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The Changing Face of Air Pollution

I. DEFINING AIR POLLUTION

Air pollution: The presence of contaminants or pollutant substances in the air that interfere with human health or welfare, or produce other harmful environmental effects.

United States Environmental Protection Agency (2007)
"Terms of Environment: Glossary, Abbreviations and Acronyms"

The US Environmental Protection Agency's (EPA) definition is a good place to start thinking about what makes something an air pollutant. The key verb in the definition is "interfere." Thus, we obviously have a desired state, but these substances are keeping us from achieving that state. So, then, what is that state? The second part of the definition provides some clues; namely, air must be of a certain quality to support human and other life.

Some decades ago, few people were familiar with the term pollution. Of course, most people knew that something was amiss when their air was filled with smoke or when they smell an unpleasant odor. But, for most pollutants, those that were not readily sensed, a baseline had to be set to begin to take action. Environmental professionals had to reach agreement on what is and what is not "pollution." We now have the opposite problem, nearly everyone has heard about pollution and many may have their own working definitions. So, once again, we have to try to reach consensus on what the word actually means.

Another way to look at the interferences mentioned in the EPA definition is to put them in the context of "harm." The objects of the harm have received varying levels of interests. In the 1960s, harm to ecosystems, including threats to the very survival of certain biological species was paramount. This concern was coupled with harm to humans, especially in terms of diseases directly associated with obvious episodes, such as respiratory diseases and even death associated with combinations of weather and pollutant releases.

Other emerging concerns were also becoming apparent, including anxiety about nuclear power plants, particularly the possibilities of meltdown and the generation of cancer-causing nuclear wastes, petrochemical concerns, such as the increasing production and release of ominous-sounding chemicals like Dichloro-Diphenyl-Trichloroethane (DDT) and other pesticides, as well as spills of oil and other chemicals. These apprehensions would increase in the next decade, with the public's growing wariness about "toxic" chemicals added to the more familiar "conventional" pollutants like soot, carbon monoxide, and oxides of nitrogen and sulfur. The major new concern about toxics was cancer. The next decades kept these concerns, but added new ones, including threats to hormonal systems in humans and wildlife, neurotoxicity (especially in children), and immune system disorders.

Growing numbers of studies in the last quarter of the twentieth century provided evidence linking disease and adverse effects to extremely low levels of certain particularly toxic substances. For example, exposure to dioxin at almost any level above what science could detect could be associated with numerous adverse effects in humans. During this time, other objects of pollution were identified, including loss of aquatic diversity in lakes due to deposition of acid rain. Acid deposition was also being associated with the corrosion of materials, including some of the most important human-made structures, such as the pyramids in Egypt and monuments to democracy in Washington, DC. Somewhat later, global pollutants became the source of public concern, such as those that seemed to be destroying the stratospheric ozone layer or those that appeared to be affecting the global climate.

This escalation of awareness of the multitude of pollutants complicated matters. For example, many pollutants under other circumstances would be "resources," such as compounds of nitrogen. In the air, these compounds can cause respiratory problems directly or, in combination with hydrocarbons and sunlight indirectly can form ozone and smog. But, in the soil, nitrogen compounds are essential nutrients. So, it is not simply a matter of "removing" pollutants, but one of managing systems to ensure that optimal conditions for health and environmental quality exist. When does something in our air change from being harmless or even beneficial to become harmful? Impurities are common, but in excessive quantities and in the wrong places they become harmful. One of the most interesting definitional quandaries about pollution has come out of the water pollution literature, especially by the language in the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500). The objective of this law is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. To achieve this objective, the law set two goals: the elimination of the discharge of all pollutants into the navigable waters of the United States by 1985; and to provide an interim level of water quality to protect fish, shellfish, and wildlife and recreation by 1983.[1] Was Congress serious? Could they really mean that they had expected all sources that drained into US lakes and rivers to be completely free of pollutants in 13 years? Or did this goal hinge upon the definition of pollutant? In other words, even toxic substances are not necessarily "pollutants" if they exist below a threshold of harm. In light of the fact that this same law established so-called "effluent limitations," there is a strong likelihood that the definition called for in this goal was concentration-based.[2]

This paradigm spilled over into air pollution circles. More recently, the term "zero emission" has been applied to vehicles, as the logical next step following low emission vehicles (LEVs) and ultra-low emission vehicles (ULEVs) in recent years. However, zero emissions of pollutants will not be likely for the foreseeable future, especially if one considers that even electric cars are not emission free, but actually emission trading, since the electricity is generated at a power plant that is emitting pollutants as it burns fossil fuels or has the problem of radioactive wastes if it is a nuclear power plant. Even hydrogen, solar and wind systems are not completely pollution free since the parts and assemblages require energy and materials that may even include hazardous substances.

These definitional uncertainties beg the question, then, of when does an impurity become a pollutant? Renaissance thinking may help us here. Paracelsus, the sixteenth century scientist is famous for his contention that "dose alone makes a poison... . All substances are poisons; there is none

[1] 33 USC 1251.

[2] In fact, my own environmental career began shortly after the passage of this law, when it, along with the National Environmental Policy Act and the Clean Air Act of 1970, was establishing a new environmental policy benchmark for the United States. At the time environmentalists recited an axiom frequently: "Dilution is not the solution to pollution!" I recall using it on a regular basis myself. However, looking back over those three decades, it seems the adage was not completely true. Cleanup levels and other thresholds are concentration based, so if one does an adequate job in diluting the concentrations (e.g. dioxin concentrations below 1 part per billion, ppb), one has at least in part solved that particular pollution problem. Also, when it came to metal pollution, dilution was a preferred solution, since a metal is an element and cannot be destroyed. A sufficient amount of the metal wastes are removed from water or soil and moved to a permanent storage site. The only other engineering solution to metal pollution was to change its oxidation state and chemical species, which is not often preferable because when environmental conditions change, so often do the oxidation states of the metals, allowing them to again become toxic and bioavailable.

which is not a poison. The right dose differentiates a poison and a remedy."[3] Paracelsus' quote illuminates a number of physical, chemical, and biological concepts important to understanding air pollution. Let us consider two. First, the poisonous nature, i.e. the toxicology, of a substance must be related to the circumstances of exposure. In other words, to understand a pollutant, one must appreciate its context. Air pollutants become a problem when they come into contact with the receptor. This leads to some important questions that must be answered if we are to address air pollution:

1. What is the physical, chemical, and biological nature of the agent to which the receptor (e.g. a person, an endangered species, or an entire population or ecosystem) is exposed?
2. What is that person's existing health status?
3. What is the condition of the ecosystem?
4. What are the chemical composition and physical form of the contaminant?
5. Is the agent part of a mixture, or is it a pure substance?
6. How was the person or organism exposed; from food, drink, air, through the skin?

These and other characterizations of a contaminant must be known to determine the extent and degree of harm.

The second concept highlighted by Paracelsus is that dose is related to response. This is what scientists refer to as a biological gradient or a *dose–response* relationship. Under most conditions, the more poison to which one is exposed the greater the harm.

The classification of harm is an expression of *hazard*, which is a component of risk. The terms hazard and risk are frequently used interchangeably in everyday parlance, but hazard is actually a component of risk. As we will see throughout this text, hazard is not synonymous with risk. A hazard is expressed as the potential of unacceptable outcome, while risk is the likelihood (i.e. probability) that such an adverse outcome will occur. A hazard can be expressed in numerous ways. For chemical or biological agents, the most important hazard is the potential for disease or death (referred to in medical literature as "morbidity" and "mortality," respectively). So, the hazards to human health are referred to collectively in the medical and environmental sciences as "toxicity." Toxicology is chiefly concerned with these health outcomes and their potential causes.

To scientists and engineers, risk is a straightforward mathematical and quantifiable concept. Risk equals the probability of some adverse outcome. Any risk is a function of probability and consequence.[4] The consequence can take many forms. In environmental sciences, a consequence is called a "hazard."

[3] Kreigher, W. C., Paracelsus: dose response in *Handbook of Pesticide Toxicology*, (San Diego, C. A, Kreiger, R., Doull, J., and Ecobichon, D., eds.), 2nd ed. Elsevier Academic Press, 2001. New York, NY.

[4] Lewis, H.W., *Technological Risk*, Chapter 5: *The Assessment of Risk*. W.W. Norton & Company, Inc., New York, 1990.

Risk, then, is a function of the particular hazard and the chances of person (or neighborhood or workplace or population) being exposed to the hazard. For air pollution, this hazard often takes the form of toxicity, although other public health and welfare hazards abound.

II. THE EMERGENCE OF AIR POLLUTION SCIENCE, ENGINEERING, AND TECHNOLOGY

Environmental science and engineering are young professions compared to many other disciplines in the physical and natural sciences and engineering. In a span of just a few decades, advances and new environmental applications of science, engineering, and their associated technologies have coalesced into a whole new way to see the world. Science is the explanation of the physical world, while engineering encompasses applications of science to achieve results. Thus, what we have learned about the environment by trial and error has incrementally grown into what is now standard practice of environmental science and engineering. This heuristically attained knowledge has come at a great cost in terms of the loss of lives and diseases associated with mistakes, poor decisions (at least in retrospect), and the lack of appreciation of environmental effects.

Environmental awareness is certainly more "mainstream" and less a polarizing issue than it was in the 1970s, when key legislation reflected the new environmental ethos (see Fig. 1.1). There has been a steady march of advances in environmental science and engineering for several decades, as evidenced by the increasing number of Ph.D. dissertations and credible scientific journal articles addressing a myriad of environmental issues. Corporations and government agencies, even those whose missions are not considered to be "environmental," have established environmental programs.

Arguably, our understanding of atmospheric processes is one of the more emergent areas of environmental science and technology; growing from the increasing awareness of air pollution and advances of control technologies in the twentieth century. However, the roots of the science of air pollution can be traced to the Ancients.

The environmental sciences, including its subdisciplines specializing in air pollution, apply the fundamentals of chemistry, physics, and biology, and their derivative sciences such as meteorology, to understand these abiotic[5]

[5] The term "abiotic" includes all elements of the environment that are non-living. What is living and non-living may appear to be a straightforward dichotomy, but so much of what we call "ecosystems" is a mixture. For example, some soils are completely abiotic (e.g. clean sands), but others are rich in biotic components, such as soil microbes. Vegetation, such as roots and rhizomes are part of the soil column (especially in the "A" horizon or topsoil). Formerly living substances, such as detritus exist as lignin and cellulose in the soil organic matter (SOM). In fact, one of the problems with toxic chemicals is that the biocidal properties kill living organisms, reducing or eliminating the soil's productivity.

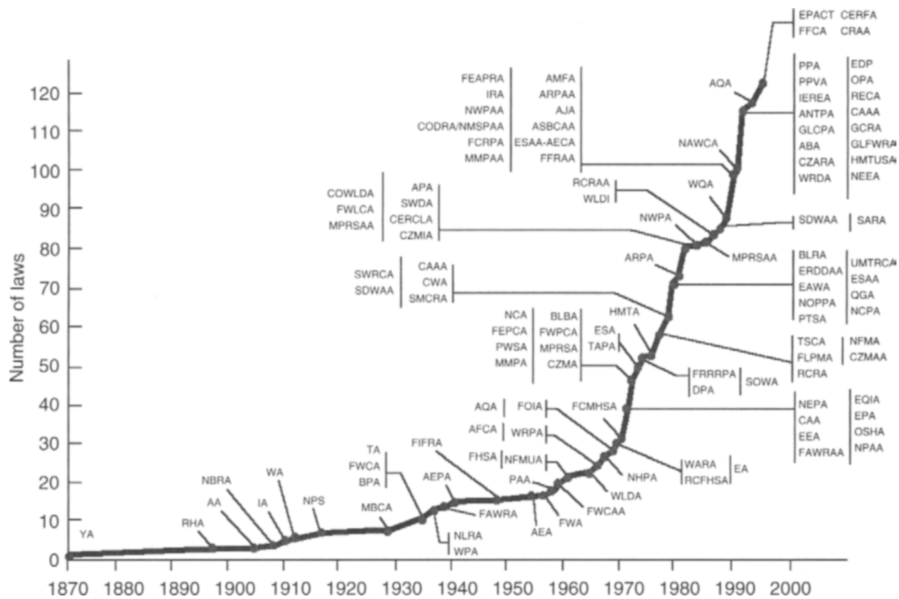


Fig. 1.1. Growth of federal environmental legislation in the United States. *Source*: US Environmental Protection Agency, 2004, Shonnard, D. R., Chapter 3, http://www.epa.gov/oppt/greenengineering/images/regulation_big.jpg; and Allen, D. T., and Shonnard, D. R., *Green Engineering: Environmentally Conscious Design of Chemical Processes*. Prentice Hall, Upper Saddle River, NJ, 2002.

and biotic relationships. Expanding these observations to begin to control outcomes is the province of environmental engineering.

As scientists often do, systematic and specific explanations must be applied to practical knowledge. So, biologists and their subdisciplines began to specialize in what came to be known as the environmental sciences. Health scientists, like Paracelsus and William Harvey, provided insights into how the human body interacts with and reacts to environmental stimuli. In fact, Paracelsus' studies of metal contamination and exposure to miners may well be among the earliest examples of *environmental epidemiology*.

Not only are the environmental disciplines young, but also many of the environmental problems faced today differ from most of the earth's history. The difference is in both kind and degree. For example, the synthesis of chemicals, especially organic compounds has grown exponentially since the mid-1900s. Most organisms had no mechanisms to metabolize and eliminate these new compounds. Also, stresses put on only small parts of ecosystems prior to the Industrial Revolution were small in extent of damage. For example, pollutants have been emitted into the atmosphere throughout human history, but only recently were such emissions so large and long lasting, or of pollutants with such high toxicity, that they have diminished the quality of entire *airsheds*.[6]

DISCUSSION: WHAT IS THE DIFFERENCE BETWEEN AN ENVIRONMENTAL ENGINEER AND A SANITARY ENGINEER?

When air pollution engineering first became recognized as a unique discipline, most of the engineers involved called themselves *sanitary engineers*, but now they are usually considered to be *environmental engineers*. Why has "environmental engineering" for the most part replaced "sanitary engineering" in the United States?

Discussion

There were many reasons for the name change. One certainly is the greater appreciation for the interconnections among abiotic and biotic systems in the protection of ecosystems and human health. Starting with the New Deal in second quarter of the twentieth century, engineers engaged in "public works" projects, which in the second half of the century evolved to include sanitary engineering projects, especially wastewater treatment plants, water supplies, and sanitary landfills. Meanwhile, sanitary engineers were designing cyclones, electrostatic precipitators, scrubbers, and other devices to remove air pollutants from industrial emissions.

The realization that there was much more that engineers design beyond these structures and devices has led to comprehensive solutions to environmental problems. Certainly, structural and mechanical solutions are still the foundation of air pollution engineering, but these are now seen as a part of an overall set of solutions. Thus, systems engineering, optimizations, and the application of more than physical principles (adding chemical and biological foundations) are better reflected in "environmental engineering" than in sanitary engineering. As mentioned by Vesilind, *et al*,[7] "everything seems to matter in environmental engineering."

[6] An airshed is analogous to a watershed, but applies to the atmosphere. For example, the California Air Resources Board defines an airshed as a subset of an "air basin, the term denotes a geographical area that shares the same air because of topography, meteorology, and climate." An air basin is defined as "land area with generally similar meteorological and geographical conditions throughout. To the extent possible, air basin boundaries are defined along political boundary lines and include both the source and receptor areas. California is currently divided into 15 air basins." *Source*: California Air Resources Board, "Glossary of Air Pollution Terms," http://www.arb.ca.gov/html/gloss.htm, update on May 3, 2006.

[7] This quote comes from Aarne Vesilind, P., Jeffrey Peirce, J., and Weiner, Ruth F., "Environmental Engineering," 4th ed. Butterworth-Heinemann: Boston, MA, 2003. The text is an excellent introduction to the field of environmental engineering and one of the sources of inspiration for this book.

Another possible reason for the name change is that "sanitary" implies human health, while "environmental" brings to mind ecological and welfare as well as human health as primary objectives of the profession. Sanitation is the province of industrial hygienists and public health professionals. The protection of the environment is a broader mandate for engineers.

THIS LEADS US TO ANOTHER QUESTION

Why is environmental engineering often a field in the general area of civil engineering, and not chemical engineering?

Discussion

The historical "inertia" may help to explain why environmental engineering is a discipline of civil rather than chemical engineering. As mentioned, environmental protection grew out of civil engineering projects of the New Deal and beyond. Chemical engineering is most concerned with the design and building of systems (e.g. "reactors") that convert raw materials into useful products. So, in a way, chemical engineering is the mirror image of environmental engineering, which often strives to return complex chemicals to simpler compounds (ultimately CO_2, CH_4, and H_2O). So, one could view the two fields as a chemical equilibrium where the reactions in each direction are equal! Most importantly, both fields are crucial in addressing air pollution, and contribute in unique ways.

A. What is a Contaminant?

The definition of air pollution considered at the beginning of this chapter included the term "contaminants." This is arguably even more daunting than "pollutant." If you were told your yard, your home, your neighborhood, or your air is contaminated, it is very likely that you would be greatly troubled. You would probably want to know the extent of the contamination, its source, what harm you may have already suffered from it, and what you can do to reduce it. Contamination is also a term that is applied differently by scientists and the general public, as well as among scientists from different disciplines.

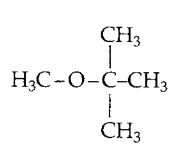
So, then, what is *contamination*? The dictionary[8] definition of the verb "*contaminate*" reads something like "to corrupt by contact or association," or "to make inferior, impure, or unfit." These are fairly good descriptions of what

[8] Webster's Ninth New Collegiate Dictionary, Merriam-Webster, Inc., Springfield, MA, 1990.

environmental contaminants do. When they come into contact with people, ecosystems, crops, materials, or anything that society values, they cause harm. They make resources less valuable or less fit to perform their useful purposes. From an air quality perspective, contamination is usually meant to be "chemical contamination" and this most often is within the context of human health. However, air pollution abatement laws and programs have recognized that effects beyond health are also important, especially *welfare* protection. Thus, public health is usually the principal driver for assessing and controlling environmental contaminants, but ecosystems are also important *receptors* of contaminants. Contaminants also impact structures and other engineered systems, including historically and culturally important monuments and icons, such as the contaminants in rainfall (e.g. nitrates and sulfates) that render it more corrosive than would normally be expected (i.e. *acid rain*).

Contaminants may also be physical, such as the energy from ultraviolet (UV) light. Often, even though our exposure is to the physical contamination, this exposure was brought about by chemical contamination. For example, the release of chemicals into the atmosphere, in turn react with ozone in the stratosphere, decreasing the ozone concentration and increasing the amount of UV radiation at the earth's surface. This has meant that the mean UV dose in the temperate zones of the world has increased. This has been associated with an increase in the incidence of skin cancer, especially the most virulent form, melanoma.

One of the advantages of working in an environmental profession is that it is so diverse. Many aspects have to be considered in any environmental decision. From a scientific perspective, this means consideration must be given to the characteristics of the pollutant *and* the characteristics of the place where the chemical is found. This place is known as the "environmental medium." The major environmental media are air, water, soil, sediment, and even biota. This book is principally concerned with the air medium, but every medium affects or is affected by air pollution actions and inactions, as demonstrated by the fuel additive MTBE:



Methyl tertiary-butyl ether (MTBE)

Automobiles generally rely on the internal combustion engine to supply power to the wheels.[9] Gasoline is the principal fuel source for most cars. The

[9] The exception is electric cars, which represent a very small fraction of motorized vehicles; although a growing number of hybrid power supplies (i.e. electric systems charged by internal combustion engines) are becoming available.

exhaust from automobiles is a large source of air pollution, especially in densely populated urban areas. To improve fuel efficiency and to provide a higher octane rating (for anti-knocking), most gasoline formulations have relied on additives. Up to relatively recently, the most common fuel additive to gasoline was tetraethyl-lead. But with the growing awareness of lead's neurotoxicity and other health effects, tetraethyl-lead has been banned in most parts of the world, so suitable substitutes were needed.

Methyl tertiary-butyl ether (MTBE) was one of the first replacement additives, first used to replace the lead additives in 1979. It is manufactured by reacting methanol and isobutylene, and his been produced in very large quantities (more than 200 000 barrels per day in the US in 1999). MTBE is a member of the chemical class of oxygenates. MTBE is a quite volatile (vapor pressure = 27 kPa at 20°C), so that it is likely to evaporate readily. It also readily dissolves in water (aqueous solubility at 20°C = 42 g L^{-1}) and is very flammable (flash point = −30°C). In 1992, MTBE began to be used at higher concentrations in some gasoline to fulfill the oxygenate requirements set the 1990 Clean Air Act Amendments. In addition, some cities, notably Denver, used MTBE at higher concentrations during the wintertime in the late 1980s.

The Clean Air Act called for greater use of oxygenates in an attempt to help to reduce the emissions of carbon monoxide (CO), one of the most important air pollutants. CO toxicity results by interfering with the protein hemoglobin's ability to carry oxygen. Hemoglobin absorbs CO about 200 times faster than its absorption rate for oxygen. The CO-carrying protein is known as carboxyhemoglobin and when sufficiently high it can lead to acute and chronic effects. This is why smoking cigarettes leads to cardiovascular problems, i.e. the body has to work much harder because the normal concentration of oxygen in hemoglobin has been displaced by CO. CO is also a contributing factor in the photochemistry that leads to elevated levels of ozone (O_3) in the troposphere. In addition, oxygenates decrease the emissions of volatile organic compounds (VOCs), which along with oxides of nitrogen are major precursors to the formation of tropospheric O_3. This is one of the most important roles of oxygenates, since unburned hydrocarbons can largely be emitted before catalytic converters start to work.

Looking at it from one perspective, the use of MTBE was a success by providing oxygen and helping gasoline burn more completely, resulting in less harmful exhaust from motor vehicles. The oxygen also dilutes or displaces compounds such as benzene and its derivatives (e.g. toluene, ethylbenzene, and xylene), as well as sulfur. The oxygen in the MTBE molecule also enhances combustion (recall that combustion is oxidation in the presence of heat). MTBE was not the only oxygenate, but it has very attractive blending characteristics and is relatively cheap compared to other available compounds. Another widely used oxygenate is ethanol.

The problem with MTBE is its suspected links to certain health effects, including cancer in some animal studies. In addition, MTBE has subsequently been found to pollute water, especially ground water in aquifers. Some of the pollution comes from unburned MTBE emitted from tailpipes, some from fueling, but a large source is underground storage tanks (USTs) at gasoline stations or other fuel operations (see Fig. 1.2). A number of these tanks have leaked into the surrounding soil and unconsolidated media and have allowed the MTBE to migrate into the ground water. Since it has such a high aqueous solubility, the MTBE is easily dissolved in the water.

When a pollutant moves from one environmental compartment (e.g. air) to another (e.g. water) as it has for MTBE, this is known as cross-media transfer. The problem has not really been eliminated, just relocated. It is also an example of a risk trade-off. The risks posed by the air pollution have been traded for the new risks from exposure to MTBE-contaminated waters.

The names that we give things, the ways we describe them, and how we classify them for better understanding is uniquely important to each discipline. Although the various environmental fields use some common language, they each have their own lexicons and systems of taxonomy. Sometimes the

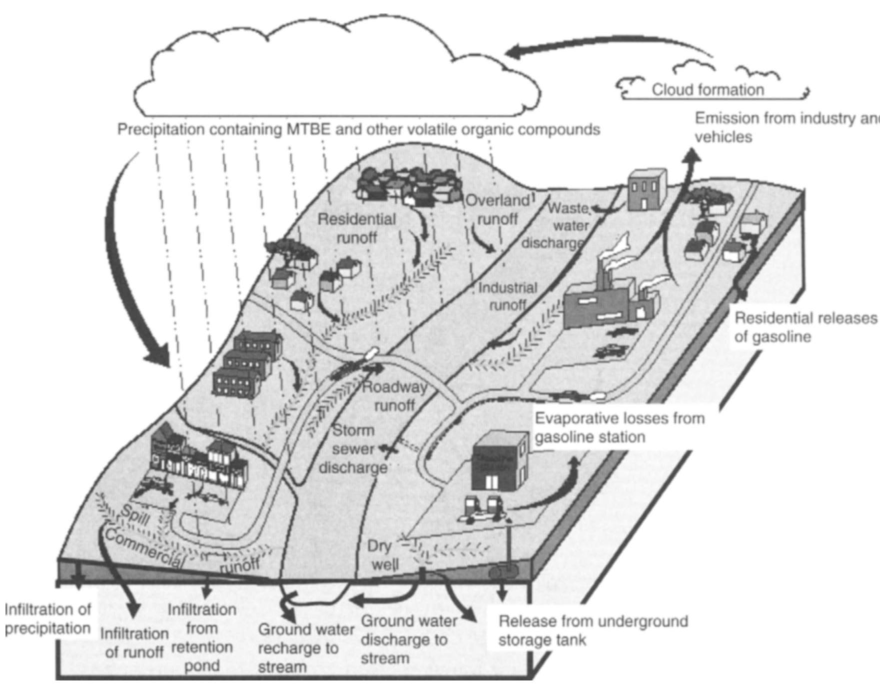


Fig. 1.2. Migration of MTBE in the environment. *Source*: Delzer, G. C., Zogorski, J. S., Lopes, T. J., and Bosshart, R. L., US Geological Survey, *Occurrence of the Gasoline Oxygenate MTBE and BTEX in Urban Stormwater in the United States, 1991–95*. Water Resources Investigation Report 96-4145, Washington, DC, 1996.

difference is subtle, such as different conventions in nomenclature and symbols.[10] This is more akin to different slang in the same language.

Sometimes the differences are profound, such as the use of the term "particle." In atmospheric dispersion modeling, a particle is the theoretical point that is followed in a fluid (see Fig. 1.3). The point represents the path that the pollutant in the air stream is expected to take. Particle is also used interchangeably with the term "aerosol" in atmospheric sciences and exposure studies (see Fig. 1.4). Particle is also commonly used to describe one part of an unconsolidated material, such as soil or sediment particle (see Fig. 1.5). In addition, engineering mechanics defines a particle as it applies to kinematics; i.e., a body in motion that is not rotating is called a particle. At an even more basic level, particle is half of the particle-wave dichotomy of physics, so the quantum mechanical properties of a particle (e.g. a photon) are fundamental to detecting chemicals using chromatography. Different members of the science community who contribute to our understanding of air pollution use the term "particle" in these different ways.

Let us consider a realistic example of the challenge of science communications related to the environment. There is concern that particles emitted from a power plant are increasing aerosol concentrations in your town. To determine if this is this case, the state authorizes the use of a Lagrangian (particle) dispersion model to see if the particles are moving from the source to the town. The aerosols are carrying pollutants that are deposited onto soil particles, so the state asks for a soil analysis to be run. One of the steps in this study is to extract the pollutants from individual soil particles before analysis. The soil scientist turns his extract into an analytical chemist who uses chromatography (which is based on quantum physics and particle-wave dichotomy).

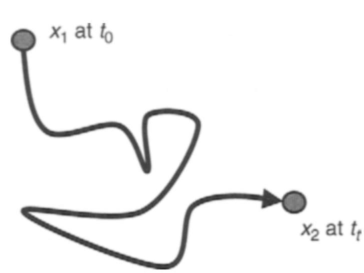


Fig. 1.3. Atmospheric modeling definition of a particle; i.e. a hypothetical point that is moving in a random path during time interval (t_0–t_t). This is the theoretical basis of a Lagrangian model.

[10] This text intentionally uses different conventions in explaining concepts and providing examples. One reason is that is how the information is presented. Environmental information comes in many forms. A telling example is the convention the use of K. In hydrogeology, this means hydraulic conductivity, in chemistry it is an equilibrium constant, and in engineering it can be a number of coefficients. Likewise, units other than metric will be used on occasion, because that is the convention in some areas, and because it demonstrates the need to apply proper dimensional analysis and conversions. Many mistakes have been made in these two areas!

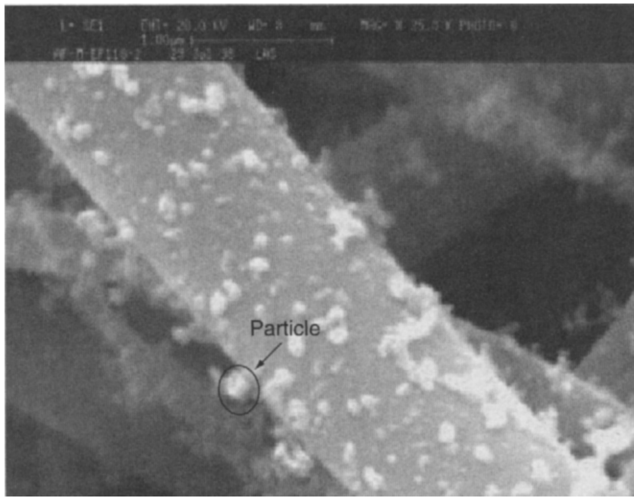


Fig. 1.4. Electron micrograph (>45 000× enlargement) showing an example of a particle type of air pollutant. These particles were collected from the exhaust of an F-118 aircraft under high throttle (military) conditions. The particles were collected with glass fiber filters (the 1 μm width tubular structures in the micrograph). Such particles are also referred to as PM or aerosols. Size of the particle is important, since the small particles are able to infiltrate the lungs and penetrate more deeply into tissues, which increases the likelihood of pulmonary and cardiovascular health problems. *Source*: Shumway, L., *Characterization of Jet Engine Exhaust Particulates for the F404, F118, T64, and T58 Aircraft Engines*. US Navy, Technical Report 1881, San Diego, CA, 2002.

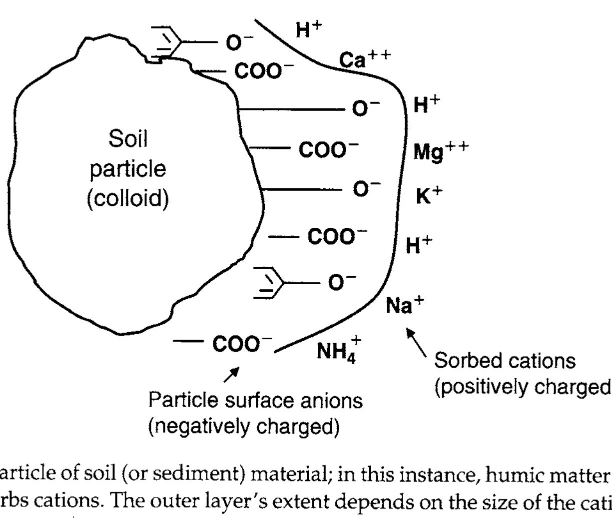


Fig. 1.5. Particle of soil (or sediment) material; in this instance, humic matter with a negative surface that sorbs cations. The outer layer's extent depends on the size of the cations (e.g. a layer of larger sodium (Na^+) cations will lead a large zone of influence than will a layer of smaller magnesium (Mg^{++}) cations.

You invite the dispersion modeler, the soil scientist, the chromatographer, as well as an exposure scientist to explain the meaning of their findings. In the process of each explanation, the scientists keep referring to particles. They are all correct within their specific discipline, but together they leave you confused. This is akin to homonyms in the same language or different languages altogether.

Under most environmental conditions, air pollution represents are solutions or suspensions of minute amounts of harmful compounds in air. For example, air's solutes represent small percentages of the solution at the highest (e.g. water vapor) and most other solutes represent parts per million (ppm). For example, on average carbon dioxide concentrations in the troposphere are a bit more than 300 ppm. Most "contaminants" in air and water, thankfully, are found in the parts per billion (ppb) range, if found at all. We usually include only the air in the atmosphere, but air exists in all media. It is dissolved in surface and ground water. In addition, soil and sediment are conglomerations of all states of matter. Soil is predominantly solid, but frequently has large fractions of liquid (soil water) and gas (soil air, methane, carbon dioxide) that make up the matrix. The composition of each fraction is highly variable. For example, soil–gas concentrations are different from those in the atmosphere and change profoundly with depth from the surface (Table 1.1 shows the inverse relationship between carbon dioxide and oxygen).

So, another way to think about these environmental media is that they are compartments, each with boundary conditions, kinetics and partitioning relationships within a compartment or among other compartments. Chemicals, whether nutrients or contaminants, change as a result of the time spent in each compartment. The environmental professional's challenge is to describe, characterize, and predict the behaviors of various chemical species as they

TABLE 1.1

Composition of Two Important Gases in Soil Air[a]

	Silty clay		Silty clay loam		Sandy loam	
Depth from surface (cm)	O_2 (% volume of air)	CO_2 (% volume of air)	O_2 (% volume of air)	CO_2 (% volume of air)	O_2 (% volume of air)	CO_2 (% volume of air)
30	18.2	1.7	19.8	1.0	19.9	0.8
61	16.7	2.8	17.9	3.2	19.4	1.3
91	15.6	3.7	16.8	4.6	19.1	1.5
122	12.3	7.9	16.0	6.2	18.3	2.1
152	8.8	10.6	15.3	7.1	17.9	2.7
183	4.6	10.3	14.8	7.0	17.5	3.0

[a] Evangelou, V.P., *Environmental Soil and Water Chemistry: Principles and Applications*, John Wiley and Sons, Inc., New York, 1998.

move through the media. When something is amiss, the cause and cure lie within the physics, chemistry, and biology of the system. It is up to the professional to properly apply the principles.

1. *Social Aspects of Air Pollution*

Environmental quality is important to everyone. We will be stressing the importance of sound science, but it should always be understood that when it comes to the environment and public health, the social sciences can never be ignored. Certain social values have been passed down for generations, while others have been recently adapted to changes. For example, if a person or neighborhood has just experienced a nasty battle with an industry or governmental organization regarding an environmental decision, such as the location of landfill or prohibition of a certain type of use of their own land, they may be reticent to trust the environmental professional who promises that it will be different this time. The second half of the twentieth century, particularly the time from the mid-1960s to through the 1970s ushered in a new environmental ethos, or at least memorialized the fact that most, if not all, people expect a certain quality of the environment. The laws and policies stemming from these years are still evolving.

Environmental awareness grew in the second half of the twentieth century. With this awareness the public demand for environmental safeguards and remedies to environmental problems was an expectation of a greater role for government. A number of laws were on the books prior to the 1960s, such as early versions of federal legislation to address limited types of water and air pollution, and some solid waste issues, such as the need to eliminate open dumping. The real growth, however, followed the tumultuous decade of the 1960s. Environment had become a social cause, akin to the civil rights and antiwar movements. Major public demonstrations on the need to protect "spaceship earth" encouraged elected officials to address environmental problems, exemplified by air pollution "inversions" that capped polluted air in urban valleys, leading to acute diseases and increased mortality from inhalation hazards, the "death" of Erie Canal and rivers catching on fire in Ohio and Oregon.

2. *The National Environmental Policy Act*

The movement was institutionalized in the United States by a series of new laws and legislative amendments. The National Environmental Policy Act (NEPA) was in many ways symbolic of the new federal commitment to environmental stewardship. It was signed into law in 1970 after contentious hearings in the US Congress. NEPA was not really a technical law. It did two main things. It created the Environmental Impact Statement (EIS) and established the Council on Environmental Quality (CEQ) in the Office of the President. Of the two, the EIS represented a sea change in how the federal government was to conduct business. Agencies were required to prepare EISs on any major action that they were considering that could "significantly" affect the quality of the environment. From the outset, the agencies had to reconcile often-competing values; i.e. their mission and the protection of the environment.

The CEQ was charged with developing guidance for all federal agencies on NEPA compliance, especially when and how to prepare an EIS. The EIS process combines scientific assessment with public review. The process is similar for most federal agencies. Agencies often strive to receive a so-called "FONSI"[11] or the finding of no significant impact, so that they may proceed unencumbered on a mission-oriented project.[12] Whether a project either leads to a full EIS or a waiver through the FONSI process, it will have to undergo an evaluation. This step is referred to as an "environmental assessment." An incomplete or inadequate assessment will lead to delays and increases the chance of an unsuccessful project, so sound science is needed from the outset of the project design. The final step is the record of decision (ROD). The ROD describes the alternatives and the rationale for final selection of the best alternative. It also summarizes the comments received during the public reviews and how the comments were addressed. Many states have adopted similar requirements for their RODs.

The EIS documents were supposed to be a type of "full disclosure" of actual or possible problems if a federal project is carried out. This was accomplished by looking at all of the potential impacts to the environment from any of the proposed alternatives, and comparing those outcomes to a "no action" alternative. At first, many tried to demonstrate that their "business as usual" was in fact very environmentally sound. In other words, the environment would be better off with the project than without it (action is better than no action). Too often, however, an EIS was written to justify the agency's mission-oriented project. One of the key advocates for the need for a national environmental policy, Lynton Caldwell, is said to have referred to this as the federal agencies using an EIS to "make an environmental silk purse from a mission-oriented sow's ear!"[13] The courts adjudicated some very important laws along the way, requiring federal agencies to take NEPA seriously. Some of the aspects of the "give and take" and evolution of federal agencies' growing commitment to environmental protection was the acceptance of the need for sound science in assessing environmental conditions and

[11] Pronounced "Fonzie" like that of the nickname for character Arthur Fonzarelli portrayed by Henry Winkler in the television show, *Happy Days*.

[12] This is understandable if the agency is in the business of something not directly related to environmental work, but even the natural resources and environmental agencies have asserted that there is no significant impact to their projects. It causes the cynic to ask, then, why are they engaged in any project that has no significant impact? The answer is that the term "significant impact" is really understood to mean "significant adverse impact" to the human environment.

[13] I attribute this quote to Timothy Kubiak, one of Professor Caldwell's former graduate students in Indiana University's Environmental Policy Program. Kubiak has since gone on to become a successful environmental policy maker in his own right, first at EPA and then at the US Fish and Wildlife Service.

possible impacts, and the very large role of the public in deciding on the environmental worth of a highway, airport, dam, waterworks, treatment plant, or any other major project sponsored by or regulated by the federal government. This was a major impetus in the growth of the environmental disciplines since the 1970s. We needed experts who could not only "do the science" but who could communicate what their science means to the public.

All federal agencies must follow the CEQ regulations[14] to "adopt procedures to ensure that decisions are made in accordance with the policies and purposes of the Act." Agencies are required to identify the major decisions called for by their principal programs and make certain that the NEPA process addresses them. This process must be set up in advance, early in agency's planning stages. For example, if waste remediation or reclamation is a possible action, the NEPA process must be woven into the remedial action planning processes from beginning with the identification of the need for and possible kinds of actions being considered. Noncompliance or inadequate compliance with NEPA rules regulations can lead to severe consequences, including lawsuits, increased project costs, delays, and the loss of the public's loss of trust and confidence, even if the project is designed to improve the environment, and even if the compliance problems seem to be only "procedural."

The US EPA is responsible for reviewing the environmental effects of all federal agencies' actions. This authority was written as Section 309 of the Clean Air Act. The review must be followed with the EPA's public comments concerning the environmental impacts of any matter related to the duties, responsibilities, and authorities of EPA's administrator, including EISs. The EPA's rating system (see Table 1.2) is designed to determine whether a proposed action by a federal agency is unsatisfactory from the standpoint of public health, environmental quality, or public welfare. This determination is published in the *Federal Register* (for significant projects) and referred to the CEQ.

3. *Clean Air Legislation*

The year 1970 was a watershed[15] year in environmental awareness. The 1970 amendments to the Clean Air Act arguably ushered in the era of environmental legislation with enforceable rules. The 1970 version of the Clean Air Act was enacted to provide a comprehensive set of regulations to control air emissions from area, stationary, and mobile sources. This law authorized the EPA to establish National Ambient Air Quality Standards (NAAQS) to protect public health and the environment from the "conventional" (as opposed to "toxic") pollutants: carbon monoxide, particulate matter (PM), oxides of nitrogen, oxides of sulfur, and photochemical oxidant smog or ozone (see Discussion Box: Evolution of Environmental Indicators for Air). The metal lead (Pb) was later added as the sixth NAAQS pollutant.

[14] 40 CFR 1507.3

[15] Pun intended! Or should it be an "airshed" year?

TABLE 1.2

Summary of the CEQ Guidance for Compliance with the NEPA of 1969[a]

Title of guidance	Summary of guidance	Citation	Relevant regulation/Documentation
Forty most often asked questions concerning CEQ's NEPA regulations	Provides answers to 40 questions most frequently asked concerning implementation of NEPA.	46 FR 18026, dated March 23, 1981	40 CFR Parts 1500–1508
Implementing and explanatory documents for Executive Order (EO) 12114, Environmental effects abroad of major federal actions	Provides implementing and explanatory information for EO 12114. Establishes categories of federal activities or programs as those that significantly harm the natural and physical environment. Defines which actions are excluded from the order and those that are not.	44 FR 18672, dated March 29, 1979	EO 12114, Environmental effects abroad of major federal actions
Publishing of three memoranda for heads of agencies on: • Analysis of impacts on prime or unique agricultural lands (Memoranda 1 and 2) • Interagency consultation to avoid or mitigate adverse effects on rivers in the Nationwide Inventory (Memorandum 3)	1 or 2 Discusses the irreversible conversion of unique agricultural lands by Federal Agency action (e.g. construction activities, developmental grants, and federal land management). Requires identification of and cooperation in retention of important agricultural lands in areas of impact of a proposed agency action. The agency must identify and summarize existing or proposed agency policies, to preserve or mitigate the effects of agency action on agricultural lands. 3 "Each Federal Agency shall, as part of its normal planning and environmental review process, take care to avoid or mitigate adverse effects on rivers identified in the Nationwide Inventory prepared by the Heritage Conservation and Recreation Service in the Department of the Interior." Implementing regulations includes	[45 FR 59189, dated September 8, 1980]	1/2 Farmland Protection Policy Act (7 USC §4201 et seq.) 3 The Wild and Scenic Rivers Act of 1965 (16 USC §1271 et seq.)

	determining whether the proposed action: affects an Inventory River; adversely affects the natural, cultural and recreation values of the Inventory river segment; forecloses options to classify any portion of the Inventory segment as a wild, scenic or recreational river area, and incorporates avoidance/mitigation measures into the proposed action to maximum extent feasible within the agency's authority.		
Memorandum for heads of agencies for guidance on applying Section 404(r) of the Clean Water Act at Federal projects which involve the discharge of dredged or fill materials into waters of the US including wetlands	Requires timely agency consultation with US Army Corps of Engineers (COE) and the US EPA before a Federal project involves the discharge of dredged or fill material into US waters, including wetlands. Proposing agency must ensure, when required, that the EIS includes written conclusions of EPA and COE (generally found in Appendix).	CEQ, dated November 17, 1980	Clean Water Act (33 USC §1251 et seq.) EO 12088, Federal compliance with pollution control standards
Scoping guidance	Provides a series of recommendations distilled from agency research regarding the scoping process. Requires public notice; identification of significant and insignificant issues; allocation of EIS preparation assignments; identification of related analysis requirements in order to avoid duplication of work; and the planning of a schedule for EIS preparation that meshes with the agency's decision-making schedule.	46 FR 25461, dated May 7, 1981	40 CFR Parts 1500–1508
Guidance regarding NEPA regulations	Provides written guidance on scoping, CatEx's, adoption regulations, contracting provisions, selecting alternatives in licensing and permitting situations, and tiering.	48 FR 34263, dated July 28, 1983	40 CFR Parts 1501, 1502, and 1508

(Continued)

TABLE 1.2 *(Continued)*

Title of guidance	Summary of guidance	Citation	Relevant regulation/Documentation
NEPA implementation regulations, Appendices I, II, and III	Provides guidance on improving public participation, facilitating agency compliance with NEPA and CEQ implementing regulations. Appendix I updates required NEPA contacts, Appendix II compiles a list of Federal and Federal-State Agency Offices with jurisdiction by law or special expertise in environmental quality issues; and Appendix III lists the Federal and Federal-State Offices for receiving and commenting on other agencies' environmental documents.	49 FR 49750, dated December 21, 1984	40 CFR Part 1500
Incorporating biodiversity considerations into environmental impact analysis under the NEPA	Provides for "acknowledging the conservation of biodiversity as national policy and incorporates its consideration in the NEPA process"; encourages seeking out opportunities to participate in efforts to develop regional ecosystem plans; actively seeks relevant information from sources both within and outside government agencies; encourages participating in efforts to improve communication, cooperation, and collaboration between and among governmental and nongovernmental entities; improves the availability of information on the status and distribution of biodiversity, and on techniques for managing and restoring it; and expands the information base on which biodiversity analyses and management decisions are based.	CEQ, Washington, DC, dated January 1993	Not applicable

Pollution prevention and NEPA	Pollution-prevention techniques seek to reduce the amount and/or toxicity of pollutants being generated, promote increased efficiency of raw materials and conservation of natural resources and can be cost-effective. Directs Federal agencies that to the extent practicable, pollution prevention considerations should be included in the proposed action and in the reasonable alternatives to the proposal, and to address these considerations in the environmental consequences section of an EIS and EA (when appropriate).	58 FR 6478, dated January 29, 1993	EO 12088, Federal Compliance with Pollution Control Standards
Considering cumulative effects under NEPA	Provides a "framework for advancing environmental cumulative impacts analysis by addressing cumulative effects in either an environmental assessment (EA) or an environmental impact statement". Also provides practical methods for addressing coincident effects (adverse or beneficial) on specific resources, ecosystems, and human communities of all related activities, not just the proposed project or alternatives that initiate the assessment process.	January 1997	40 CFR §1508.7
Environmental justice guidance under NEPA	Provides guidance and general direction on EO 12898 which requires each agency to identify and address, as appropriate, "disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations."	CEQ, Washington, DC, dated December 10, 1997	EO 12898, Federal actions to address environmental justice in a minority populations and low-income populations

[a] *Source*: National Aeronautics and Space Administration, 2001, Implementing The National Environmental Policy Act And Executive Order 12114, Chapter 2.

DISCUSSION: EVOLUTION OF ENVIRONMENTAL INDICATORS FOR AIR

The term *smog* is a shorthand combination of "smoke–fog." However, it is really the code word for photochemical oxidant smog, the brown haze that can be seen when flying into Los Angeles, St. Louis, Denver, and other metropolitan areas around the world (see Fig. 1.6). Point-of-fact

Fig. 1.6. Photo of smog episode in Los Angeles, CA taken in May of 1972. *Source:* Documerica, US Environmental Protection Agency's Photo Gallery; Photographer: Gene Daniels.

is that to make smog, at least three ingredients are needed: light, hydrocarbons, and radical sources, such the oxides of nitrogen. Therefore, smog is found most often in the warmer months of the year, not because of temperature, but because these are the months with greater amounts of sunlight. More sunlight is available for two reasons, both attributed to the earth's tilt on its axis. In the summer, the earth is tilted toward the sun, so the angle of inclination of sunlight is greater than when the sun tipped away from the earth leading to more intensity of light per earth surface area. Also, the days are longer in the summer, so these two factors increase the light budget.

Hydrocarbons come from many sources, but the fact that internal combustion engines burn gasoline, diesel fuel, and other mixtures of hydrocarbons makes them a ready source. Complete combustion results in carbon dioxide and water, but anything short of complete combustion will be a source of hydrocarbons, including some of the original ones found in the fuels, as well as new ones formed during combustion. The compounds that become free radicals, like the oxides of nitrogen, are also readily available from internal combustion engines, since the three quarters of the troposphere is made up of molecular nitrogen (N_2). Although N_2 is relatively not chemically reactive, with the high temperature and pressure conditions in the engine, it does combine with the O_2 from the fuel/air mix and generates oxides that can provide electrons to the photochemical reactions.

The pollutant most closely associated with smog is ozone (O_3), which forms from the photochemical reactions mentioned above. In the early days of smog control efforts, O_3 was used more as a surrogate or *marker* for smog, since one could not really take a sample of smog. Later, O_3 became recognized as a pollutant in its own right since it was increasingly linked to respiratory diseases.

The original goal was to set and to achieve NAAQS in every state by 1975. These new standards were combined with charging the 50 states to develop state implementation plans (SIPs) to address industrial sources in the state. The ambient atmospheric concentrations are measured at over 4000 monitoring sites across the US. The ambient levels have continuously decreased, as shown in Table 1.3.

The Clean Air Act Amendments of 1977 mandated new dates to achieve attainment of NAAQS (many areas of the country had not met the prescribed dates set in 1970). Other amendments were targeted at insufficiently addressed types of air pollution, including acidic deposition (so-called "acid rain"), tropospheric ozone pollution, depletion of the stratospheric ozone layer, and a new program for air toxics, the National Emission Standards for Hazardous Air Pollutants (NESHAPs).

TABLE 1.3

Percentage Decrease in Ambient Concentrations of National Ambient Air Quality Standard Pollutants from 1985 through 1994

Pollutant	Decrease in Concentration
CO	28%
Lead	86%
NO_2	9%
Ozone	12%
PM_{10}	20%
SO_2	25%

Source: US Environmental Protection Agency

The 1990 Amendments to the Clean Air Act profoundly changed the law, by adding new initiatives and imposing dates to meet the law's new requirements. Here are some of the major provisions.

Urban Air Pollution Cities that failed to achieve human health standards as required by NAAQS were required to reach attainment within 6 years of passage, although Los Angeles was given 20 years, since it was dealing with major challenges in reducing ozone concentrations.

Almost 100 cities failed to achieve ozone standards, and were ranked from *marginal* to *extreme*. The more severe the pollution, the more rigorous controls required, although additional time was given to those extreme cities to achieve the standard. Measures included new or enhanced inspection/maintenance (I/M) programs for autos; installation of vapor recovery systems at gas stations and other controls of hydrocarbon emissions from small sources; and new transportation controls to offset increases in the number of miles traveled by vehicles. Major stationary sources of nitrogen oxides will have to reduce emissions.

The 41 cities failing to meet carbon monoxide standards were ranked *moderate* or *serious*; states may have to initiate or upgrade inspection and maintenance programs and adopt transportation controls. The 72 urban areas that did not meet PM_{10} standards were ranked *moderate*; states will have to implement Reasonably Available Control Technology (RACT); use of wood stoves and fireplaces may have to be curtailed.

The standards promulgated from the Clean Air Act Amendments are provided in Table 1.4. Note that the new particulate standard addresses smaller particles; i.e., particles with diameters $\leq 2.5\ \mu m$ ($PM_{2.5}$). Research has shown that exposure to these smaller particles is more likely to lead to health problems than do exposures to larger particles. Smaller particles are able to penetrate further into the lungs and likely are more bioavailable than the larger PM_{10}. Recently, however, concerns about larger particles (e.g. PM_{10}) have increased, particularly as research is beginning to link coarse particles to chronic diseases like asthma.

TABLE 1.4

National Ambient Air Quality Standards

Pollutant	Averaging period[a]	Standard	Primary standards[b]	Secondary standards[c]
Ozone	1 h	Cannot be at or above this level on more than 3 days over 3 years	125 ppb	125 ppb
	8 h	The average of the annual 4th highest daily 8 h maximum over a 3-year period cannot be at or above this level	85 ppb	85 ppb
Carbon monoxide	1 h	Cannot be at or above this level more than once per calendar year	35.5 ppm	35.5 ppm
	8 h	Cannot be at or above this level more than once per calendar year	9.5 ppm	9.5 ppm
Sulfur dioxide	3 h	Cannot be at or above this level more than once per calendar year	—	550 ppb
	24 h	Cannot be at or above this level more than once per calendar year	145 ppb	—
	Annual	Cannot be at or above this level	35 ppb	—
Nitrogen dioxide	Annual	Cannot be at or above this level	54 ppb	54 ppb
Respirable PM (aerodynamic diameter $\leq 10\,\mu m = PM_{10}$)	24 h	The 3-year average of the annual 99th percentile for each monitor within an area cannot be at or above this level	$155\,\mu g\,m^{-3}$	$155\,\mu g\,m^{-3}$
	Annual	The 3-year average of annual arithmetic mean concentrations at each monitor within an area cannot be at or above this level	$51\,\mu g\,m^{-3}$	$51\,\mu g\,m^{-3}$
Respirable PM (aerodynamic diameter $\leq 2.5\,\mu m = PM_{2.5}$)	24 hr	The 3-year average of the annual 98th percentile for each population-oriented monitor within an area cannot be at or above this level	$66\,\mu g\,m^{-3}$	$66\,\mu g\,m^{-3}$
	Annual	The 3-year average of annual arithmetic mean concentrationsfrom single or multiplecommunity-oriented monitors cannot be at or above this level	$15.1\,\mu g\,m^{-3}$	$15.1\,\mu g\,m^{-3}$

(*Continued*)

TABLE 1.4 (Continued)

Pollutant	Averaging period[a]	Standard	Primary standards[b]	Secondary standards[c]
Lead	Quarter	Cannot be at or above this level	$1.55\,\mu g\,m^{-3}$	$1.55\,\mu g\,m^{-3}$

[a] Integrated time used to calculate the standard. For example, for particulates, the filter will collect material for 24 h and then analyzed. The annual integration will be an integration of the daily values.
[b] Primary NAAQS are the levels of air quality that the EPA considers to be needed, with an adequate margin of safety, to protect the public health.
[c] Secondary NAAQS are the levels of air quality that the EPA judges necessary to protect the public welfare from any known or anticipated adverse effects.

Mobile Sources Vehicular tailpipe emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen were to be reduced with the 1994 models. Standards now have to be maintained over a longer vehicle life. Evaporative emission controls were mentioned as a means for reducing hydrocarbons. Beginning in 1992, "oxyfuel" gasolines blended with alcohol began to be sold during winter months in cities with severe carbon monoxide problems. In 1995, reformulated gasolines with aromatic compounds will were introduced in the nine cities with the worst ozone problems; but other cities were allowed to participate. Later, a pilot program introduced 150 000 low emitting vehicles to California that meet tighter emission limits through a combination of vehicle technology and substitutes for gasoline or blends of substitutes with gasoline. Other states are also participating in this initiative.

Toxic Air Pollutants The number of toxic air pollutants covered by the Clean Air Act was increased to 189 compounds in 1990. Most of these are carcinogenic, mutagenic, and/or toxic to neurological, endocrine, reproductive, and developmental systems. All 189 compound emissions were to be reduced within 10 years. The EPA published a list of source categories issued Maximum Achievable Control Technology (MACT) standards for each category over a specified timetable.

The next step beyond MACT standards is to begin to address chronic health risks that would still be expected if the sources meet these standards. This is known as residual risk reduction. The first step was to assess the health risks from air toxics emitted by stationary sources that emit air toxics after technology-based (MACT) standards are in place. The residual risk provision sets additional standards if MACT does not protect public health with an "ample margin of safety," as well as additional standards if they are needed to prevent adverse environmental effects.

What an "ample margin of safety" means is still up for debate, but one proposal for airborne carcinogens is shown in Fig. 1.7. That is, if a source can demonstrate that it will not contribute to greater than 10^{-6} cancer risk, then

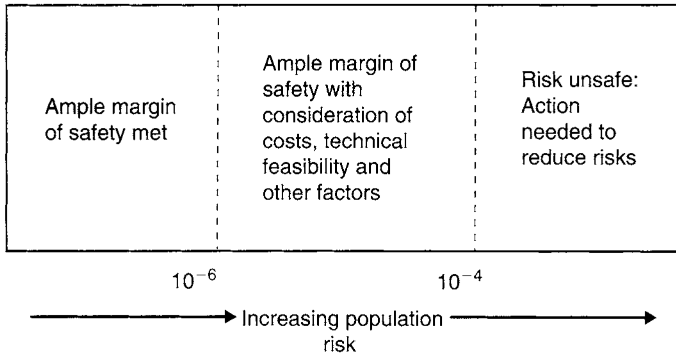


Fig. 1.7. Ample margin of safety based on airborne contaminant's cancer risk.

it meets the ample margin of safety requirements for air toxics. The ample margin needed to protect populations from non-cancer toxins, such as neurotoxins, is being debated, but it will involve the application of some type of hazard quotient (HQ). The HQ is the ratio of the potential exposure to the substance and the level at which no adverse effects are expected. An HQ < 1 means that the exposure levels to a chemical should not lead to adverse health effects. Conversely, an HQ < 1 means that adverse health effects are possible. Due to uncertainties and the feedback that is coming from the business and scientific communities, the ample margin of safety threshold is presently ranging from HQ $= 0.2$ to 1.0. So, if a source can demonstrate that it will not contribute to greater than the threshold (whether it is 0.2, 1.0, or some other level established by the federal government) for non-cancer risk, it meets the ample margin of safety requirements for air toxics.

Acid Deposition The introduction of acidic substances to flora, soil, and surface waters has been collectively called "acid rain" or "acid deposition." Acid rain is generally limited to the so-called "wet" deposition (low pH precipitation), but acidic materials can also reach the earth's surface by dry deposition ("acid aerosols") and acid fog (airborne droplets of water that contains sulfuric acid or nitric acid). Generally, acid deposition is not simply materials of pH < 7, but usually of pH < 5.7, since "normal" rainfall has a pH of about 5.7, due to the ionization of absorbed carbon dioxide (see discussion in Chapter 3). There is much concern about acid deposition because aquatic biota can be significantly harmed by only slight changes in pH. The problem of acidified soils and surface waters is a function of both the increase in acidity of the precipitation and the ability of the receiving waters and soil to resist the change in soil pH. So, it is the contribution of the human generated acidic materials, especially the oxides of sulfur and the oxides of nitrogen, that are considered to be the sources of "acid rain."

The 1990 amendments introduced a two-phase, market-based system to reduce sulfur dioxide emissions from power plants by more than half. Total annual emissions were to be capped at 8.9 million tons, a reduction of 10 million tons from the 1980 baseline levels. Power facilities were issued allowances based on fixed emission rates set in the law, as well as their previous fossil-fuel use. Penalties were issued for exceedances, although the allowances could be banked or traded within the fuel burning industry. In Phase I, large, high-emission plants in eastern and Midwestern US were required to reduce emissions by 1995. Phase II began in 2000 to set emission limits on smaller, cleaner plants and further tightening of the Phase I plants' emissions. All sources were required to install continuous emission monitors to assure compliance. Reductions in the oxides of nitrogen were also to be reduced; however, the approach differed from the oxides of sulfur, using EPA performance standards, instead of the two-phase system.

Protecting the Ozone Layer[16] The ozone layer filters out significant amounts of UV radiation from the sun. This UV radiation can cause skin damage and lead to certain forms of cancer, including the most fatal form, melanoma. Therefore, the international scientific and policy communities have been concerned about the release of chemicals that find their way to stratosphere and accelerate the breakdown of the ozone (see Discussion box: Ozone: Location, Location, and Location).

OZONE: LOCATION, LOCATION, AND LOCATION

Like the three rules of real estate, the location of ozone (O_3) determines whether it is essential or harmful. As shown in Fig. 1.8, O_3 concentrations are small, but increase in the stratosphere (about 90% of the atmosphere's O_3 lies in the layer between 10 and 17 km above the earth's surface up to an altitude of about 50 km). This is commonly known as the ozone layer. Most of the remaining ozone is in the lower part of the atmosphere, the troposphere. The stratospheric O_3 concentrations must be protected, while the tropospheric O_3 concentrations must be reduced.

Stratospheric ozone (the "good ozone") absorbs the most of the biologically damaging UV sunlight (UV-B), allowing only a small amount to reach the earth's surface. The absorption of UV radiation by ozone

[16] Sources for this discussion are: "Frequently Asked Questions" of the World Meteorological Organization/United Nations Environment Programme report, Scientific Assessment of Ozone Depletion: 1998 (WMO Global Ozone Research and Monitoring Project-Report No. 44, Geneva, 1999); and the Center for International Earth Science Information Network (CIESIN) website: http://www.ciesin.org/index.html.

generates heat, which is why Fig. 1.8 shows an increase in temperature in the stratosphere. Without the filtering action of the ozone layer, greater amounts of the sun's UV-B radiation would penetrate the atmosphere and would reach the earth's surface. Many experimental studies of plants and animals and clinical studies of humans have shown the harmful effects of excessive exposure to UV-B radiation.

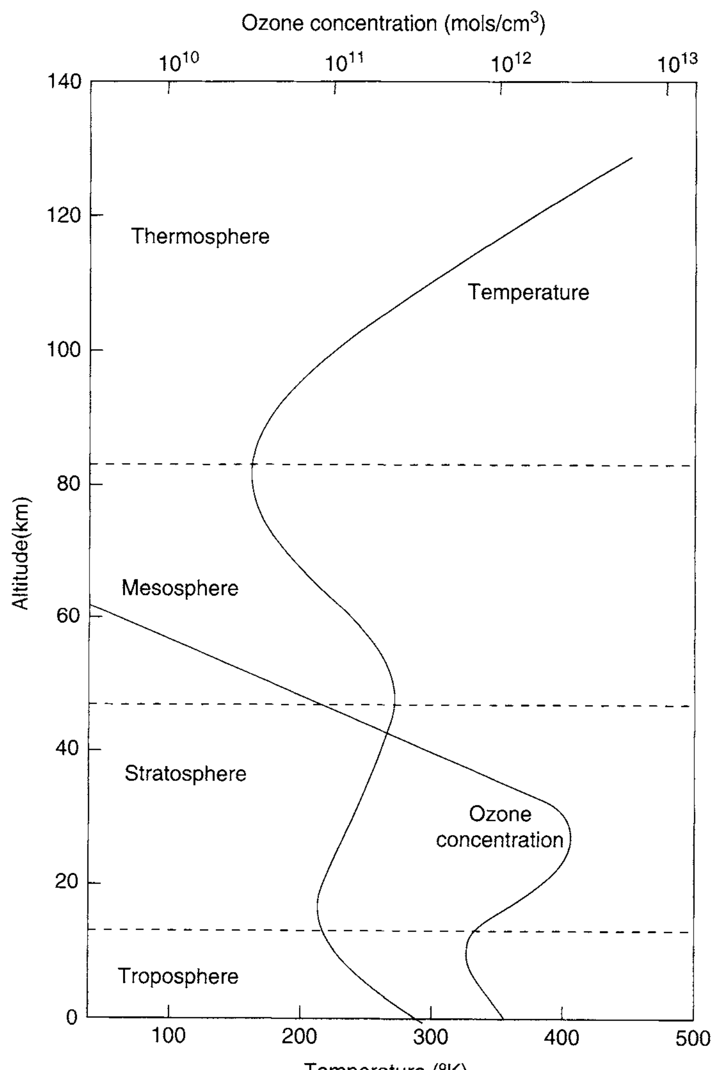


Fig. 1.8. Ozone concentrations and temperature profile of the earth's atmosphere. *Source*: Watson, R. T., Geller, M. A., Stolarski, R. S., and Hampson, R. F., *Present State of Knowledge of the Upper Atmosphere: An Assessment Report*, NASA Reference Publication, 1986.

In the troposphere, O_3 exposure is destructive ("bad ozone"), because it is highly reactive with tissues, leading to ecological and welfare effects, such as forest damage and reduced crop production, and human health effects, especially cardiopulmonary diseases.

Chlorofluorocarbons (CFCs), along with other chlorine- and bromine-containing compounds, can accelerate the depletion of stratospheric O_3 layer. CFCs were first developed in the early 1930s for many industrial, commercial, and household products. They are generally compressible, non-flammable, and nonreactive, which led to many CFC uses, including as coolants for commercial and home refrigeration units, and aerosol propellants. In 1973, chlorine was found to catalyze ozone destruction. Catalytic destruction of ozone removes the odd-numbered oxygen species [atomic oxygen (O) and ozone (O_3)], but leaves the chlorine unaffected. A complex scenario involving atmospheric dynamics, solar radiation, and chemical reactions accounts for spring thinning of the ozone layer at the earth's poles. Global monitoring of ozone levels from space using National Aeronautics and Space Administration's (NASA) Total Ozone Mapping Spectrometer (TOMS) instrument has shown significant downward trends in ozone concentrations at all of the earth's latitudes, except the tropics. Even with the international bans and actions, stratospheric ozone levels are expected to be lower than pre-depletion levels for many years because CFCs are persistent in the troposphere, from where they are transported to the stratosphere. In the high-energy stratosphere, the compounds undergo hundreds of catalytic cycles involving O_3 before the CFCs are scavenged by other chemicals.

A search for more environmentally benign substances has been underway for some time. One set of potential substitutes is the hydrochlorofluorocarbons (HCFCs). Obviously, the HCFC molecules contain Cl atoms, but the hydrogen increases the reactivity of the HCFCs with other tropospheric chemical species. These low altitude reactions decrease the probability of a Cl atom finding its way to the stratosphere. Hydrofluorocarbons (HFCs) are potential substitutes that lack chlorine.

The new act built upon the Montreal Protocol on substances that deplete the ozone layer, the international treaty where nations agreed to reduce or eliminate ozone-destroying gas production and uses of chemicals that pose a threat to the ozone layer. The amendments further restricted the use, emissions, and disposal of these chemicals, including the phasing out of the production of CFCs, as well as other chemicals that lead to ozone attacking halogens, such as tetrachloromethane (commonly called carbon tetrachloride) and methyl chloride by the year 2000, and methyl chloroform by 2002. The act also will freeze the production of

CFCs in 2015 and requires that CFCs be phased out completely by 2030. Companies servicing air conditioning for vehicles are now required to purchase certified recycling equipment and train employees. EPA regulations require reduced emissions from all other refrigeration sectors to lowest achievable levels. "Nonessential" CFC applications are prohibited. The act increases the labeling requirements of the Toxic Substances Control Act (TSCA) by mandating the placement of warning labels on all containers and products (such as cooling equipment, refrigerators, and insulation) that contain CFCs and other ozone-depleting chemicals.

4. *Solid and Hazardous Wastes Laws*

Although the Clean Air Act and its amendments comprise the most notable example of US legislation passed to protect air quality, other laws address air pollution more indirectly. For example, air pollution around solid and hazardous waste facilities can be problematic. The two principal US laws governing solid wastes are the Resource Conservation and Recovery Act (RCRA) and Superfund. The RCRA law covers both hazardous and solid wastes, while Superfund and its amendments generally address abandoned hazardous waste sites. RCRA addresses active hazardous waste sites.

Management of Active Hazardous Waste Facilities With RCRA, the US EPA received the authority to control hazardous waste throughout the waste's entire life cycle, known as the "cradle-to-grave." This means that manifests must be prepared to keep track of the waste, including its generation, transportation, treatment, storage, and disposal. RCRA also set forth a framework for the management of non-hazardous wastes in Subtitle D.

The Federal Hazardous and Solid Waste Amendments (HSWA) to RCRA required the phase out of land disposal of hazardous waste. HSWA also increased the federal enforcement authority related to hazardous waste actions, set more stringent hazardous waste management standards, and provided for a comprehensive UST program.

The 1986 amendments to RCRA allowed the federal government to address potential environmental problems from USTs for petroleum and other hazardous substances.

Addressing Abandoned Hazardous Wastes The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is commonly known as Superfund. Congress enacted it in 1980 to create a tax on the chemical and petroleum industries and to provide extensive federal authority for responding directly to releases or threatened releases of hazardous substances that may endanger public health or the environment.

The Superfund law established prohibitions and requirements concerning closed and abandoned hazardous waste sites; established provisions for the liability of persons responsible for releases of hazardous waste at these sites; and established a trust fund to provide for cleanup when no responsible party could be identified.

The CERCLA response actions include:

- Short-term removals, where actions may be taken to address releases or threatened releases requiring prompt response. This is intended to eliminate or reduce exposures to possible contaminants.
- Long-term remedial response actions to reduce or eliminate the hazards and risks associated with releases or threats of releases of hazardous substances that are serious, but not immediately life threatening. These actions can be conducted only at sites listed on EPA's National Priorities List (NPL).

Superfund also revised the National Contingency Plan (NCP), which sets guidelines and procedures required when responding to releases and threatened releases of hazardous substances.

CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986. These amendments stressed the importance of permanent remedies and innovative treatment technologies in cleaning up hazardous waste sites. SARA required that Superfund actions consider the standards and requirements found in other state and federal environmental laws and regulations and provided revised enforcement authorities and new settlement tools. The amendments also increased state involvement in every aspect of the Superfund program, increased the focus on human health problems posed by hazardous waste sites, encouraged more extensive citizen participation in site cleanup decisions, and increased the size of the Superfund trust fund.

SARA also mandate that the Hazard Ranking System (HRS) be revised to make sure of the adequacy of the assessment of the relative degree of risk to human health and the environment posed by uncontrolled hazardous waste sites that may be placed on the NPL.

Environmental Product and Consumer Protection Laws Although most of the authorizing legislation targeted at protecting and improving the environment is based on actions needed in specific media (i.e. air, water, soil, and sediment), some law has been written in an attempt to prevent environmental and public health problems while products are being developed and before their usage. In this way, air pollution is prevented to some extent at the potential source, such as products that can lead to indoor air pollution.

The predominant product laws designed to protect the environment are the Federal Food, Drug, and Cosmetics Act (FFDCA); the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA); and the Toxic Substances Control

Act (TSCA). These three laws look at products in terms of potential risks for yet-to-be-released products and estimated risks for products already in use. If the risks are unacceptable, new products may not be released as formulated or the uses will be strictly limited to applications that meet minimum risk standards. For products already in the marketplace, the risks are periodically reviewed. For example, pesticides have to be periodically re-registered with the government. This re-registration process consists of reviews of new research and information regarding health and environmental impacts discovered since the product's last registration.

FIFRA's major mandate is to control the distribution, sale, and applications of pesticides. This not only includes studying the health and environmental consequences of pesticide usage, but also to require that those applying the pesticides register when they purchase the products. Commercial applicators must be certified by successfully passing exams on the safe use of pesticides. FIFRA requires that the EPA license any pesticide used in the US. The licensing and registration makes sure that pesticide is properly labeled and will not cause unreasonable environmental harm.

An important, recent product production law is the Food Quality Protection Act (FQPA), including new provisions to protect children and limit their risks to carcinogens and other toxic substances. The law is actually an amendment to FIFRA and FFDCA that includes new requirements for safety standard—reasonable certainty of no harm—that must be applied to all pesticides used on foods. FQPA mandates a single, health-based standard for all pesticides in all foods; gives special protections for infants and children; expedites approval of pesticides likely to be safer than those in use; provides incentives for effective crop protection tools for farmers; and requires regular re-evaluation of pesticide registrations and tolerances so that the scientific data supporting pesticide registrations includes current findings.

There is some ongoing debate about the actual routes and pathways that contribute the most to pesticide exposure. For example, certain pesticides seem to be most likely to be present in dietary pathways (e.g. the purchased food contains the pesticide), nondietary ingestion (e.g. the food is contaminated by airborne pesticides in the home or the people living in the home touch contaminated surfaces and then touch the food), and dermal exposure (people come into contact with the pesticide and it infiltrates the skin). This seems to vary considerably by the type of pesticide, but it suffices to say that the air pathways are important.

Another product-related development in recent years is the screening program for endocrine disrupting substances. Research suggests a link between exposure to certain chemicals and damage to the endocrine system in humans and wildlife. Because of the potentially serious consequences of human exposure to endocrine disrupting chemicals, Congress added specific language on endocrine disruption in the FQPA and recent amendments to the Safe Drinking Water Act (SDWA). The FQPA mandated that the EPA develop an endocrine disruptor screening program, and the SDWA authorizes EPA to screen endocrine disruptors found in drinking water systems. The newly developed Endocrine Disruptor Screening Program focuses on methods and procedures to detect and to characterize the endocrine activity of pesticides and other chemicals (see Fig. 1.9). The scientific data needed for the estimated 87 000 chemicals in commerce does not exist to conduct adequate assessments of potential risks. The screening program is being used by EPA to collect this information for endocrine disruptors and to decide appropriate regulatory action by first assigning each chemical to an endocrine disruption category.

The chemicals undergo sorting into four categories according to the available existing, scientifically relevant information:

1. Category 1 chemicals have sufficient, scientifically relevant information to determine that they are not likely to interact with the estrogen, androgen, or thyroid systems. This category includes some polymers and certain exempted chemicals.
2. Category 2 chemicals have insufficient information to determine whether they are likely to interact with the estrogen, androgen, or thyroid systems, thus will need screening data.
3. Category 3 chemicals have sufficient screening data to indicate endocrine activity, but data to characterize actual effects are inadequate and will need testing.
4. Category 4 chemicals already have sufficient data for the EPA to perform a hazard assessment.

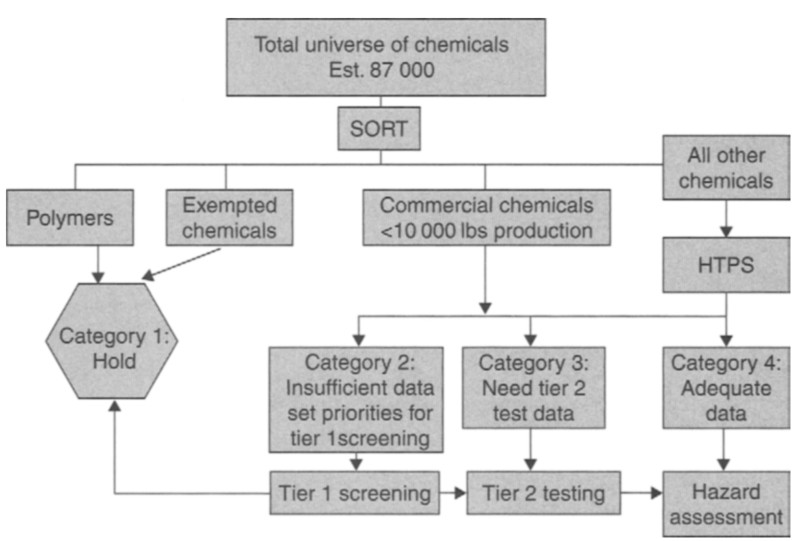


Fig. 1.9. Endocrine disruptor screening program of the US Environmental Protection Agency. *Source*: US EPA, *Report to Congress: Endocrine Disruptor Screening Program*, 2000.

TSCA gives the EPA the authority to track 75 000 industrial chemicals currently produced or imported to the US. This is accomplished through screening the chemicals and requiring that reporting and testing be done for any substance that presents a hazard to human health or the environment. If chemical poses a potential or actual risk that is unreasonable, the EPA may ban the manufacture and import of that chemical.

The EPA has tracked thousands of new chemicals being developed by industries each year, if those chemicals have either unknown or dangerous characteristics. This information is used to determine the type of control that these chemicals would need to protect human health and the environment. Manufacturers and importers of chemical substances first submitted information about chemical substances already on the market during an initial inventory. Since the initial inventory was published, commercial manufacturers or importers of substances not on the inventory have been subsequently required to submit notices to the EPA, which has developed guidance about how to identify chemical substances to assign a unique and unambiguous description of each substance for the inventory. The categories include:

- polymeric substances;
- certain chemical substances containing varying carbon chains;
- products containing two or more substances, formulated, and statutory mixtures; and
- chemical substances of unknown or variable composition, complex reaction products and biological materials (UVCB Substance).

Environmental policy and science set a framework for addressing air pollution. While the programs to address air pollution are recent, controlling air pollution is rooted in Antiquity.

III. AIR POLLUTION BEFORE THE INDUSTRIAL REVOLUTION

One of the reasons the tribes of early history were nomadic was to move periodically away from the stench of the animal, vegetable, and human wastes they generated. When the tribesmen learned to use fire, they used it for millennia in a way that filled the air inside their living quarters with the products of incomplete combustion. Examples of this can still be seen today in some of the more primitive parts of the world. After its invention, the chimney removed the combustion products and cooking smells from the living quarters, but for centuries the open fire in the fireplace caused its emission to be smoky. In AD 61 the Roman philosopher Seneca reported thus on conditions in Rome:

> As soon as I had gotten out of the heavy air of Rome and from the stink of the smoky chimneys thereof, which, being stirred, poured forth whatever pestilential vapors and soot they had enclosed in them, I felt an alteration of my disposition.

Air pollution, associated with burning wood in Tutbury Castle in Nottingham, was considered "unendurable" by Eleanor of Aquitaine, the wife of King Henry II of England, and caused her to move in the year 1157. One hundred sixteen years later, coal burning was prohibited in London; and in 1306, Edward I issued a royal proclamation enjoining the use of *sea coal* in furnaces. Elizabeth I barred the burning of coal in London when Parliament was in session. The repeated necessity for such royal action would seem to indicate that coal continued to be burned despite these edicts. By 1661, the pollution of London had become bad enough to prompt John Evelyn to submit a brochure "Fumifugium, or the Inconvenience of the Aer, and Smoake of London Dissipated (together with some remedies humbly proposed)" to King Charles II and Parliament. This brochure has been reprinted and is recommended to students of air pollution [1].

Fig. 1.10. Lead smelting furnace. *Source*: Agricola, G., *De Re Metallica*, Book X, p. 481, Basel, Switzerland, 1556. Translated by Hoover, H. C. and Hoover, L. H. *Mining Magazine*, London, 1912. Reprinted by Dover Publications, New York, 1950.

It proposes means of air pollution control that are still viable in the 21st century.

The principal industries associated with the production of air pollution in the centuries preceding the Industrial Revolution were metallurgy, ceramics, and preservation of animal products. In the bronze and iron ages, villages were exposed to dust and fumes from many sources. Native copper and gold were forged, and clay was baked and glazed to form pottery and bricks before 4000 BC. Iron was in common use and leather was tanned before 1000 BC. Most of the methods of modern metallurgy were known before AD 1. They relied on charcoal rather than coal or coke. However, coal was mined and used for fuel before AD 1000, although it was not made into coke until about 1600; and coke did not enter metallurgical practice significantly until about 1700. These industries and their effluents as they existed before 1556 are best described in the book "De Re Metallica" published in that year by Georg Bauer, known as Georgius Agricola (Fig. 1.10). This book was translated into English and published in 1912 by Herbert Clark Hoover and his wife [2].

Examples of the air pollution associated with the ceramic and animal product preservation industries are shown in Figs. 1.11 and 1.12, respectively.

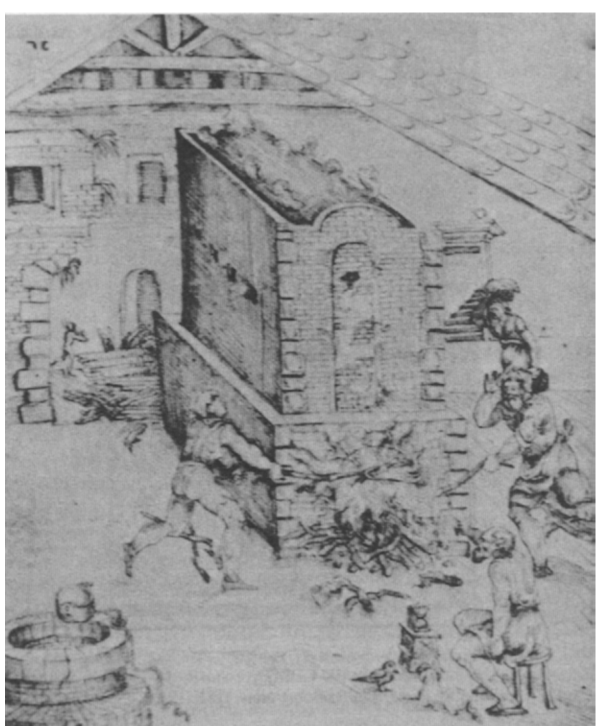


Fig. 1.11. A pottery kiln. *Source*: Cipriano Piccolpasso, *The Three Books of the Potters's Art*, fol. 35C, 1550. Translated by Rackham, B., and Van de Put, A. Victoria and Albert Museum, London, 1934.

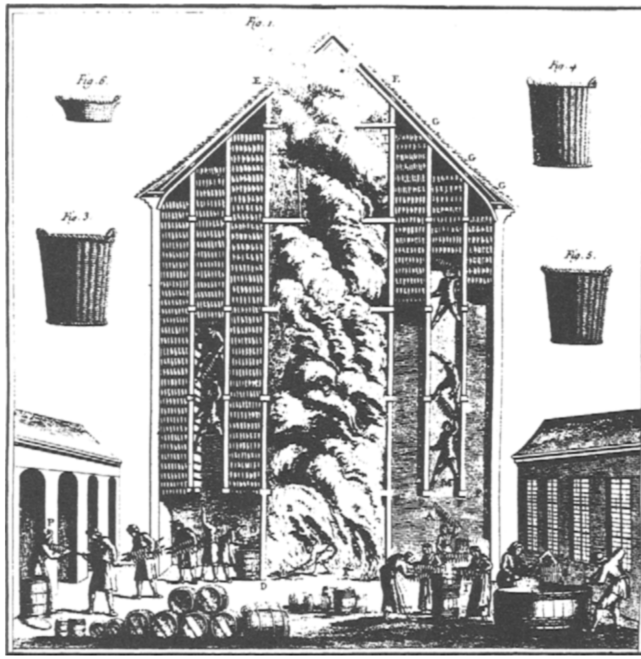


Fig. 1.12. A kiln for smoking red herring. *Source*: Duhamel due Monceau, H. L., Traité général des pêches, Vol. 2, Section III, Plate XV, Fig. 1, Paris, 1772.

IV. AIR POLLUTION AND THE INDUSTRIAL REVOLUTION

The Industrial Revolution was the consequence of the harnessing of steam to provide power to pump water and move machinery. This began in the early years of the eighteenth century, when Savery, Papin, and Newcomen designed their pumping engines, and culminated in 1784 in Watt's reciprocating engine. The reciprocating steam engine reigned supreme until it was displaced by the steam turbine in the twentieth century.

Steam engines and steam turbines require steam boilers, which, until the advent of the nuclear reactor, were fired by vegetable or fossil fuels. During most of the nineteenth century, coal was the principal fuel, although some oil was used for steam generation late in the century.

The predominant air pollution problem of the nineteenth century was smoke and ash from the burning of coal or oil in the boiler furnaces of stationary power plants, locomotives, and marine vessels, and in home heating fireplaces and furnaces. Great Britain took the lead in addressing this problem, and, in the words of Sir Hugh Beaver [3]:

> By 1819, there was sufficient pressure for Parliament to appoint the first of a whole dynasty of committees "to consider how far persons using steam engines and furnaces could work them in a manner less prejudicial to public health and comfort." This committee confirmed the practicability of smoke prevention, as so many succeeding committees were to do, but as was often again to be experienced, nothing was done.

> In 1843, there was another Parliamentary Select Committee, and in 1845, a third. In that same year, during the height of the great railway boom, an act of Parliament disposed of trouble from locomotives once and for all (!) by laying down the dictum that they must consume their own smoke. The Town Improvement Clauses Act 2 years later applied the same panacea to factory furnaces. Then 1853 and 1856 witnessed two acts of Parliament dealing specifically with London and empowering the police to enforce provisions against smoke from furnaces, public baths, and washhouses and furnaces used in the working of steam vessels on the Thames.

Smoke and ash abatement in Great Britain was considered to be a health agency responsibility and was so confirmed by the first Public Health Act of 1848 and the later ones of 1866 and 1875. Air pollution from the emerging chemical industry was considered a separate matter and was made the responsibility of the Alkali Inspectorate created by the Alkali Act of 1863.

In the United States, smoke abatement (as air pollution control was then known) was considered a municipal responsibility. There were no federal or state smoke abatement laws or regulations. The first municipal ordinances and regulations limiting the emission of black smoke and ash appeared in the 1880s and were directed toward industrial, locomotive, and marine rather than domestic sources. As the nineteenth century drew to a close, the pollution of the air of mill towns the world over had risen to a peak (Fig. 1.13); damage to vegetation from the smelting of sulfide ores was recognized as a problem everywhere it was practiced.

The principal technological developments in the control of air pollution by engineering during the nineteenth century were the stoker for mechanical firing of coal, the scrubber for removing acid gases from effluent gas streams,

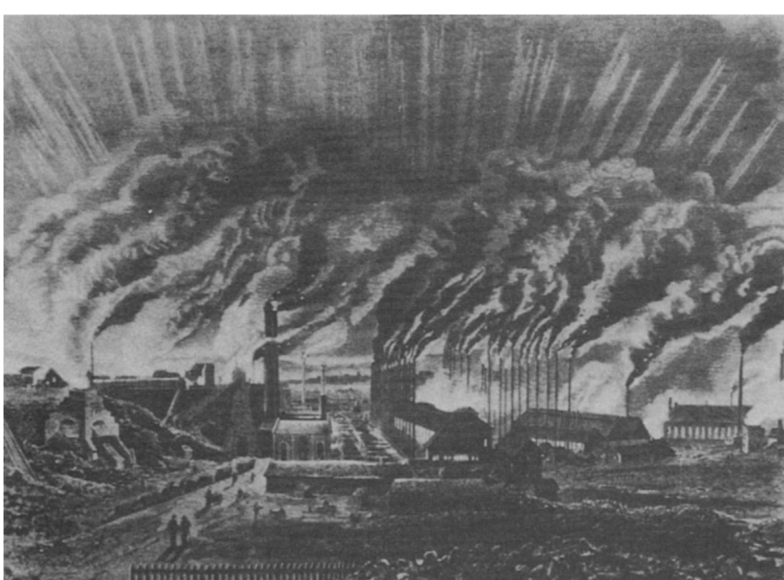


Fig. 1.13. Engraving (1876) of a metal foundry refining department in the industrial Saar region of West Germany. *Source*: The Bettmann Archive, Inc.

cyclone and bag house dust collectors, and the introduction of physical and chemical principles into process design.

V. RECENT AIR POLLUTION

A. 1900–1925

During the period 1900–1925 there were great changes in the technology of both the production of air pollution and its engineering control, but no significant changes in legislation, regulations, understanding of the problem, or public attitudes toward the problem. As cities and factories grew in size, the severity of the pollution problem increased.

One of the principal technological changes in the production of pollution was the replacement of the steam engine by the electric motor as the means of operating machinery and pumping water. This change transferred the smoke and ash emission from the boiler house of the factory to the boiler house of the electric generating station. At the start of this period, coal was hand-fired in the boiler house; by the middle of the period, it was mechanically fired by stokers; by the end of the period, pulverized coal, oil, and gas firing had begun to take over. Each form of firing produced its own characteristic emissions to the atmosphere.

At the start of this period, steam locomotives came into the heart of the larger cities. By the end of the period, the urban terminals of many railroads had been electrified, thereby transferring much air pollution from the railroad right-of-way to the electric generating station. The replacement of coal by oil in many applications decreased ash emissions from those sources. There was rapid technological change in industry. However, the most significant change was the rapid increase in the number of automobiles from almost none at the turn of the century to millions by 1925 (Table 1.5).

TABLE 1.5

Annual Motor Vehicle Sales in the United States[a]

Year	Total	Year	Total
1900	4192	1945	725 215
1905	25 000	1950	8 003 056
1910	187 000	1955	9 169 292
1915	969 930	1960	7 869 221
1920	2 227 347	1965	11 057 366
1925	4 265 830	1970	8 239 257
1930	3 362 820	1975	8 985 012
1935	3 971 241	1980	8 067 309
1940	4 472 286	1985	11 045 784
		1990	9 295 732

[a] Data include foreign and domestic sales for trucks, buses, and automobiles.

The principal technological changes in the engineering control of air pollution were the perfection of the motor-driven fan, which allowed large-scale gas-treating systems to be built; the invention of the electrostatic precipitator, which made particulate control in many processes feasible; and the development of a chemical engineering capability for the design of process equipment, which made the control of gas and vapor effluents feasible.

B. 1925–1950

In this period, present-day air pollution problems and solutions emerged. The Meuse Valley, Belgium, episode [4] occurred in 1930; the Donora, Pennsylvania, episode [5] occurred in 1948; and the Poza Rica, Mexico, episode [6] in 1950. Smog first appeared in Los Angeles in the 1940s (Fig. 1.14). The Trail, British Columbia, smelter arbitration [7] was completed in 1941. The first National Air Pollution Symposium in the United States was held in Pasadena, California, in 1949 [8], and the first United States Technical Conference on Air Pollution was held in Washington, DC, in 1950 [9]. The first large-scale surveys of air pollution were undertaken—Salt Lake City, Utah (1926) [10]; New York, (1937) [11]; and Leicester, England (1939) [12].

Air pollution research got a start in California. The Technical Foundation for Air Pollution Meteorology was established in the search for means of disseminating and protecting against chemical, biological, and nuclear warfare agents. Toxicology came of age. The stage was set for the air pollution scientific and technological explosion of the second half of the twentieth century.

Fig. 1.14. Los Angeles smog in the 1940s. *Source*: Los Angeles County, California.

(a)

Fig. 1.15. (a) Pittsburgh after the decrease in black smoke. *Source*: Allegheny County, Pennsylvania. (b) Pittsburgh before the decrease in black smoke.

A major technological change was the building of natural gas pipelines, and where this occurred, there was rapid displacement of coal and oil as home heating fuels with dramatic improvement in air quality; witness the much publicized decrease in black smoke in Pittsburgh (Fig. 1.15) and St. Louis. The diesel locomotive began to displace the steam locomotive, thereby slowing the pace of railroad electrification. The internal combustion engine bus started its displacement of the electrified streetcar. The automobile continued to proliferate (Table 1.5).

During this period, no significant national air pollution legislation or regulations were adopted anywhere in the world. However, the first state air pollution law in the United States was adopted by California in 1947.

(b)

Fig. 1.15. *(Continued)*

C. 1950–1980

In Great Britain, a major air pollution disaster hit London in 1952 [13], resulting in the passage of the Clean Air Act in 1956 and an expansion of the authority of the Alkali Inspectorate. The principal changes that resulted were in the means of heating homes. Previously, most heating was done by burning soft coal on grates in separate fireplaces in each room. A successful effort was made to substitute smokeless fuels for the soft coal used in this manner, and central or electrical heating for fireplace heating. The outcome was a decrease in "smoke" concentration, as measured by the blackness of paper filters through which British air was passed from $175\,\mu g\,m^{-3}$ in 1958 to $75\,\mu g\,m^{-3}$ in 1968 [14].

During these two decades, almost every country in Europe, as well as Japan, Australia, and New Zealand, experienced serious air pollution in its larger cities. As a result, these countries were the first to enact national air pollution control legislation. By 1980, major national air pollution research centers had been set up at the Warren Springs Laboratory, Stevenage, England; the Institut National de la Santé et de las Recherche Medicale at Le Visinet, France; the Rijksinstituut Voor de Volksgezondheid, Bilthoven and the Instituut voor Gezondheidstechniek-TNO, Delft, The Netherlands; the Statens Naturvardsverk, Solna, Sweden; the Institut für Wasser-Bodenund Luft-hygiene, Berlin; and the Landensanstalt für Immissions und Bodennutzungsshutz, Essen, Germany. The important air pollution research centers in Japan are too numerous to mention.

In the United States, the smog problem continued to worsen in Los Angeles and appeared in large cities throughout the nation (Fig. 1.16). In 1955 the first federal air pollution legislation was enacted, providing federal support for air pollution research, training, and technical assistance. Responsibility for the administration of the federal program was given to the Public Health Service (PHS) of the United States Department of Health, Education, and Welfare, and remained there until 1970, when it was transferred to the new US EPA. The initial federal legislation was amended and extended several times between 1955 and 1980, greatly increasing federal

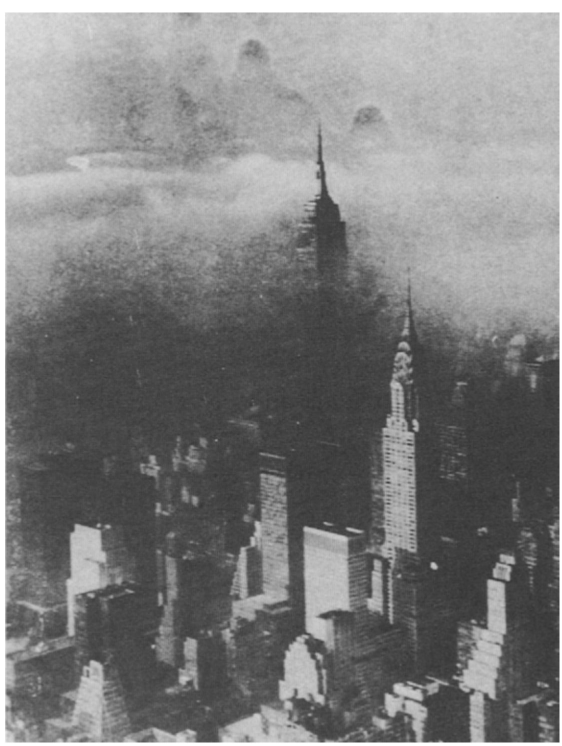


Fig. 1.16. Smog in New York City in the 1950s. *Source*: Wide World Photos.

authority, particularly in the area of control [15]. The automobile continued to proliferate (Table 1.5).

As in Europe, air pollution research activity expanded tremendously in the United States during these three decades. The headquarters of federal research activity was at the Robert A. Taft Sanitary Engineering Center of the PHS in Cincinnati, Ohio, during the early years of the period and at the National Environmental Research Center in Triangle Park, North Carolina, at the end of the period.

An International Air Pollution Congress was held in New York City in 1955 [16]. Three National Air Pollution Conferences were held in Washington, DC, in 1958 [17], 1962 [18], and 1966 [19]. In 1959, an International Clean Air Conference was held in London [20].

In 1964, the International Union of Air Pollution Prevention Associations (IUAPPA) was formed. IUAPPA has held International Clean Air Congresses in London in 1966 [21]; Washington, DC, in 1970 [22]; Dusseldorf in 1973 [23]; Tokyo in 1977 [24]; Buenos Aires in 1980 [25]; Paris in 1983 [26]; Sydney in 1986 [27]; The Hague in 1989 [28]; and Montreal in 1992 [29].

Technological interest during these 30 years has focused on automotive air pollution and its control, on sulfur oxide pollution and its control by sulfur oxide removal from flue gases and fuel desulfurization, and on control of nitrogen oxides produced in combustion processes.

Air pollution meteorology came of age and, by 1980, mathematical models of the pollution of the atmosphere were being energetically developed. A start had been made in elucidating the photochemistry of air pollution. Air quality monitoring systems became operational throughout the world. A wide variety of measuring instruments became available.

VI. THE 1980s

The highlight of the 1970s and 1980s was the emergence of the ecological, or total environmental, approach. Organizationally, this has taken the form of departments or ministries of the environment in governments at all levels throughout the world. In the United States there is a federal EPA, and in most states and populous counties and cities, there are counterpart organizations charged with responsibility for air and water quality, sold waste sanitation, noise abatement, and control of the hazards associated with radiation and the use of pesticides. This is paralleled in industry, where formerly diffuse responsibility for these areas is increasingly the responsibility of an environmental protection coordinator. Similar changes are evident in research and education.

Pollution controls were being built into pollution sources—automobiles, power plants, factories—at the time of original construction rather than later on. Also, for the first time, serious attention was directed to the problems caused by the "greenhouse" effect of carbon dioxide and other gases building up in the atmosphere, possible depletion of the stratospheric ozone layer by fluorocarbons, long-range transport of pollution, prevention of significant deterioration (PSD), and acidic deposition.

VII. RECENT HISTORY

The most sweeping change, in the United States at least, in the decade of the 1990s was the passage of the Clean Air Act Amendments on November 15, 1990 [29]. This was the only change in the Clean Air Act since 1977, even though the US Congress had mandated that the Act be amended much earlier. Michigan Representative John Dingell referred to the amendments as "the most complex, comprehensive, and far-reaching environmental law any Congress has ever considered." John-Mark Stenvaag has stated in his book, "Clean Air Act 1990 Amendments, Law and Practice" [30], "The enormity of the 1990 amendments begs description. The prior Act, consisting of approximately 70 000 words, was widely recognized to be a remarkably complicated, unapproachable piece of legislation. If environmental attorneys, government officials, and regulated entities were awed by the prior Act, they will be astonished, even stupefied, by the 1990 amendments. In approximately 145 000 new words, Congress has essentially tripled the length of the prior Act and geometrically increased its complexity."

The 1990s saw the emergence, in the popular media, of two distinct but closely related global environmental crises, uncontrolled global climate changes and stratospheric ozone depletion. The climate changes of concern were both the warming trends caused by the buildup of greenhouse gases in the atmosphere and cooling trends caused by PM and sulfates in the same atmosphere. Some researchers have suggested that these two trends will cancel each other. Other authors have written [31] that global warming may not be all bad. It is going to be an interesting decade as many theories are developed and tested during the 1990s. The "Earth Summit," really the UN Conference of Environment and Development, in Rio de Janeiro during June 1992 did little to resolve the problems, but it did indicate the magnitude of the concern and the differences expressed by the nations of the world.

The other global environmental problem, stratospheric ozone depletion, was less controversial and more imminent. The US Senate Committee Report supporting the Clean Air Act Amendments of 1990 states, "Destruction of the ozone layer is caused primarily by the release into the atmosphere of chlorofluorocarbons (CFCs) and similar manufactured substances—persistent chemicals that rise into the stratosphere where they catalyze the destruction of stratospheric ozone. A decrease in stratospheric ozone will allow more UV radiation to reach Earth, resulting in increased rates of disease in humans, including increased incidence of skin cancer, cataracts, and, potentially, suppression of the immune system. Increased UV radiation has also been shown to damage crops and marine resources."

The Montreal Protocol of July 1987 resulted in an international treaty in which the industrialized nations agreed to halt the production of most ozone-destroying CFCs by the year 2000. This deadline was hastily changed to 1996, in February 1992, after a US NASA satellite and high-altitude sampling aircraft found levels of chlorine monoxide over North America that were 50% greater than that measured over Antarctica.

Global problems continue to hold sway. In the early years of the 21st Century, global air pollution has taken on a greater urgency, both within the scientific community and the general public. Courts in the United States have mandated that carbon dioxide be considered and regulated as an air pollutant due to its radiant properties and link to global warming. The long-range atmospheric transport of persistent, bioaccumulative toxic substances (PBTs) has led to elevated concentrations in the tissues of marine and arctic mammals, as well as increased PBT levels in the mother's milk of indigenous people, such as the Inuit. Stratospheric ozone depletion is strongly suspected to have played a role in diminished biodiversity around the world.

VIII. THE FUTURE

The air pollution problems of the future are predicated on the use of more and more fossil and nuclear fuel as the population of the world increases. During the lifetime of the students using this book, partial respite may be offered by solar, photovoltaic, geothermal, wind, non-fossil fuel (hydrogen and biomass), and oceanic (thermal gradient, tidal, and wave) sources of energy. Still, many of the agonizing environmental decisions of the next decades will involve a choice between fossil fuel and nuclear power sources and the depletion of future fuel reserves for present needs. Serious questions will arise regarding whether to conserve or to use these reserves—whether to allow unlimited growth or to curb it.

Other problems concerning transportation systems, waste processing and recycling systems, national priorities, international economics, employment versus environmental quality, and personal freedoms will continue to surface. The choices will have to be made, ideally by educated citizens and enlightened leaders.

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QUESTIONS

1. Discuss the development of the use of enclosed space for human occupancy over the period of recorded history.
2. Discuss the development of the heating and cooling of enclosed space for human occupancy over the period of recorded history.
3. Discuss the development of the lighting of enclosed space for human occupancy over the period of recorded history.
4. Discuss the development of means to supplement human muscular power over the period of recorded history.
5. Discuss the development of transportation over the period of recorded history.
6. Discuss the development of agriculture over the period of recorded history.
7. Discuss the future alternative sources of energy for light, heat, and power.
8. Compare the so-called soft (i.e. widely distributed small sources) and hard (i.e. fewer very large sources) paths for the future provision of energy for light, heat, and power.
9. What have been the most important developments in the history of the air pollution problem since the publication of this edition of this book?
10. Explain the science behind the phrase, "Think globally, but act locally."
11. What are some of the major differences between how the Clean Air Act (NESHAPs) addresses hazardous chemicals and how they are addressed by the hazardous waste laws (RCRA and Superfund)?
12. Choose two chemicals from the list of 189 "air toxics" (visit: http://www.epa.gov/ttn/atw/orig189.html). Give at least three steps that a business can take to approach air pollution from these substances.