



# **Air Pollution Control Technology Handbook**

**Second Edition**

**Karl B. Schnelle, Jr.  
Russell F. Dunn  
Mary Ellen Ternes**



**CRC Press**  
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## *Dedication*

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*The authors would like to dedicate this book to all the students who have been in their air pollution control courses at Vanderbilt University, Western Washington University, Gonzaga University, Auburn University, and Education Services of the American Institute of Chemical Engineers. We appreciate your attendance, your attentiveness, and your desire to improve our environment.*



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# Preface

This book has been written to serve as a reference handbook for the practicing engineer or scientist who needs to prepare the basic process engineering and cost estimation required for the design of an air pollution control system. The user of this book should have a fundamental understanding of the factors resulting in air pollution and a general knowledge of the techniques used for air pollution control. The topics presented in this handbook are covered in sufficient depth so the user can proceed with the basic equipment design using the methods and design equations presented. Although moving sources, especially those powered by internal combustion engines, are serious contributors to the air pollution problem, this book will focus on stationary sources. Furthermore, this handbook will not consider nuclear power plants or other radioactive emissions. Therefore, the major audience for this book will be engineers and scientists in the chemical- and petroleum-processing industry and steam power plant and gas turbine industry.

Using this book, the air pollution control systems designer may

- Begin to select techniques for control
- Review alternative design methods
- Review equipment proposals from vendors
- Initiate cost studies of control equipment

This book is certainly suitable for anyone with an engineering or science background who needs a basic introduction to air pollution control equipment design. It can also be used as a textbook or reference in a continuing education program or a university classroom.

**Karl B. Schnelle, Jr.**  
and  
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# 1 Historical Overview of the Development of Clean Air Regulations

## 1.1 A BRIEF HISTORY OF THE AIR POLLUTION PROBLEM

Media reports about air pollution might lead us to think of air pollution as being something that developed in the second half of the twentieth century. But this is not so. The kind of air pollution to which human beings have been exposed has changed with time, as well as what we recognize as *air pollution*, but air pollution has been known in larger cities at least from the twentieth century, when people first started using coal for heating their homes.<sup>1</sup>

In England, during the reign of Edward I, there was a recorded protest by the nobility about the use of *sea* coal, which burned in an unusually smoky manner. Under his successor, Edward II (1307–1327), a man was put to torture for filling the air with a “pestilential odor” through the use of coal. Under the reign of Richard III and Henry V, England undertook to restrict the use of coal through taxation. Nevertheless, the situation continued to grow worse in the larger cities, so much so that during the reign of Elizabeth I (1533–1603; Queen, 1558–1603) Parliament passed a law forbidding the use of coal in the city of London while Parliament was in session. While this may have eased the pollution for the parliamentarians, it did very little to actually solve the problem.

As cities grew and the Industrial Revolution developed, the spread of coal smoke grew. In 1686, a paper was presented to the Royal Philosophical Society: “An Engine That Consumes Smoke.” To this day, we have been working on this same problem, as yet to no avail. Legislation that was introduced often ignored the technical aspects of the problem, and hence was unenforceable. For example, a law passed by Parliament in 1845 stated that locomotives must consume their own smoke, which would be grand but, of course, it is not realizable.

The air pollution problem in the United States was first recognized as being due to coal smoke. In 1881, Chicago adopted a smoke control ordinance. St. Louis, Cincinnati, and other cities also adopted smoke ordinances in the years that followed. In these early years, it was established that the responsibility rested with the state and local governments.

Nashville, Tennessee, had a population of 80,865 in 1900, and it was a typical community of that period that depended on bituminous coal for heating. A short story written by O’Henry describes his visit to Nashville in 1900 as follows:

### A MUNICIPAL REPORT

Nashville—a city, port of delivery, and the capital of the state of Tennessee, is on the Cumberland River and on the N.C. & St. L. and the L&N Railroads. This city is regarded as the most important educational centre in the South. I stepped off the train at 8 P.M. Having searched thesaurus in vain for adjectives, I must, as a substitution, hie me to comparison in the form of a recipe:

Take [a] London fog, thirty parts; malaria, ten parts; gas leaks, twenty parts; dewdrops gathered in a brick-yard at sunrise, twenty-five parts; odor of honeysuckle, fifteen parts. Mix. The mixture will give you [an] approximate conception of a Nashville drizzle. It is not so fragrant as a moth ball, nor as thick as pea soup; but 'tis enough—'twill serve.

From 1930 to 1941, the focus of air pollution was on smoke control laws. Public protest groups from Chicago, St. Louis, Cincinnati, and Pittsburgh had some success. However, air pollution was not recognized as the health hazard we know it to be today.

In 1941, war broke out with the Axis powers of Germany and Japan and their allies, and from late 1941 until 1945, there was an all-out effort to defeat these countries. This effort allowed no time or materials for air pollution control. Smoke levels reached new highs as the national effort rallied to the war. Finally, with a return to peace, action on pollution control was initiated.

In the prewar era, Pittsburgh had enacted a stringent new control regulation. In October 1946, a regulation that centered on the type of coal used was put into effect. Then, in October of 1948, tragedy struck at Donora, Pennsylvania.<sup>2</sup> Weather conditions were perfect for a stagnating inversion. As the inversion deepened, people in Donora became ill, and 20 died from the effects of the excessive air pollution that was prevalent. The result was an awakening to the health hazards of air pollution. Other such incidents were recognized throughout the world and are indicated in Table 1.1 compiled from several sources.<sup>2-4</sup>

October 1948 marks the start of a more vigorous program of air pollution control in the United States. For example, on May 1, 1949, the Pittsburgh smoke ordinance was extended to the whole of Allegheny County. Air pollution abatement was soon to attract the public's eye and money, but it was not until the advent of the Clean Air Act of 1963 that there was a national awakening to the value of our air environment.

During World War II, a new type of air pollution had been discovered in the Los Angeles atmosphere. New effects were manifest in the form of eye and skin irritation and plant damage not evident from simple smoke pollution. It was the result of a photochemical smog that was at first attributed to the oil refineries and storage facilities. When controls of these facilities did not result in a significant reduction of the problem, it was then discovered that the internal combustion engine was a major cause of this new type of pollution. The result of photochemical oxidation is seen in the brown haze apparent in the upper layer of the atmosphere. The brown haze is a mixture of particulates, oxides of nitrogen, sulfuric acid mist condensed from the oxidation of sulfur dioxide, and particles produced from photochemical reaction in the atmosphere. The haze limits visibility, decreases the amount of sunlight reaching the earth, results in an increase in the amount of cloudy weather present, and, when it accumulates, results in all the unpleasant effects associated with air pollution.

Perhaps it was in response to these visual signs of air pollution that people could see occurring that the nation decided to act. Most certainly, it was at this point that

**TABLE 1.1**  
**Horrible Total—Man Breathes, Coughs, and Dies**

Location	Date	Deaths <sup>a</sup>	Reported Illness	Common Conditions
Meuse Valley, Belgium	12/1/30	63	6000	Low atmospheric dilution
Donora, Pennsylvania	10/26/48	18	5900 (43%)	Fog and gaseous materials
London	11/26/48	700–800		
Poza Rica, Mexico	11/21/50	22	>320	
London	12/5/52	3500–4000	Unknown	
New York	11/22/53	175–260	Unknown	
London	11/56	1000	Unknown	
London	12/2/57	700–800		
London	1/26/59	200–250		
London	12/5/62	700	Unknown	
London	1/7/63	700		
New York	1/9/63	200–400		
New York	11/23/66	170		

<sup>a</sup> Number of deaths above expected average death rate.

the federal government entered the picture with statutes and regulations governing conventional pollutants such as particulate and acid gases. More recently, the federal government began to regulate air pollution that people cannot see and with broader effects, specifically, ozone-depleting chemicals and greenhouse gases,<sup>5</sup> to protect stratospheric ozone and mitigate global climate change.

1.2 FEDERAL INVOLVEMENT IN AIR POLLUTION CONTROL

After World War II and the advent of the air pollution episodes in Donora and London, it became apparent that more concerted federal action was required. Congress first passed an air pollution law in 1955. At this time, Congress was particularly reluctant to interfere in states’ rights, and early laws were not strong. These laws more or less defined the role of the federal government in research and training in air pollution effects and control. The following brief summary leads to the 1970 amendments to the Clean Air Act, beginning with the following:

*The Air Pollution Control Act of 1955, Public Law 84–159, July 14, 1955*

- Left states principally in charge of prevention and control of air pollution at the source
- Recognized the danger to the population of the growing problem
- Provided for research and training in air pollution control

*Air Pollution Control Act Amendments of 1960, Public Law 86–493, June 6, 1960 and Amendments of 1962, Public Law 87–761, October 9, 1962*

- Directed the Surgeon General to conduct a thorough study of the effects of motor vehicle exhausts on human health

*The Clean Air Act of 1963, Public Law 88–206, December 1963*

- Encouraged state and local programs for the control and abatement of air pollution while reserving federal authority to intervene in interstate conflicts
- Required development of air quality criteria which would be used as guides in setting ambient and emission standards
- Provided research authority to develop methods for removal of sulfur from fuels

*Motor Vehicle Air Pollution Control Act of 1965, Public Law 89–272, October 20, 1965*

- Recognized the technical feasibility of setting automobile emission standards
- Determined that such standards must be national standards and relegated automotive emission control to the federal government
- Gave the state of California waivers to develop standards more appropriate to the local situation

*The Air Quality Act of 1967, Public Law 90–148, November 21, 1967*

- Designated air quality control regions (AQCRs) within the United States, either inter- or intrastate
- Required issuance of air quality criteria
- Required states to establish air quality standards consistent with air quality criteria in a fixed time schedule
- Gave states primary responsibility for action, but a very strong federal authority was provided
- Required development and issuance of information on recommended air pollution control technique

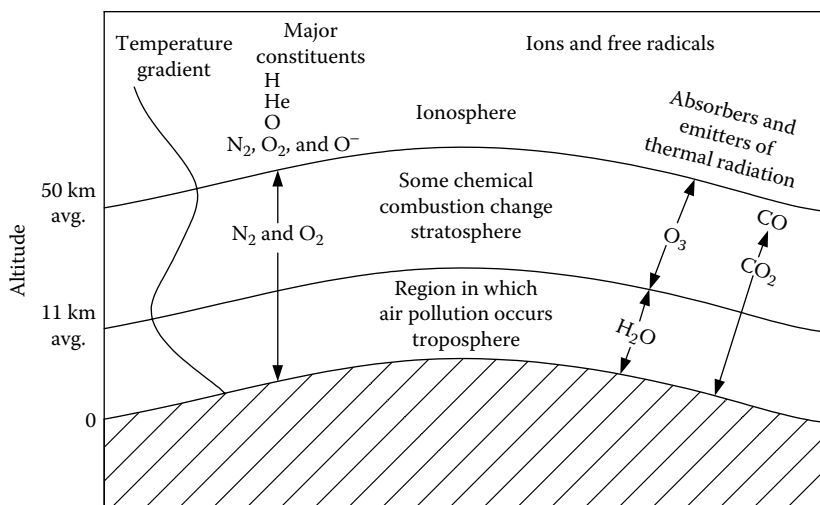
*The Clean Air Amendments Act of 1970, Public Law 91–604, December 31, 1970*

- Created the Environmental Protection Agency (EPA)
- Required states to prepare implementation plans on a given time schedule
- Set automotive emission standards
- Set the following basic control strategy to be employed, establishing
  - National Ambient Air Quality Standards (NAAQS)
  - Standards of performance for new stationary sources
  - National emission standards for hazardous pollutants

The Clean Air Act of 1970, subsequent amendments in 1990 and 1997, and judicial decisions followed by greenhouse gas regulations are discussed in more detail in Chapter 2.

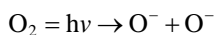
### 1.3 CHARACTERIZING THE ATMOSPHERE

The atmosphere seems boundless, but of course it isn't! If we consider the relative amount of all living matter of mass equivalent to 1.0 unit, then the atmosphere, that is, all gases as we know them, would be about 300 units, and the hydrosphere, all waters, oceans, lakes, rivers, streams, ponds, and so on, would be about 70,000 units. Figure 1.1 illustrates the layers of the atmosphere.

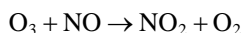
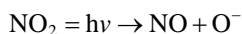


**FIGURE 1.1** Layers of the atmosphere.

- Ionosphere (above 50 km)—ions and activated molecules produced by ultraviolet radiation such as in the following reaction:



- Stratosphere (11–50 km)—the layer in which chemical composition changes takes place as illustrated by the following chain reaction:



Sinks above polar caps may be responsible for these actions. Temperature variation with altitude is small.

- Troposphere (0–11 km)—area of major concern in air pollution: Temperature decreases with altitude. Micrometeorological processes control the amount of pollution as it spreads and reaches ground level.

Table 1.2 records the chemical composition of air. Air normally contains water vapor, which would be somewhere around 1% by volume of the total mixture. The concentrations in Table 1.2 remain nearly constant or vary slowly. The following are variable in their concentration:

1. Water > variable 1.0% by volume
2. Meteoric dust



**TABLE 1.2**  
**Chemical Composition of Normal Air**

Substance	Percent by Volume in Dry Air
N <sub>2</sub>	78.09
O <sub>2</sub>	20.94
Ar	0.93
CO <sub>2</sub>	0.03
Ne	0.0018
He	0.00052
CH <sub>4</sub>	0.00022
Kr	0.00010
N <sub>2</sub> O	0.00010
H <sub>2</sub>	0.00005
Xe	0.00008

*Note:* 1 ppm by volume = 0.0001% by volume.

- 3. Sodium chloride
- 4. Soil
- 5. NO<sub>2</sub> formed by electric discharge
- 6. O<sub>3</sub> formed by electric discharge
- 7. Pollen
- 8. Bacteria
- 9. Spores
- 10. Condensation nuclei
- 11. SO<sub>2</sub> volcanic oxygen
- 12. HCl volcanic origin
- 13. HF of volcanic origin

When doing combustion calculations, it is usual to assume that dry air contains 21% by volume of O<sub>2</sub> and 79% by volume of N<sub>2</sub>. Table 1.3 compares concentrations of what could be considered pure air to concentrations in polluted air, including concentrations of CO<sub>2</sub> in 1750, before the industrial revolution, compared to 2010.

Table 1.4 is a historical record of concentrations of pollutants in cities in the United States in 1956, compiled by H. C. Wohlers and G. B. Bell at the Stanford Research Institute.

**1.4 RECIPE FOR AN AIR POLLUTION PROBLEM**

To have an air pollution incident, such as the one that occurred in Donora, or to have a problem, such as the one in Nashville, there are three factors that must occur simultaneously. There must be sources, a means of transport, and receptors.

**TABLE 1.3**  
**Comparison of Pure Air and a Polluted Atmosphere**

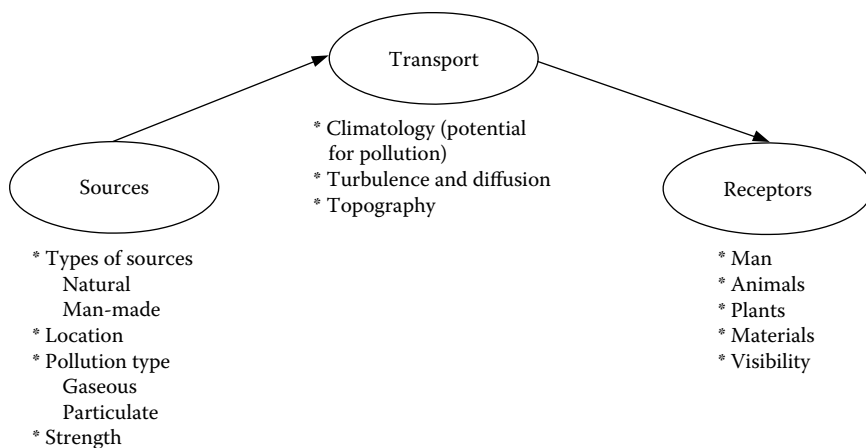
Component	Considered to Be Pure Air	Typical Polluted Atmosphere
Particulate matter	10–20 µg/m <sup>3</sup>	260–3200 µg/m <sup>3</sup>
Sulfur dioxide	0.001–0.01 ppm	0.02–3.2 ppm
Carbon dioxide	300–330 ppm	350–700 ppm
Carbon monoxide	1 ppm	2–300 ppm
Oxides of nitrogen	0.001–0.01 ppm	0.30–3.5 ppm
Total hydrocarbons	1 ppm	1–20 ppm
Total oxidant	0.01 ppm	0.01–1.0 ppm

**TABLE 1.4**  
**Ranges of Concentrations of Gaseous Pollutants—A Historical Record from 1956**

Pollutant	Range of Average Concentrations (ppm)	Range of Maximum Concentrations (ppm)	Number of Cities from Which Data Was Compiled
Aldehyde (as formaldehyde)	0.02–0.2	0.03–2.0	8
Ammonia	0.02–0.2	0.05–3.0	7
Carbon monoxide	2.0–10.0	3.0–300	8
Hydrogen fluoride	0.001–0.02	0.005–0.08	7
Hydrogen sulfide	0.002–0.1	Up to 1.0	4
Nitrogen oxides	0.02–0.9	0.03–3.5	8
Ozone	0.009–0.3	0.03–1.0	8
Sulfur dioxide	0.001–0.7	0.02–3.2	50

*Source:* Wohlers, H.C. and Bell, G.B., Stanford Research Institute Project No. SU-1816, 1956.

Figure 1.2 illustrates the process. Air pollution sources are relatively common knowledge. Their strength, type, and location are important factors. By transport, reference is made to the meteorological conditions, and the topography and climatology of a region, which are the important factors in dispersion—that is, in getting the material from the sources to the receptors. The receptors include human beings, other animals, materials, and plants. We also know that air pollution can affect visibility and can endanger our lives simply by making it difficult to travel on the highways and difficult for planes to land. The dollar cost of air pollution is the subject of much debate. However, it must be an astronomical figure, especially when you add such things as the extra dry cleaning and washing, houses that need more paintings than they should, and so on. The dollars lost to poor crops is a costly item in our economy, notwithstanding the impairment to shrubs, flowers, and trees.



**FIGURE 1.2** The trilogy: sources—transport—receptors.

### 1.4.1 SOURCES OF AIR POLLUTION

Sources of air pollution are either man-made or natural. Man-made sources are what we focus on because we may be able to effect some control on these sources. Both gaseous and particulate sources are troublesome. We have set standards for concentrations for both these materials in the atmosphere and in emission from chimneys for those sources we have recognized to be harmful. The concentration and the flow rate of the emissions are information required to determine the downwind transport of the pollutants. Knowing the location of the source relative to the receptor would allow us to calculate the concentration at a particular downwind receptor using a dispersion model. Chapter 2 details more about the pollutants that we are trying to control.

The EPA estimates the quantities of pollutants emitted each year. This information and many other facts are available at EPA's Air Trends website and other air pollution tracking websites available at: <http://www.epa.gov/ttnchief1/trends/>. Figure 1.3 records the annual production of air pollution by categories from Air Trends and the Inventory of U.S. Greenhouse Gas Emissions and Sinks.

### 1.4.2 METEOROLOGICAL PARAMETERS AFFECTING TRANSPORT OF POLLUTANTS

While ozone-depleting chemicals rise to the stratosphere, and greenhouse gases are recognized as being well-mixed in earth's atmosphere, the same is not true for conventional pollutants. The meteorological characteristics of the Los Angeles and Donora areas combine with the topographical features to form a container that traps conventional air pollution contaminants. The mountains in Los Angeles and the river valley in Donora form the walls of the containers that hamper horizontal air flow through these areas. A high-pressure area over the region forms the lid of such a container. A temperature inversion occurs, and the air becomes thermally stable, which has the effect of stopping vertical air flow, reinforcing the *lid* effect. In this way, the polluted air is not allowed to flow up and over the mountains or hills.

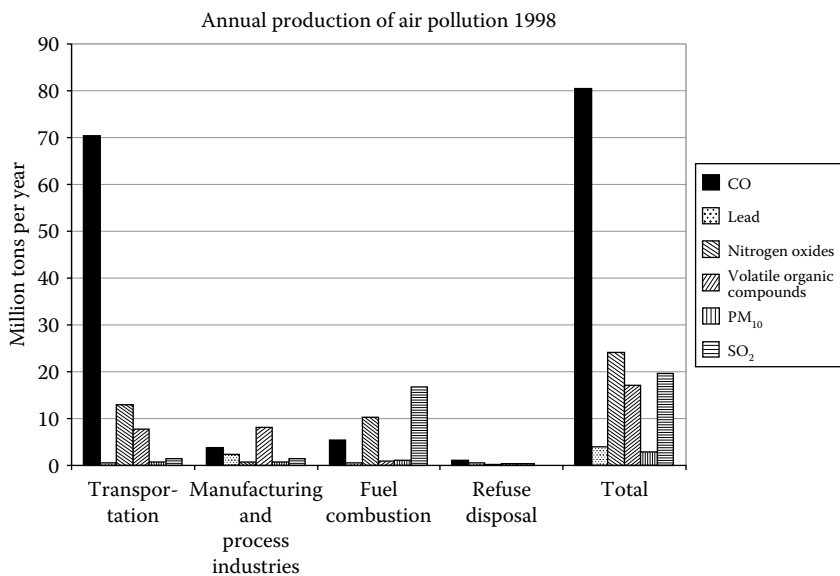


FIGURE 1.3 Annual production of pollutants by categories.

Meteorologists have long known that the amount of vertical motion of the atmosphere depends to an important extent on how the temperature varies with altitude. Near the ground, air temperature normally decreases with height. When the rate of decrease is rapid, there is a pronounced tendency toward vertical air mixing. On the other hand, when the air temperature increases with height, vertical air motions are suppressed. This temperature structure is called a *temperature inversion* because it is *inverted* from the normal condition of temperature decreasing with height.

Under adiabatic conditions, the temperature of dry air decreases at 5.45°F for each gain in altitude of 1000 ft. This temperature gradient is known as the *dry adiabatic lapse rate*. However, when the temperature of the air increases as the altitude increases; a condition known as *inversion* is present. An inversion may take place at the surface or in the upper air. A surface or a radiation inversion usually occurs on clear nights with low wind speed. In this situation, the ground cools the surface air by nature of its own cooling due to long wave radiation of heat to the outer atmosphere. The surface air becomes cooler than the upper layers, and vertical air flow is halted (hot air rises and cool air sinks). A parcel of warm air trying to rise finds the air above it hotter than itself. Thus, it will not rise because the temperature gradient is inverted. This type of inversion is common and is broken up as the sun once again heats the ground the next morning.

In Los Angeles, California, the typical inversion occurs in the upper air. There is an almost permanent high-pressure area centered over the north Pacific near the city. The axis of this high is inclined in such a way that air reaching the California coast is descending or subsiding. During the subsidence, the air is heated by compression, creating an inversion of the temperature gradient in the upper atmosphere over the city as the air moves from the sea over the land. This is termed as *subsidence inversion*.

Since the surface air in the Los Angeles area usually results from the sea breeze, the temperature difference between the upper layer and the surface is increased. The water is relatively cold and so the surface air that moves on over the land as the sea breeze is also cold. One might think that the daily cycle of sea and land breezes would break up the inversion, but this is not the case. The sea breezes only serve to raise and lower the altitude of the inversion layer. In the Los Angeles area, the effect of large air masses overrides the effect of the less powerful local heating from the surface.

In Donora, Pennsylvania, in the fall of 1948, as in London four years later, the weather was the wicked conspirator. A high-pressure area moved over western Pennsylvania on October 26, 1948, and remained fairly stationary for the next five days. Winds in the lowest 2000 ft of the atmosphere were quite weak. Mostly they were between a dead calm and 3 mph, but for brief periods they were slightly higher. The air was *thermally stable*, a formal description implying that there was very little vertical motion of the air.

Donora, lying near the bottom of a steep valley, is about 500 ft below the surrounding terrain. During the period October 26–31, 1948, an inversion capped the valley. Pilot reports and weather balloons showed that the cap, at least part of the time, was less than 1000 ft above the town. Thus, smoke fed to the atmosphere was largely confined within the valley walls and the inversion top. The air near the ground was very humid. Fog formed in the night, and in some low-lying areas of western Pennsylvania, it persisted during the day. At Donora, the visibility, cut by smoke and fog, ranged from about 0.6 to 1.5 miles. The overall weather conditions were similar to those that occurred in London, and the consequences tragically alike.

### 1.4.3 EFFECTS OF AIR POLLUTION—A COMPARISON OF LONDON SMOG AND LOS ANGELES SMOG

What makes a Los Angeles smog different from a London smog? A few conditions that apply to both cities are as follows. They are both similar in that they result in community air pollution, and the major source is the combustion of fuels. In London, it is coal and many hydrocarbons. In Los Angeles, it is primarily hydrocarbons. The peak time in London is early morning. In Los Angeles, the peak time is midday. In London, the temperature is 30°F–40°F; in Los Angeles, 75°F–90°F. The humidity is high with fog in London. Generally speaking, in Los Angeles, pollution occurs on a relatively clear day with low humidity. The inversions in London are at the surface; in Los Angeles, inversions are overhead. Visibility is severely reduced in London, but only partially reduced in Los Angeles. The effects in London are to produce bronchial irritation, whereas in Los Angeles, the effects are to produce eye and skin irritations. In Los Angeles, the smog is primarily produced through photochemical oxidation of the hydrocarbons by the ozone and nitrogen oxides that are in the atmosphere. The product of this photochemical reaction is an organic type molecule that causes plant damage and reduced visibility, and irritates skin and eyes very badly. The London type chokes us. We get a feeling of being in the midst of a big smoke, because that is primarily what it is—smoke and fumes mixed with moisture in the air. A summary of these conditions is given in Table 1.5. Both problems result

**TABLE 1.5**  
**Comparison of London Smog and Los Angeles Smog**

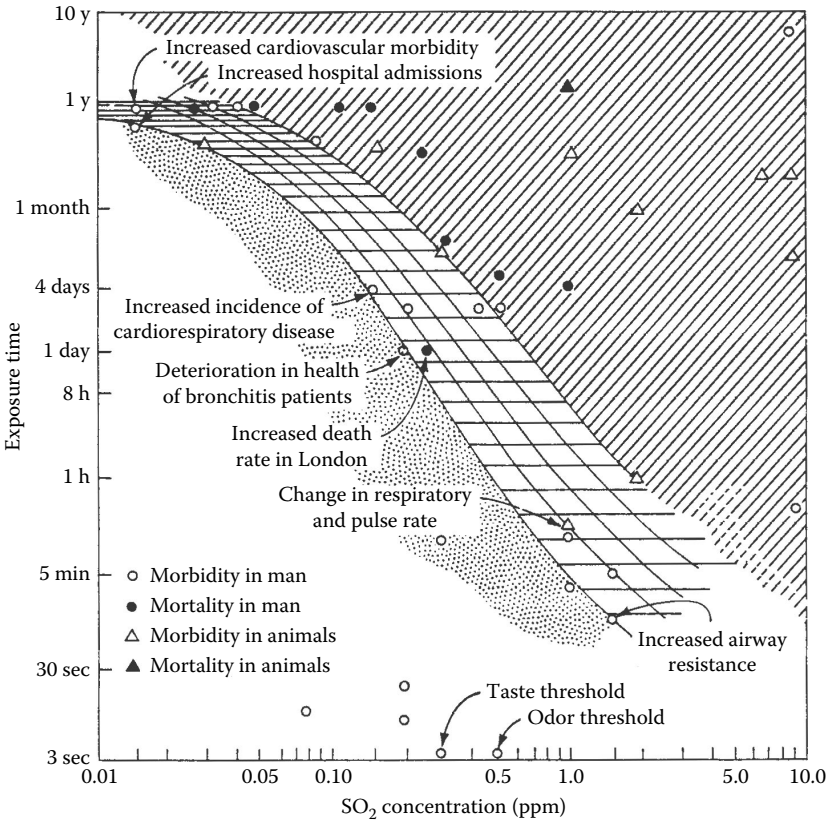
Condition	London	Los Angeles
Fuel	Coal and hydrocarbons	Hydrocarbons
Season during year	December–January	August–September
Peak time	Early morning	Midday
Temperature	30°F–40°F	75°F–90°F
Humidity	High with fog	Low—relatively clear sky
Wind speed	Calm	<5 mph
Inversions	Surface (radiation)	Overhead (subsidence)
Visibility	Severely reduced (<1000 ft)	Reduced (½ to 1 mile)
Principal constituents	Sulfur compounds, carbon monoxide, and particulates	Ozone, nitrogen, oxides, organics, peroxyacetyl nitrate, and carbon monoxide
Effects on humans	Bronchial irritation	Eye and skin irritation
Chemical effects	Reducing	Oxidizing

from community air pollution. However, Los Angeles is different from London, Pittsburgh, and St. Louis.

Undesirable effects in Los Angeles are due to photochemical reactions irradiated by solar radiation. Due to oxidant formation, such as peroxyacetyl nitrate, photochemical smog produces undesirable effects such as eye and skin irritation, plant damage, and reduced visibility. The sources of the organic compounds and oxides of nitrogen largely are from the internal combustion engine.

It is the effects of air pollution on human beings, animals, plants, materials, and visibility that the EPA must consider when setting standards. Scientific evidence must be reviewed to support the standards selected. Therefore, the EPA has studied a great number of research documents and supported research to furnish the evidence needed for setting the standards.

Effects in all cases are dependent on a concentration–time effect, which can be called the *dosage*. All effects, especially health effects, are difficult to quantify. The problem is that people differ in their makeup and sensitivity to the various pollutants. Williamson<sup>6</sup> made an early attempt to quantify health effects, as can be seen in Figure 1.4. Here, the effects are shown as a function of concentration and exposure time. For example, the increased death rate in London occurred when people were exposed to a concentration of 0.30 ppm SO<sub>2</sub> for a period of one day. It is interesting to note that this time period was shorter than the other data showing mortality in humans. As discussed previously, we do know that the SO<sub>2</sub> emissions in London were accompanied by particulate matter, which formed the London smog. Experiments with exposure of individuals to controlled concentrations of SO<sub>2</sub> in otherwise pure air indicated that the human body can stand higher levels of SO<sub>2</sub> without the detriment experienced in the Donora incident. This incident also was accompanied by a high concentration of particulate matter. When the experiments were carried out with particulates mixed in the air along with the SO<sub>2</sub>, the level of tolerance dropped well below the value, which can be tolerated for SO<sub>2</sub> alone.



**FIGURE 1.4** Health effects due to exposure to  $\text{SO}_2$ . Shaded area—range of exposures where excess deaths have been reported, grid area—range of exposures in which increased morbidity has been reported, speckled area—range of exposures where health effects are suspected. (Data from Williamson, S., *Fundamentals of Air Pollution*, Addison-Wesley, Reading, MA, 1973. With permission.)

These results can be summarized by noting that two plus two is greater than four when dealing with air pollution effects. Single contaminants in significant concentrations produce effects, but the effect is more generally associated with the mixture. Furthermore, the effect is intensified when a mixture is in the air. Thus, the total effect is greater than the sum of the effects of each individual pollutant. In other words, air pollution effects are synergistic.

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# 2 Clean Air Act

## 2.1 HISTORY OF THE CLEAN AIR ACT

The development and maturation of the Clean Air Act (CAA) in the United States demonstrates an increasing federal role in the regulation of air pollution, including a broader scope to address the global issues, stratospheric ozone protection, and climate change. Until the 1950s, air pollution generally was perceived as a local and regional problem to be regulated at the local and state levels. California was the first state to act against air pollution, primarily because of deteriorating air quality in the already highly populated Los Angeles basin area with its unique geography and meteorology that exacerbated the problem.

The Air Pollution Control Act of 1955 authorized air pollution research and training programs and technical assistance to state and local governments, but the responsibility for air pollution control was left to state and local governments. The Air Pollution Control Act was amended in 1961 and again in 1962 to authorize special studies for health effects associated with motor vehicle pollutants.

The CAA was passed in 1963, establishing for the first time federal responsibility for air pollution control. In addition to authorizing grant research and training and technical assistance, federal enforcement authority was granted to abate interstate air pollution control problems. Also, air quality criteria were required to be developed for the protection of public health and welfare. The Motor Vehicle Air Pollution Control Act of 1965 authorized the Department of Health, Education, and Welfare to promulgate emission standards for motor vehicles, and the first federal emission standards for light motor vehicles were established for the 1968 model year.

### 2.1.1 1970 CLEAN AIR ACT AMENDMENTS

The 1970 Clean Air Act Amendments (CAAA) produced a dramatic change in broadening the federal responsibility for air pollution control. It created the U.S. Environmental Protection Agency (EPA), and it established the following programs for new air quality standards:

- National Ambient Air Quality Standards (NAAQS)
- New Source Performance Standards (NSPS)
- National Emission Standards for Hazardous Air Pollutants (NESHAP)
- Citizen suits for enforcement
- New automobile emission standards

States received EPA's delegation to implement and enforce the CAA upon obtaining EPA's approval of a state's proposed state implementation plan. The EPA-approved state implementation plans are promulgated in the federal regulations at 40 CFR



Part 52, so that they are federally enforceable. However, even in CAA-delegated states, EPA retains oversight and enforcement authority.

### 2.1.1.1 National Ambient Air Quality Standards

The NAAQS for criteria pollutants were to be established by the EPA at two levels: (1) primary standards to protect health and (2) secondary standards to protect welfare (e.g., crops, vegetation, buildings, visibility). The following six criteria pollutants were specified:

1. Particulate
2. Carbon monoxide (CO)
3. Ozone (O<sub>3</sub>)
4. Sulfur dioxide (SO<sub>2</sub>)
5. Nitrogen dioxide (NO<sub>2</sub>)
6. Lead

Note that volatile organic compounds (VOCs) are not a criteria pollutant, but they are regulated like a criteria pollutant because VOCs and nitrogen oxides are precursors to ozone, which is produced by photochemical reactions.

Specifying lead as a criteria pollutant instead of a hazardous air pollutant is interesting, and this distinction proved to be effective. At that time, tetraethyl lead was prevalent in leaded gasoline as an inexpensive way to boost the octane rating. Controlling the spread of lead molecules throughout the environment as gasoline was burned was accomplished effectively as a criteria pollutant. Conversely, the hazardous air pollutant program, NESHAP, became bogged down in establishing health-based standards.

The EPA was required to review the NAAQS every five years to ensure that new research would be considered. The standard could remain at the same level if the review proved that the standard provides sufficient protection for health and welfare.

### 2.1.1.2 New Source Performance Standards

The 1970 amendments established a program of technology-based NSPS, so that any new source of air pollution would be required to apply effective air pollution controls. The NSPS are codified at 40 CFR Part 60. Existing sources were *grandfathered* and were not required to retrofit pollution controls. Existing sources that are modified are considered new sources, so old plants have to upgrade their air pollution control equipment as the plant is upgraded. The definition of *modified* is a subject of controversy to this day, centering on the distinction between *modification* and *maintenance*.<sup>1</sup>

### 2.1.1.3 Hazardous Air Pollutants

The NESHAP program for hazardous air pollutants required setting pollutant-specific, health-based standards for each hazardous air pollutant. Unfortunately, this program turned out to be too cumbersome to be implemented effectively. One significant problem was that the EPA administrator was to set the standard “at the level which in his judgment provides an ample margin of safety to protect the public from such hazardous pollutant.”<sup>2</sup> First, it takes a great deal of research to

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**TABLE 2.1**  
**Hazardous Air Pollutants for Which NESHAP Standards**  
**Were Established**

Asbestos
Benzene
Beryllium
Inorganic arsenic
Mercury
Radionuclides
Radon-22
Vinyl chloride
Coke oven emissions (listed, but not promulgated)

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establish a human health-based standard. Second, establishing an ample margin of safety was problematic, especially for the portion of the public that is sensitive to air pollution. It required court decisions to determine that cost of control could not be a factor in determining a health-based standard, but cost could be used to establish an ample margin of safety. Finally, establishing standards for over a 100 hazardous chemicals proved to be too burdensome. NESHAP standards were promulgated and codified at 40 CFR Part 61 for only the few hazardous pollutants listed in Table 2.1.

#### **2.1.1.4 Citizen Suits**

Determining that any person has sufficient interest to protect a universal resource such as clean air, Congress established citizen suits that authorize civil action against any person, including a government entity, who is alleged to be in violation of an emission standard or limitation. It also authorized suits against the EPA administrator when the administrator is alleged to fail to perform acts or duties required by the CAA. Costs of litigation, including reasonable attorney and expert witness fees, may be awarded. A key concept associated with citizen suits is the granting of *standing* to any individual, corporation, state, or municipality, doing away with the normal requirement of *injury in fact*.

There are procedural requirements, codified at 40 CFR Part 54, to limit excessive use of citizen litigation. One is providing 60 days' notice of a violation to the EPA, state, and alleged violator prior to starting a civil action. This is intended to allow agencies and violators the opportunity to correct a problem. Another condition barring a citizen suit is that the EPA or state has not already commenced and is not diligently pursuing a civil action. Again, citizen suits come into play when the enforcement agencies fail to meet their duties.

#### **2.1.2 1977 CLEAN AIR ACT AMENDMENTS**

Two highlights of the 1977 amendments were (1) codifying of the concept of prevention of significant deterioration (PSD) and (2) establishing an emission offset policy in areas that are not in attainment of the NAAQS.

### 2.1.2.1 Prevention of Significant Deterioration

The concept of preventing an area with good air quality from deteriorating to a lesser quality was introduced with the 1970 amendments. However, the wording was thin and controversy erupted. In 1973, the EPA proposed a plan for defining no significant deterioration, and repropose and adopted the concept in 1974. The 1977 amendments removed the controversy by codifying PSD.

Three classifications of geographical areas were established, with boundaries initially set by the EPA. Changes could be made by state and local officials to allow local determination of land use. Class I areas were designated to allow very little deterioration of the existing air quality. Pristine areas were to remain pristine. These areas include national parks and wilderness areas and many Indian reservations. Class II areas allow a moderate decline from existing ambient air quality as growth occurs. Class III areas are specifically designated as heavy industrial areas, where a larger amount of deterioration of the existing ambient air quality is allowed. In no case are any areas allowed to have pollution levels that exceed the NAAQS, so if the existing air quality is already poor, limited or no additional deterioration is allowed.

Each area classification allows a specified incremental increase in the ambient pollutant concentration above the ambient background level as of 1977. Thus, a permanent cap is established, which may be lower than the NAAQS.

Areas with air pollutant concentrations below the applicable NAAQS are referred to as *attainment areas*. Any new major stationary source of air emissions, or major modification of an existing stationary source, which proposes to construct in an NAAQS attainment area, or an area that is unclassified, must first obtain a PSD construction permit issued pursuant to an approved state implementation plan, where both the permit and the plan satisfy substantive requirements provided by 40 CFR §§ 51.165 and 51.166, respectively. The PSD air permit authorizes the projected increase in ambient pollutant concentration. New source review for PSD air permit applications is discussed in Chapter 3. An approved PSD air permit allots a portion of the available increment for deterioration to that source. Later, new sources wishing to locate in the area, or major modifications of existing sources, must consider the amount of the increment that has already been consumed. Delegated air permitting agencies must consider reasonable increment consumption and projected growth in the area to avoid granting the increment spuriously on a *first come, first served* basis.

### 2.1.2.2 Offsets in Nonattainment Areas

A new air pollution source that wishes to locate in an area that does not meet the NAAQS is precluded from doing so, unless a net decrease in air pollution can be demonstrated. The proposed new source can agree to control or shut down emission sources of like pollutant in exchange, in order to offset the new source of pollution. To ensure that progress is made toward bringing the ambient air quality closer to the NAAQS, the offset ratio must be greater than 1 to 1.

To avoid putting industry in the position of keeping old, dirty emission sources operating to preserve offsets for future expansions, and to encourage emission reductions, the offset policy was accompanied by banking. When emission reductions were made, emission reduction credits could be applied for and granted. Banked emission reduction credits could be used as offsets in the future. Under federal

guidance, credits were only good for a five-year contemporaneous period, however. Some state agencies, to which air permitting authority has been delegated by the EPA, use different contemporaneous periods. This is the type of discrepancy that has led to confusion between federal and state authority and program implementation.

2.2 1990 CLEAN AIR ACT AMENDMENTS

The 1990 CAAA made major, sweeping changes to the Act. They have been hailed<sup>3</sup> as “one of the most significant pieces of environmental legislation ever enacted.” There was significant and lengthy Congressional debate throughout the 1980s as to how to address shortcomings of the Act, especially over provisions for acid rain control and air toxics.

The previous CAAA fell short of their goal of achieving acceptable air quality throughout the United States. Indeed, every major urban area was in violation of at least one of the NAAQS, affecting over 100 million people.<sup>4</sup> NESHAP had been promulgated for only eight hazardous air pollutants in the 20 years since the program has been established by the 1970 amendments. The EPA estimated that an excess of 1000–3000 cancer deaths per year were occurring as a result of hazardous air pollutants.

The political mandate for the 1990 amendments was large. The U.S. House of Representatives passed the amendments by a vote of 401 to 21, and the Senate voted in favor by 89 to 11.

The 1990 amendments were organized in 11 Titles, as listed in Table 2.2. The major changes include new provisions addressing visibility to mitigate *regional haze* (Title I), a completely overhauled hazardous air pollutant program (Title III), specific provisions to control pollutants that cause acid rain (Title IV), a new operating permit program (Title V), and a specific program to control pollutants that cause stratospheric ozone depletion (Title VI).

Concerns about the effectiveness of implementing the 1990 amendments still remain. There are numerous deadlines that the EPA must meet, but few *statutory hammers* or consequences to ensure that they are met. This opens the door to resorting

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TABLE 2.2	
1990 Clean Air Act Amendments	
Title I	Attainment and Maintenance of NAAQS
Title II	Mobile Sources
Title III	Hazardous Air Pollutants (Air Toxics)
Title IV	Acid Rain (Acid Deposition Control)
Title V	Operating Permits
Title VI	Stratospheric Ozone and Global Climate Protection
Title VII	Enforcement
Title VIII	Miscellaneous Provisions
Title IX	Research
Title X	Disadvantaged Business
Title XI	Employment Transition Assistance

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to lawsuits to force the EPA to meet the deadlines, diverting the EPA’s budget resources to the defense of those lawsuits.

2.2.1 TITLE I: PROVISIONS FOR ATTAINMENT AND MAINTENANCE OF NAAQS

The 1990 CAAA recognized that many urban areas were not in attainment of the NAAQS, and that there were major problems with high levels of tropospheric ozone and CO. To address the problems practically, the amendments extended the time for states to achieve compliance, but required constant progress in reducing emissions and established provisions for sanctions on areas of the country that do not meet the conditions.

The new amendments also established degrees of severity for nonattainment for O<sub>3</sub>, CO, and particulate matter with an aerodynamic diameter of less than 10 μ (PM<sub>10</sub>).

Ozone nonattainment was broken into five degrees of severity, as listed in Table 2.3. Areas of extreme severity were allowed more time to achieve attainment, but receive increased federal scrutiny for new source review of major sources. The definition of *major* stationary source, discussed further in new source review permit applications in Chapter 3, applies to smaller sources, and the emission offset ratio requirement for new sources is increased.

Carbon monoxide and particulate matter degrees of severity for nonattainment were established at two levels as shown in Table 2.4.

Also in 1990, Congress added Section 169B, *Visibility*, to better address regional haze issues, which were not sufficiently addressed with Section 169A. Pursuant to

TABLE 2.3  
Degrees of Severity for Ozone Nonattainment

	1-h Avg.	Attainment Date	Major Source Threshold (tons/year)	Offset Ratio for New Sources
Marginal	0.12–0.138	11/15/1993	100	1.1
Moderate	0.138–0.16	11/15/1996	100	1.15
Serious	0.16–0.18	11/15/1999	50	1.2
Severe	0.18–0.19	11/15/2005	25	1.3
	0.19–0.28	11/15/2007		
Extreme	>0.28	11/15/2010	10	1.5

TABLE 2.4  
Degrees of Severity for CO and PM Nonattainment

	CO	PM
Moderate	9–16.5 ppm	Area that can achieve attainment by November 1996
Serious	>16.5 ppm	Area that cannot achieve compliance by November 1996