Case Study: Sustainable Skylines: Dallas and Kansas City
Cities that participate in the EPA's Sustainable Skyline program develop voluntary initiatives to achieve lower levels of pollutants from yards, vehicles, and buildings and to develop a tree canopy. Cities are more vulnerable to air quality issues due to concentration of emissions, the "heat island" effect, and decreases in albedo.

Chapter 21

AIR POLLUTION

21.1 AIR POLLUTION IN THE LOWER ATMOSPHERE

● A Brief Overview

There is a long history of air pollution. Written accounts can be found in the 16th century. Acid rain was described in the 17th century, and its potential to do harm was established by the 18th century. The term "smog" was coined in 1905. In the U.S., an air pollution episode in Donora, PA in 1948 caused 20 deaths and 5,000 illnesses. The Donora event was followed by a London event in 1952 that caused thousands to become ill or die prematurely.

● Stationary and Mobile Sources of Air Pollution

Air pollutants are either from mobile or stationary sources. **Mobile sources** derive from transportation. **Stationary sources** are further described as being **point sources** (e.g. a smoke stack), **fugitive sources**, and **area sources**. Fugitive sources generate air pollutants from open areas exposed to wind (e.g. dust from a construction site). Area sources are defined areas, such as an urban community or an industrial complex.

● General Effects of Air Pollution

There are effects on fauna and flora as well as infrastructure. The effects on vegetation include damage to leaves, suppression of growth/photosynthesis, increased susceptibility to disease, and increased susceptibility to extreme climate. Air pollution can also make soil and water toxic, and leach minerals form soil.

Air pollution is a significant source of mortality for people in urban areas and carries a health cost estimated to be $50 billion annually in the U.S. The primary health effects include toxic poisoning, cancer, birth defects, irritation of the eyes and respiratory system. Exposure to air pollutants also increases susceptibility to hearth disease, emphysema, viral and bacterial infection. Air pollution can also damage surfaces, paint, and materials.

● The Major Air Pollutants

Air pollutants are classified as being primary or secondary. **Primary pollutants** are those emitted directly (e.g. CO), while **secondary pollutants** are produced through reactions among primary pollutants and normal atmospheric compounds. Some 140 million metric tons of primary pollutants are emitted annually in the U.S., consisting mostly of CO, NOx, SOx, and particulates. (The term "NOx" refers to multiple nitrogen oxide compounds.) In addition to the human sources of pollutants, there are natural pollutant sources, including forest fire (particulates and NOx), volcanic eruptions (SOx), vegetation (VOCs), and hot springs, geysers, and salt marshes (H_2S), and natural hydrocarbon seeps.

Major air pollutants either occur in **gaseous** form or as **particulate** matter (PM). Particulates are solids or liquids, and they are further classified according to size, e.g. PM10 is a particulate less than 10 um. The gases include SO_2 or SOx, NOx, CO, O_3, volatile organic compounds (VOCs), H_2S, and hydrogen fluoride (HF). The six most common pollutants are called **criteria pollutants**.

● Criteria Pollutants

Sulfur dioxide gas (SO_2) is colorless, toxic and even fatal at high concentrations. It oxidizes to SO_4 in the atmosphere and combines with water to from H_2SO_4, the main component of acid rain. Combustion of coal is the major source

Nitrogen oxide gases (NOx) occur in several oxide forms, but largely as NO and NO_2. It contributes to acid rain as nitric acid, and is a major contributor to smog and secondary pollutants (PANs). Nearly all NOx is anthropogenic and from combustion sources. NO and NO_2 suppress plant growth, but NO_3 stimulates plant growth and contributes to aquatic eutrophication.

Carbon monoxide gas (CO) is colorless and odorless and extremely toxic to humans and animals. CO has a greater affinity for hemoglobin than O_2. About 90% of the CO in the atmosphere is from natural sources, the other comes from fires, autos, and other sources of incomplete burning of organic compounds. Emissions in the U.S. peaked in the early 1970s.

Ozone (O_3) and other **photochemical oxidants** result from atmospheric interactions of NO_2 and sunlight, hence they are secondary pollutants and are components of smog. O_3 is most common and is extremely reactive. It has a short half-life. It is extremely toxic to plants and animals, and in low concentrations it burns the eyes and irritates the sinuses. It attacks rubber and plastic. O_3 sometimes manufactured for use as a sterilizing agent. It is sometimes used instead of Cl^- to sanitize drinking water. It forms naturally in the stratosphere, where it forms a protective layer that blocks much of the UV radiation.

A CLOSER LOOK 21.1: Acid Rain
Acid rain is precipitation in which the pH is below 5.6. pH is a measure of the concentration of hydrogen ions. As pH decreases, the concentration hydrogen ion rises and the concentration of hydroxyl ion (OH^-) declines. pH 7 is neutral (equal concentrations of H and OH. Acid rain is **caused** primarily by SOx emissions, with a significant contribution made by NOx. Coal-burning electric power plants are the major source of SOx for acid rain. Ironically, the problem was made worse when higher air quality standards forced electric utilities to raise the heights of their smoke stacks based on the premise that dilution is the solution to pollution. Acid rain dissolves stone monuments and bridge supports, corrodes metals, damages aquatic systems (there are lakes in the Adirondacks that are too acidic to support fish), damages the foliage on vegetation (removes protective waxes) making the leaves susceptible to fungal attack, and solubilizes aluminum in the soil (toxic to plants). The **sensitivity** of the environment to acid rain varies with the buffering capacity of the soil. Regions with

Particulate matter (PM 10 and PM 2.5) (less than 10 μm and 2.5 μm respectively) applies to solid particles in the air and is often visible as smoke. The composition of PM varies greatly, and includes heavy metals, arsenic and asbestos. PM 2.5 is of greatest concern because they can embed in lung tissue for long periods. 2-9% of mortality in urban areas is attributed to PMs. **Ultrafine particles**, which are small enough to enter the bloodstream, may contribute to heart disease. PM is especially high in cities. Widespread PM entering the atmosphere due to human activities has contributed to **global dimming**.

Lead (Pb) is a constituent of auto batteries and was an additive in gasoline. Lead was phased out of gasoline when catalytic converters were added to cars, because the Pb ruined the catalytic converters. Pb poisoning causes mental retardation, neurological damage, and behavioral problems. When used in gasoline it was the major source of airborne Pb pollutions. Since the phase-out, Pb emissions have greatly declined. This is one of the success stories.

● Air Toxics
Air toxics are among those pollutants known or suspected to cause cancer or other serious health problems after exposure. They include 150 known gases, metals, and organics typically emitted in relatively small volumes.

Hydrogen sulfide (H_2S) is highly toxic, corrosive, and has a rotten egg odor. It is produced from natural sources (sulfate reduction in salt marshes, volcanoes) and industrial sources.

Hydrogen fluoride (HF) is released from industrial sources and is extremely toxic, even at 1 part per billion. It has been known to enter grazing animals after deposition on grass.

Mercury (Hg) is released from coal-burning plants, industrial sources, and mining. Hg causes neurological and developmental damage. It is deposited on soil and directly in water, where it enters the food chain and undergoes biomagnification.

Volatile organic compounds (VOCs) include a variety of chemicals, including solvents, gasoline vapors, natural gas, and may others. Many are toxic and some are carcinogenic (e.g. benzene). About 15% of VOCs emitted globally are anthropogenic, and about 50% of VOC emissions in the U.S. are anthropogenic. Catalytic converters have greatly reduced VOC emissions from autos.

Methyl isocyanate is a chemical used in pesticide production, and inhalation of it causes severe respiratory distress and death. In 1984 an accident in Bhopal, India released a cloud of methyl isocyanate that killed over 2,000 people and injured 15,000. Such chemicals need careful handling and should not be used near high-density populations.

Benzene is used in gasoline and solvents, and can be an important indoor pollutant released from glue, paint, furniture wax and detergent (CDC, http://www.bt.cdc.gov/agent/benzene/basics/facts.asp). Benzene exposure is linked to cancer and other serious human diseases.

Acrolein is released by petroleum burning and is in tobacco smoke. It has both acute and chronic effects ranging from eye and throat irritation to possible cancer. (EPA, http://www.epa.gov/iris/subst/0364.htm)

● Variability of Air Pollution

The severity of air pollution varies regionally and temporally with climate, season, source strength, and even time of day. "Haze from afar" refers to pollutants which travel long distances, even across oceans.

● Urban Air Pollution: Chemical and Atmospheric Processes

Sulfurous smog, also known as "London smog" or "gray air", is produced by burning coal or oil at large power plants. It can cause severe throat and lung irritation due to its acidic character.

Photochemical smog, also known as "L.A. smog" or "brown air" is directly linked to automobile emissions and is a particular problem in urban areas during daylight hours where concentrations of the primary pollutants are sufficiently high as they often are on the road during rush hour. Sunlight reacts with hydrocarbons and nitrogen oxides to form ozone and other irritating compounds.

Meteorological conditions can determine if air pollution if a nuisance or a major health threat. Air pollution can become severe during atmospheric inversions, which occur when a blanket of cool air is trapped at ground level and overtopped by warmer air. Since cooler air is denser than warm air, the cool air does not rise and pollutants can accumulate. The susceptibility of an area to **inversion** is a function of local topography and weather. The potential for air pollution depends on the rate of emissions, the average wind speed, the distance downwind through the city, elevation of mixing.

● **Future Trends for Urban Air Pollution**
Strategies to reduce air pollution include reducing the use of automobiles, stricter emission controls and fuel efficiency for autos, encouragement of greater use of electric and hybrid vehicles, use of cleaner burning fuels, improved public transportation, and improved controls on industrial pollutants, and mandatory car pooling.

In the United States, air quality has improved overall in the last 40 years, but some cities remain a problem. In the future more attention may be paid to pollutants that are emitted in smaller amounts but can be serious health problems, such as air toxics, or are subject to biomagnification, such as mercury.

Interesting question for discussion: Air quality standards have been developed to protect the people most at risk; these are people that suffer from asthma, emphysema, and other respiratory ailments. Air pollution control adds to the price of goods and services. Should healthy people have to pay this added cost?

● **Developing Countries**
Developing countries often stress development over pollution control and public health, as do most countries trying to compete in a global economy. Public pressure in places such as Mexico City may soon lead to change.

Another interesting question: The major industrial powers went through a phase of development in which there were no pollution controls. These wealthy nations have now taken steps to improve the environment, including air quality. Should these nations expect that developing countries should adopt the same costly standards?

21.2 CONTROLLING COMMON POLLUTANTS OF THE LOWER ATMOSPHERE

The most reasonable ways to reduce air pollution is through **reducing emissions**, **capturing them before release**, or **removal from the atmosphere**.

● **Particulates**
Mobile sources are difficult to control. Industrial PMs can be controlled with electrostatic precipitators, scrubbers and filters.

● **Automobiles**
Catalytic converters are used on autos to reduce VOCs and CO. Auto emissions of NO_x are reduced by recirculating exhaust gas and adjusting the air:fuel ratio, which also leads to lessening photochemical smog. Of course, reducing the number of vehicles emitting pollutants and reducing miles driven is also effective.

Interesting question for discussion: Given that transportation is one of the major sources of urban air pollution, what could be done to change the habits of people so that they would rely on alternative and cleaner forms of transportation?

● Sulfur Dioxide
SO_2 can be controlled by using scrubbers on smoke stacks and by using cleaner or gasified coal as a fuel source. Technology also exists to capture sulfur compounds and incorporate them into products such as sheetrock.

● Air Pollution Legislation and Standards
The **Clean Air Amendments of 1990** are comprehensive regulations that address acid rain, toxic emissions, ozone depletion, and auto exhaust. The legislation provides incentives to utilities to reduce SO_2 emissions by providing marketable permits that allow companies to buy and sell the right to pollute. The total amount of pollution allowed is divided into a fixed number of permits. This provides an economic incentive for using clean technologies. The legislation also called mandated a reduction in NO_2. The law also dealt with O_3 depletion by phasing out CFC production completely by 2030. Tougher standards for PM 2.5 and ozone were established in 1997 by the EPA.

National **Ambient Air Quality Standards** (NAAQS) are a set of target standards that have been established by the EPA for each major air pollutant.

The **Air Quality Index** (AQI) is a standard used to define the quality of air. The index is expressed on a continuous scale from 0, with 0-50 being good and healthy, 51-100 moderate and unhealthy for some, and over 300 being hazardous. If the AQI exceeds 400, an air pollution emergency is declared, and people are requested to remain indoors. Moreover, the EPA is empowered to limit the use of automobiles and emissions by industry.

● The Cost of Controlling Outdoor Air Pollution
Cost varies by industry. Cost increases with the degree of control, and while the effectiveness of pollution control rises to an asymptotic level, the cost has no limit. Consequently, the cost effectiveness of pollution control declines as the amount of control increases. However, as the controls for air pollution increase, the loss from pollution damages decreases. The total cost of air pollution is the cost of pollution control plus the environmental damages of the pollution.

21.3 HIGH-ALTITUDE (STRATOSPHERIC) OZONE DEPLETION
Ozone (O_3) is an irritating and destructive pollutant in the lower atmosphere, but in the stratosphere it acts as a screen against ultraviolet radiation that is harmful to life.

● Ultraviolet Radiation and Ozone
The **ozone shield** is a thick region of the atmosphere in which ozone is scattered at concentrations up to 400 parts per billion. Ozone forms after the reaction of highly energetic **ultraviolet C** (UVC) light splits O_2 molecules to form free radical oxygen that then combines with free O_2 to form O_3. As such, very little UVC reaches the surface.

Ultraviolet B is also highly energetic and harmful to life. Ozone absorbs this light and prevents much of it from reaching living organisms. The amount of this radiation that reaches Earth varies with ozone concentration.
Another frequency, **ultraviolet A**, is not absorbed by ozone. Some reaches the Earth and causes some damage to cells.

● Measuring Stratospheric Ozone
Ozone levels can be measured from the ground by spectrometers or from planes or satellites. Measurements over 50 years have indicated thinning of ozone in various parts of the atmosphere, usually seasonally. The thinning over the Antarctic was termed the **"ozone hole"**.

● Ozone Depletion and CFCs
Ground release of extremely stable **chlorofluorocarbons** (CFCs) such as those used in propellants and air conditioning units has permitted these gases to work their way up to the stratosphere. Sunlight eventually destroys them, releasing free chlorine, a highly reactive free radical that catalyses the destruction of ozone back to oxygen.

● Simplified Stratospheric Chlorine Chemistry
Key concepts of the chemistry of CFCs: they are very stable in the lower atmosphere, so are not removed by conventional forces; they are susceptible to UV light in the stratosphere, allowing breakdown and the release of free Cl; the Cl can **catalyze** the breakdown of ozone, often destroying many molecules before it is removed by downward diffusion.

Free chlorine can bind with nitrogen dioxide and be removed from the reaction cycle temporarily. It can be released later, so $ClONO_2$ is a reservoir for chlorine.

● The Antarctic Ozone Hole
The ozone hole over Antarctica grew from its first observation in the 1970s until it stabilized in the 2000s.

● Polar Stratospheric Clouds
Polar stratospheric clouds tend to sequester nitrogen oxides during the winter when temperatures drop. This sequestered nitrogen is therefore unavailable when spring sun returns and causes the release of chlorine, resulting in the typical increased ozone thinning associated with the end of winter. Later in the year, when the polar stratospheric clouds thin, nitrogen is released to once again slow the catalytic effects of free chlorine.

● Environmental Effects of Ozone Depletion
Ozone depletion is dangerous to people and other animals (even furred ones) due to its relation to skin cancer. Increases in ultraviolet radiation can also disrupt oceanic food chains.

● The Future of Ozone Depletion
Hopefully ozone depletion is a success story. It was detected, measured and studied, and steps were taken for control. Ozone thinning has slowed and recovery may be noticeable by 2020, assuming our models are correct. Error may result from predictions of CFC release from materials and the fact that much of our released CFCs have not yet reached the stratosphere.

21.4 INDOOR AIR POLLUTION

Humans have a history of building structures and breathing the inside air, which was often contaminated by smoke from cook/heating fires. People today spend 70-90% percent of thier time inside, so quality of indoor air is of major importance.

● Sources of Indoor Air Pollution
Sources include tobacco smoke, *Legionella pneumophila* (a bacterium), mold spores, radon gas from soil under the building, pesticides used in the building, asbestos from insulation and tile, formaldehyde gas from decomposing particle board, and dust mites. Unfortunately, two of the best ways to conserve energy in buildings, namely to increase insulation and eliminate air leaks, exacerbates the problem of indoor air pollution.

● Pathways, Processes, and Driving Forces
Pressure differences between the inside and outside of a building create **chimney effects**. These effects can cause outside air to be drawn in through cracks, or pollutants to be drawn from one part of a building to another.

Heating, ventilation, and air-conditioning systems move a great deal of air, and should be properly designed to provide comfort and humidity control. These systems provide an opportunity to filter air, and filters should be replaced regularly.

The combustion products from **burning tobacco** include NOx, CO, hydrogen cyanide, and about 40 carcinogenic chemicals. In the U.S. 3,000 cancer deaths and 40,000 more from heart disease are thought to be related to second hand smoke. There are still 40 million smokers in the U.S. Fortunately, many buildings have banned smoking, but people smoking in doorways still contaminate indoor air.

Radon is a naturally occurring radioactive gas that is colorless, odorless and tasteless. It is produced from the decay of ^{238}U. Radon is known to be a risk factor for lung cancer, and indoor radon gas poses risks that are 100s of times greater than those from outdoor pollutants in the air. The production of radon gas varies with the local geology and, thus, varies spatially. There are large areas of PA, NJ and NY that are notorious for high radon levels. High concentrations have been identified in other states as well. Radon enters homes by migrating up from the soil into basements and lower floors, from groundwater

Critical Thinking Issue – Should Carbon Dioxide Be Regulated Along with Other Major Air Pollutants?
Carbon dioxide is implicated in climate change but has no direct toxic effect on people at concentrations normally found in the atmosphere. It is a nutrient for plants, but that does not necessarily mean it is not a pollutant; excess nitrogen compounds are considered pollutants in water even though they are necessary nutrients. (This is a good time to recall the definition of "pollutant".) Many would oppose carbon dioxide as a nutrient because it might mean intense regulation of any industry that burns fossil fuel. Your students can probably think of other problems as well.

that sometimes is pumped into homes, and from radon-contaminated building materials such as building blocks. There are simple test kits available through commercial testing laboratories. When it is identified as a problem, it can be controlled by sealing the entry points and improving the ventilation.

The EPA estimates that 14,000 lung cancer deaths annually in the U.S. are related to radon gas exposure. This compares with a total annual mortality rate from lung cancer of about 140,000. However, there are few studies and risk estimates are controversial. The greatest risk is thought to be from the particles of a radon daughter product such as polonium-218 that adhere to dust and becomes trapped in the lung. The EPA equates the risk associated with exposure of a nonsmoker to 4 pCi/liter with that of drowning. The EPA's established action level for indoor concentrations (average in the outdoor environment is 0.4 pCi/liter, average indoor is 1 pCi/liter).

● **Symptoms of Indoor Air Pollution**
The sensitivity of people to indoor pollutants varies depending on genetic factors, lifestyle, and age. Symptoms also vary as a function of the particular pollutant. Some can be fatal under special circumstances (e.g. CO poisoning). The problems in **sick buildings** may be traceable to specific sources, or they may be unknown (sick building syndrome). Sick building syndrome can be brought on by stress from various sources, even employment-related stress.

A case of sick building syndrome was seen in the Massachusetts Registry of Motor Vehicles. Constructed in April 1994, the first problems were reported in June of the same year. These included unpleasant odors, respiratory problems, eye irritations, rashes and other symptoms. The cooling system condensed water vapor onto ceiling tiles, which were composed of a starch that fermented when wet. Fire proofing around the ductwork was also wet and falling apart, releasing fibers into the air. The building was closed after 15 months of occupancy.

21.5 CONTROLLING INDOOR AIR POLLUTION
There are financial incentives for controlling indoor air pollution in the workplace, because of time lost from work and associated health care costs. Legislation requiring a

minimum level of indoor air quality and building codes that require proper ventilation would be desirable. Such codes exist in Europe.

Education is also important. The public can protect themselves against many hazards simply by exercising good judgment and some behavior modification (e.g. not smoking indoors).

● Making Homes and Other Buildings Radon-Resistant
Radon resistance involves sealing leaks that could permit radon to enter as well as making sure that buildings are adequately ventilated.

Web Resources
http://www.sustainableskylines.org/Dallas/home.html is for Dallas' Sustainable Skylines program. Kansas City's is also online.

http://www.epa.gov/iaq/radon/riskcht.html This site gives a nice risk comparison chart for radon exposure and links to 'how to get a qualified radon service professional' and others.

http://www.epa.gov/iaq/radon/pubs/citguide.html The citizen's guide to radon.

http://www.epa.gov/iaq/ This is EPA's comprehensive web site

http://www.epa.gov/airlinks/ This is the EPA portal to air quality information, acid rain, climate change, and other related topics.

http://books.nap.edu/books/0309086094/html/index.html The National Academy of Sciences report, 'Estimating the Public Health Benefits of Proposed Air Pollution Regulations (2002).

http://www.flexcar.com/ This is the Flexcar site. Flexcar provides a revolutionary way of mass transit for urban people who commute to or live in the city and need a car only infrequently while in the city.