and integrated multipollutant programs. Although reductions in urban air pollution have benefited the substantial poor and minority populations living there,^{224,225} some issues remain. Part II of the previous section discussed how the NAAQS and early implementation of the risk-based version of Section 112 resulted in a gap in protection for people who reside very

near localized point sources of pollution. A similar challenge may be presented by emerging information from a number of epidemiology and roadside measurements that are suggesting that people who live near heavily traveled highways are subject to an unusually high risk of increased mortality and illness.²²⁶ If this proves to be the case, it could have implications for urban planning, traffic control, and air quality network design, as well as for identifying approaches to address the source emissions responsible.

Protecting against Non-Threshold Pollutants. This restatement of a now 30-yr-old NRC observation¹³⁸ reflects a continuing challenge that EPA confronted in the 1978 O₃ review. But in the early years of the NAAQS, the information on air pollution effects at lower levels was almost nonexistent, in part because air pollution levels were high. The idea of margin of safety as a concentration below the “lowest demonstrated effects level” (not a threshold) made science/policy sense. By the first O₃ review, EPA staff had restated the concept in terms of “acceptable risk” and worked to improve both quantitative risk assessment and presentation of qualitative information in the SP to provide a sense of the risk in terms of its severity and its potential societal impact, as indicated by the size of the sensitive populations exposed at alternative levels.

As we have seen, continued research on the health effects of air pollution over the last 50 yr appears to be finding effects at ever lower concentrations. Many of these effects remain adverse, and some are serious, even at lower levels. As the uncertainties are reduced and the tools for quantitative risk assessments are improved, the concept of interpreting the margin of safety in terms of acceptable risk will force decision makers to face harder choices. For policy makers, there is a substantial difference in the following two hypothetical risk statements: 1) “mortality effects may extent to lower levels than those measured in this study” and 2) “based on subjective probability encoding of expert judgment and the underlying epidemiology, there is a 95% probability that between 1000 and 5000 additional deaths will occur nationwide at that level.”

It is not clear that we have reached that point yet, as evidenced by extensive science and risk-based arguments submitted by a number of groups who opposed tightening the PM NAAQS.^{227–230} Still, the NRC is right to suggest that may be where things are heading, and this issue will continue to be raised in the context of the NAAQS. Two D.C. Circuit Court judges have already suggested the adoption of generic principles for acceptable risk decisions in NAAQS. An example is the one-in-a-million incidence rate sometimes used in making decisions on carcinogens. Yet we know far more about each of the highly studied criteria pollutants than we do about most toxic air pollutants. Given the widely divergent nature of the effects and populations exposed among these six pollutants (Supplemental Tables 1–7), this is a daunting task. How does one develop a “common risk metric” to compare time to angina attack with reduced IQ in children or a 15% reduction in lung function (e.g., FEV) in an asthmatic? Some suggest placing an economic value on such

effects as a metric, perhaps in terms of "quality of life years (QALYs)."173 But others17,231 find methodological and ethical issues with use of such an approach as an environmental policy decision rule. The QALY approach, which discounts the values assigned to the lives of asthmatics or the elderly, would represent a departure from the CAA focus on protecting sensitive populations.

Since 1970, Congress and the courts consistently have concluded that an explicit consideration of costs and benefits in setting the NAAQS is not permitted. Costs and feasibility have, however, repeatedly been central to decisions about the extent and timing of the implementation of the standards. This has occurred in state and local actions, in EPA policy decisions, and in Congressional actions to extend deadlines and alter requirements for attainment in the 1977 and 1990 CAA Amendments. Experience shows that setting unrealistic attainment deadlines leads to problems in implementation from failure to respond to the development and approval of paper programs that cannot be implemented or that contained rigged attainment demonstrations.191

Those who argue that the system would be more efficient if NAAQS decisions reflected a balance of costs and benefits173 typically fail to recognize this would not necessarily be the case, even in theory. For example, in balancing the national costs and benefits of tightening the O₃ NAAQS, the costs might well be driven by a limited number of locations such as Southern California and the Northeast Corridor, whereas other areas of the country might meet the NAAQS at lower costs. The result would be a national standard that is less stringent because of high costs in a limited number of areas, which means less than "optimal protection" in much of the country. The current system can be theoretically more efficient by allowing more localized consideration of costs and feasibility and adjusting attainment deadlines that vary with the severity of the problem. It also provides an incentive to continue making progress even in areas that do not attain. This has indeed been the experience in Southern California.

As for the NAAQS themselves, various observers have suggested that because they are not set at zero, as would appear necessary if there is no threshold, costs must have been taken into account, with the "real" rationale left unexplained. But as we have seen in the 1979 O₃ preamble and the 2001 Supreme Court decision, EPA administrators are clearly aware that NAAQS decisions have significant societal consequences and a balance is struck between establishing a standard that the administrator judges results in an acceptable risk. Congress was aware in 1977 and 1990 that NAAQS do not provide an absolute level of safety, and continued to place the decision in the hands of a politically responsible decision-maker, not a panel of scientists. This does not mean that the decision is unfettered. The scientific review and policy assessments place limits on the range of supportable alternatives. The judicial review, although typically giving great deference to the administrator's decisions, is a check against wholly unreasonable decisions that are clearly not supported by the science. Meanwhile, both Congress and the public are apprised of the scientific uncertainties, risks, as well as costs and benefits of alternative decisions through the publication of the risk and policy assessments and RIAs

that accompany the NAAQS decisions. This oversight also serves as a long-term check on the system.

In practice, NAAQS decisions and resulting implementation have not resulted in the kinds of problems feared by some.13,92 Between 1970 and 1990, the estimated benefits of the evolving system actually increased at a faster rate than costs.232 If future developments suggest changes are necessary or desirable, then the initial focus should be on expanded authority or specific legislative rules for cost-effective multipollutant emissions reductions from existing sources. The acid rain cap, for example, has proven to be less litigious, faster to implement, and easier to enforce than ambient standards. A problem with such legislative rules is that it may take an act of Congress to change them. An alternative that recognizes the more recent science is national, regional, or local declining emissions caps, or rate of progress requirements that are dependent on more systematic accountability measures than are possible with limited ambient monitoring. The acid rain cap experience shows the critical importance of continuous emissions monitoring to such programs. Ambient standards or targets still play a vital role by providing a metric against which to judge progress, to compare areas, and to stimulate additional research into the nature of the benefits and costs of air programs.

Climate Change and Intercontinental Transport. These are long-term issues with multiple dimensions. An obvious AQM concern is that air strategies may need to be adjusted to compensate for changes in temperature and weather patterns that accompany climate "forcings."233 But an equally important dimension is how to integrate traditional air quality programs with the programs and strategies that are likely to be aimed at limiting climate change in the future. Some state air programs are already facing the issue. The prospects for near-term legislation234 are enhanced by the recent Supreme Court ruling that the CAA provides EPA authority to regulate CO₂ (*Massachusetts et al. vs. Environmental Protection Agency et al.*, D.C. Circuit Court, 2007). A related issue is the international transport of conventional air pollution,235 which can affect progress in attaining NAAQS and visibility goals,97,176 and PM and O₃ also affects climate236,237 by radiative forcing (e.g., warming and cooling by various particles), and nucleation effects on the location and amount of precipitation.238 Consideration of climate effects suggests strategies to address background O₃ should reduce methane, not NO_x.

The remaining NRC challenge, *protecting ecosystems*, is discussed in part II of the previous section.

The CAA Advisory Committee (CAAAC) Recommendations. In 2004, EPA asked the multi-stakeholder CAAAC to begin working on the NRC recommendations to improve the AQM process. In early 2005, a CAAAC AQM subcommittee issued a Phase I report containing 47 interim recommendations related to accountability, streamlining approvals and other aspects of the system.6 Phase II is

nearing completion.⁷ CAAAC is actively considering approaches that would replace the current NAAQS pollutant-specific SIP process with comprehensive AQM planning. This process would create comprehensive AQM plans that result in an integrated, multiple pollutant approach to managing air quality that would encompass both criteria and HAPs. Based on the Phase I recommendations, the approach would put less emphasis on upfront modeling demonstrations in SIP development, and more on accountability measures that would trigger additional measures if the plan proved to be inadequate. Making this approach work would require a number of accommodations at all levels of government, but it appears to be worth the effort.

CONCLUSIONS

This review is timed to coincide with the celebration of the 100th anniversary of A&WMA. It has examined over 100 yr of air pollution history in an effort to illuminate how we arrived at the present hybridized U.S. AQM system. We have seen that the lack of progress in addressing oppressive levels of coal smoke and gases between 1900 and 1940 appears largely because of a common view that the air pollution "nuisance" was inextricably linked to economic progress. With few exceptions, notably the Mellon Foundation, there was little scientific curiosity about the effects, amounts, and nature of air pollution and no comprehensive urban programs to reduce it until the 1940s. The emergence of Los Angeles smog and the Donora and London episodes did much to kindle a national recognition of the problems, which in turn stimulated funding for research and monitoring needed to understand and address them.

Although at least one visionary grasped the potential value of pollutant-specific ambient air quality limits in the 1930s, the first attempts to develop them in the United States came from officials in Los Angeles and California in 1955 and 1959. The first federal legislation mandating an AQM program driven by regional ambient standards was the 1967 CAA. An alternative approach, uniform technology standards on stationary as well as mobile sources, was set aside. Societal and political forces in the 1968–1970 prompted the more far reaching and challenging 1970 CAA, which established the basic framework still in use.

From 1971 onward, experience in implementing the CAA provisions, advances in scientific and technical information, and changes in economic, energy, and societal conditions have resulted in changes in the practice of all aspects of AQM, as well as legislative changes, many of which have resulted in improving the efficiency and effectiveness of the system. Making improvements based on continuous monitoring and assessment of what works and what doesn't is the principal advantage of the AQM system, as summarized in Figure 2. As a result, by almost any measure, U.S. air quality today is dramatically improved over 1970, with cumulative benefits estimated in trillions of dollars.

Yet not every program worked as well as intended, and delays and administrative burdens have plagued the approach as well. The administrative burdens had economic and efficiency consequences for affected parties,

and hurt the overall credibility of the program. Some delays in standard setting and implementation prolonged effects on public health and the environment that might well be measured in hundreds of billions of dollars in benefits foregone.

NAAQS-driven AQM was initially most successful in reducing primary particles and gases from stationary sources in urban and industrial areas. The federal and California automotive standards began making significant reductions after introduction of the catalytic converter in 1975. As understanding of effects and atmospheric sciences improved through the 1980s and 1990s, AQM programs in California and portions of the East were better able to address O₃, and later PM_{2.5}. Between 1975 and 1990, however, other developed countries did far more than the United States to reduce total loadings of SO_x. The 1990 CAA represented a breakthrough with the highly effective market-based program for power sector SO_x emissions, and technology based standards for HAPs. Even though market-based SO_x programs had been advanced by the Nixon administration as early as 1971,²³⁹ it is not clear they could have functioned well without adequate emissions monitoring systems.²³² During this period, the NAAQS and periodic reviews provided important benchmarks that stimulated important new research, required development of improved state and local control programs, and drove increasingly stringent national legislative and regulatory limits for mobile sources. After some unfortunate delays, the PM_{2.5} and O₃ NAAQS have resulted in recent major new cap-and-trade programs that will continue to reduce multiple stationary source pollutants.

As noted in the previous sections, we are not quite finished, and a number of challenges remain to be addressed. The CAAAC recommendations reflects a growing understanding that AQM must do a better job of integrating with other priorities facing state and local governments, such as smart growth and related national issues such as energy policy and climate programs. We appear to be at one of those critical times when a science-policy-political consensus may emerge with respect to legislation on climate, and this may well be accompanied by a re-opening of the CAA. We need to be ready. The NRC and CAAAC recommendations are a good place to start. The recursive approach to AQM is a sound idea. Happy birthday A&WMA, and as the song says, if we keep working at this circle, "there's a better home a waitin' in the sky."²⁴⁰

ACKNOWLEDGMENTS

Thanks to the A&WMA's Critical Review Committee for the opportunity to address this broad topic as I completed my EPA career. I particularly recognize Drs. Judith Chow and John Watson at Desert Research Institute (DRI) for their guidance and thoughtful comments on the drafts, as well as the support of DRI's Jo Gerrard, who formatted the manuscript, including figures, tables, and references, and Mary MacLaren, who recorded the references. Eric Dietlerle and his editing group in the Engineering Communications and Marketing Department at Iowa State University provided editing support as well. Members of the Committee and Susan Wierman (Mid-Atlantic Regional Air Management Association) provided helpful comments on an interim draft. Many former EPA colleagues

(some retired) provided references, figures, historical insights, or reviews of some sections. These include Harvey Richmond, John Hannon, Steven Silverman, Gerry Gleason, Neil Frank, Douglas Solomon, David Mintz, Dave Mckee, William Wilson, Joann Rice, Dale Evarts, Rob Brenner, Alan Basala, Les Grant, Michael Berry, John O'Connor, Bob Neligan, Darryl Tyler, Mike Jones, Joe Paisie, Tom Helms, Barry Gilbert, Joe Tikvart, Bill Cox, and John Silvasi. I also appreciated insights and assistance from Rudi Husar (Washington University in St. Louis), Arlene Fiore (National Oceanic and Atmospheric Administration), Peter Mueller (TropoChem), Dan Greenbaum (Health Effects Institute), James Reisa (NAS), and Mike Koerber (Lake Michigan Air Directors Consortium). The staff and collection at the EPA library in Research Triangle Park, NC, were invaluable in accessing historical documents on legislative history, early editions of the Stern compendium, and out-of-print PHS documents. Lisa Bucher and Andy Knopes of A&WMA provided timely assistance and guidance during production of the paper and the platform presentation.

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