UEGO	universal exhaust gas sensor
ULEV	ultra-low emission vehicles
VOC	volatile organic compounds
ZEV	zero emission vehicles

Chapter 17

CDC	Center for Disease Control and Prevention
COL	conservation of life
EIA	environmental impact assessment
GE	green engineering
HAZOP	hazard and operability analysis
LCA	life cycle analysis
MSDS	material safety data sheets
NEPA	National Environmental Policy Act
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limits
PI	process integration
REL	recommended exposure limits

CHAPTER 1

Air Pollution: Introduction

1.1 Introduction

All living things interact with their surroundings. They consume resources and emit wastes. These wastes become pollutants when they accumulate in concentrations beyond the normal, self-cleaning or dispersive capabilities of the environment. Air pollution occurs when such wastes accumulate in the atmosphere.

There are many definitions of air pollution; each is somewhat different, but most definitions include the idea of the presence of substances in outdoor air that cause harm to humans, animals, plants and/or property, and exist in concentrations above that found in clean air. See table 5-1 for a list of the constituents of clean air, and which constituents are currently changing.

The substances can be dusts, fumes, mists, liquids, smokes, vapors, gases, odorous substances, or any combination thereof while excluding uncombined water vapor. Typical substances that are considered pollutants include:

- Particle matter (PM),
- Sulfur Oxides (SO_x),
- Volatile Organic Compounds (VOC),
- Nitrogen Oxides (NO_x),
- Carbon Monoxide (CO),
- Fluorine, Chlorine, Bromine, and their compounds,
- Radioactive substances,
- Hazardous substances (carcinogens, mutagens, teratogens, …),
- Photochemical substances (chemically react in sunlight to form ozone and smog), and
- Metals (mercury, lead, nickel, zinc, …).

Harm includes discomfort or damage to the body, or prevention of the enjoyment of one's property. The harm from air pollution has been a concern of people and governments for hundreds of years. The first known air pollution law occurred in 1306 when King Edward I of England banned the burning of sea-coal in London's craftsman furnaces due to the foul smelling fumes.

There are four basic categories or types of air:

- Outdoor air, also called ambient air, is monitored nationwide and regulated at the national level by the Environmental Protection Agency (EPA). It is the most studied and most regulated type of air. The majority of this textbook focuses on the study and control of ambient air quality.

- Indoor air within public buildings or vehicles includes privately owned buildings where the public has access, such as restaurants, banks, sport stadiums, schools, universities, government buildings, and vehicles such as buses, trains, and airplanes. State and local governments typically oversee indoor air with very limited federal government oversight. See Chapter 15 for more information.
- Workplace or occupational air includes any air, indoor or outdoor, where people work. It is the right and responsibility of the worksite owner/operator to maintain air quality that does not cause harm to any employee. The Occupational Health and Safety Administration (OSHA) oversee the monitoring and regulation for workplace air quality. See Chapter 15 for more information.
- Indoor air within private building or vehicles where the public does not have general access, such as residential homes and automobiles. There are few if any national or local regulations concerning private indoor air. However, many state and local building codes either require or encourage builders to include provisions for creating and maintaining indoor air quality. Leadership in Energy and Environmental Design, LEED, is a green building certification program that recognizes best practices during design and construction (US-GBC, 2014). Indoor environmental quality is an area with such standards. The standards promote better indoor air quality and access to daylight.

A particular air space may include multiple categories. For example, a college classroom is public air for the students and workplace air for the faculty and staff that work there. A restaurant can be private air for the owner, public air for the customers, and workplace air for the employees. In such cases, the most stringent requirements for air quality must be met.

Some additional concepts in air pollution definitions, though not as common, include: the pollution must be caused by human activities, the pollutant must cause harm, and that the harm (not the pollutant) must be controllable. All of these concepts concern identifying and solving air pollution problems. An example of an air pollution source that would be excluded from these definitions is the emissions from a volcano, which cause genuine harm and generate airborne pollutants, but laws against volcanic eruptions do not work, nor is it possible to control these emissions.

1.2 Air Pollution Problems

There are many air pollution problems. The most serious affect people and their possessions everywhere, other problems are more localized such as in urban areas or near particular sources. A few problems have been solved and are no longer a concern; most problems that have been identified are being improved. A few problems are just starting to be addressed and may still be getting worse. This section will introduce several of the most important air pollution problems.

Above ground testing of nuclear weapons.

The United States, The Union of Soviet Socialist Republics, United Kingdom, France, The People's Republic of China, and South Africa detonated more than 500 nuclear devices in the atmosphere between 1945 and 1980, see Table 1-1. These tests released vast quantities of radioactive material into the atmosphere and lifted huge quantities of radioactively contaminated earth high into the atmosphere (more than 15 km above the Earth's surface during some tests). By the early 1960's these materials could be found everywhere on Earth (Simon, et al., 2006).

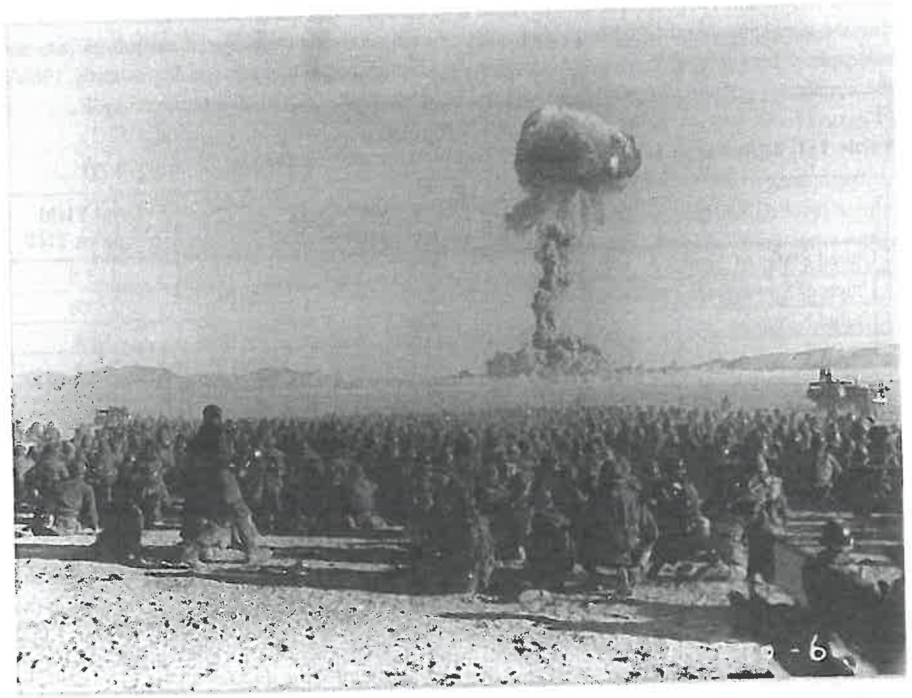
Table 1-1. Summary of Above Ground Nuclear Device Testing.

Nation	Number of Above Ground Detonations	Years	Total Yield megatons TNT
United States of America	216	1945-1962	153.8
Union of Soviet Socialist Republics	214	1949-1962	281.6
United Kingdom	21	1952-1958	10.8
France	46	1960-1974	11.4
People's Republic of China	23	1964-1980	21.5
South Africa	1	1979	0.003

The released materials usually start as a vertical moving column or cloud. Once it reaches its stabilization height (where the initial velocity and heat induced buoyancy are balanced by gravity) it forms a mushroom-shaped cloud, see Figure 1-1. Next, vertical and horizontal winds begin to disperse it, and the materials move downwind. The material spreads over large areas because the winds speed and direction vary over the height of the cloud. The largest particles settle first, in the local area near the test (within 500 km). Medium sized particles fallout regionally (within 3,000 km). The smallest particles, gases, and vapors travel more than 3,000 km and become global fallout. Highly local and concentrated fallout may occur at great distances due to rainfall.

People, animals, and plants are exposed to the fallout once it deposits on the earth's surface. Exposure may be external or internal. Gamma radiation emitted from the various radioactive particles causes external irradiation. Internal irradiation results from inhaling or ingesting the fallout materials, which release radiation inside the organism when the radioactive atoms decay. A study by the US National Cancer Institute found that any person living in the United States since 1951 has been exposed to radioactive fallout from these above ground tests, and all of a person's organs and tissues have received some exposure (NCI, 1997). The most common contaminants of concern are cesium-137, iodine-131, and strontium-90. Cesium-137 has a half-life of 30 years. It reacts with water to form a soluble salt. When ingested it is uniformly distributed throughout the body. It releases gamma radiation when it decays, which damages DNA and can cause a variety of cancers. Stron-

FIGURE 1-1. US Military Observing a Nuclear Test. This photo shows the November 1, 1951, "Dog" detonation, conducted as part of the Buster/Jangle test series between October and November of 1951. The test was an airdrop with a yield of 21 kilotons of TNT. The troops were located approximately 10 km from the blast. (NDEP, 2011).



tium-90 has a half-life of 28 years. Results from a study of baby teeth from children in St. Louis, MO, USA, showed increasing levels of strontium-90 throughout the 1950's. Children born in 1963 had levels 50 times greater than children born before nuclear testing began (Gould, 2000), (Mangano, 2003). Iodine-131 has a half-life of eight days. When released it can accumulate on plants and become ingested by the animals feeding on the plants. A typical human exposure comes from ingesting milk from animals that have consumed plants contaminated by fallout. It tends to concentrate in the thyroid gland and can cause cancer and other diseases in the thyroid. If it is inhaled or ingested by a nursing mother, it can be transferred to the infant via the mother's breast milk.

In 1963 the Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Under Water was signed in Moscow by the United States, the Soviet Union, and the United Kingdom as well as over 100 non-nuclear nations. Notably, France and China have not signed the treaty, but France has not conducted an above ground test since 1974 and China has not since 1980. The treaty bans all tests of nuclear weapons except those conducted underground.

The levels of radioactive contaminants in the environment have decreased since the above-ground test ban, with noticeable increases after the nuclear accidents at Chernobyl, Ukraine, (1986) and Fukushima, Japan (2011). The long-term reduction is directly attributable to the test ban, and this can be considered an air pollution problem that has been solved.

Lead pollution from fuel additives.

Lead, in the chemical form of tetraethyl lead (TEL), was used as a fuel additive for gasoline powered engines beginning in the 1920s. It boosted fuel octane rating, increased engine power and performance, and decreased pre-ignition problems (often called engine knocking or pinging). TEL began to be phased out in the US between the 1970s and 1995. As of 2011 only a few countries still allow its use (Afghanistan, Algeria, Burma, Georgia, Iraq, The Democratic People's Republic of Korea, and Yemen). It is a known neurotoxin, and poisoned the man who discovered this application, as well as many of the workers in its manufacturing facilities. Combustion destroys the TEL compound, but the lead is still released in either the gas phase or particle phase (as atomic lead or lead oxide). After release, it remains harmful to living things. See Section 13.3 for greater detail.

The levels of lead in the atmosphere have decreased significantly in the US and worldwide as more countries banned the use of lead fuel additives. The remaining amounts of lead originate from re-emission of previously deposited lead and the few remaining users of lead additives, chiefly in aviation and racing fuels. The reduction is directly attributable to the ban, and this air pollution problem can be considered mostly solved.

Acid Rain

Acid rain, or more appropriately named acid precipitation, originates from the byproducts of combustion of fossil fuels. The combustion process generates heat and/or electricity, which has great demand worldwide, and polluting byproducts. The most important byproducts that generate acid rain are sulfur oxides (SO_x) and nitrogen oxides (NO_x). Sulfur is often a contaminant in the coal and oil used in combustion. Nitrogen may be a fuel contaminant or may be from the air used to obtain the oxygen needed to combust the fuels. Uncontrolled emissions of these compounds cause the acidification of water and soil downwind from the sources. If many sources are located close together, huge regions may be contaminated. As much as one-third of the United States saw significant acidification by the late 1980s. The levels of acidification did not pose a direct threat to human health – only the most sensitive skin would notice the difference between acidified rain and normal rain, and such skin may develop a rash that would usually go away after a short time. However, the acidification causes harm to plants and animals. The acid leaches nutrients from soil and solubilizes metals such as aluminum in soils that cause toxic effects to nearby organisms. This reduced ability to collect nutrients and resources combined with increased exposure to greater levels of toxins leads to a decrease in ecosystem diversity.

The US and other developed nations started to control the emissions of these byproducts from fossil fuels in the 1990s. Strategies include replacing high-sulfur fuels with low-sulfur fuels, removing sulfur from the fuels, or capturing the sulfur oxides from the emissions. By 2010, the US had reduced sulfur emissions by over 50% even while increasing the amount of electricity produced. Nitrogen emissions are more difficult to control, though they have also been reduced by 50% by 2010. Control methods include changing the way fuel and air are added to the furnace, changing the flame zone shape, and/or reducing the amount emitted by treating the emissions. The amount of land that is still being acidified is greatly reduced. This problem is not yet fully solved, but impacts from it have been greatly reduced. A continuation of current strategies and controls on additional sources could see reductions from 1980 emission levels of 75 – 90% by 2020. See Chapters 9 and 10 for greater details about this problem.

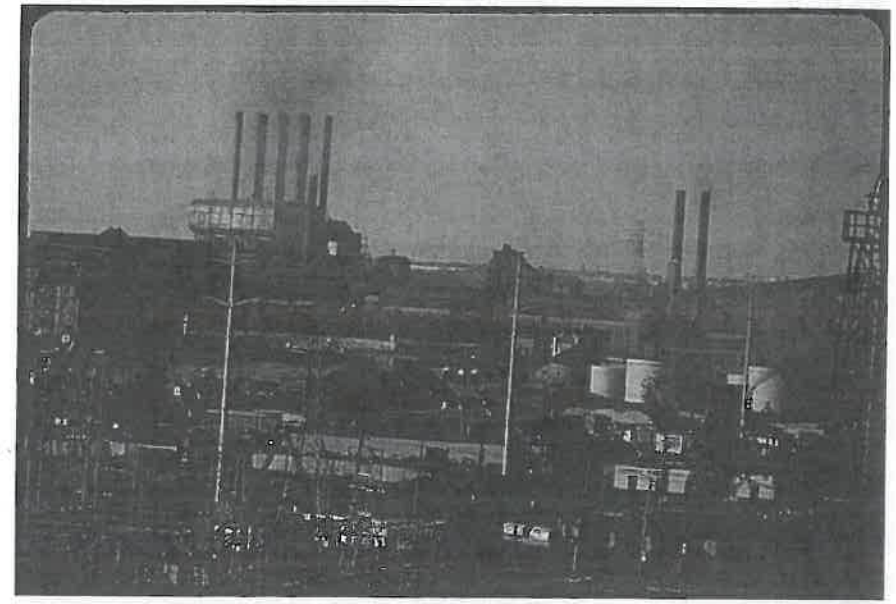
Particulate Matter

Particulate Matter (PM) refers to any liquid or solid particle in the air. Almost every activity people do such as mining, burning, transportation, grinding, sanding, and cleaning generates PM. There are also many natural sources such as plant pollen, sea salt, volcanoes, wind erosion, and forest or grass fires. PM can limit visibility and can cause respiratory problems to people that are exposed to them.

Primary PM form during the activity and are emitted directly to the atmosphere. Secondary PM form after the release of the emissions – they form due to many mechanisms including coagulation, condensation, precipitation, chemical reactions, and agglomeration. Figure 1-2 and Figure 1-3 show typical releases of PM and other common air pollutants from normal human activity before implementation of the Clean Air Act regulations.

PM are removed from the atmosphere by either wet or dry deposition. Wet deposition involves the particles being swept from the air by water (e.g. rain, snow, fog) and then being deposited onto the ground. Dry deposition occurs when the particles deposit on the ground due to gravity or diffusion. Large particles, greater than 100 μm diameter (1 meter = 10^6 μm), settle very close to the source and only cause localized problems. Medium particles, 2.5 - 100 μm diameter, take longer to settle and are easily returned to the atmosphere. They may create a regional problem. Smaller

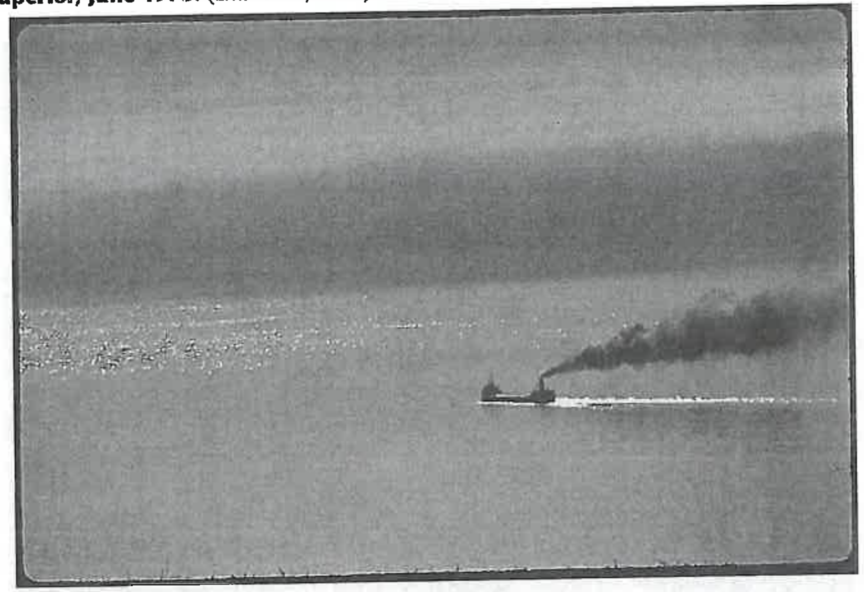
FIGURE 1-2. Skyline Showing Particulate Matter and Smog from Air Emissions. Background Shows the Ford River Rouge Plant in Dearborn,MI, USA, July 1973. (Clark, 1973)



particles, 0.1 – 2.5 μm diameter, can remain in the atmosphere long enough to circle the globe (20 days) and thus create a global problem. The smallest sizes, less than 0.1 μm diameter, are removed at the local to regional scale by dry deposition, as they can diffuse quickly to the Earth's surface. It is entirely likely that the particles will change size while in the atmosphere. Generally, particles tend to increase in size by joining together or with other constituents in the air, particularly water. Larger particles are generally more quickly removed.

Historically, coal-fueled power plants were the largest human caused sources of PM. Coal is a mixture that includes minerals that form ash during the combustion process. A coal may contain 1 to 10% ash. A large power plant may use 100 railway cars worth of coal in a day. The emission of the ash caused black plumes from each site and deposited ash downwind for miles. Emission controls are capable of capturing more than 99% of the particles, and this source has greatly reduced its impact on air pollution. However, not all sources can be controlled, and many remain unregulated. Much progress has been made on this problem, but it remains one of the main causes for unhealthy air in the US. See Chapters 7 and 8 for more detail about this issue.

FIGURE 1-3. Uncontrolled Emission from Ore Carrier Contributes to Smog over Lake Superior, June 1973. (Emmerich, 1973)



Smog and Ozone

Smog is a word made by combining the words smoke and fog. There are two types of smog. A *London type* results from sulfur dioxide emissions that combine with high humidity or foggy weather to form liquid particles that remain in the atmosphere for extended times. This smog consists of particles such as fly ash and sulfur compounds. It is also called classic smog, and it is reducing. A *Los Angeles type* smog forms during sunny weather due to photochemical reactions between other pollutants - particulate matter, nitrogen oxides, and volatile organic compounds. It creates a yellowish-brownish haze in the air. This type of smog is oxidizing. The reactions happen within the lowest part of the atmosphere called the troposphere (ground level to an elevation of 10 km). These substances react in the presence of sunlight to form ozone (O_3) and often creates peroxy acetyl nitrate (PAN). Beijing, China, is one of the most polluted cities in the world today. It has air quality that frequently causes severe health problems for its people, see Figure 1-4. The smog in Beijing is mostly caused by particulate matter, sulfates, and nitrates that combine with moisture during stagnant weather conditions that last several days to several weeks.

FIGURE 1-4. Smog in Beijing, China. May, 2014. The visibility in this photo only allows buildings one mile from the photographer to be seen. Photo courtesy of Mitchell Kruse, 2014.

Ozone is more difficult to control than most other air pollutants. It is not discharged directly into the atmosphere, so it is considered a secondary pollutant. Ozone is a known respiratory irritant, harms animals, damages plants, see Figure 1-5, and causes the degradation of plastics and textiles. Control relies on reducing the emissions of the precursor emissions, primarily volatile organic compounds and nitrogen oxides. Both of these pollutants have large natural sources as well as anthropogenic sources. It is also a seasonal problem, occurring during sunny and warm conditions. One significant problem in controlling it is that the chemical precursors can be transported hundreds of miles from the source before the conditions for the formation of ozone lead to their degradation. The time delay and travel distance means a particular source helping to cause an ozone event in a location one day may not contribute at all several days later due to a shift in wind patterns. It also means that the emissions may not cause a problem in the local region where they are emitted, but instead cause the problem hundreds of miles down-wind. In the US, the intermingling of pollutants between different States creates many legal issues, as

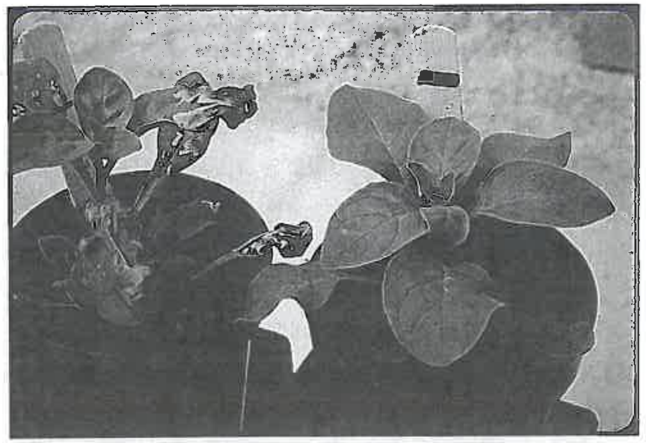


FIGURE 1-5 Smog-Damaged and Clean-Air Plants Shown Together. (Daniels, 1972)

one State does not have authority to control emissions in another state. Ozone is one of the biggest current air pollution problems and much work, legal and technical, is focused on its control. See Chapters 10, 11, and 12 for more information.

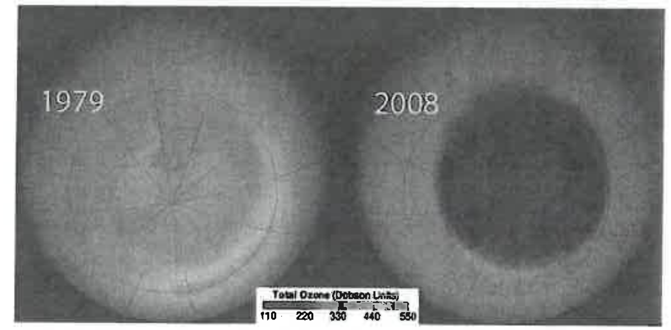
Ozone Hole

The ozone in smog is harmful to human health. However, the same ozone in the region of the atmosphere called the stratosphere, which is about 10 km to 60 km above the Earth's surface, provides a very beneficial service. Stratospheric ozone absorbs ultraviolet (UV) radiation from the Sun. UV radiation can damage living organisms and is capable of breaking DNA molecules. The ozone is destroyed by reactions involving chlorofluorocarbons (CFCs) and sunlight. CFCs are nontoxic and have excellent properties that make them useful for refrigeration and cleaning, including being stable, non-toxic, easy to manufacture, and relatively inexpensive. It is interesting to note that the discoverer of these compounds was the same person who discovered the use of tetraethyl lead as a fuel additive.

The CFCs do not react in the troposphere, and are thus able to disperse and accumulate throughout the lower atmosphere until they cross into the stratosphere. In the stratosphere, they encounter UV radiation that destroys the molecule and releases chlorine. The chlorine catalyzes a reaction which destroys ozone molecules. One CFC molecule can destroy thousands of ozone molecules. This destruction creates what is called the ozone hole, which is just a region of the atmosphere with a reduced concentration of ozone (sometimes as much as 50%, see Figure 1-6). This reduction allows more UV radiation to pass through the stratosphere and impact organisms in the troposphere. The increase in UV radiation leads to skin cancers and eye disease in the people exposed to them.

Concern for this problem led the nations of the world to ban the use and manufacture of C
A process started by the United Nations treaty called the Montreal Protocol (1987). This treaty only the first step and by itself, it would not solve the problem. However, there have been n revisions to this document as more information became available and with the creation of technologies. The rate of destruction of ozone has leveled out, and it is expected to begin recc ing within the next few decades. The time lag is caused by the very long lifetime CFC molec have in the atmosphere, 15 – 150 years. The ozone layer will not fully recover until all of t compounds have been destroyed, and then only if no new ozone-destroying compounds take place. See section 12.2. for more information.

FIGURE 1-6. False Color Views of Total Ozone Over the Antarctic Pole. Views compa changes between 1979 to 2008 maximum extent of ozone hole. Darker shading has lower to ozone. The lowest level in 1979 was 280 DU and in 2008 it was 100 DU. The extent in 2008 i more than 10 times larger.



Mercury

Mercury is a known toxic material and is considered to be a hazardous air pollutant (HAP). Emissions occur as a direct result from mercury mining and as a byproduct of burning coal and mining gold. Once emitted it inter-converts between its elemental, +2 ion, and particle forms. The ionic form is water soluble and can be in either organic or inorganic forms. The water-soluble forms can be chemically converted to insoluble forms, and it then can be re-emitted into the atmosphere. It is only quite slowly removed from the environment by

FIGURE 1-7. Sign posted in The Everglades National Park. (Dragonfly, 2010)

burial in sediments. There is no known safe dose for humans, and even minuscule doses (micrograms) can cause harm. Toxic effects on plant and animal life are less well understood, but again very low doses lead to harm for these organisms.

An additional concern for mercury is its ability to bio-accumulate. Bio-accumulation means the mercury stored in plants, animals and fish, is passed on to the consumers of these organisms and stored within them at much higher amounts than in the material eaten. This process can occur over many levels of consumer, and top predators (bears, birds of prey, and humans) can receive very high doses of mercury from certain foods. Many lakes in the US have mercury advisories that inform fish consumers to limit their intake of fish to a few fish a week or month. This mercury can be passed from mother to fetus or to an infant through breast milk.

Mercury has only very recently (since the 2000s) been the subject of regulation and control. All major sources of mercury have been subject to control since 2012 in the US. The primary control methods are reduction of use or capture and removal from emission sources. It is not well understood how long it takes until contaminated soils and surface waters recover from mercury pollution or when it will be safe to eat fish from such areas as often as one likes. See section 13.4 for more information.

Visibility and Haze

Haze is one of the easiest to notice forms of air pollution. It reduces visibility and can add color to the air – most often whites, browns and yellows, but may include greenish-reds. Haze results from sunlight encountering tiny pollution particles in the air. Some light is absorbed by particles. Other light is scattered away before it reaches an observer. The absorption and scattering of the light reduces the clarity and color of distant landscapes. More pollutants mean more absorption and scattering of light, which reduce the clarity and color of what we see. Haze is similar to smog and shares may of the same causes - PM, ozone, sulfates and nitrates. Haze can occur anywhere the air is contaminated by pollutants.

Some haze-causing particles are directly emitted to the air. Others form when gases emitted to the air create particles as they react with other pollutants. Formation and effects depend on the types of pollutants and the weather. Sulfur emissions combined with humid conditions form small droplets. Nitrogen oxides react with organic compounds during warm, sunny weather to form particulates and other pollutants. The wind can transport either the haze or the precursor pollutants by hundreds of miles from where they originated. In the eastern United States, average visual range has decreased from 90 miles to 15-25 miles. In the western United States, average visual range has decreased from 140 miles to 35-90 miles.

The pollutants that form haze are linked to serious health problems and environmental damage. Exposure to small particles contributes to increased respiratory illness, decreased lung function, and premature death. Particles of nitrates and sulfates contribute to acid rain formation that makes

lakes, rivers, and streams unsuitable for many fish, and erodes buildings, historical monuments, paint on cars. Control of haze requires control of the emissions of the pollutants that create the h

Climate Change

The release of carbon from fossil fuel sources is causing an increase in environmental le of carbon dioxide (CO_2) and methane (CH_4). CO_2 has increased in the atmosphere by over 4 from preindustrial times, and methane has increased by over 100%. An additional climate chan chemical compound, N_2O, is also increasing – in large part due to combustion and agricultural of fertilizer. CO_2 is also increasing in the oceans and soil, but not at a rate sufficient to preve change in the atmosphere. The main problem is that there is no natural removal mechanism to co terbalance this increase, meaning that the extra carbon remains in the environment for thous of years. This extra carbon partitions between the atmosphere, ocean, and soil with each accep part of the increased emissions, and it causes changes in each. The only known long-term rem mechanism is geological burial (sequestration) in deep ocean sediments

CO_2 and CH_4 are greenhouse gases, which means they absorb infrared radiation and l re-emit it, but in a random direction. The random re-emission causes some of the radiation to re to the earth, which leads to an increase in atmospheric and ocean temperatures. The phenome was first discussed in the 1890s. Atmospheric models suggest that a doubling of CO_2 concen tion will cause the average temperature at the earth's surface to increase by 4 to 8°F (2 to 5 with larger increases at the poles and less in the tropics. Like the increase in CO_2, the increas temperature also partitions between the atmosphere, soil, and ocean. A change of this magnit is extremely rare in geological history, especially over the given timescale of a few hundred ye More commonly geological changes occur over hundreds of thousands of years. The full impa unknowable, although it is very clear that the impact will be large and worldwide.

Human society greatly values the energy produced from using fossil fuels. This valua leads many people to not accept the problem as real, or to assume it can be dealt with in future. No nation has addressed this problem at the level required to make an impact. The o long-term solution is to stop using fossil fuels and to somehow capture the already relea carbon and remove it from the environment. These tasks are non-trivial, especially given timescale (30 – 80 years) required to prevent a larger than 2°C increase in global temperatur is believed that the global impacts of a 2°C will change the global climate and ecosystems serious way, but that humans will be able to adapt to the changes. It is unknown what will hap if this threshold is exceeded.

Solution to this problem require new energy sources, new ways to govern the use of resour the creation of laws and regulations on a multinational scale, and the development of methods capturing carbon, transporting it, and storing it. Combined these ideas will ultimately restruc the entire world economy. While work has started in each area, much more needs to be done. Chapter 14 for more information.

1.3 Control of Air Pollutants

Solutions to air pollution problems are complex and require that many different groups in society work together. The control of air pollution is based on four assumptions (AAAS, 1965):

1. Air is in the public domain. No one owns the air, nor can one control the flow of the atmosphere, even if allowed to control the airspace over a property. Release of an air pollutant will inevitably trespass onto another's property and become a public problem
2. Air pollution is an inevitable concomitant of modern life. It is not possible to maintain today's lifestyle without using resources and creating waste.
3. Scientific knowledge can be applied to the shaping of public policy. The best tool for understanding the material world is the scientific method. It provides reliable, reproducible, and consistent information.
4. Methods to reduce air pollution must not increase pollution in other sectors of man's environment. Simple tradeoff between air pollution and water pollution do not solve a problem, it just shifts the burden from one group to another. Such methods may at times be used, but they do not help the environment to sustain life.

Figure 1-8. Shows a simplified flow chart for controlling pollution.

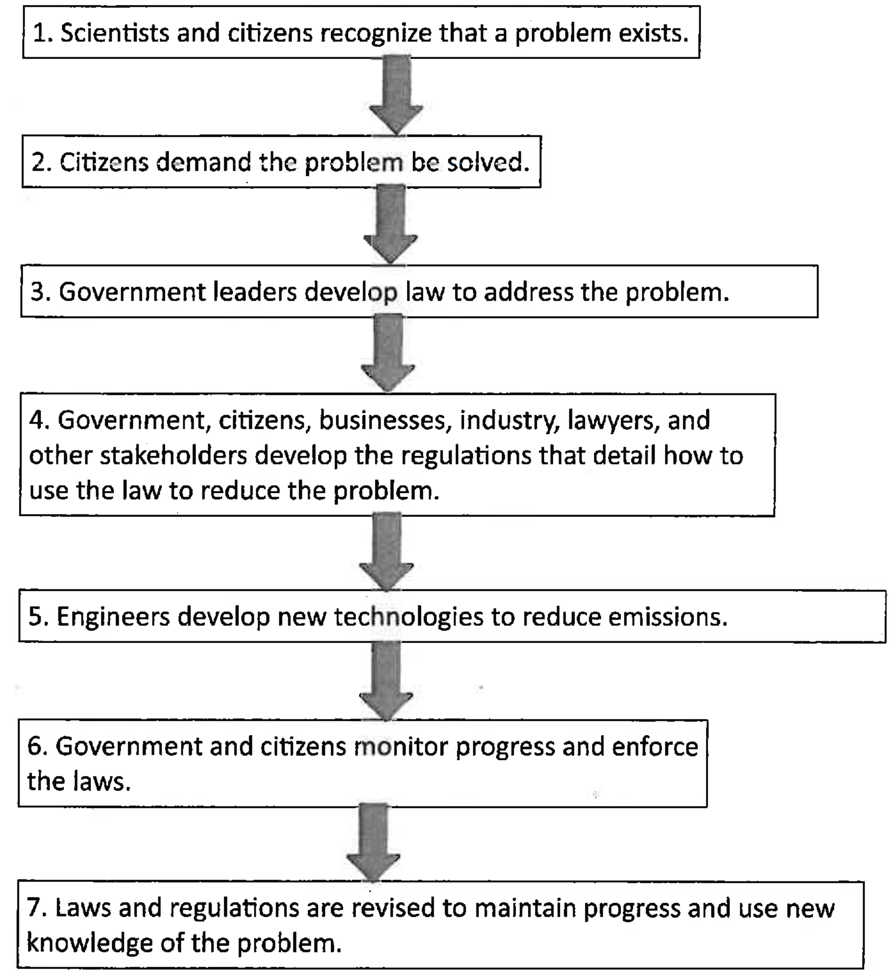
The first step is discovering that a problem exists. It is often scientists that make this discovery. Sometimes the problem is well known but poorly understood (i.e. smog), other times it is discovered while looking for something else (stratospheric ozone depletion). Scientists then attempt to build a model of the phenomenon to determine the causes and effects. The results of these models are used to show how important the problem is.

Once the importance of the problem is understood, the members of society must decide that the problem needs to be addressed. Most governments do not work on solving an issue unless there is consensus among many groups of citizens. There will always be some groups opposed to doing anything and other groups that want to do more. The more groups in favor of doing something (or not doing it) the more likely that will happen.

After it is decided to address the issue, the government creates a law. Laws are somewhat vague and do not specify every action nor when those actions must occur. Overall, the law sets the basic framework, guidelines, and goals.

The details of how to make a law work are detailed in a set of regulations. A law may be five to twenty pages long, and the pages of associated regulation may number in the thousands. Regulations have public comment periods, and the issuing government agency then addresses all comments and may make modifications before issuing the official regulation. One of the guiding principles of the US-EPA in creating environmental regulations is to achieve environmental justice, such that the benefits and burdens of implantation of pollution control should be shared by everyone, and not just a particular group. The EPA's definition is the following:

FIGURE 1-8. Steps in Addressing an Air Pollution Problem.



"Environmental Justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. EPA has this goal for all communities and persons across this Nation. It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work" (US-EPA, 2013a).

The equipment, systems, and policies needed to comply with a regulation do not exist before the law is passed. Regulations typically provide a number of years between implementation and enforcement. The time is needed to develop the infrastructure for compliance. Regulations are frequently adapted to this learning process and very rarely do they require activities that are found to be impossible or unrealistic.

Methods for reducing harm from air pollution include:

Substitution – change the nature of emissions by using different materials or methods that cause less harm.

Zoning – allowing emissions to occur in limited areas, usually away from population centers.

Market mechanisms – whereby an emitter is charged some amount to remedy the problems caused by the emissions. The amount should reflect the cost of the harm and can also be used to change behavior.

Banning – general prohibitions to prevent harmful emissions.

Each of these methods can be used to control air pollution, and usually one works better for certain pollutants than another one, but no single one is always the best choice.

The progress made in controlling emissions requires that every emitter be held to the same standard and that every emitter monitors all their emissions. Equal enforcement prevents the creation of unfair market advantages by a subset of favored emitters. It also means that the cost of complying with the law is passed onto those that consume the products and services. Without the consumers, the business would not be polluting.

Most regulations and some laws require timely review. Such review allows the methods to be adapted to actual circumstances and allows new information to drive the improvement of future regulation.

1.4 Public Information and Tools

There are many sources of information available to anyone who is interested. Data sets and maps for other air pollution related issues are available from the US-EPA at www.epa.gov/airdata/ . A similar site for the European Union is www.eea.europa.eu/data-and-maps. These sites provide

information ranging from very basic to extremely detailed on the topics of air quality s monitoring site data including location, daily measurement values and summary informa pollution deposition maps, and pollutant concentration plots. Detailed current and historic mation of the six most common air pollutants in the US (carbon monoxide, lead, nitrogen sulfur oxides, particulate matter, and ozone) can be found at www.epa.gov/air/emissions . T provides basic information, air quality trends, laws and regulations, and lists of regulated s Other information sources in the US include:

National Aeronautics and Space Administration – www.nasa.gov
National Oceanic and Atmospheric Administration – www.noaa.gov
Department of Energy – www.energy.gov
Center for Disease Control and Prevention – www.cdc.gov

One of the primary tools the US-EPA uses to communicate information for citizens to their daily life is called the Air Quality Index (AQI). It is a tool used to communicate simpl mation on air quality to local communities (US-EPA, 2003). It provides an estimate of how p the air is, what the health concerns are, and who may be affected. It focuses on the health a person may experience within a few hours or days after breathing the outdoor air. The i based on measurements of five major air pollutants - ozone, particulate matter, carbon mo sulfur dioxide, and nitrogen dioxide. Each of the five AQI substances is also a criteria pollu defined by the US-EPA, see section 3.2.1. The sixth criteria pollutant, lead, is not included longer creates much health risk, except in a few locations.

The AQI is a value that ranges from 0 to 500. High values represent greater health co The number is calibrated such that an index level of 100 corresponds to the national ambi quality standard for each of the five pollutants. The AQI is a national index, which means t values and colors are the same everywhere in the US. The AQI is divided into six categorie

Table 1-2. The Air Quality Index.

AQI Value	Level of Health Concern	Color Code
"When the AQI is in this range ...	...air quality conditions are	... as symbolized by this col
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

The six levels are:

Good – The air quality is considered satisfactory, and air pollution poses little or no risk

Moderate – The air quality is considered acceptable, however there may be some concern for a small number of people who are unusually sensitive to the pollutant.

Unhealthy for Sensitive Groups (USG) – These levels are of concern for some people, and they may experience health effects. This group includes those with lung disease when the pollutant is ozone and heart disease when the pollutant is ozone or particulate matter. Children, the elderly, and those who exercise outdoors are more susceptible to any pollutant at this level. The general population is not likely to be affected when the AQI is in this range.

Unhealthy – Everyone may begin to experience health effects, and sensitive groups may experience more serious health effects.

Very Unhealthy – This level triggers a health alert, and everyone may experience more serious health effects.

Hazardous – This level triggers emergency conditions, and the entire population is likely to be affected.

Air quality is measured from concentrations of each pollutant every day at a set of more than 1000 monitors across the country. The AQI value is calculated for each pollutant in an area, and the highest value of the five is the AQI value for that day. The model assumes that there are no synergies between pollutants. Some communities also provide a forecast for the next day's AQI to help residents plan their outdoor activities to protect their health.

All communities (or statistical metropolitan areas) with a population of 350,000 or more are required to report the AQI to the public daily. When AQI is above 100 the state or local agencies are also required to report which groups (such as children, the elderly, and people with asthma, heart disease or lung disease) may be sensitive to the specific pollutant. If more than one pollutant has an AQI value above 100, the agencies must report all the groups that are sensitive to those pollutants. Many smaller communities also report the AQI as a public health service. Most communities in the US have AQI values below 100 most of the time. Values above 100 happen just a few times each year. Larger cities have more severe air pollution problems, and their AQI may exceed 100 more often. Values above 200 are infrequent, and values above 300 are extremely rare. In addition to local communication in each community, the US-EPA maintains a central database that shows the AQI across the country, see www.airnow.gov (US-EPA, 2013b). A similar site for the European Union is located at www.airqualitynow.eu/. Many other nations also provide air quality index values using similar schemes.

1.5 Questions

* – Questions and problems may require additional information not included in the textbook.

1. Work with another student to generate a definition of air pollution. Try to iden several possible stakeholders that will use the law and make it fair for each.

2. Find a process flow diagram of a fossil fuel powered electricity generating facility. N any pollution control equipment that is shown. Try to think of three other ways facility could reduce emissions of air pollutants.*

3. Visit the US-EPA RAdNet Air Monitoring site (http://www.epa.gov/radnet/index.htr Find the location of the nearest monitoring location to where you live. Explore the d from the monitor. Does the site help you interpret the information? Write a paragra or two discussing your findings.*

4. What substances are currently used to replace lead additives in gasoline? Compare th short and long term potential for harm to human health.*

5. Collect a sample of rain water and measure its pH (your instructor should provide pH t paper to help). Compare your results with your classmates and with the National Atn spheric Deposition Program data (http://nadp.sws.uiuc.edu/). Note the location and time your sample.*

6. When was the last time the air where you live had an ozone pollution episode, defined as an Quality Index greater than 100 for ozone. US data is available at www.airnow.gov.*

7. Use your state government's environmental quality website and determine if any near surface water has a mercury / fish consumption advisory.*

8. Do you think the smog in Beijing China is the London type or the LA type? Why?

9. Pick one of the four assumptions that form the basis for modern air pollution control. Wr a paragraph explaining why the assumption is necessary. Consider how things could different if the assumption is not used.

10. Find an environmental justice issue in the region you live. Prepare a five minute discussion share with your class.