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Control of Air Pollution

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33.1 Introduction

Far from being a mere nuisance, air pollution can cause serious health problems. The United States Environmental Protection Agency (EPA) estimates that its regulations prevent 230 000 early deaths per year. At the beginning of 2011, the EPA began regulating greenhouse gases. This was much to the chagrin of several States that are now seeking an injunction on the regulations, arguing that the EPA does not have the constitutional authority to expand its own jurisdiction. This highlights one of the challenges in regulating air, namely balancing health safety needs with society's need for goods and services and the economy's need for productive industry (Environmental Protection Online, 2012).

Today, pollution prevention is the primary and preferred method of dealing with environmental degradation as air pollution is no longer a by-product of industrial emissions but one of the social demands of living. Air pollution is the contamination of the ambient air by presence of solids, liquids, gases, or fibers in outdoor air in amounts that are injurious or detrimental to humans, animals, plants, or property, or unreasonably interfere with the comfortable enjoyment of life and property. Air pollution is primarily concerned with human health, but is also concerned with visibility, property damage, and threats to the global climate.

Facts and concepts regarding air pollution and its control are discussed in this chapter. Air pollution may be caused by Nature or by human activity. Dust, smoke, pollen, and wind-transported salts are natural air pollutants. Major air pollutants caused by human activities include carbon monoxide, oxides of sulfur and nitrogen, reactive volatile organic compounds (VOCs), and particulates. Ambient air quality is a concern because of detrimental effects on the public health and the environment and also physical structures such as buildings and statues. Indoor air quality (IAQ) is also important since many people spend the majority of their time in enclosed structures. The information presented in this chapter was extracted primarily from the published literature, such as the American Society of Safety Engineers (ASSE) *The Safety Professionals Handbook* (Joseph and Nguyen, 2012), *Handbook of Environmental Health and Safety* (Koren and Bisesi, 1995), and *Air Pollution Control*

(Cooper and Alley, 2002). Information was also extracted from the EPA web site along with media gathered from the World Wide Web.

33.2

History of Air Pollution Regulations

The Air Pollution Control Act of 1955 was enacted on 14 July 1955. This Act was the first federal legislation to address the national environmental problem of air pollution. It provided research and technical assistance relating to air pollution control.

The Clean Air Act (CAA) of 1963 and Amendments (1965–1969) dealt with reducing air pollution by setting emissions standards for stationary sources such as steel mills and power plants. It established a federal program within the US Public Health Service and authorized research into techniques for monitoring and controlling air pollution. The Amendments set standards for auto emissions, expanded local air pollution control programs, established air quality control regions, set air quality standards and compliance deadlines for stationary source emissions, and authorized research on low-emission fuels and automobiles. Funding was made available to States and local authorities to assist in implementing programs, enforcing regulations, and supporting research programs into pollution control technologies.

The CAA of 1970 emphasized the need for active participation of the national government in the protection of natural resources. Provisions within the Act created:

- the National Ambient Air Quality Standards (NAAQS)
- State implementation plans (SIPs)
- new source performance standards for major stationary sources of air pollution
- requirements for best available control technology
- regulation of asbestos, vinyl chloride, radionuclides, arsenic, mercury, beryllium, radon, and benzene
- increased enforcement authority of the EPA
- control technology guidelines for specific-source industrial categories.

The 1977 Amendments to the 1970 CAA tightened some of the then existing standards but also relaxed the enforcement authority of the EPA at the State level. These 1977 Amendments allowed individual SIPs to set extended timeframes for implementing air quality emission standards for vehicles and industry. By the late 1970s, pollutants that are known or suspected to cause serious health problems such as cancer or birth defects were identified and were later referred to as “hazardous air pollutants” or “toxic air pollutants,” or simply “air toxics.”

The CAA of 1990 and Amendments: prior to 1990, standards for each hazardous air pollutant were set based on its health risks. This approach proved difficult and minimally effective at reducing emissions. The 1990 Act and Amendments

used a technology-based and performance-based approach to reduce significantly emissions of air toxics from major sources of air pollution, followed by a risk-based approach to address any remaining or residual risks. Major changes included holding States responsible for implementing and enforcing the Act, conducting hearings for permits to build power or chemical plants, and setting fines for violating air pollution limits. States were allowed to establish standards more stringent than federal standards and were also required to develop SIPs. The SIPs required EPA approval. In States with no approved SIP, the federal CAA was enforced. The ultimate responsibility to enforce the CAA remained with the EPA.

33.3

Benefits of the Clean Air Act and Amendments (CAA) from 1990 to 2020

Key elements of the Clean Air Act and Amendments (CAA) include:

- cleaning up commonly found air pollutants
- reducing car, truck, bus, and non-road equipment emissions
- facilitating inter-State and international air pollution understanding
- clearing the air in the US national parks
- reducing acid rain
- reducing air pollutants
- protecting the stratospheric ozone layer
- issuing permits and enforcing the Act
- encouraging public participation.

The EPA develops periodic reports that estimate the benefits and costs of the CAA. The main goal of these reports is to provide Congress and the public with comprehensive, up-to-date, peer-reviewed information on the CAAA's social benefits and costs, including improvements in human health, welfare, and ecological resources, and also the impact of the Act's provisions on the US economy. This report is the result of *The Benefits and Costs of the Clean Air Act – Second Prospective Study from 1990 to 2020* (EPA, 2011a). The analysis estimates the costs and benefits achieved by comparing a “with CAAA” scenario that reflects expected or likely future measures implemented under the CAAA against a “without CAAA” scenario that freezes the scope and stringency of emission controls at the levels that existed prior to implementing the CAAA. The EPA believes that environmental improvements were made in the following areas:

- preventing premature mortality associated with ozone exposure
- preventing morbidity, including acute myocardial infarctions and chronic bronchitis
- improving the quality of ecological resources and other aspects of the environment, the largest component of which is visibility.

This EPA report estimates that the annual dollar value of benefits of air quality improvements will be substantial, and will grow over time as emission control

programs take full effect, reaching a level of approximately two trillion dollars (\$2T) in 2020 (EPA, 2011a).

33.4 Atmospheric Factors

33.4.1 Composition

The atmosphere is an important resource for the survival of all species on the planet, as a source of fresh air for breathing, and as a protective layer against direct solar radiation. The Earth's atmosphere is composed of a constant composition of 78.084% nitrogen, 20.948% oxygen, and 0.934% argon (Figure 33.1). Variable concentrations of 0.031% water vapor and methane along with 0.003% trace gases make up the remainder (Kidd and Kidd, 2006).

People can live for days without food and hours without water, but would only last a few minutes without air. On average, humans breathe over 3000 gal of air each day. Oxygen is a necessary reactant in the critical set of chemical reactions that combust the human heat engine (the human body) to keep it going. When we breathe air into our lungs, we absorb a portion of its oxygen into the bloodstream. We mix carbon dioxide and water with the air in our lungs before we breathe it out again. Less than 20% of the air's oxygen is replaced by carbon dioxide in each lungful, but a continuous supply of outside air must be available to the body to avoid oxygen depletion and carbon dioxide narcosis through repeated breathing of the

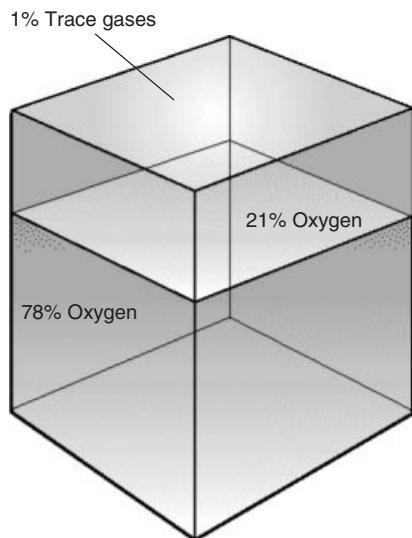


Figure 33.1 Composition of air (World Wide Web image).

same air. People must have air to live. Breathing polluted air tends to compromise people's health. Pollutants in air can trigger respiratory problems, especially for people with asthma. Air pollution can also aggravate health problems for the elderly and others with heart or respiratory diseases.

Some chemicals released in the air such as benzene and vinyl chloride are highly toxic and can cause cancer, birth defects, long-term injury to the lungs, and brain and nerve damage. In some cases, breathing these chemicals can even cause death.

Other pollutants make their way up into the upper atmosphere, causing thinning of the protective ozone layer. This air pollution also damages the environment. Pollutants and the chemicals that form acid rain and ground-level ozone can damage trees, crops, wildlife, lakes, and other bodies of water. Those same pollutants can also harm fish and other aquatic life.

Outdoor air quality may be degraded by transportation, energy production, manufacturing, hazardous waste treatment processes, and other activities. Some of the compounds released by these activities include particulates (soot and metals), VOCs, oxides of sulfur and nitrogen, carbon monoxide (CO), and carbon dioxide (CO_2). Chlorofluorocarbons (CFCs) are strongly implicated in the depletion of the stratospheric ozone layer. Sulfur oxides and nitrogen oxides may damage woodland and aquatic ecosystems through acid deposition. Additionally, high ambient levels of ozone may adversely affect human health and vegetation.

According to Wikipedia, the free encyclopedia (Wikipedia, 2012b): "Indoor air quality is a term which refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. IAQ can be affected by gases (including carbon monoxide, radon, and VOCs), particulates, microbial contaminants (mold, bacteria), or any mass or energy stressor that can induce adverse health conditions. Source control, filtration, and the use of ventilation to dilute contaminants are the primary methods for improving IAQ in most buildings."

Determination of IAQ involves the collection of air samples, monitoring human exposure to pollutants, collection of samples on building surfaces, and computer modeling of air flow inside buildings."

IAQ is adversely affected by emissions from a variety of sources. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines indoor air quality as follows: "IAQ represents the indoor air concentrations of pollutants that are known or suspected to affect people's comfort, environmental satisfaction, health, or work or school performance" (ASHRAE, 2011).

33.4.2

Atmospheric Layers

The atmosphere comprises a mixture of many different gases; mostly it consists of molecular nitrogen and oxygen (Figure 33.2). The atmosphere is the envelope of gases surrounding the Earth that provides the air we breathe, traps heat to allow life to flourish, and transfers water vapor from the seas to the land as part of the hydrologic cycle.

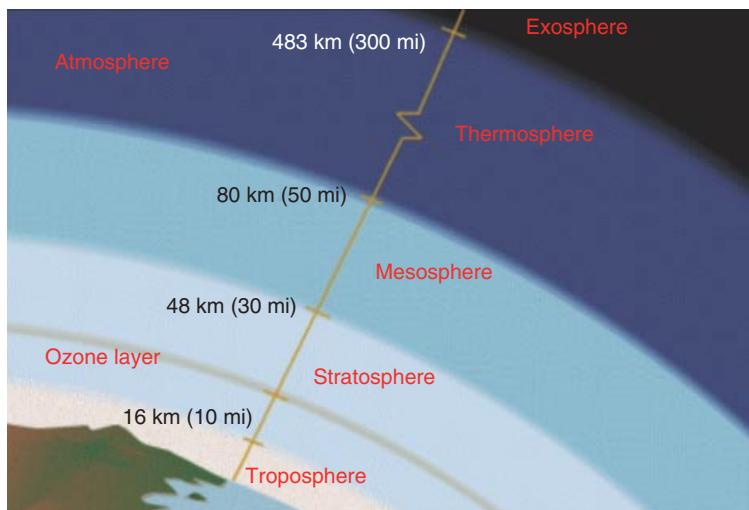


Figure 33.2 Atmospheric layers (World Wide Web image).

The atmosphere, which is divided into zones or spheres, grows thinner with increasing altitude, that is, it becomes significantly less dense the further it is from the Earth. About 70% of the total atmospheric air mass is contained in the first 10 or so miles (the troposphere) of the Earth's atmosphere (the entire atmosphere is ~90 miles thick). Temperature also decreases uniformly with increasing altitude up to about 7 miles, because the lower region is heated from below by the Earth's radiation. As a result of this temperature and density decrease, the atmosphere is layered, with the troposphere layer below and the stratosphere layer above. This layer in effect serves as a lid and limits the atmosphere's ability to dilute or disperse pollutants emitted from ground-based sources.

The full atmosphere extends upwards to about 160 km or 100 miles above the surface of the Earth. However, the mixture of gases refers only to the troposphere, the lowermost surface layer of the atmosphere. The troposphere contains about 95% of the total air mass. It is in this relatively thin layer of air that oxygen-dependent lift is sustained, clouds are formed, weather patterns develop, and most air pollution problems occur. The density of air increases significantly with a decrease in altitude or distance above Earth's surface, and it is for this reason that most of the total air mass is in the bottom layer. Above the troposphere, there is not enough oxygen to support life (The Diagram Group, 2006).

33.4.3

Effects of Weather

The fate of pollutants entering the atmosphere is subject to four effects:

- **Transport:** The downwind transport of pollutants is the most obvious meteorological effect on emissions. Although wind speed and direction have the greatest

effect, the actual profile of atmospheric influences is usually more complex. As an example, the emissions from a tall smokestack will disperse faster than emissions from ground level.

- **Dilution:** The turbulent motions of the air mix and dilute pollutants entering the atmosphere. The degree of turbulence can vary significantly within distances of several feet in the horizontal direction, particularly when the ground surface, temperature, or roughness of the terrain changes rapidly within short distances.
- **Transformation:** Pollutants frequently undergo significant transformation and modification in the atmosphere, including physical, chemical, and photochemical transformation. Typical physical and chemical transformations include joining together of particles, oxidation of substances, and chemical combinations. Photochemical changes are those triggered by solar energy (ultraviolet radiation).
- **Removal:** Pollutants are removed from the atmosphere by three major processes: rainout, washout, and fallout. Rainout occurs when particles attach to water vapor and subsequently form rain or ice droplets and fall to the ground as precipitation. Washout occurs when substances are collected by falling raindrops, such as gases that are water soluble. Fallout, also called >dry deposition, occurs when particulate substances become sufficiently heavy to overcome turbulent mixing and drop to the ground (Kidd and Kidd, 2006).

33.5

Air Pollution Types, Sources, and Effects

Sources of air pollution are both natural and man-made (Table 33.1). Natural sources include volcanoes, forest fires, bacterial action, weather (dust, ozone), plants, and radioactive natural sources. Man-made sources include fuel and energy production that result in coal hydrocarbons, SO₂, oil, fuel utilization, power plants (stationary/point source), automobiles (mobile/non-point source), and stationary industrial processes.

Pollution sources are suspended in the atmosphere and emitted from different stationary or mobile sources. Pollution sources can be located in outdoor or indoor environments, and as a result the pollution levels are location dependent.

Sulfur dioxide (SO₂) gas is one of the worst air pollutants for many reasons. In addition to being an irritant to the human eyes, lungs, and nasal passages, SO₂ is a highly acidic compound that can attack stone buildings and monuments, and has caused extensive damage to many marble statues in Europe. Furthermore, SO₂ dissolves in rain to produce acid rain. This phenomenon is harmful to buildings and statues; it is also harmful to forests and to people. Another aspect of SO₂ that makes it a bad air pollutant is that the SO₂ molecule can serve as the nucleus of a growing particle. Other chemical agents can adhere to the SO₂ molecule, forming larger particulate matter and causing additional concern for the environment (Blatt, 2005).

Typical outdoor pollutants are particulate matter resulting from different combustion processes, including transportation. The gaseous pollutants resulting

Table 33.1 Pollution sources (Williams, 2005).

Pollution source	Composition of pollutant
Automobiles	Burning of oil and gas produces carbon monoxide, VOCs, hydrocarbons, nitrogen oxides, peroxyacetyl nitrate, benzene, and lead
Utility power plants	Burning of coal, oil, and gas produces nitrogen oxides, heavy metals, fluoride, CFCs, and dioxins
Industry	Particulates, sulfur dioxide, nitrogen oxides, heavy metals, fluoride, CFCs, and dioxins
Incineration	Carbon monoxide, nitrogen oxides, particulates, dioxins, and heavy metals
Biomass burning	Burning of grasslands, crop stubble, agricultural waste, organic fuel, and forests produces sulfur, methane, radon, carbon dioxide, nitrogen oxides, carbon monoxide, and particulates
Small engines	Mowers, blowers, trimmers, chain saws, and other machines produce nitrogen oxides and hydrocarbons
Disasters	Radiation leaks, chemical leaks, burning of oil wells produce radiation, nitrogen oxides, carbon monoxide, sulfur, heavy metals, and particulates
Mining	Rock breakdown and processing produce nitrogen oxides, heavy metals, radiation particles, and particulates
Erosion	Road work and farm work produce dust, particulates, dried pesticides, and fertilizers
Indoor air pollution	Carpeting, cooking, and other indoor products and activities produce formaldehyde, lead and asbestos dust, radon, and other incorporated chemicals
Nature	Volcanic eruptions and forest fires produce dust and particles, sulfur dioxide, carbon monoxide, carbon dioxide, chlorine, nitrogen oxides, heavy metals, radon, and particulates

Adapted from *Environmental Science Demystified: a Self-Teaching Guide* (Williams, 2005).

from transportation combustion include nitrogen oxides, sulfur oxides, and carbon monoxide. These primary pollutants can have chemical reactions in the atmosphere and create secondary air pollutants such as chemical substances forming smog (smoke + fog). An example of a naturally occurring pollutant is radon (Rn), a radioactive gas, which is released from the soil, and can be dangerous when trapped in poorly ventilated building basements.

IAQ is also important because symptoms called “sick building syndrome” (SBS) were correlated with the high levels of indoor air pollutants such as VOCs emitted from common building materials.

Air pollution takes several forms that cause local, regional, and even global problems. Most air pollution results from the burning of either carbon-based fuels such as coal, oil, or natural gas, or by burning solid and liquid waste to reduce their volume. Other pollutants evaporate into the air from such diverse sources as chemical manufacturing, paint and industrial solvents, fresh asphalt, and cooking

grease from homes and restaurants. Emissions of terpenes and other organic compounds from trees add additional VOCs to the air.

Carbon monoxide, a primary air pollutant that blocks hemoglobin in the blood from carrying oxygen, is released when fossil fuels or wood are burned without sufficient air. Non-combustible material contained in fuel and burned carbon soot are released as particulates and reduce visibility, soil clothing and other materials, and can carry cancer-causing chemicals into people's lungs. Finally, nitrogen oxides are produced during combustion from the two dominant components of air (i.e., nitrogen and oxygen). These oxides are transformed chemically and by sunlight into brown smog, common in California, Mexico City, and other sunny regions. Some oxides of nitrogen react with VOCs from both technological and natural sources to produce secondary pollutants, such as ozone. Some nitrogen oxides are also converted to nitric acid along with sulfur oxides generated from impurities in coal and oil, and contribute to acid rain that falls hundreds of miles from their source. One business strategy for keeping sulfur oxide emissions low near their source has been to build tall stacks to dilute and disperse the emissions, inadvertently turning a local air pollution problem into a regional one.

These harmful substances that are released into the air, their sources, dispersion, transport, and effects on people and other parts of ecosystems are pollutants that range from chemicals that are naturally occurring and enhanced by human activity to other substances that are uniquely the result of modern technology. The zone of concern ranges from the immediate proximity of the source of the pollutant (the workplace or home) to regionally distributed pollutants to a few instances where the concern is of a global nature.

Major classes of air pollution or atmospheric contaminants (Table 33.2) are:

- 1) carbon oxides
- 2) sulfur oxides
- 3) nitrogen oxides
- 4) VOCs (ozone)
- 5) suspended particles
- 6) photochemical oxidants
- 7) radioactive substances
- 8) toxic compounds.

33.5.1

Types and Sources of Outdoor Pollutants

As clean air in the troposphere moves across the Earth's surface, it collects the products of natural events such as volcanic eruptions and dust storms and human activities such as emissions from cars and smokestacks. These potential pollutants, called primary pollutants, mix with the churning air in the troposphere. Some may react with one another or with the basic components of air to form new pollutants, called secondary pollutants. Long-lived pollutants travel far before they return to the Earth as particles, droplets, or chemicals dissolved in precipitation. Because

Table 33.2 Major classes of atmospheric contaminants.

Inorganic	Organic	Miscellaneous coarse dust	Smoke and tarry organic material	Aerosol – inorganic	Aerosol – organic
Sulfur dioxide	Aliphatic and aromatic hydrocarbons	Silica	Anthracene	Alkali metal compounds	Oily and solid organic material
Hydrogen sulfide	Ozonides and peroxides of hydrocarbons	Alumina	Phenanthrene	Light and heavy metals and a variety of inorganic oxides, carbonates, chlorides, fluorides, nitrates, phosphates, and sulfates	Heterocyclic compounds, proteins and other organics of high molecular weight
Nitrogen oxides	Organic products of photochemical reactions	Clay	Polynuclear aromatic and carcinogenic hydrocarbons of the pyrene, benzanthracene, fluoranthene series, etc.	Sulfur trioxide	
Oxidants	Aldehydes, ketones, alcohols, acids, ethers, esters, and oxides	Fly ash	Carbon	Sulfur acids	
Ammonia	Chlorinated hydrocarbons	Iron oxides	Soot	Nitric acid	
Hydrofluoric acid and volatile fluorides	Organic halides, nitro compounds, sulfonic acids, and phenols	Calcite			
Chlorine and hydrochloric acid	Amines and other miscellaneous volatile organics	Gypsum			
Carbon dioxide	Volatile organic sulfur compounds				
Carbon monoxide					
Ozone					

Adapted from the *Air Pollution Manual* (American Industrial Hygiene Association, 1972).

we all must breathe air from a shared global atmospheric supply, air pollution anywhere is a potential threat elsewhere, and in some cases everywhere.

Criteria air contaminants (CACs) were the first set of pollutants recognized by the EPA as needing standards on a national level. The US NAAQS requires the EPA to set standards on six CACs (Table 33.3). A summary of the CACs and their human health effects is as follows:

- 1) **Ozone (O_3)** – Exposure for 6–7 h to relatively low concentrations of ozone affects healthy adults, children, and asthmatics. Such exposure has been found to reduce lung function significantly and cause chest pain, coughing, nausea, and pulmonary congestion.
- 2) **Particulate matter** – Aggravates existing respiratory and cardiovascular disease, alters the body's defense systems against foreign materials, damages lung tissue, and can cause cancer and premature mortality. Persons with influenza, asthma, or pulmonary or cardiovascular disease are most sensitive, and also children and the elderly. The sizes of particulate matter can be classified as follows:
 - PM₁₀, coarse particles: 2.5–10 μm in size (although current implementation includes all particles 10 μm or less in the standard)
 - PM_{2.5}, fine particles: 2.5 μm in size or less.
- 3) **Carbon monoxide (CO)** – Enters the bloodstream and reduces the delivery of oxygen to the body's organs and tissues. The health threat is most serious for those who suffer from angina or peripheral vascular disease. Exposure to elevated levels is associated with impairment of visual perception, work capacity, and manual dexterity.
- 4) **Sulfur dioxide (SO₂)** – Affects breathing, respiratory illness and symptoms, alterations in the lung's defenses, aggravation of existing respiratory and cardiovascular disease, and death. Asthmatics and individuals with chronic lung disease (bronchitis or emphysema) are especially sensitive.
- 5) **Nitrogen oxides (NO_x)** – Irritation to the lungs and lowered resistance to respiratory infection, such as influenza.
- 6) **Lead (Pb)** – Accumulates in the body in blood, bone, and soft tissue. Because it is not readily excreted, lead also affects the kidneys, liver, nervous system, and blood-forming organs. Excessive exposure may cause neurological impairments, such as seizures, mental retardation, and/or behavioral disorders. Fetuses, infants, and children are most susceptible.

The United States regulates VOCs, but not as CACs. Based on the emissions of the six designated criteria pollutants, sulfur dioxide, nitrogen oxides, VOCs, particulate matter, carbon monoxide, and lead, the following are considered major sources of air pollution:

- 1) **Transportation** – Cars, trucks, buses, airplanes, and trains are responsible for a significant percentage of criteria pollutants. Automobile emissions are the major source of urban pollution as emissions from millions of vehicles add up. The power to move an automobile results from burning fuel in an internal

Table 33.3 Criteria air pollutants, chemical reactions, and control technology.

Criteria air pollutant	Chemical reactions	Control technology
Sulfur dioxide (SO_2)	Reacts in the atmosphere to form acid rain: $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$	Scrubbing
Corrosive gas		
Particulate matter	Coarse: road dust, sea spray, construction Fine: fossil fuel combustion from vehicles and industry	Mechanical separators, fabric filters, electrostatic precipitators, and wet scrubbers
Carbon monoxide (CO)	CO does not react readily in the atmosphere:	Promote complete combustion or oxidation
Odorless gas emitted from fossil fuel combustion, primarily vehicles	$\text{CO} + \text{O}_2 \rightarrow \text{CO}_2$	
Ozone (O_3)	$\text{NO} + \text{HC} + \text{sunlight} \rightarrow \text{NO}_2 + \text{O}_3$	Reduce emissions of its precursors
Troposphere ozone gas is a contributor to smog		
Nitrogen dioxide (NO_2)	$\text{NO} + \text{HC} + \text{sunlight} \rightarrow \text{NO}_2 + \text{O}_3$	Combustion modifications
Reddish brown gas generated from fossil fuel combustion	$\text{NO}_2 + \text{H}_2\text{O} \rightarrow$ nitric acid (acid rain) $\text{NO}_2 + \text{cation} \rightarrow$ particulate matter	and flue gas treatment
Lead (Pb)	Tetraethyllead $[\text{Pb}(\text{C}_2\text{H}_5)_4]$ in gasoline	Substitution
Toxic blue-gray metal		

Adapted from *Air Pollution Control and Mitigation* (Joseph and Nguyen, 2012).

combustion engine. Pollution from automobiles comes from by-products of this combustion process (exhaust) and from evaporation of the fuel itself. Although individual vehicle emissions have fallen dramatically, the use and number of vehicles have increased significantly. The overall outlook will depend on the total number of cars and the total number of miles driven, which are influenced by the price of gasoline.

Citing the EPA 2006 National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data, the Union of Concerned Scientists stated that “transportation is the largest single source of air pollution in the United States. It causes over half of the carbon monoxide, over a third of the nitrogen oxides, and almost a quarter of the hydrocarbons in our atmosphere in 2006. With the number of vehicles on the road and the number of vehicle miles traveled escalating rapidly, we are on the fast lane to smoggy skies and dirty air” (The

Union of Concerned Scientists, 2012). In a photo finish, Honda claimed a narrow victory over Toyota and Hyundai as the Greenest Automaker in the Union of Concerned Scientists' 2010 comprehensive environmental rankings (The Union of Concerned Scientists, 2010).

- 2) **Energy production** – Energy production from fossil fuel is another major source of air pollution in the United States. The primary air pollutants generated from the burning of fossil fuels are sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulates, and carbon dioxide. SO_2 and NO_x are responsible for the formation of acid deposition. As the world population continues to increase, energy needs will also increase. Lower emissions limits could bring about reductions of SO_2 and NO_x allowing the energy production sector to decide which combination of pollution control equipment, fuel, and energy conservation is suitable to ensure compliance with the emissions levels.
- 3) **Industry** – Because industrial processes are so diverse, so are the air pollutants that they generate. Although industry as a whole generates the conventional criteria pollutants, primarily VOCs, lead, and particulates, the hazardous air pollutants and air toxics that it generates have a greater impact on local air quality. The Community Right-to-Know prompted industry to reduce its emissions voluntarily and significantly starting in the 1990s. Nearly 10 million pounds of reported emissions were targeted as reduction goals. They included arsenic and arsenic compounds, asbestos, benzene, beryllium and beryllium compounds, mercury and mercury compounds, and vinyl chloride.
- 4) **Solid waste combustion** – Solid waste combustion converts carbon into carbon dioxide and hydrogen into water and destroys pathogens and toxic chemicals. The emissions from solid waste combustion include carbon monoxide, particulate matter, NO_x , VOCs, mercury, lead, hydrogen chloride, and minor amounts of chlorinated dioxins and chlorinated furans. As landfill capacity continues to shrink, public opposition to incineration and new landfills will continue. However, controls over emission from solid waste combustors were strengthened by the CAA and its amendments (CAA) since the 1990s. The CAA mandated additional controls on solid waste incinerators and thus made a difference in decreasing their contribution to air pollution.

33.5.2

Effects of Air Pollution Problems

- 1) **Global** – There is concern about greenhouse gas buildup (carbon dioxide, NO_x , ozone, and methane), global warming, and the effect of aerosols (CFCs and halons) and other pollutants on the protective ozone layer in the upper atmosphere. A CFC is an organic compound that contains carbon, chlorine, and fluorine, produced as a volatile derivative of methane and ethane. A common subclass is the hydrochlorofluorocarbons (HCFCs), which contain hydrogen. They are also commonly known by the DuPont trade name Freon. At first, CFCs were used almost exclusively in air-conditioning and refrigeration

systems, but soon the gases were found useful for other industry applications, including cleaning of metal parts and flash-freezing of foods. Deodorants, paints, insecticides, whipped cream, or anything that could be sprayed was soon dispensed through an aerosol dispenser in the 1970s. In 1973, almost 3 billion aerosol containers were sold in the United States using CFCs as the propellant gases. When released at ground level, the CFC gas from spray cans and other sources remains intact and does not react with other chemicals. However, scientists discovered in 1973 that a CFC molecule broke down and released free chlorine when bombarded by undiluted sunlight in the stratosphere. The free chlorine released from the gas then attacks and destroys many ozone molecules. As the ozone layer is depleted, more harmful ultraviolet radiation reaches the surface of the Earth.

In 1978, the United States passed firm regulations to ban the use of CFCs in aerosol dispensers, and Sweden, Norway, and Canada passed similar laws. Of note is that 50% of CFCs produced at the time were used in aerosol cans in the mid-1970s before the ban was in effect. CFCs do not deteriorate under normal conditions. When an old air conditioner is removed to the junkyard, the metal parts deteriorate and the CFCs are released into the atmosphere. The same process occurs with empty aerosol cans, discarded refrigerators, and every other product using CFCs. In 1986, news of the ozone hole was reported by the media. By 1987, the United States was a leader in the movement to restrict or cease the production of CFCs to help prevent depletion of the ozone layer. By mid-March 1988 the main US producer of CFCs announced that production would soon cease. The EPA administrator announced a total ban on CFC production in 1996.

Following the ban of CFC production, other ozone-depleting concerns developed:

- a. US farmers in the western States used methyl bromide to control infestations of nematodes and beetle larvae by injecting the methyl bromide gas into the soil from pressurized tanks. This chemical is an ozone-depleting agent and researchers have found it in the stratosphere. The chemical is also highly toxic to animals and humans. Exemption for agriculture use was extended to 2010, with safeguards required for people who live near the fields being treated. American scientists are currently exploring other alternatives to replace the fumigant methyl bromide (O'Brien, 2011).
Replacements for California strawberry production may be just as bad as “other fumigants, including Telone and Chloropicrin. On the State’s Proposition 65 list, Telone is a chemical known to cause cancer. Chloropicrin causes acute symptoms, including irritation to the nose, eyes, throat, and upper respiratory tract, according to the California Office of Environmental Health Hazard Assessment.” (Cal/EPA, 2012).
- b. Substitutes for CFCs introduced in the 1990s are, in fact, serious greenhouse gases. Radiation reflection tests indicate that the substitutes are stronger greenhouse gases than carbon dioxide.

- 2) **Intercontinental** – Problems include acid rain pollution from sulfur oxides contained in airborne moisture, but may also include long-distance transport of other pollutants. Polluted air masses causing acid rain dissipate in a short time, but the effects on water and soil may be long-lasting. The Geneva Convention on Long-Range Trans-boundary Air Pollution Treaty was signed in Geneva on 13 November 1974 by 29 European countries, the United States, and Canada. The concept that air knows no boundaries recognized that air pollution originating in one country was causing damage in another country.
- 3) **Regional** – This corresponds to a single air basin that has a common weather pattern and air mass. Many of the air quality standards are set at this regional basis. Regional problems typically have short durations, usually days, after which air currents transport and diffuse pollutants throughout the atmosphere. Climatic conditions that stagnate the air within a region lead to high emission concentrations from which large quantities of derivative compounds form through chemical and photochemical reactions.
- 4) **Local** – These problems occur in the vicinity of the polluting sources. They may be found in downtown areas, steep valleys, around busy intersections, near toll plazas, air terminals, and downwind of stationary sources. The air mass is normally not confined for more than a few hours. As a result, most of the pollutant species are direct emission products.
- 5) **Confined space** – May occur wherever physical barriers restrict air movement, for example, outdoors in some street canyons between high-rise buildings or inside tunnels and parking garages. The longevity of an air pollution problem in a confined space depends on its shape and the exhaust system provided.

The American Lung Association's *State of the Air 2010* (American Lung Association, 2010) found that:

- 1) Nearly six out of 10 people in the United States live in counties that have unhealthy levels of either ozone or particle pollution. Almost 175.3 million Americans live in the 445 counties where they are exposed to unhealthy levels of air pollution in the form of either ozone or short-term or year-round levels of particles.
- 2) Over half of all people in the United States live in areas with unhealthy levels of ozone. The monitored air quality in these places puts them at risk for decreased lung function, respiratory infection, lung inflammation, and aggravation of respiratory illness.
- 3) Nearly one-quarter of people in the United States live in an area with unhealthy short-term levels of particle pollution. Short-term spikes in particle pollution can last from hours to several days and can increase the risk of heart attacks, strokes, and emergency room visits for asthma and cardiovascular disease, and most importantly, can increase the risk of early death.
- 4) Roughly one in 10 people in the United States live in an area with unhealthy year-round levels of particulate pollution. Even when levels are fairly low,

exposure to particulates over time can increase the risk of hospitalization for asthma, damage to the lungs, and, significantly, increase the risk of premature death.

33.6

Indoor Air Quality

Studies by the American Lung Association indicate that residents of highly developed countries such as the United States spend little time outdoors (Table 33.4). This raises the question of indoor air quality, not only at home but also in the sealed office buildings where many Americans work. Studies by the World Health Organization indicate that 3 billion people are exposed daily to indoor air pollution with high concentrations of CO and other pollutants due to reliance on solid fuels for cooking and heating. Indoor air pollution kills 1.6 million people per year and represents 2.7% of the global burden of disease (World Health Organization, 2011). It is common for some air pollutants to be two to five times more concentrated inside buildings than outdoors.

Indoor air quality (IAQ) is a term referring to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.

IAQ can be affected by microbial contaminants (mold, bacteria), gases (including carbon monoxide, radon, VOCs), particulates, or any mass or energy stressor that can induce adverse health conditions. Increasingly, indoor air is becoming more of a health hazard than outdoor air. Using ventilation to dilute contaminants, filtration, and source control are the primary methods for improving IAQ in most buildings.

Determination of IAQ involves the collection of air samples, monitoring human exposure to pollutants, collection of samples on building surfaces, and computer modeling of air flow inside buildings. Common pollutants of IAQ include radon, molds and other allergens, carbon monoxide, VOCs, *Legionella*, asbestos fibers, carbon dioxide, and ozone.

Radon is an invisible, radioactive atomic gas that results from the radioactive decay of radium, which may be found in rock formations beneath buildings or in certain building materials themselves. Radon is probably the most pervasive serious hazard for indoor air in the United States and Europe, and is almost certainly responsible for tens of thousands of deaths from lung cancer each year. There are relatively simple tests for radon gas, but these tests are not commonly done, even in areas of known systematic hazards. Radon is a heavy gas and thus will tend to accumulate at the floor level. Building materials can actually be a significant source of radon, but little testing is done for stone, rock, or tile products brought into building sites; radon accumulation is greatest for well-insulated homes. The half-life for radon is 3.8 days, indicating that once the source is removed, the hazard will be greatly reduced within a few weeks. Radon mitigation methods include sealing concrete slab floors, basement foundations, water drainage systems, and

Table 33.4 Average hours spent per day in various locations by adults in 44 US cities.

Location	Employed men	Employed women	Homemakers
At home	13.4 h (55.8%)	15.4 h (64.2%)	20.5 h (85.4%)
At work	6.7 h (27.9%)	5.2 h (21.7%)	0
In transit	1.6 h (6.7%)	1.3 h (5.4%)	1 h (4.2%)
Outside	0.7 h (2.9%)	0.3 h (1.3 %)	0.4 h (1.7%)
Inside other structures	1.6 h (6.7%)	1.8 h (7.5%)	2.1 h (8.8%)

Adapted from *America's Environmental Report Card, Are We Making the Grade?* (Blatt, 2005).

increasing ventilation. Mitigation is usually cost-effective and can greatly reduce or even eliminate the contamination and the associated health risks.

Molds and other allergens – These biological chemicals can arise from a host of processes, but there are two common classes: (i) moisture-induced growth of mold colonies and (ii) natural substances released into the air such as animal dander and plant pollen. Moisture buildup inside buildings may arise from water penetrating compromised areas of the building envelope or skin, from plumbing leaks, from condensation due to improper ventilation, or from ground moisture penetrating a building part. In areas where cellulosic materials (paper and wood, including drywall) become moist and fail to dry within 48 h, mold and mildew can propagate and release allergenic spores into the air.

In many cases, if materials have failed to dry out several days after the suspected water event, mold growth should be suspected within wall cavities even if it is not immediately visible. Through a mold investigation, which may include destructive inspection, one should be able to determine the presence or absence of mold. In a situation where there is visible mold and the IAQ may have been compromised, mold remediation may be needed.

There are some varieties of mold that contain toxic compounds (mycotoxins). However, exposure to hazardous levels of mycotoxins via inhalation is not possible in most cases, as toxins are produced by the fungal body and are not at significant levels in the released spores. The primary hazard of mold growth, as it relates to IAQ, comes from the allergenic properties of the spore cell wall. More serious than most allergenic properties is the ability of mold to trigger episodes in persons who already have asthma, a serious respiratory disease.

Mold is always associated with moisture, and its growth can be inhibited by keeping humidity levels below 50%. Moisture problems causing mold growth can be from direct sources such as a water leaks and/or from indirect sources such as condensation due to humidity levels.

Carbon monoxide – One of the most acutely toxic indoor air contaminants is carbon monoxide (CO), a colorless, odorless gas that is a byproduct of incomplete combustion of fossil fuels. Common sources of CO are tobacco smoke, space heaters using fossil fuels, defective central heating furnaces, and automobile exhaust.

Improvements in indoor levels of CO are systematically improving due to the increasing numbers of smoke-free restaurants and other legislated non-smoking buildings. By depriving the brain of oxygen, high levels of CO can lead to nausea, unconsciousness, and death. According to the American Conference of Governmental Industrial Hygienists (ACGIH), the time-weighted average (TWA) limit for CO is 25 ppm.

VOCs – VOCs are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to 10 times higher) than outdoors simply due to the abundant amount of available natural outdoor air versus indoor air per unit volume. VOCs are emitted by thousands of products. Examples include paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids, carbonless copy paper, graphics, and craft materials including glues and adhesives, permanent markers, and photographic solutions.

Organic chemicals are widely used as ingredients in household products. Paints, varnishes, and wax all contain organic solvents, as do many cleaning, disinfecting, cosmetic, degreasing, and hobby products. Fuels are made up of organic chemicals. All of these products can release organic compounds during usage and, to some degree, when they are stored. Testing emissions from building materials used indoors has become increasingly common for floor coverings, paints, and many other important indoor building materials and finishes.

VOCs can also be microbial volatile organic compounds (MVOCs). At least 18 have been characterized, including “mushroom alcohol” and *Stachybotrys chartarum*, which has been linked with SBS.

33.6.1

Legionella

According to Wikipedia, legionellosis or Legionnaire’s disease is caused by the waterborne bacterium *Legionella* (Figure 33.3) that grows best in slow-moving or still, warm water (Wikipedia, 2012c). The primary route of exposure is aerosolization, most commonly from evaporative cooling towers or showerheads. A common source of *Legionella* in commercial buildings is from poorly placed or maintained evaporative cooling towers, which often release aerosolized water that may enter nearby ventilation intakes. Outbreaks in medical facilities and nursing homes, where patients are immuno-suppressed and immuno-weak, are the most commonly reported cases of legionellosis. More than one case has involved outdoor fountains in public attractions. The presence of *Legionella* in commercial building water supplies is highly under-reported, as healthy people require heavy exposure to acquire infection.

Legionella testing typically involves collecting water samples and surface swabs from evaporative cooling basins, shower heads, faucets, and other locations where warm water collects. The samples are then cultured and colony-forming units (cfus) of *Legionella* are quantified as cfu l⁻¹.



Figure 33.3 *Legionella* sp. under UV illumination (Wikipedia image.) Scientific classification – Domain: Bacteria. Phylum: Proteobacteria. Class: Gammaproteobacteria. Order: Legionellales. Family: Legionellaceae. Genus: *Legionella*.

Legionella is a parasite of protozoans such as amoeba, and thus requires conditions suitable for both organisms. The bacterium forms a biofilm which is resistant to chemical and anti-microbial treatments, including chlorine. Remediation for *Legionella* outbreaks in commercial buildings varies, but often includes very hot water flushes (160 °F; 70 °C), sterilization of standing water in evaporative cooling basins, replacement of shower heads, and in some cases flushes with heavy metal salts. Preventive measures include adjusting normal hot water levels to allow for 120 °F (50 °C) at the tap, evaluating facility design layout, removing faucet aerators, and periodic testing in suspect areas.

Asbestos fibers – The US Federal Government, Occupational Safety and Health Administration (OSHA) and some States have set standards for acceptable levels of asbestos fibers (Figure 33.4) in indoor air. Many common building materials used before 1975 contain asbestos, such as some floor tiles, ceiling tiles, taping muds, pipe wrap, mastics, and other insulation materials. Normally significant releases of asbestos fiber do not occur unless the building materials are disturbed, such as by cutting, sanding, drilling, or building remodeling. There are particularly stringent regulations applicable to schools.

Inhalation of asbestos fibers over long exposure times is associated with an increased incidence of lung cancer.

Asbestos is found in older homes and buildings, and it is most dangerous in schools and industrial settings. It was once widely used in shingles, fire-proofing, heating systems, and floor and ceiling tiles in older buildings. When asbestos-containing material is damaged or disintegrates, microscopic fibers are dispersed into the air. The risk of lung cancer from inhaling asbestos fibers is greater to smokers. The symptoms of the disease do not usually appear until about 20–30 years after the first exposure to asbestos. Removal of asbestos-containing materials is not always optimal because the fibers can be spread into the air during

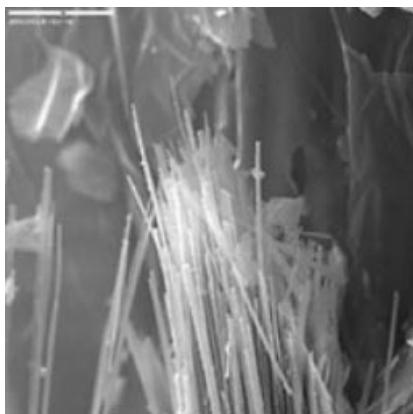


Figure 33.4 Micrograph of asbestos-form amphibole from a former vermiculite mining site near Libby, Montana. (Photograph courtesy of Agency for Toxic Substances and Disease Registry, Center for Disease Control.)

the removal process. A management program for intact asbestos-containing materials is often recommended instead.

Carbon dioxide (CO_2) is an indoor pollutant emitted by humans and correlates with human metabolic activity. Carbon dioxide at levels that are unusually high indoors may cause occupants to become drowsy, get headaches, or function at lower activity levels. Humans are the main indoor source of carbon dioxide. Indoor levels are an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity. To eliminate most IAQ complaints, total indoor carbon dioxide should be reduced to a difference of less than 600 ppm above outdoor levels. The National Institute of Occupational Safety and Health (NIOSH) considers that indoor air concentrations of carbon dioxide that exceed 1000 ppm are a marker suggesting inadequate ventilation. ASHRAE recommend that carbon dioxide levels not exceed 700 ppm above outdoor ambient levels. The United Kingdom standards for schools say that carbon dioxide in all teaching and learning spaces, when measured at seated head height and averaged over the whole day, should not exceed 1500 ppm. The whole day refers to normal school hours and includes unoccupied periods such as lunch breaks. European standards limit carbon dioxide to 3500 ppm. OSHA limits the carbon dioxide concentration in the workplace to 5000 ppm for prolonged periods, and 35 000 ppm for 15 min.

Ozone – Ozone is produced by ultraviolet light from the sun hitting the Earth's atmosphere (especially in the ozone layer), lightning, certain electrical devices (such as air ionizers), and as a by-product of other types of pollution.

Ozone exists in greater concentrations at altitudes flown by passenger jets. Reactions between ozone and onboard substances, including skin oils and cosmetics, can produce toxic chemicals as by-products. Ozone itself is also irritating to lung tissue and harmful to human health. Larger jets have ozone filters to reduce the cabin concentration to safer and more comfortable levels.

Outdoor air used for ventilation may have sufficient ozone to react with common indoor pollutants and also skin oils and other common indoor air chemicals or surfaces. Particular concern is warranted when using “green” cleaning products based on citrus or terpene extracts as these chemicals react very quickly with ozone to form toxic and irritating chemicals and also fine and ultrafine particles. Ventilation with outdoor air containing elevated ozone concentrations may complicate remediation attempts (Wikipedia, 2012d).

33.6.2

Sick Building Syndrome

SBS is a combination of ailments (a syndrome) associated with an individual’s place of work (office building) or residence. Elevated indoor concentrations of VOCs may trigger symptoms of SBS, for example, headaches, fatigue, and eye and upper respiratory irritation. Sick building causes are frequently traced back to flaws in the heating, ventilation, and air conditioning (HVAC) systems. Other causes have been attributed to contaminants produced by outgassing of some types of building materials, VOCs, molds, improper exhaust ventilation of ozone (by-product of some office machinery), light industrial chemicals used within, or lack of adequate fresh-air intake/air filtration.

Symptoms are often dealt with after-the-fact by boosting the overall turnover rate of fresh air exchange with the outside air, but the new green building design goals of energy efficiency and renewable energy technologies in non-residential buildings should be able to avoid most of the SBS problem sources in the first place, minimize the ongoing use of VOC cleaning compounds, and eliminate conditions that encourage allergenic, potentially deadly bacteria growth.

The causes of SBS can be attributed to inadequate ventilation, chemical contaminants from indoor or outdoor sources, and also biological contaminants. Many VOCs can cause acute effects on the occupants of a building. “Bacteria, molds, pollen, and viruses are types of biological contaminants,” and can all cause SBS. ASHRAE recently revised its ventilation standard to provide a minimum of 15 cfm (cubic feet per minute) of outdoor air per person (20 cfm/person in office spaces). In addition, pollution from outdoors such as motor vehicle exhaust, can contribute to SBS (Wikipedia, 2012e).

33.7

Air Pollution Control

In modern society, it is difficult to avoid generating at least some waste products that will enter the atmosphere. A combination of realistic pollution control strategies, laws, and air quality standards is necessary. Principles of engineering and technology must be directed towards the development and use of pollution control equipment.

The most effective control measure is one that prevents injuries and illnesses to people, prevents environmental degradation and limits property damage. There are several approaches or strategies for air pollution control. The most effective control would be to prevent the pollution from occurring in the first place. Complete source shutdown would accomplish this, but shutdown is only practical under emergency conditions, and even then it causes economic loss. Nevertheless, State public health officials can force industries to stop operations and can curtail highway traffic if an air pollution episode is imminent or occurring. Weather is the current condition produced by temperature, humidity, wind, and precipitation. Source shutdown offers only a temporary solution to local problems of air pollution.

In northern California Greater Bay Area, depending on a number of factors including weather patterns, the Bay Area Air Quality Management District (BAAQMD) can declare “spare the air” days to encourage people to limit the use of motor vehicles and, in winter, limit wood burning fires in order to help reduce emission levels and improve air quality. The BAAQMD issued three alerts on Christmas Eve 2011, Christmas Day 2011, and New Year’s Day 2012 due to a stubborn weather system that brought a high-pressure system that dominated the atmospheric conditions. The conditions were unusually low temperatures – 19 of 31 days in December that were at freezing ($32^{\circ}\text{F}/0^{\circ}\text{C}$) or below – trapped dirty air near the ground because of that pressure. When temperatures began to increase, the air became less dense and the particulate matter became less concentrated at ground level, resulting in more good air days (Rick, 2012).

Source location is another option to minimize the adverse impacts of air pollution in a particular locality. Community air zoning may be included in municipal master plans, requiring power plants or industrial facilities to be located where fewer people will be affected by the pollutants. The location of these zones can be established on the basis of prevailing wind patterns and weather conditions. This option is limited as local air quality may be somewhat protected, but the pollutants can still be carried to neighboring communities by the dispersion of the plumes emitted from tall chimneys or smoke stacks.

Tall smoke stacks release pollutants high into the atmosphere, allowing the processes of mixing and dispersion to dilute the contaminants, reducing pollution levels. However, when these contaminants settle, the problem returns. Acid deposition or acid rain is a notable example of an air pollution problem that transcends local boundaries.

33.7.1

Acid Deposition

To reduce local air pollution and meet government standards without having to add expensive air pollution control devices, coal-burning power plants, ore smelters, and industries began to use tall smokestacks to spew sulfur dioxide, suspended particles, and nitrogen oxides above the inversion layer. What is an inversion? Simply put: an inversion is when a layer of warm air traps a layer of cold air underneath it (Figure 33.5).

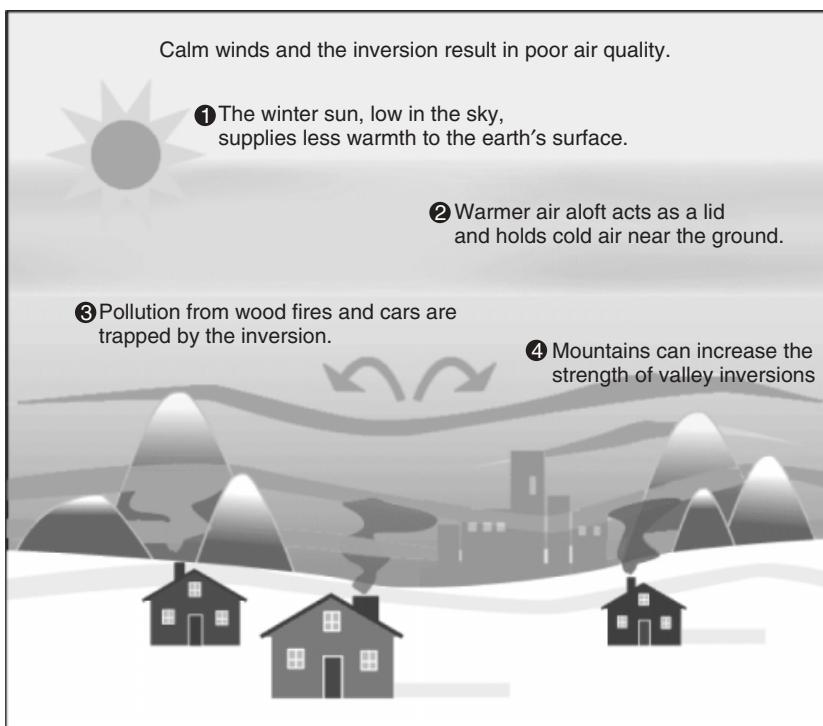


Figure 33.5 An inversion layer. (Source: Mendocino County, CA.)

As this practice spread in the 1960s and 1970s, pollution in downwind areas began to rise. In addition to smokestack emissions, large quantities of nitrogen oxides are also released by motor vehicles.

As sulfur dioxide and nitrogen oxides are transported as far as 1000 km (600 miles) by prevailing winds, they form secondary pollutants such as nitric acid vapor, droplets of sulfuric acid, and particles of sulfate and nitrate salts. These chemicals descend to the Earth's surface in two forms: wet as acidic rain, snow, fog, and cloud vapor, or dry as acidic particles. The resulting mixture is called acid deposition, or commonly acid rain. Because these acidic components remain in the atmosphere for only a few days, acid deposition occurs on a regional rather than global basis.

Acid deposition has a number of harmful effects, especially when the pH falls below 5.1 and below 5.5 for aquatic systems. It can:

- Cause damage to statues, buildings, metals, and car finishes.
- Contaminate fish in some lakes with highly toxic methylmercury.
- Increase the acidity of lakes, converting inorganic mercury compounds in lake-bottom sediments into more toxic methylmercury, which is more soluble in the fatty tissue of animals.
- Cause damage to foliage and weaken trees, especially conifers such as red spruce at high elevations that can be bathed continuously in very acidic fog and clouds.

- Along with other air pollutants, make trees more susceptible to stresses such as low temperatures, diseases, insects, drought, and fungi that thrive under acidic conditions.
- Release soluble aluminum ions from soil, which damage tree roots. When washed into lakes, the released aluminum ions can also kill many kinds of fish by clogging their gills with mucous.
- Lead to excessive levels of nitrogen in the soil, which can overstimulate plant growth and increase depletion of other soil nutrients.
- Contribute to human respiratory diseases such as bronchitis and asthma, which can cause premature death.

Acid deposition is a serious problem in many areas downwind of coal-burning power plants, smelters, and factories. On a larger scale, a large portion of the acid-producing chemicals generated in one country may be exported to others by prevailing winds.

33.7.2

Smog

In 1905, an English public health official coined the word *smog* to describe a mixture of smoke and fog. In those times, the smoke from household coal fires contained significant amounts of sulfur dioxide and fine particles of soot-like materials. The water vapor in the foggy portion of the smog combined with the sulfur dioxide in the smoke to form sulfuric acid (H_2SO_4). This made the smog a serious health hazard. In most parts of the world today, coal and heavy oil are burned only in large boilers with reasonably good pollution control or with tall smokestacks, so industrial smog, sometimes called gray-air smog, is not the problem it once was (Bjorn, 2001).

Photochemical smog is more dangerous as it is generated by materials released from automobile exhaust. Photochemical smog is a mixture of primary and secondary pollutants that forms when some of the primary pollutants interact under the influence of sunlight. The resulting mix of more than 100 chemicals is dominated by ozone, a highly reactive gas that harms most living organisms. When sunlight strikes these gases, ozone is formed by a complicated series of chemical reactions. Each molecule of ozone is composed of three atoms of oxygen (O_3). Ozone thus differs from life-giving oxygen molecules, which have two atoms of oxygen (O_2).

Photochemical smog becomes most dangerous when three conditions prevail and combine: heavy automobile traffic, bright sunlight, and stagnant air mass. All modern cities have photochemical smog, but it is much more common in cities with sunny, warm, dry climates, and large numbers of motor vehicles, such as Los Angeles. In cities with many motor vehicles, the hotter the day, the higher are the levels of ozone and other components of photochemical smog form.

The frequency and severity of smog in an area depend on several factors: the local climate and topography, the density of the population, the amount of industry, and

the fuels used in industry, heating, and transportation. In areas with high average annual precipitation, rain and snow help cleanse the air of pollutants. Winds also help sweep pollutants away and bring in fresh air, but they may transfer some pollutants to distant areas. Hills and mountains tend to reduce the flow of air in valleys below and allow pollutant levels to build up at ground level. Buildings in cities also slow wind speed and reduce dilution and removal of pollutants.

During the day, the Sun warms the air near the Earth's surface. Normally, this heated air expands and rises, carrying low-lying pollutants higher into the troposphere. Colder, denser air from surrounding high-pressure areas then sinks into the low-pressure area created when the hot air rises. This continual mixing of the air helps keep pollutants from reaching dangerous levels near the ground.

Sometimes, however, weather conditions trap a layer of dense, cool air beneath a layer of less dense, warm air in an urban basin or valley. This is called a temperature inversion or a thermal inversion. In effect, a lid of warm air covers the region and prevents the upward-flowing air currents that would disperse pollutants. These inversions usually last for only a few hours; but sometimes when a high-pressure air mass stalls over an area, they may last for several days. Thermal inversions also enhance the harmful effects of urban heat islands and dust domes that build up over urban areas. A common factor of air pollution is a temperature inversion, experienced by Los Angeles – one of many large cities that are built in valleys or surrounded by hills. Photochemical smog reached dangerous levels in Los Angeles in the 1940s and 1950s (Carle, 2006).

Pollutants from automobile exhaust include gaseous oxides of nitrogen and other impurities such as carbon monoxide, which is toxic by itself. For 20 years, scientists and engineers worked on the problem of removing contaminants from automobile exhausts. This research resulted in the design and production of the catalytic converter. The converter is a small canister connected to the exhaust pipe of a vehicle. It contains a series of ceramic screens coated with platinum and other rare metals. Chemicals in the hot gases generated by a gasoline engine pass through the canister and are broken down into relatively harmless molecules. Nitrogen oxide becomes molecules of pure oxygen and pure nitrogen. Unburned gasoline, carbon monoxide, and particles of carbon-based substances are broken down into water vapor and carbon dioxide. The carbon dioxide gas is the only contaminant that remains. The EPA decreed that the newly designed catalytic converter must be installed in most cars manufactured in 1976. The following year, 1977, the requirement applied to every new automobile and truck manufactured in the United States and this has been the practice to date.

33.7.3 **Global Warming**

Global warming refers to the rising average temperature of the Earth's atmosphere and oceans and its related effects. In the last 100 years, the Earth's average surface temperature increased by about 0.8°C (1.4°F) with about two-thirds of the increase occurring over just the last three decades. Warming of the climate

system is unequivocal, and many scientists are certain that most of it is caused by increasing concentrations of greenhouse gases produced by human activities such as deforestation and burning fossil fuel.

An increase in global temperature will cause sea levels to rise and will change the amount and pattern of precipitation, with a probable expansion of subtropical deserts. Warming is expected to be strongest in the Arctic and would be associated with continuing retreat of glaciers, permafrost, and sea ice. Other likely effects of the warming include more frequent occurrence of extreme weather events including heat waves, droughts, and heavy rainfall events, species extinctions due to shifting temperature regimes, and changes in agricultural yields. Warming and related changes will vary from region to region around the globe, although the nature of these regional changes is uncertain.

Proposed responses to global warming include mitigation to reduce emissions, adaptation to the effects of global warming, and geo-engineering to remove greenhouse gases from the atmosphere or reflect incoming solar radiation back into space.

The main concern of climate change is global warming and the predicted warming is based on the so-called greenhouse effect. The fundamental principle of the greenhouse effect is as follows. Several types of gases can reflect or trap heat, including water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), CFC gases, and ozone. These greenhouse gases trap some of the heat emitted by the Earth, analogous to having a blanket wrapped around the globe. The basic greenhouse effect is good because without it the Earth would be much colder and without life as it currently exists. People have increased the quantity of greenhouse gases, CO_2 in particular, in the atmosphere. Everything else being equal, logic dictates that if the extra greenhouse gases reflect heat then more greenhouse gases in the atmosphere will lead to an increase in the temperature on Earth.

Human activity since the Industrial Revolution has increased the amount of greenhouse gases in the atmosphere, leading to increases from carbon dioxide, methane, tropospheric ozone, CFCs, and nitrous oxide. The concentrations of CO_2 and methane have increased by 36 and 148%, respectively, since 1750. These levels are much higher than at any time during the last 800 000 years, the period for which reliable data has been extracted from ice cores. Less direct geological evidence indicates that CO_2 values higher than this were last seen about 20 million years ago. Fossil fuel burning has produced about three-quarters of the increase in CO_2 from human activity over the past 20 years. The rest of this increase is caused mostly by changes in land use, particularly deforestation.

33.7.4

Stationary Sources

A variety of approaches are available to reduce emissions from stationary sources (e.g., process modifications or product substitution to prevent pollution and control technology to remove the pollutants from flue gases). Particulates are emitted in the gases or smoke from smokestacks. Koren and Bisesi, (1995) concluded that a

considerable quantity of particles could be removed from gas streams by applying the following principles:

- 1) Reduce the velocity of the gas to allow the particles to settle by gravity.
- 2) Change the direction of the gas flow to cause the particles to flow straight ahead because of inertia.
- 3) Filter dust-laden gas.
- 4) Electrostatically charge particles to cause the charged particles to be attracted to objects with opposite charge.

Major particulate control equipment used in the United States includes gravity settlers, cyclones, electrostatic precipitators, fabric filters, and wet scrubbers. Major methods to control gaseous emissions include methods of absorption or adsorption, combustion, or incineration. The specific method depends on the nature and properties of the gas or vapor to be controlled.

33.7.5

Control of Stationary Sources

33.7.5.1 Particulate Control

33.7.5.1.1 Electrostatic Precipitator

This is an air purifier that allows the user to clean the air circulating within the home or office using electronic cells that can be washed (Figure 33.6). The electronic cells come in magnetically charged strips of metal that collect airborne particles. When the air enters the electrostatic precipitator, the particles that it carries pass through an electric field that charges the particles. The charged particles then pass through a set of alternately charged aluminum collector plates and are attracted to the plates that have an opposite polarity to that of the type of particle being filtered. In dual-stage electrostatic precipitators, the positively charged contaminants are collected on the negatively charged plates. This removes smoke, grease, mist, and other polluting particles from the air stream (Nathason, 2000a).

33.7.5.1.2 Fabric Filters

Commonly known as *baghouses*, fabric collectors use filtration to separate dust particulates from dusty gases (Figure 33.7). They are one of the most efficient and cost-effective types of dust collectors available and in theory can achieve a collection efficiency of more than 99% for very fine particulates.

This dust collection system is an integral air pollution control method, used to filter out harmful particles from the emissions of industrial sources. These compounds include particles from combustion, such as ash and soot, mercury and VOCs. Dust-laden gases enter the baghouse and pass through fabric bags that act as filters. The bags can be of woven or felted cotton, synthetic, or glass-fiber material in either a tube or envelope shape. It works by forcing the dirty air through a set of filter bags that are housed within an enclosure before releasing the air into the atmosphere. Periodically, the filters are cleaned, usually using a system of

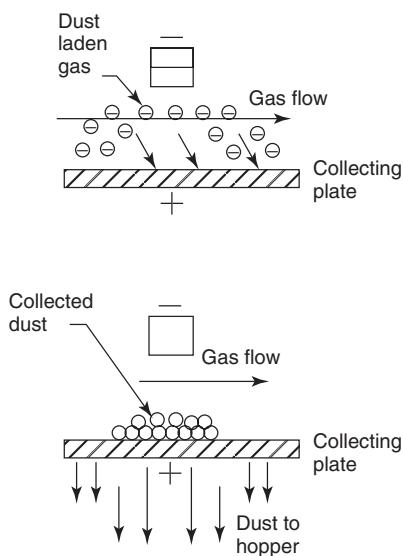


Figure 33.6 Schematic diagram of an electrostatic precipitator (World Wide Web image).

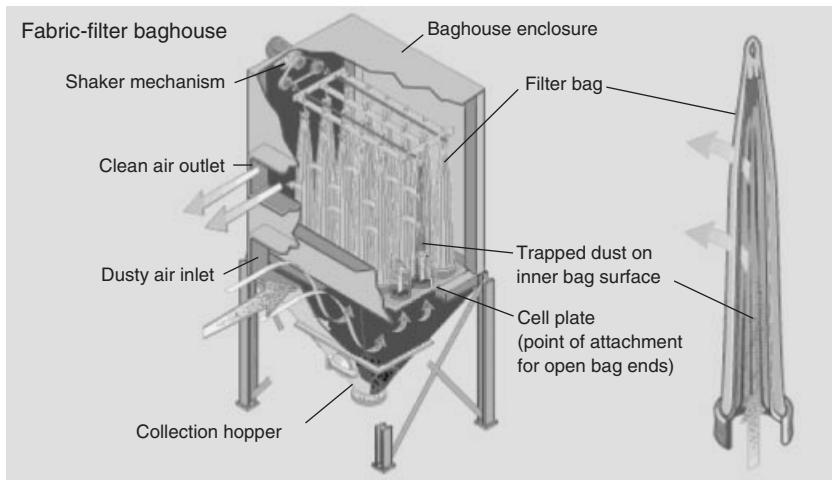


Figure 33.7 Fabric filter baghouse (World Wide Web image).

compressed air within the baghouse to blow off the excess dust buildup, known as filter cake, which is then dropped into a hopper to be either disposed of in landfills or used in other products, such as in cement production (Nathason, 2000b).

Recently, the EPA has tightened existing clean air regulations and standards, making air pollution control technology vital to ensuring compliance. The NAAQS and National Emission Standard for Hazardous Air Pollutants regulations – among

many others – were revised to include more stringent emissions limits for particulate matter (PM_{2.5} or particulates smaller than 2.5 µm) and other pollutants. In December 2011, the EPA also codified the long-awaited Mercury and Air Toxics Standards (EPA, 2011b).

These regulations require coal-burning operations, such as coal-fired power plants, to reduce mercury emissions to acceptable levels using the most efficient current technology, known as Maximum Achievable Control Technology. Dust collection technology is integral to meeting all of these standards.

33.7.5.1.3 Cyclone Dust Collectors

Many industrial processes require dust-size pieces of process material to be collected for reuse or disposal. Cyclone dust collectors are an efficient and low-maintenance means of removing fine material from an air stream (Figure 33.8). Unlike filter-based dust collectors, cyclone dust collectors use the physics of air pressure, mass, and momentum to cause particulate material to fall to the bottom of a chamber where it can be collected. A cyclone dust collector has no moving parts and no filters; instead, it relies on the design and shape of the dust collector chamber. In cyclone dust collection, the air stream passes through tubes or around a stationary spinner that direct the air to rotate inside the chamber. Centrifugal force causes particulate matter to move to the walls of the chamber where it strikes, losing momentum. Then gravity pulls the particulates into a hopper at the bottom of the chamber. The particulate-free air (or other gas) rises through the center of the vortex and is vented at the top of the chamber (Nathason, 2000c).

33.7.5.2 Gas Control

Methods of *absorption* or *adsorption*, similar to techniques used for air sampling on a much larger scale, are used. Another method to control gaseous emissions involves *combustion* or *incineration*.

The transfer of a gaseous pollutant into a contacting liquid, such as water, is an *absorption* process. The gas must be soluble in the liquid, or a reactive liquid absorbent is used to capture the pollutant by chemical reaction. The removal efficiency depends on the solubility or reactivity of the gas, gas and liquid flow rates, and contact time between the gas and liquid. Industry applications include removal of SO₂ from combustion sources, recovery of ammonia in fertilizer manufacture, and control of odors from rendering plants (Nathason, 2000d).

Adsorption is a surface phenomenon where the gas molecules are attracted to and held on the surface of a solid. Activated carbon is the most common adsorbent material. It is very porous and has an extremely high surface area-to-volume ratio. Activated carbon or heated charcoal is particularly useful as an adsorbent for purifying gases containing organic vapors, and also for solvent recovery and odor control (Nathason, 2000e).

Wet and dry flue gas desulfurization systems for sulfur dioxide control – flue-gas desulfurization (FGD) – is a technology used to remove sulfur dioxide (SO₂) from the exhaust flue gases of fossil-fuel power plants and chemical producers of sulfur oxides (Figure 33.9).

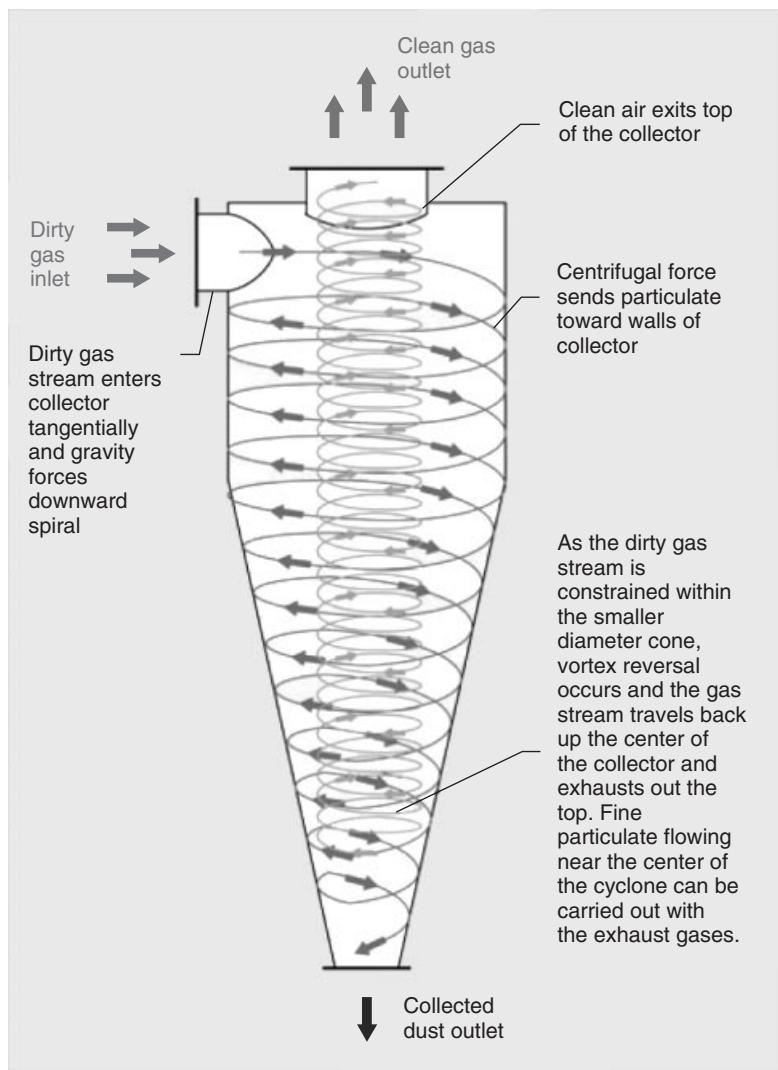


Figure 33.8 Cyclone dust collector (World Wide Web image).

33.7.5.2.1 Basic Principles of Flue Gas Desulfurization Systems

Most FGD systems employ two stages: one for fly ash removal and the other for SO₂ removal. Attempts have been made to remove both the fly ash and SO₂ in one scrubbing vessel. However, these systems experienced severe maintenance problems and low removal efficiency. In wet scrubbing systems (Figure 33.10), the flue gas normally passes first through a fly ash removal device, either an electrostatic precipitator or a wet scrubber, and then into the SO₂ absorber. However, in dry injection or spray drying operations, the SO₂ is first reacted with the sorbent, and then the flue gas passes through a particulate control device (Figure 33.11).



Figure 33.9 Power plant sulfur emissions in New Mexico (Wikipediaimage.)

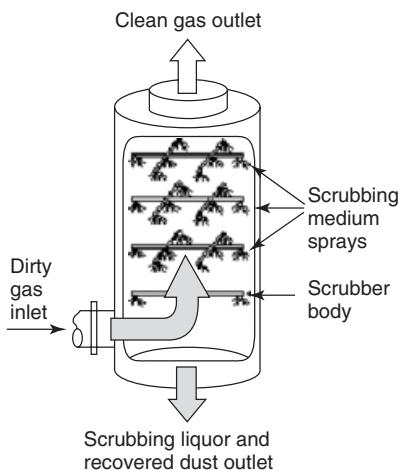


Figure 33.10 Flue gas scrubbing cutaway (World Wide Web image).

Another important design consideration associated with wet FGD systems is that the flue gas exiting the absorber is saturated with water and still contains some SO₂. These gases are highly corrosive to any downstream equipment such as fans, ducts, and stacks. Two methods that can minimize corrosion are (i) reheating the gases to above their dew point or (ii) choosing construction materials and design conditions that allow equipment to withstand the corrosive conditions. Both alternatives are expensive, and engineers designing the system determine which method to use on a site-by-site basis (Wikipedia, 2012a).

33.7.5.2.2 Combustion Modification and Flue Gas Treatment for Nitrogen Oxide Control

NO_x refers to NO (nitric oxide) and NO₂ (nitrogen dioxide). They are produced during combustion, especially at high temperature. These two chemicals are important trace species in the Earth's atmosphere. In the troposphere, during

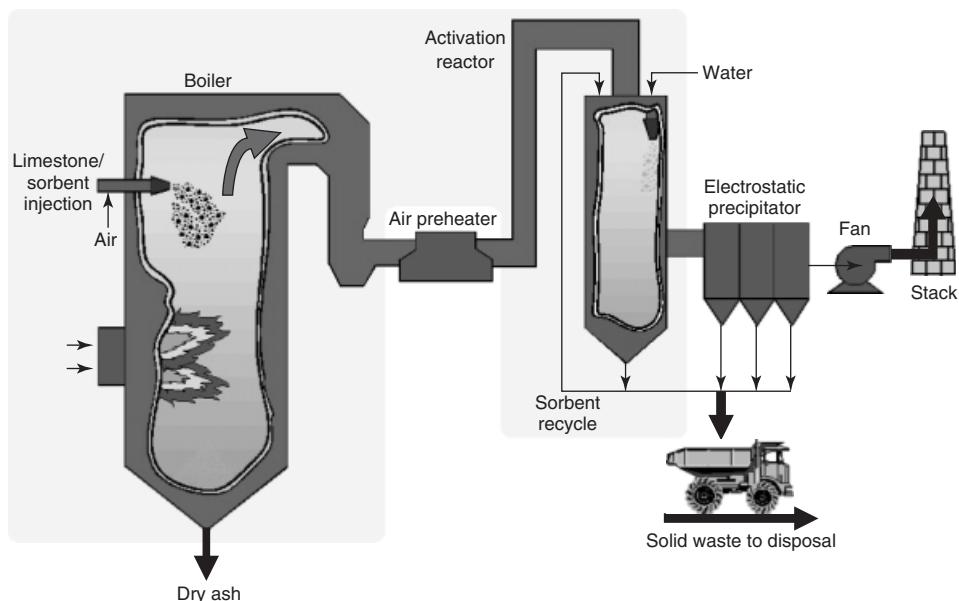
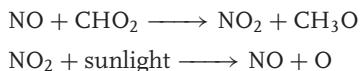


Figure 33.11 Dry flue gas desulfurization system (World Wide Web image).

daylight, NO reacts with partly oxidized organic species (or the peroxy radical) to form NO_2 , which is then photolyzed by sunlight to re-form NO:



The oxygen atom formed in the second reaction then goes on to form ozone. This series of reactions is the main source of tropospheric ozone. CHO_2 is just one example of many partly oxidized organic molecules that can react with NO to form NO_2 .

These reactions are rather fast so NO and NO_2 cycle, but the sum of their concentration ($[\text{NO}] + [\text{NO}_2]$) tends to remain fairly constant. Because of this cycling, it is convenient to think of the two chemicals as a group – hence the term NO_x . In addition to acting as a main precursor for tropospheric ozone, NO_x is also harmful to human health in its own right. NO_x may react with water to form nitric acid, which may end up in the soil, where it makes nitrate, which is of use to growing plants.

On 20 October 2011, California approved one of the broadest and most controversial components of its climate change law, pushing the State towards a low-carbon economy that relies less on imported foreign oil. California became the first State to cap greenhouse gas emissions across its major industries, including oil and gas companies, electric utilities, transportation companies, farmers, and cement makers. The plan allows companies to sell pollution credits as a way to ratchet down

production of heat-trapping gases (California Environmental Protection Agency Air Resources Board, 2012).

The cap-and-trade system, which will begin operating in January 2013, is a key component of the State's landmark climate change law, which aims to reduce carbon emissions to the 1990 level by 2020. The plan places a hard cap on the amount of carbon dioxide produced by the State's largest industrial polluters. By 2013, refineries, power plants and the rest of the State's top 600 industrial sources of greenhouse gases will have to cut emissions on average by 10% or pay to make up the difference.

The State then provides a limited amount of carbon pollution allowances that can be bought and sold on the open market (Barringer, 2011).

Under the plan, companies that pollute less than their limit can sell their unused allowances to companies that pollute heavily, creating market incentives for everyone to reduce emissions voluntarily.

The plan is that 90% of the allowances will be given out to the companies. The remaining 10% will be sold on the open market, where some experts predict that they could raise \$500 million a year for the State. The money collected will go towards funding the State's climate change programs. Environmentalists and clean energy advocates say the program will not only cut greenhouse gases but will also spur innovation in the clean technology sector.

In 2015, the rules will begin also to cover the carbon content of transportation and other fuels. About 85% of California's greenhouse gas emissions will eventually be covered under the plan. Overall, the cap-and-trade program is expected to achieve 20% of the reductions mandated by California's landmark 2006 greenhouse gas law, known as Assembly Bill (AB) 32. That law requires the State to cut greenhouse gas emissions to 1990 levels by 2020, a substantial reduction (California Environmental Protection Agency Air Resources Board, 2012).

Other strategies in place to meet the greenhouse gas targets are standards for renewable electricity, low-carbon fuels, and more efficient appliances and cars. The regulations being considered represent the first time a State has capped greenhouse gas emissions across industries and allowed for pollution credit tracings. A similar strategy is under way in several northeastern States, but that program applies only to power generators.

33.7.6 Control of Mobile Sources

Mobile source air pollution includes any air pollution that is emitted by motor vehicles, engines, and equipment that can be moved from one location to another. Many of these pollutants contribute to environmental degradation and adverse human health effects. To prevent unnecessary health and environmental damage, numerous environmental regulatory committees have established policies aimed at minimizing air pollution from mobile sources. Owing to the large number of sources and their ability to move from one location to another, mobile sources are

regulated differently than stationary sources. Because of the continuing increase in the number of motor vehicles driven in the United States, the effort to limit mobile source pollution is even more challenging. As a result, there have been a number of different regulatory instruments implemented to reach the desired emissions goals.

Specific limits were set for emissions of carbon monoxide, hydrocarbons, and oxides of nitrogen from automobiles. This forced the automobile industry to develop new technologies for emission control. Currently, a wide variety of mobile sources are subjected to control under the CAA. Strategies used to control mobile-source emissions include the new source certification programs that specify emission standards applicable to new vehicles and motors, in-use technological measures and controls that include specification for fuel properties, vehicle inspections, maintenance programs, and retrofits to existing vehicles, and non-technological measures to control usage or activity.

Road sources includes cars, light- and heavy-duty trucks, buses, and motorcycles.

Non-road sources includes aircraft, motorboats (diesel and gasoline), locomotives, lawn and garden equipment, and construction equipment. Engineering measures available to reduce automobile emission pollutants in order to achieve better results include:

- 1) Modifying internal combustion engines, primarily by making them smaller. Other redesigns, adding new devices, and tune-ups are other modifications. Newer engines run at a leaner fuel/air ratio, reducing VOC and NO emissions, and at retarded spark ignition timing, reducing nitrogen oxide emissions.
- 2) Addition emission controls:
 - a. Crankcase emission controls recycle gases emitted from the oil sump into the combustion chamber.
 - b. Exhaust gas recycling introduces a portion of the exhaust gases into the fuel-air mixture before it enters the combustion chamber, thereby reducing the emission of nitrogen oxides.
 - c. Catalytic converters treat exhaust gases catalytically, reducing carbon monoxide, hydrogen carbon and nitrogen oxide concentration levels. Converters must use lead-free fuel and do not become fully operational until they are warmed up. So-called “cold start” can account for 40–70% of total emissions on a typical urban trip.
- 3) Modifying fuel consumption to burn more completely and to eliminate harmful additives, lead in particular. Aromatic hydrocarbons or alcohols that burn smoothly are introduced in a higher proportion to eliminate engine knock. Other fuels, such as compressed natural gas, liquefied natural gas, and liquefied petroleum gas, could be used. These fuels ignite easily and burn more completely than present-day gasoline. A conversion of engine fuel control systems is required.
- 4) Developing new propulsion systems includes:
 - a. battery-powered
 - b. fuel cells

- c. external combustion engines
- d. other internal combustion engines.

Table 33.5 lists then advantages and disadvantages of alternative fuels.

33.8

Best Practices and Solutions

Federal, State, and local governments utilize a wide range of policy instruments to control pollution from mobile sources. At the federal level, many different agencies are responsible for regulating, or at least creating policies, to limit pollution from mobile sources. This is necessary given the broad range of objects that are considered “mobile sources,” from aircraft and off-road vehicles, to locomotives and on-road vehicles. The Federal Aviation Administration, for example, establishes standards to limit emissions from aircraft, whereas the Department of Transportation and EPA administer various aspects of on-road vehicle fuel economy regulations. At the State level, mandatory vehicle emissions-testing programs are often required as part of the annual motor-vehicle registration process.

Many governments throughout the world require manufacturers of particular products to attach information-related labels to their products. Like mobile sources of air pollution, there is a broad range of products that may require government labeling regulation. In the United States, numerous federal agencies oversee various label-related regulation programs. Common examples in the United States include food nutrition and ingredient labels for food products, overseen by the US Food and Drug Administration, Surgeon General Labels on alcohol and tobacco products, and labels for common household pesticides set by the EPA.

In the United States, all new cars and light-duty trucks are required to have labels that display specific fuel economy information. The EPA calculates the average fuel economy for each vehicle manufactured, and provides the data to the National Highway Traffic Safety Administration (NHTSA), which administers and enforces the Corporate Average Fuel Economy (CAFE) program. The purpose of the program is (i) to reduce emissions by requiring vehicle manufacturers to meet minimum fuel economy levels and (ii) to provide consumers with fuel economy information before purchasing new vehicles.

The CAFE was first enacted by US Congress in 1975 and was intended to improve the average fuel economy of cars and light trucks (trucks, vans, and sport utility vehicles (SUVs)) sold in the United States in the wake of the 1973 Arab oil embargo. Historically, it is the sales-weighted harmonic mean fuel economy, expressed in miles per US gallon (mpg), of a manufacturer’s fleet of current model year passenger cars or light trucks with a gross vehicle weight rating (GVWR) of 8500 lb (3856 kg) or less, manufactured for sale in the United States. If the average fuel economy of a manufacturer’s annual fleet of vehicle production falls below the defined standard, the manufacturer must pay a penalty, currently \$5.50 per 0.1 mpg under the standard, multiplied by the manufacturer’s total production for the US domestic market. In addition, a Gas Guzzler Tax is levied on individual

Table 33.5 Alternative fuels: pros and cons.

Fuel	Advantages	Disadvantages
“Clean” gasoline mixtures	Immediate reduction in pollution emissions Fuel distribution system in place Requires no engine modifications	Net environmental benefits uncertain Fuel at least 2–3 cents more per gallon Dependence on imported crude oil No reduction in carbon dioxide emissions
Ethanol	Higher octane than regular or premium gasoline Renewable resource (based on corn or sugar cane) Reduces carbon dioxide emissions Lowers CO emissions for gasoline mixtures	Less energy per gallon Expensive Causes smog when used with gasoline
Methanol	Higher octane than gasoline Overall reduction in hydrocarbon emissions Reduces carbon dioxide emissions Lowers total airborne toxics, except for formaldehyde	Less energy per gallon, more frequent refueling Can be dangerous to handle Corrosive Cold engine starts difficult
Natural gas	Abundant supplies Currently inexpensive Lower hydrocarbon emissions than gasoline Reduced CO emissions Small reduction in carbon dioxide emissions Distribution system largely in place	Clumsy fuel tank Must refuel every 100 miles Refueling time is 2–3 times longer
Electricity	Quiet Virtually no vehicle emissions	Technology is about 5–10 years away Currently, less than 100 miles per charge Maximum speeds 30–65 miles per hour today Recharge 6–8 h Environmental impact varies with source of electricity
Solar-generated hydrogen	Renewable energy source Virtually emission free Does not contribute to global warming	Technology is at least 20 years away

Adapted from *Earth under Siege: from Air Pollution to Global Change* (Turco, 2002).

passenger car models (but not trucks, vans, minivans, or SUVs) that get less than 22.5 mpg (10.5 l per 100 km).

Beginning in 2011, the CAFE standards were newly expressed as mathematical functions depending on the vehicle “footprint,” a measure of vehicle size determined by multiplying the vehicle’s wheelbase by its average track width. CAFE footprint requirements are designed such that a vehicle with a bigger footprint has a lower fuel economy requirement than a vehicle with a smaller footprint. For example, the 2012 Honda Fit has a footprint of 40 ft^2 (3.7 m^2) and must achieve a fuel economy (as measured for CAFE) of 36 mpg (6.5 l per 100 km), equivalent to a published fuel economy of 27 mpg (8.7 l per 100 km), whereas a Ford F-150 with a footprint of $65\text{--}75 \text{ ft}^2$ ($6.0\text{--}7.0 \text{ m}^2$) must achieve a CAFE fuel economy of 22 mpg (11 l per 100 km), equivalent to a published fuel economy of 17 mpg (14 l per 100 km).

CAFE has separate standards for “passenger cars” and “light trucks,” despite the majority of “light trucks” actually being used as passenger cars. The market share of “light trucks” grew steadily from 9.7% in 1979 to 47% in 2001 and continues to be about 50% of market share in 2011. More than 500 000 vehicles in the 1999 model year exceeded the 8500 lb (3900 kg) GVWR cutoff and were therefore omitted from CAFE calculations.

CAFE does not directly offer incentives for customers to choose fuel-efficient vehicles, nor does it directly affect fuel prices. Rather, it attempts to accomplish these goals indirectly by making it more expensive for automakers to build inefficient vehicles by introducing penalties.

The NHTSA regulates CAFE standards and the EPA measures vehicle fuel efficiency. Congress specifies that CAFE standards must be set at the “maximum feasible level” given consideration for:

- technological feasibility
- economic practicality
- effect of other standards on fuel economy
- need of the nation to conserve energy.

33.8.1

Taxation and Incentives

Another common policy instrument used by governments to influence market behavior is taxation. In the case of mobile source air pollution, the US government has established many different taxes to limit emissions from various mobile sources. Perhaps one of the best known is the Gas Guzzler Tax, established by the Energy Tax Act of 1978. The act set minimum fuel economy standards for all new cars sold in the United States.

The tax is levied against manufacturers of new cars that fail to meet the minimum fuel economy level of 22.5 mpg. The tax does not apply to minivans, SUVs, or pick-up trucks, as these made up a small portion of the US fleet when the tax was established in 1978. Manufacturers pay a level of tax based on the average fuel economy for each particular vehicle produced, ranging from \$1000 for vehicles

achieving at least 21.5 but less than 22.mpg, to \$7000 for each vehicle achieving less than 12.mpg. Vehicles that achieve a minimum average fuel economy of 22.mpg are not subject to the tax.

33.8.2

Tax Credits

Governments may also offer tax credits to encourage certain types of behavior within market economies. For example, if a government wants to encourage consumers to purchase more fuel-efficient vehicles, it could offer tax credits to lower the price of each vehicle. The logic of this approach is consistent with the laws of supply and demand, namely, as the price of a good decreases, the quantity demanded of that good will increase. This is true given that other important factors, such as current levels of supply and demand, remain constant.

The US Federal Government currently utilizes numerous tax credits to reduce emissions from mobile sources. One of the most common tax credits is the “Qualified Plug-In Electric Drive Motor Vehicle Tax Credit.” This credit is available “for the purchase of a new qualified plug-in electric drive motor vehicle that draws propulsion using a traction battery that has at least 4 kWh of capacity, uses an external source of energy to recharge the battery, has a GVWR of up to 14 000 lb, and meets specified emission standards.” The credit ranges from \$2500 to \$7000, depending on the vehicle’s weight rating. At one extreme of the vehicle’s weight rating is the Chevrolet Volt. Consumers who purchase the new Chevrolet Volt are eligible for the full \$7500 credit. Another tax credit targeted at consumers is the “Fuel Cell Motor Vehicle Tax Credit,” which was originally set at \$8000 for the purchase of qualified light-duty fuel cell vehicles. On 31 December 2009, the tax credit was reduced to \$4000.

On 29 July 2011, President Obama announced a historic agreement with 13 major automakers to pursue the next phase in the Administration’s national vehicle program, increasing fuel economy to 54.5 mpg for cars and light-duty trucks by Model Year 2025. The President was joined by Ford, GM, Chrysler, BMW, Honda, Hyundai, Jaguar/Land Rover, Kia, Mazda, Mitsubishi, Nissan, Toyota, and Volvo – which together account for over 90% of all vehicles sold in the United States – and also the United Auto Workers (UAW) and the State of California, who were integral to developing this agreement.

33.8.3

Hybrid Cars

These vehicles combine two well-established methods of propulsion: the internal combustion engine and the electric motor. The internal combustion engine can be kept relatively small and can run on conventional gasoline or compressed natural gas (methane). Alternatively, the engine can be a diesel and run on a mixture of petroleum and vegetable oils. All options yield benefits of lower emissions.

33.8.4

Hydrogen as Fuel

Natural gas produces much less pollution-causing nitrogen oxides than other fuels. Cars that run on natural gas are also manufactured and produced.

One of the most appealing alternative fuels is pure hydrogen. Hydrogen is very efficient and generates only water vapor as an emission. However, pure hydrogen can be costly to produce and its use will require changes in engine design.

33.9

Conclusion

The information related to air pollution presented in this chapter is intended to increase awareness of the problem and of the need for prevention and control. It also identified regulatory and compliance issues related to controlling and preventing air pollution. The chapter provides basic information for assisting, evaluating, and selecting air pollution control equipment and systems and also guidelines for evaluating air-pollution control systems and programs.

Air pollutants cause serious health problems together with adverse environmental and ecological effects and property damage. Hence air pollutants must be controlled at the source or diluted before being emitted into the atmosphere. Preventing pollutants from forming is definitely the preferred method. Air pollution is a global concern that creates a need for international strategies and agreements – reflections of the social demands of the way we live.

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