Environmental Engineering

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Content

Chapter 9 Air pollution

Learning Objectives

- understand the different types, sources, and effects of air pollutants, including local and global impacts;
- understand the fundamentals of how meteorology impacts the evaluation of air pollutant emissions, and the basis of atmospheric dispersion modeling;
- understand the basic design and function of different types of air pollution control technologies for par ticulate and gaseous air pollutants.

Chapter 9 Air pollution

9.1 Principal air pollutants

Air pollutants are generally categorized as either Criteria Pollutants or Hazardous Air Pollutants (HAPs). Criteria pollutants are regulated under Title 40 of **the Code of Federal Regulations**, Part 50. This regulatory framework presents maximum allowable ambient air concentrations for six compounds, for different averaging periods ranging from one-hour average to annual average. The six pollutants identified as Criteria Pollutants are:

- **sulfur dioxide (SO_2), PM_{10} (particulate matter greater than 2.5 micrometers (μm) and less than or equal to 10 μm in size);**
- **$PM_{2.5}$ (particulate matter less than or equal to 2.5 μm);**
- **carbon monoxide (CO);**
- **ozone (O_3);**
- **nitrogen dioxide (NO_2);**
- **lead (Pb)** (Lead is not air pollutants routinely monitored in China, because that China has banned the use of leaded petrol since the 1990s).

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In order to limit exposure to these six compounds, EPA has developed **National Ambient Air Quality Standards (NAAQS)**, which consist of primary and secondary standards. In many cases, the primary and secondary standards are the same.

- **Primary standards** provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly.
- **Secondary standards** provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

In addition to the six criteria pollutants, **hydrocarbons or volatile organic compounds (VOCs)** are regulated as source level emissions. There are no specific ambient air quality standards for VOCs, but their emissions are regulated because, when present in the ambient air, they react to form the criteria pollutant ozone.

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9.1 Principal air pollutants

Table 9.1 National Ambient Air Quality Standards for criteria pollutants.

Pollutant	Standard type	Maximum allowable concentration	Averaging period	Regulatory citation
Sulfur dioxide (SO_2)	Primary	0.14 ppm (365 μg/m^3)	24-hour	40 CFR 50.4(b)
	Primary	0.03 ppm (80 μg/m^3)	Annual	40 CFR 50.4(a)
	Secondary	0.50 ppm (1,300 μg/m^3)	3-hour	40 CFR 50.5(a)
PM_{10}	Primary and secondary	150 μg/m^3	24-hour	40 CFR 50.6(a)
$PM_{2.5}$	Primary and secondary	35 μg/m^3	24-hour	40 CFR 50.7(a)
	Primary and secondary	15 μg/m^3	Annual	40 CFR 50.7(a)
Carbon monoxide (CO)	Primary	35 ppm (40 mg/m^3)	1-hour	40 CFR 50.8(a)(2)
	Primary	9 ppm (10 mg/m^3)	8-hour	40 CFR 50.8(a)(1)
Ozone (O_3)	Primary and secondary	0.12 ppm (235 μg/m^3)	1-hour	40 CFR 50.9(a)
	Primary and secondary	0.075 ppm (150 μg/m^3)	8-hour	40 CFR 50.10(a)
Nitrogen dioxide (NO_2)	Primary and secondary	0.075 ppm (150 μg/m^3)	Annual	40 CFR 50.10(a) and (b)
Lead (Pb)	Primary and secondary	0.15 μg/m^3	Rolling 4 months	40 CFR 50.12

Table 9.2 Health and environmental impacts of criteria pollutants.

Pollutant	Type of impact	Pollutant effects
Sulfur dioxide (SO_2)	Primary	Increased asthma symptoms Bronchoconstriction Worsening of emphysema Worsening of bronchitis
	Secondary	Visibility reduction Acid rain
PM_{10} and $PM_{2.5}$	Primary	Increased respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing, e.g., decreased lung function Aggravated asthma Development of chronic bronchitis Irregular heartbeat Nonfatal heart attacks Premature death in people with heart or lung disease
	Secondary	Visibility reduction Acid rain Aesthetic damage to stone and other building materials
Carbon monoxide (CO)	Primary	Reduced oxygen delivery to the body's organs
Ozone (O_3)	Primary	Airway irritation, coughing, and pain when taking a deep breath Wheezing and breathing difficulties during exercise or outdoor activities Inflammation, which is much like a sunburn on the skin Aggravation of asthma and increased susceptibility to respiratory Illnesses like pneumonia and bronchitis Permanent lung damage with repeated exposures
	Secondary	Interfering with the ability of sensitive plants to produce and store food Damaging the leaves of trees and other plants Reducing forest growth and crop yields
Nitrogen dioxide (NO_2)	Primary	Increased asthma symptoms Airway inflammation Worsening of emphysema Worsening of bronchitis
	Secondary	Visibility reduction Acid rain
Lead (Pb)	Primary	Adversely affects the nervous system, kidney function, immune system, reproductive and developmental systems and the cardiovascular system. Restricts blood's ability to carry oxygen. Neurological effects in children and cardiovascular effects (e.g., high blood pressure and heart disease) in adults
	Secondary	Contamination of food supply Health impacts on animals

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9.1 Principal air pollutants

- To achieve attainment of the NAAQS, emissions of criteria pollutants are regulated on the federal level by New Source Performance Standards (NSPS), which are contained in Part 60 of Title 40 of the Code of Federal Regulations. These regulations limit emissions from a broad spectrum of new, modified, or reconstructed industrial facilities, by requiring them to install Best Available Control Technology (BACT). BACT consists of the technology that will reduce emissions to the lowest possible level, taking into consideration the capital and operating costs of the available options for emissions reduction.
- Emissions from existing facilities are regulated by individual state regulatory agencies, whose programs are contained in State Implementation Plans (SIPs), which must be approved by EPA.
- In addition, permit requirements for new major facilities in areas that have attained compliance with NAAQS are required to obtain Prevention of Significant Deterioration (PSD) permits.

9.1 Principal air pollutants

Similarly, new facilities wishing to locate in an area that is not in attainment with NAAQS may be allowed to do so under available permitting regulations. This consists of a two-phased approval process.

- First, the facility will be required to install and operate the level of emissions control equipment known as Lowest Achievable Emission Rate (LAER). The difference between this and BACT is that it must achieve the lowest possible level of emissions, regardless of capital and operating cost.

- The second criterion is that the proposed new facility must also facilitate emissions reductions in the same air quality basin by an amount greater than the quantity of emissions to be generated by the facility.

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9.1 Principal air pollutants

- **Hazardous Air Pollutants (HAPS)** comprise a list of 187 compounds, or classes of compounds, contained in Title I,Section 112 of **the Clean Air Act**. Provisions requiring control of the emissions of these compounds were added to the Clean Air Act as of the amendments to the act enacted in 1990. On the federal level, the Clean Air Act Amendments of 1990 required EPA to develop emissions standards for these compounds, for major emission sources. Federal regulations limiting emissions of **HAPS are contained in Part 63 of Title 40 of the Code of Federal Regulations**. Such regulations require implementation of **Maximum Achievable Control Technology (MACT)**. MACT is defined as a level of control that must not be less stringent than the average emission level achieved by controls on the best-performing 12% of existing sources of similar industrial and utility sources. MACT regulations apply to both new and existing facilities, but economic and technical considerations may result in lesser levels of stringency for existing facilities.

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9.1 Principal air pollutants

- 《中华人民共和国大气污染防治法》 - Air Pollution Prevention and Control Law of the People's Republic of China
- 《大气污染物综合排放标准》（GB 16297-1996） - Integrated Waste Gas Emission Standard (GB 16297-1996)
- 《环境空气质量标准》（GB 3095-2012） - Ambient Air Quality Standards (GB 3095-2012)
- 《重点区域大气污染防治“十二五”规划》 - "Twelfth Five-Year" Plan for the Prevention and Control of Air Pollution in Key Regions
- 《重点行业挥发性有机物削减行动计划》 - Action Plan for the Reduction of Volatile Organic Compounds (VOCs) in Key Industries
- 《机动车排放标准》 - Motor Vehicle Emission Standards
- 《工业炉窑大气污染物排放标准》 - Emission Standards for Air Pollutants from Industrial Furnaces and Kilns
- 《火电厂大气污染物排放标准》 - Emission Standards for Air Pollutants from Thermal Power Plants
- 《大气污染防治行动计划》（2013-2017） - Air Pollution Prevention and Control Action Plan (2013-2017), also known as the "Air Ten"
- 《打赢蓝天保卫战三年行动计划》 - Three-Year Action Plan to Win the Blue Sky Defense Battle

9.2 Air pollution sources

Air pollutants are emitted into the atmosphere from a variety of industrial, commercial, natural, and transportation related sources. Some emission sources are referred to as point sources, because they are released from fixed stacks or vents, whereas fugitive emissions are generated from widespread areas, such as fields, roads, construction sites, or quarries, or from specific source operations from which emissions are released over the area of operations, rather than through a stack or vent. Transportation sources include on-road and off-road vehicles, as well as other means of transportation, including trains and aircraft.

9.2 Air pollution sources

- **Carbon monoxide** is generated as a product of incomplete combustion, and is released therefore, exclusively from combustion processes. **The vast majority of carbon monoxide emissions are generated by mobile sources, primarily on-road vehicles.**

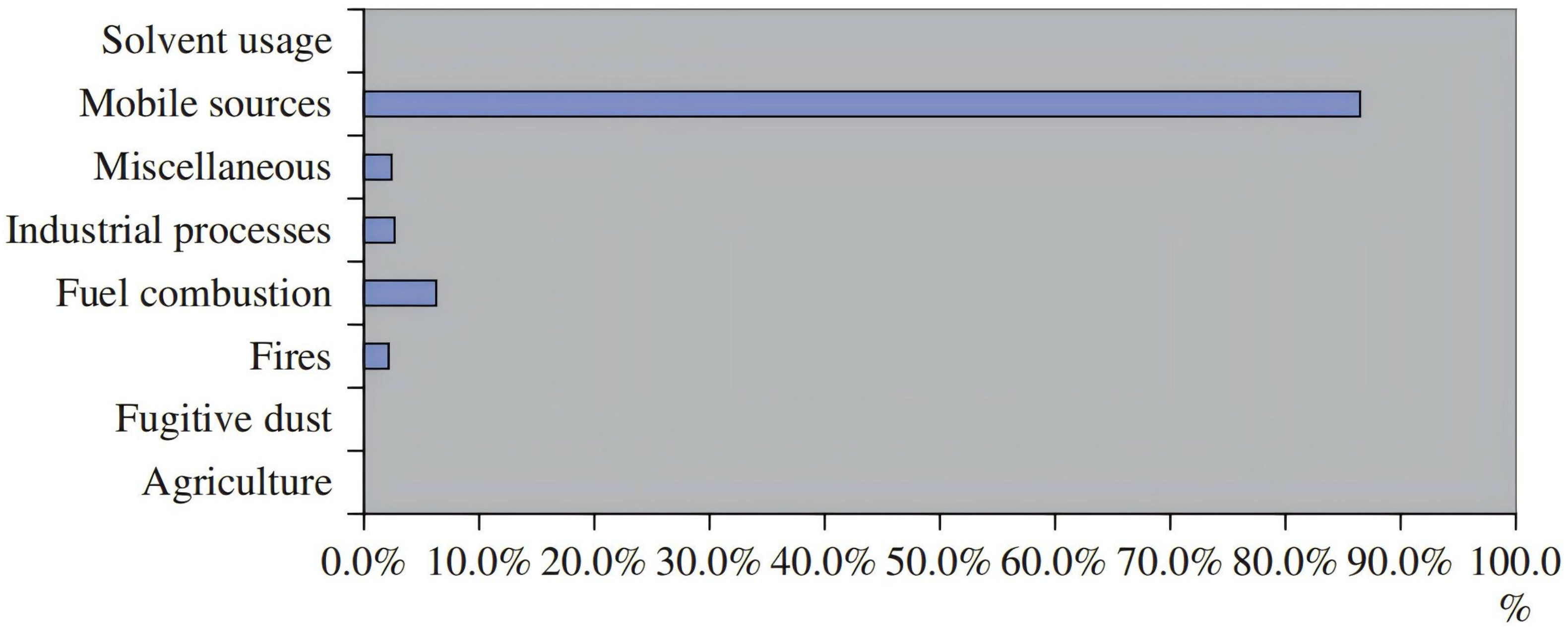

Figure 9.1 Sources of CO emissions. Based on EPA National Emissions Inventory – http://www.epa.gov/air/emissions/

9.2 Air pollution sources

- **Lead emissions, are generated from a mix of transportation sources, industrial sources, and fuel combustion sources.** On-road transportation sources were, at one time, a major source of lead emissions, but the advent of unleaded gasoline eliminated those emissions. The single largest source of lead emissions is still from transportation sources, but it is now primarily from aircraft engines. Industrial lead emissions are primarily generated by ferrous and non-ferrous metals production, and fuel combustion lead emissions are primarily from utility power plants.

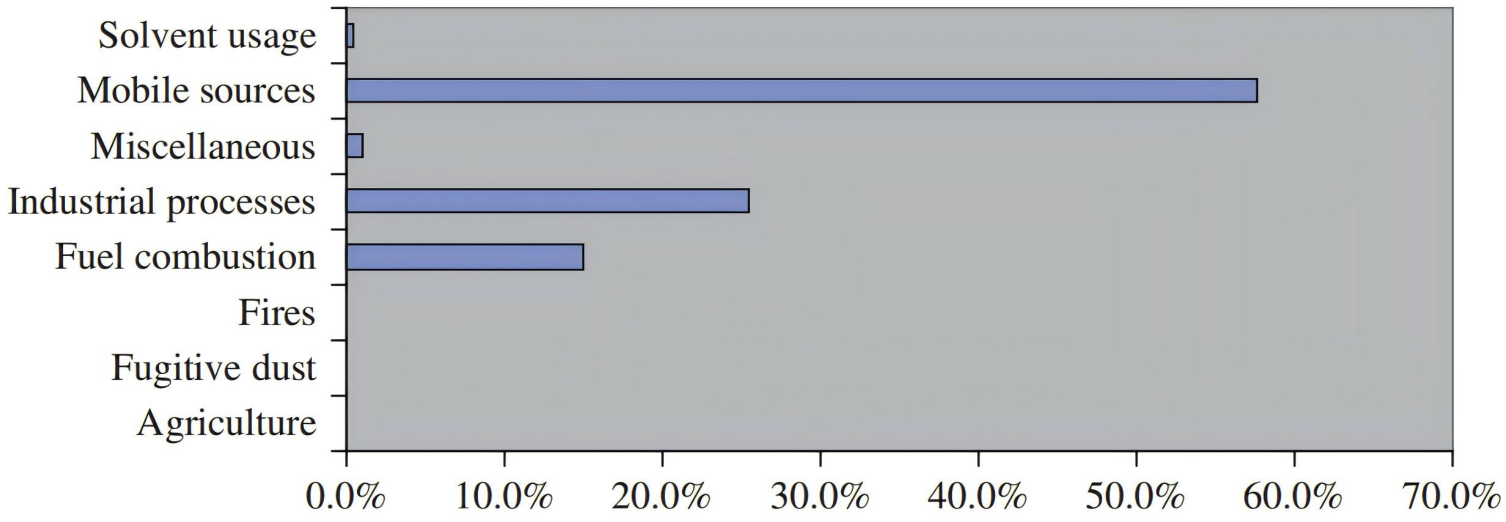

Figure 9.2 Sources of lead emissions. Based on EPA National Emissions Inventory – http://www.epa.gov /air/emissions/

9.2 Air pollution sources

- **The majority of nitrogen oxides emissions are generated by transportation sources, largely by on-road vehicles**, and to a lesser degree from off-road vehicles, locomotives, and commercial marine operations. Secondary to transportation sources is utility fuel combustion. Industrial sources constitute a minority of overall NOx emissions and are released from a variety of different sources, including oil production, cement plants, chemical production, and pulp and paper production.

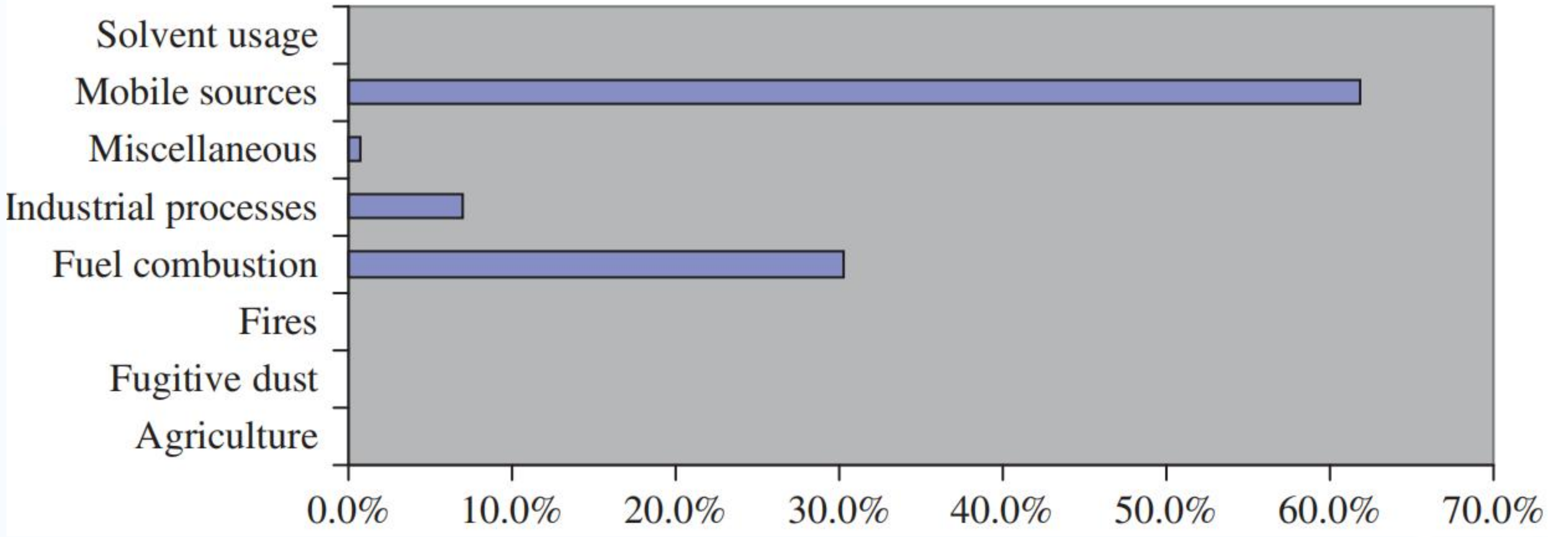

Figure 9.3 Sources of NO_x emissions. Based on EPA National Emissions Inventory – http://www.epa.gov/air/emissions/

9.2 Air pollution sources

- **Volatile organic compounds are emitted from a variety of different sources.** The largest overall source is transportation related, from on-road and off-road vehicles. Emissions from these sources are primarily related to the evaporation of fuel, as well as from hydrocarbons contained in the vehicle engine exhaust. Solvent usage sources include a broad spectrum of consumer and commercial product usage, industrial surface coating, graphic arts, degreasing, and dry cleaning operations. Industrial process VOC emissions are generated primarily from oil and gas production operations. There are also a number of miscellaneous sources of VOCs, including gas stations and bulk gasoline terminal operations.

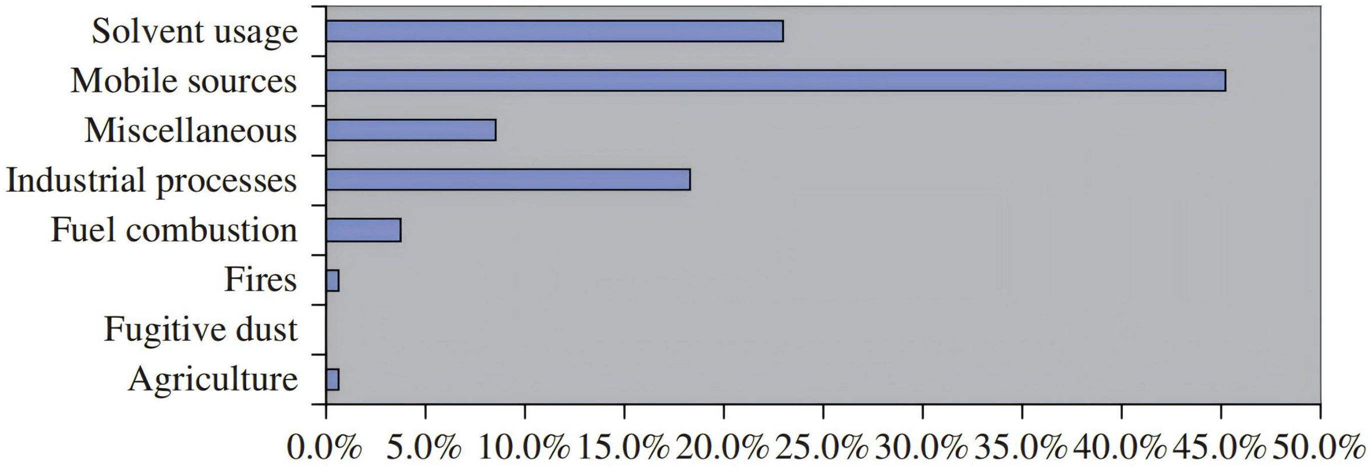

Figure 9.4 Sources of VOC emissions. Based on EPA National Emissions Inventory – http://www.epa.gov/air/emissions/

9.2 Air pollution sources

- Emissions of particulate matter (PM) are generated, from a wide and diverse number of sources. **The largest source of emissions overall is fugitive dust from unpaved roads, construction operations, and paved roadways. Second to that is emissions from fuel combustion**, with these emissions split almost evenly between residential heating and utility power plants. Other sources of PM emissions include on-road and off-road vehicle engines, waste disposal, cooking operations, and numerous industrial operations.

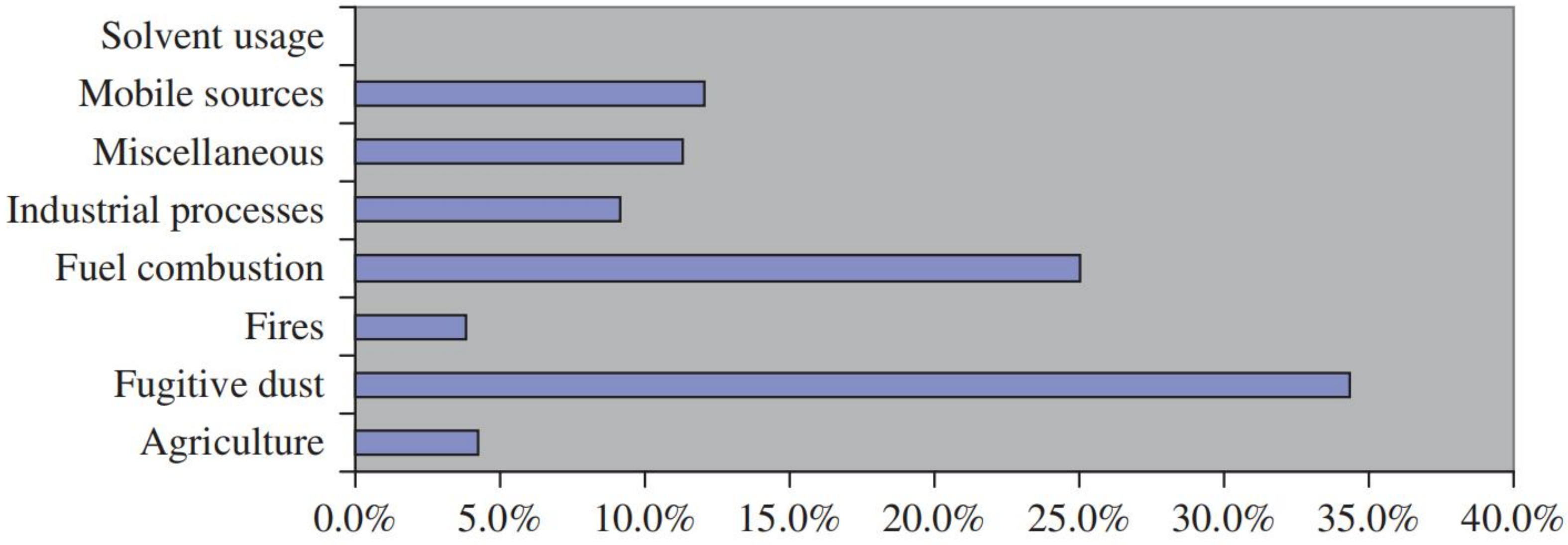

Figure 9.5 Sources of PM emissions. Based on EPA National Emissions Inventory – http://www.epa.gov/air/emissions/

9.2 Air pollution sources

- **Sulfur dioxide emissions are generated by the oxidation of sulfur in fuels in different combustion processes. The vast majority of SO_2 emissions are produced from utility power plants, with lesser amounts generated by industrial and commercial boilers, and combustion of sulfur-containing diesel fuels.**

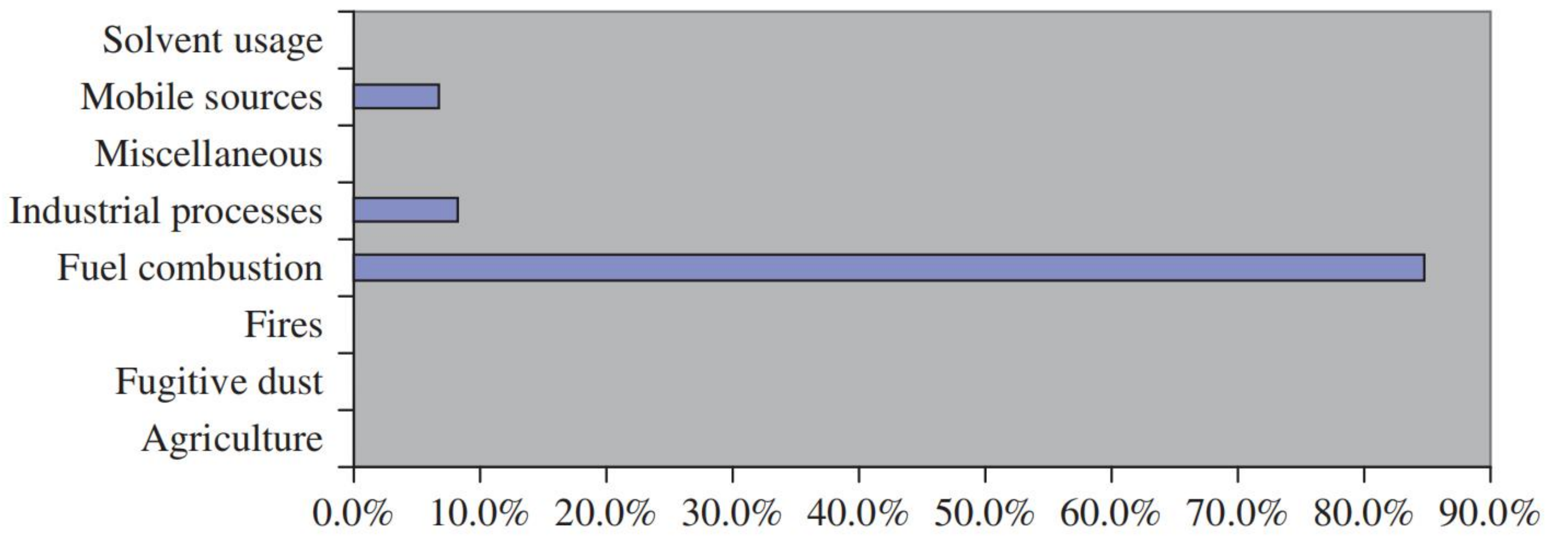

Figure 9.6 Sources of SO_2 emissions. Based on EPA National Emissions Inventory – http://www.epa.gov/air/emissions/

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9.2 Air pollution sources

- **Hazardous air pollutants are generated primarily from industrial and transportation related sources.** HAPS are, in general, process-specific, with some HAP compounds generated by a limited number of different industrial processes. EPA has issued rules covering over **96 categories of major industrial sources, such as chemical plants, oil refineries, aerospace manufacturers, cement plants, waste incineration facilities, utility power plants, and steel mills, as well as categories of smaller sources**, such as dry cleaners, commercial sterilizers, secondary lead smelters, industrial boilers, and chromium electroplating facilities.

9.2 Air pollution sources

- Air pollutant emissions from a large number of sources can be estimated utilizing air pollutant emission factors developed by EPA and various industrial organizations. **Emission factors provide a mechanism for calculating emissions on the basis of different production information that may be available regarding a facility.** In their simplest form, air pollutant emission factors follow the form as shown in Equation (9.1).

$$E = P \times F \times (1 - ER/100) \qquad (9.1)$$

where:

E = emissions, lb/h

P = product production rate, tons/h

F = emission factor, lb/ton

ER = overall emission reduction efficiency of air pollution control equipment.

9.2 Air pollution sources

- **In other cases, the factor is based upon the content of a given substance in the raw material or fuel used in an industrial process. An example of this is the calculation of emission of sulfur oxides (SOx) from a coal fired boiler. This is calculated as shown below.**

$$E = P \times 38(S) \quad (9.2)$$

where:

E = emissions, lb/h

P = coal firing rate, tons/h

S = coal sulfur content, %

38 = EPA emission factor for SO_x emissions.

9.2 Air pollution sources

- **Example 9.1 Calculation of air pollutant emissions**

For example, a boiler burning 50 tons per hour of coal containing 1.5% sulfur, the total SOx emissions from the boiler would be calculated as follows using Equation (9.2):

9.2 Air pollution sources

- **Example 9.1 Calculation of air pollutant emissions**

Solution

$$E = P \times 38(S) \tag{9.2}$$

$$E = 50\,\frac{\text{ton}}{\text{h}} \times 38(1.5\%)$$

$$E = \boxed{2,850\,\frac{\text{lb}}{\text{h}}}$$

9.2 Air pollution sources

- Many emission factors are contained in the EPA Compilation of Emission Factors, referred to as AP-42, which is contained on the EPA website at http://www.epa .gov/ttn/chief/ap42/index.html. This consists of a living compilation of emission factors that is updated frequently, and it contains hundreds of emission factors in 15 different broad source categories, ranging from fossil fuel combus_x0002_tion, through chemical plant operations, to ordinance detonation. AP-42 emission factors are assigned an emission factor rating ranging from A to E. Emission factors assigned a rating of A are considered to be highly accurate and reliable, as they are based upon a large database of measured emission rates from a large spectrum of emission sources throughout the United States. Emission factors with a rating of E, on the other hand, are considered rough estimates only, and are subject to significant variability from source to source. Based upon the emission factor rating, environmental regulatory agencies may or may not use the published emission factors in developing air pollutant emission limits for industrial or commercial facilities for which air permits are granted.

9.2 Air pollution sources

- **In the absence of published emission factors,** and in the case of many HAPs, **emission rates are estimated using mass balances** coupled with engineering knowledge about the process in question. For example, a mercury balance across a chemical process can be employed to estimate the quantity of mercury emission from a facility if enough information is available about **the mercury content of the raw materials, the quantity of raw materials utilized, the quantity of product produced, the mercury content of the final product, and the mercury content and quantity of any solid waste and/or byproduct materials generated in the production process. By knowing the total quantity of mercury entering a process and subtracting from that the total quantity leaving a process in the form of the final product, and all wastes and byproducts, the remainder is assumed to have been released to the atmosphere.**

9.2 Air pollution sources

- Emission factors and mass balances, no matter how well defined, are still just estimates of the quantities of emissions from varying emission sources. The only way to know the quantity of emissions with certainty is to perform actual emissions measurements. This is particularly important for operations for which well-defined factors (emission factor rating A or B) are not available. In order to fill this need, detailed source emission testing procedures have been developed by EPA and some state agencies, to standardize the practice of emissions testing and to insure the proper application of analytical chemistry procedures and quality assurance and control mechanisms to all source test data generated in the United States.

9.2 Air pollution sources

- **All emission testing procedures developed by EPA are contained in Title 40 of the Code of Federal Regulations, Part 60, Appendix A. All of these test procedures are also accessible at http://www.epa.gov/ttn/emc.**
- **For mobile emission sources, manufacturers are required to conduct a series of emissions tests on every vehicle type, engine style, etc. to demonstrate that each such vehicle meets the established emission limits. Beyond that, the only ongoing testing occurs in a limited number of geographic areas that are non-attainment for photochemical oxidants. In those areas, privately owned vehicles must take and pass an annual emission test as part of a vehicle inspection and maintenance program, designed to reduce overall vehicle emissions in the area.**
- **《大气污染物排放标准》（GB系列）**

9.3 Pollutant affects on humans and environment

- The impact of air pollutants on humans varies by pollutant and location. Other nearby impacts are as discussed relative to secondary impacts, and as referenced by the NAAQS secondary standards.

- Large area impacts are generally more related to the cumulative effects of a broad spectrum of emission sources located throughout a region, or even throughout the world. Some of these impacts include global climate change, acid rain, tropospheric ozone, and stratospheric ozone. Each of these environmental impacts is discussed in the following sections.

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9.3 Pollutant affects on humans and environment

9.3.1 Global climate change

The term **“climate change”** is often used interchangeably with the term “global warming”, because it helps convey that there are other changes in addition to rising temperatures.” Climate change refers to any significant change in measures of climate (such as **temperature, precipitation, or wind**) lasting for an extended period (decades or longer). Climate change may result from:

- **natural factors**, such as changes in the sun’s intensity, slow changes in the Earth’s orbit around the sun, or changes in activity levels of the sun itself;
- **natural processes within the climate system** (e.g., volcanic eruptions or changes in ocean circulation);
- **human activities that change the atmosphere’s composition** (e.g., increases in concentrations of greenhouse gases resulting from burning fossil fuels) and the land surface (e.g., deforestation, reforestation, urbanization, desertification, etc.).

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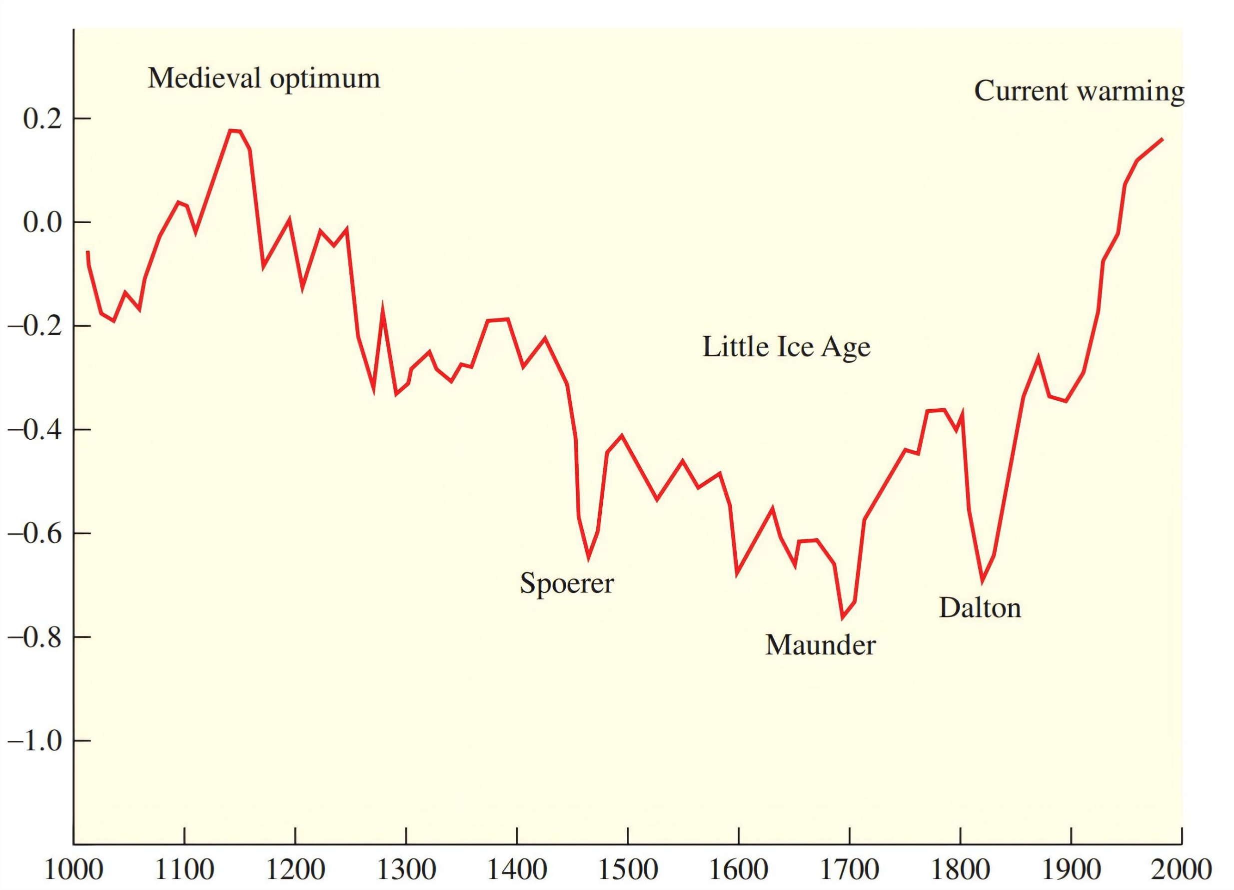
9.3 Pollutant affects on humans and environment

9.3.1 Global climate change

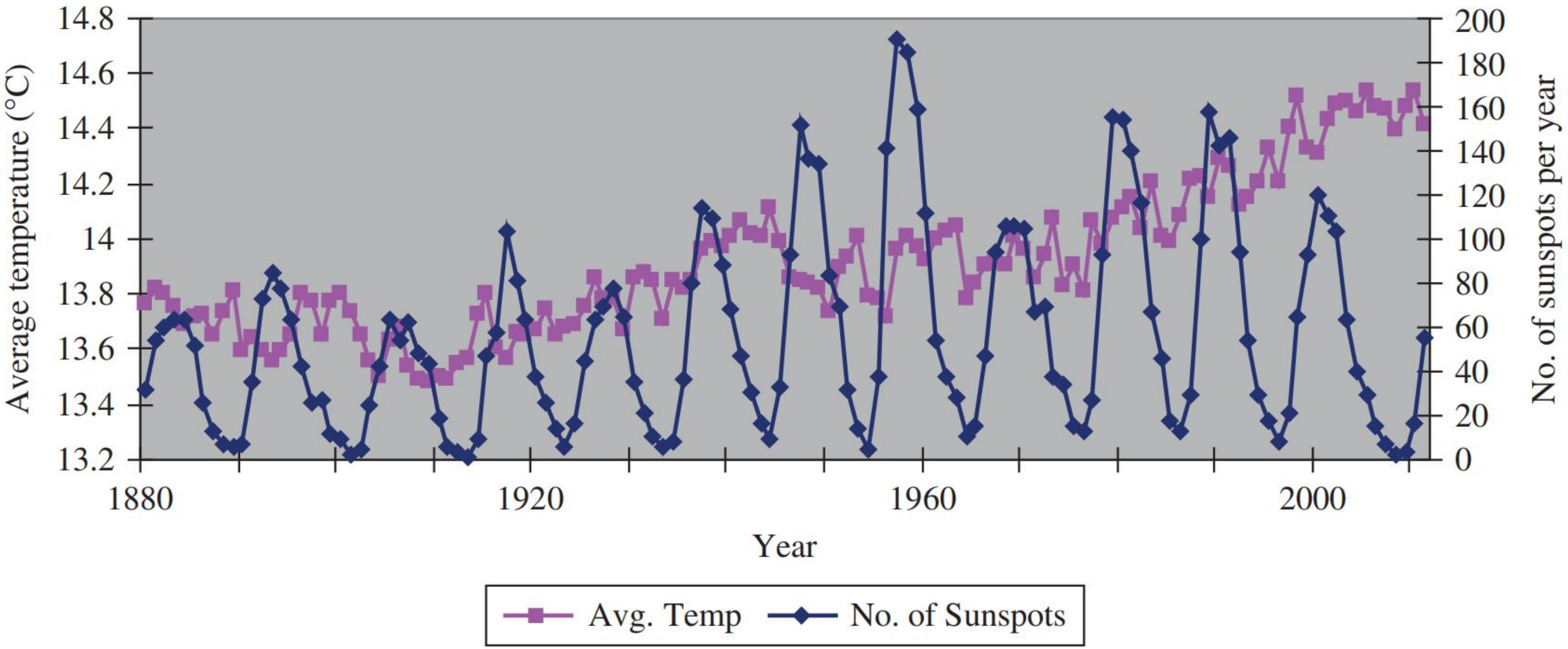
Climate change is not a recent phenomenon, given that **the Earth's climate has changed constantly for millions of years.** As presented in Figure 9.7, there have been significant changes in global temperatures over the last 1,000 years, including such peaks as the high temperatures of the medieval period, and the "little ice age" of the 1600s.



9.3 Pollutant affects on humans and environment

9.3.1 Global climate change

There are numerous natural phenomena that can be related to global climate change, including slight changes in the Earth's axis, **the presence or absence of volcanic eruptions, and sunspots.**



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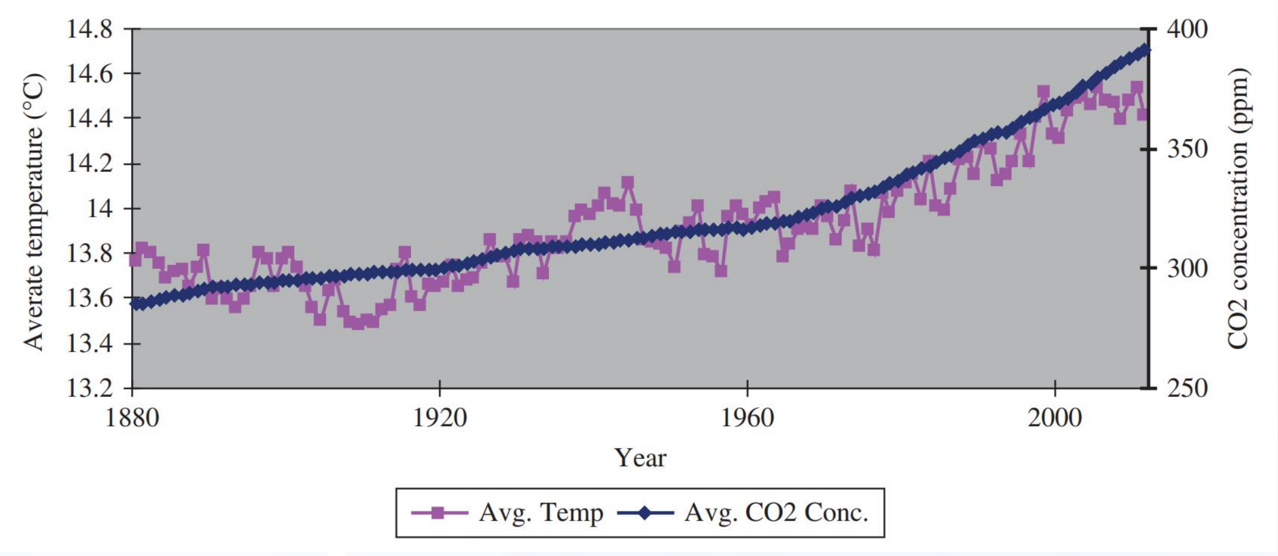
9.3 Pollutant affects on humans and environment

9.3.1 Global climate change

Although the Earth's climate has changed many times throughout its history, **recent more-rapid warming cannot be explained only by natural processes**. Human activities are increasing the amount of greenhouse gases in the atmosphere. Some amount of greenhouse gases is necessary for life to exist on Earth, as they provide for photosynthesis of plant life and they trap heat in the atmosphere, keeping the planet warm and in a state of equilibrium. This natural greenhouse effect is being strengthened by human activities (combustion of fossil fuels), which are adding more of these gases to the atmosphere, resulting in a shift in the Earth's equilibrium.



9.3 Pollutant affects on humans and environment

9.3.1 Global climate change

The most commonly identified greenhouse is CO_2, however there are numerous other compounds that produce the same effect, including **methane (CH_4), nitrous oxide (N_2O), halocarbons, ozone, and aerosols**. These other compounds are, however, minor contributors to global climate change, relative to carbon dioxide. Atmospheric CO_2 concentrations in the late 19th century were less than 300 ppm, but they **increased gently until the late 20th century, at which time the concentration started to increase at a more rapid rate.** Measurements of atmospheric CO_2 concentrations at the Mauna Lua monitoring station reveal a saw tooth pattern each year, with peak concentrations in the winter, and lower concentrations in the summer. This tends to link measured concentrations with increased heating activities for homes, businesses, etc. during the winter, as well as increased vegetative activity resulting in CO_2 collection during summer months.

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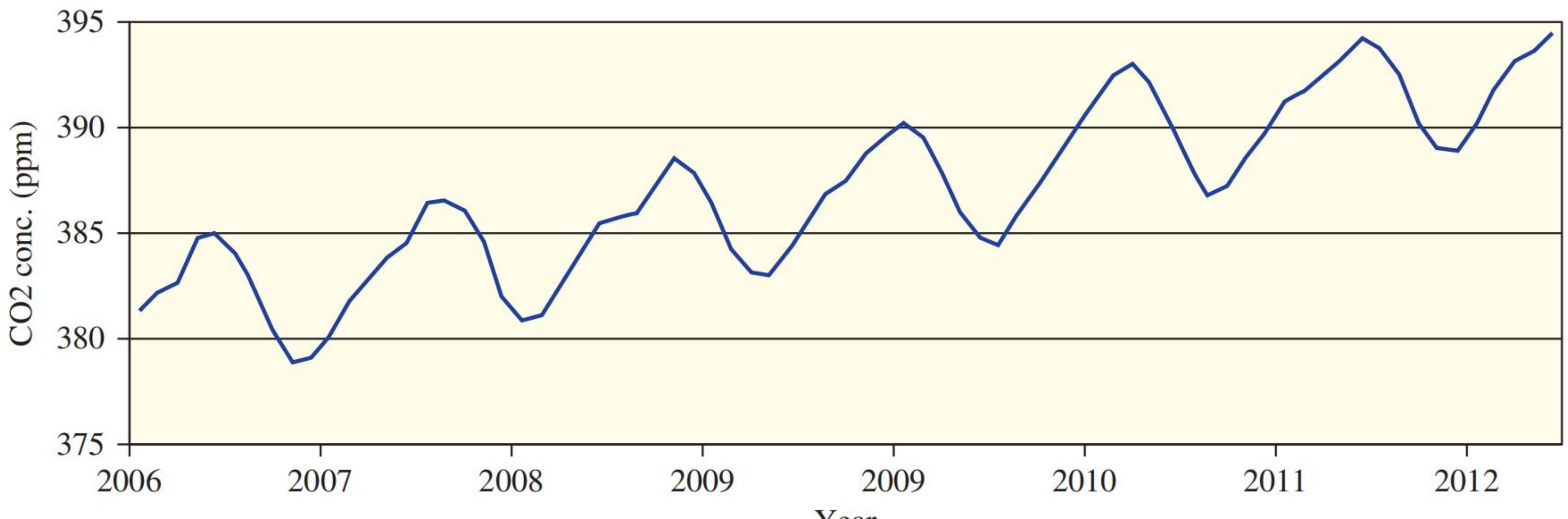
9.3 Pollutant affects on humans and environment

9.3.1 Global climate change

Table 9.3 CO_2 emissions in the United States.

Emission Source	Tg of CO_2 emissions
Electricity generation	2,228.4
Transportation	1,745.5
Industrial fuel combustion	777.8
Residential fuel combustion	340.2
Commercial fuel combustion	224.2

Based on EPA National Emissions Inventory Worldwide; the Carbon Dioxide Information Analysis Center (http://www.cdiac.gov) estimates total 2010 CO_2 emissions to be approximately 30,000 Tg.



9.3 Pollutant affects on humans and environment

9.3.2 Tropospheric ozone (对流层中臭氧)

- Tropospheric, or ground level ozone, is a concern because of the direct human health effects discussed previously, as well as the fact that it is a greenhouse gas and a contributor to visibility impairment. It is also a strong oxidizing compound, which reacts with other pollutants in the atmosphere to form fully or partially oxidized chemical products, some of which may be toxic air contaminants.
- Ozone is not emitted directly into the atmosphere, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOCs) emitted by a wide variety of fuel combustion and associated industrial processes. Ozone most often reaches unhealthy levels on hot sunny days in urban environments. It can also, however, be transported long distances by wind. For this reason, even rural areas can experience high ozone levels. Ozone is also the primary constituent of smog, occurring predominantly in urban areas. Ozone can affect human health, even at relatively low levels. People with lung disease, children, older adults, and people who are active outdoors, may be particularly sensitive to ozone. Children are at greatest risk, because their lungs are still developing. Children are also more likely than adults to have asthma（哮喘）. Ozone also impacts sensitive vegetation, including trees and plants during the growing season.

9.3 Pollutant affects on humans and environment

9.3.3 Stratospheric ozone（平流层中的臭氧）

- The region of the Earth’s atmosphere from 6–30 miles (10–50 kilometers) above the Earth’s surface is known as the stratosphere. In this region, ozone plays a vital role in absorbing harmful ultraviolet radiation from the sun. During the past 20 years, concentrations of ozone have been threatened by human-made gases released into the atmosphere, including those known as **chlorofluorocarbons (CFCs)**. The ozone layer absorbs a portion of the radiation from the sun, preventing it from reaching the Earth’s surface. The most important aspect of this is that it absorbs the portion of ultraviolet light called UVB, which has been linked to **skin cancer and cataracts（白内障）**.
- **Ozone molecules are constantly formed and destroyed in the stratosphere. The total amount, however, remains relatively stable.** While ozone concentrations vary naturally with sunspots, the seasons, and latitude, these processes are well understood and predictable. **Each natural reduction in ozone levels has been followed by a recovery.** Recently, however, scientific evidence has shown that the ozone shield is being depleted well beyond changes due to natural processes.

9.3 Pollutant affects on humans and environment

9.3.3 Stratospheric ozone（平流层中的臭氧）

- Chlorofluorocarbons (CFCs) have been used for decades for various purposes because they are very stable, non-toxic, and relatively inexpensive to produce. Evaluation of the depletion of stratospheric ozone, however, has lead to the conclusion that it is these CFCs that are depleting the ozone layer. As stated, CFCs are very stable compounds, which allow them to exist for long periods of time in the atmosphere, and they are eventually carried up into the stratosphere. There, these CFCs can be broken down by very strong UV radiation. Upon breakdown, chlorine atoms are released, and it is these chlorine atoms that react with ozone molecules, thereby depleting the ozone concentration. One chlorine atom can destroy over 100,000 ozone molecules. The net effect is to destroy ozone faster than it can be naturally created (http://www.epa.gov/ozone/science/sc_fact.html). There are natural sources of chlorine that can be transported to the troposphere. These include large fires, some forms of marine life, and volcanic eruptions. It is estimated, however, that these natural sources comprise only approximately 15% of the chlorine contribution to stratospheric ozone depletion.

9.3 Pollutant affects on humans and environment

9.3.3 Stratospheric ozone（平流层中的臭氧）

- In addition to chlorine, from CFCs or other sources, other compounds have been linked to stratospheric ozone depletion. These include **nitric oxide (NO), nitrous oxide (N_2O), and compounds with hydroxyl (OH^-) radicals.** While these compounds will react with, and thereby deplete, ozone, neither their potency nor their prevalence in the troposphere is believed to approach that of CFCs.

- Reductions in ozone levels will increase the amount of UVB reaching the Earth's surface. The sun's output of UVB does not change, but less ozone means less protection, and hence more UVB reaching the Earth. Laboratory and epidemiological studies have demonstrated that UVB causes nonmelanoma（非黑色素瘤） skin cancers and plays a major role in malignant melanoma（恶性黑色素瘤）development.

9.3 Pollutant affects on humans and environment

9.3.4 Acid rain

- Acid rain is a term referring to **the formation and ultimate deposition of sulfuric and nitric acids onto the Earth's surface and waterways**. The pollutants that are involved in the formation of acid rain are sulfur dioxide (SO_2) and nitrogen oxides (NOx). These compounds are generated **by natural sources such as volcanic eruptions and decaying vegetation, and from anthropogenic sources such as combustion of fossil fuels.** Acid rain occurs when these gases react in the atmosphere with water, oxygen, and other chemicals to form acidic compounds.**This may occur hundreds of miles from the source of emissions of the precursor compounds,** because these compounds can be carried long distances by the prevailing winds in the area.

- Acid rain can cause **acidification of lakes and streams and can contribute to damage to trees at high elevations** (e.g., red spruce trees above 2,000 feet). **Damage to some sensitive forest soils** can also occur. In addition, **acid rain accelerates the decay of building materials and paints**. This produces an economic impact to building owners and structural infrastructure. There is also a potential for **cultural impact** by egradation of statues and other works of art.

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9.3 Pollutant affects on humans and environment

9.3.5 Visibility

- One of the most readily identifiable forms of air pollution is **haze** (雾霾), which degrades visibility in many cities and scenic areas, such as national parks. Haze is caused when sunlight encounters tiny pollution particles in the air, which reduces the clarity and color of areas and objects viewed through the haze. **Some light is absorbed by particles, while other light is scattered by particles. There is a direct relationship between the number of particles in the air and the degree of obstruction of visibility.**
- Air pollutants which obstruct visibility come from a variety of natural and anthropogenic sources. **Natural sources can include windblown dust and soot from wildfires. Anthropogenic sources can include motor vehicles, electric utility and industrial fuel burning, and manufacturing operations.** Some haze-causing particles are directly emitted to the air. Others are formed when gases, which are emitted to the air, form particles as **they are carried many miles from the source of the pollutants**.

Thanks!