7.6.4: Clean Air

Learning Objectives

- Identify ways to limit particulate emissions to the atmosphere.
- Describe how various command and control measures have affected air pollution levels.
- Describe how the Clean Air Acts and the resulting regulations have affected air pollution levels and productivity.

As we have seen in the preceding sections, there are many different chemicals which are released into the atmosphere, both due to natural processes and to human activity. These chemicals can undergo reactions which create various forms of air pollution resulting in decreased visibility, adverse health affects, and damage to buildings and infrastructure. No one enjoys the effects of air pollution and so efforts must be made to deal with it. One rather obvious way of eliminating the chemicals that result from human activities is to just stop most of the activities that generate them. It was demonstrated that it is possible to curb some types of air pollution at the 2008 and 2022 Beijing Olympics and during the lockdown that occurred during the pandemic in 2020 by simply stopping the human activities that cause them. However, we do need the energy that is created by these activities in order to function efficiently. So this is not a practical, long term solution. What other options are there?

Limiting Particulate **Emissions**

The first widespread measures to limit air pollution were directed at control of particle emissions. Because of their ability to reduce visibility and light, atmospheric particles are the most visible form of air pollution. Commonly called **particulates** in air pollution terminology, atmospheric *aerosols* are solids or liquids less than 100 micrometers in diameter, but are most often found in a size range of 0.001 to 20 µm. One type is **dispersion aerosols** formed by grinding solids, dispersing dusts, or atomizing liquids. Common dispersion aerosols include water droplets from sea spray, solid particles of NaCl left over when water evaporates from sea spray droplets, cement dust, soil dust dispersed by wind, foundry dust, and pulverized coal. A second type of atmospheric aerosol is **condensation aerosols** produced by the condensation of gases or vapors, often formed as the result of atmospheric chemical processes. Carbon black, metal fumes, and combustion nuclei form as condensation aerosols from combustion or partial combustion reactions. Liquid particle **mists** include raindrops, fog, cloud droplets, and droplets of sulfuric acid produced when atmospheric SO_2 is oxidized. Organisms also produce an abundance of particles. For those afflicted with allergies, the most annoying such particles are plant pollen. Other particles of biological origin include viruses, bacteria, and spores of bacteria and fungi.

In the past and even now in some areas of the world, one of the more troublesome sources of atmospheric particles was **fly ash**, a byproduct residue from combustion of liquids or very finely divided coal. Often the most abundant component of fly ash is elemental carbon left over from incompletely burned fuel. Fly ash commonly includes oxides of aluminum, calcium, iron, and silicon, as well as some magnesium, sulfur, titanium, phosphorus, potassium, and sodium. With properly operating emission control devices, fly ash emissions are now well controlled. These measures have become very effective so that the “smoke” that one sees emanating from smokestacks usually consists of droplets of water formed by condensation of steam.

The simplest method of particle control from stack gas and other gases released to the atmosphere consists of **sedimentation** in which particles contained in stack gas are allowed to settle by gravity in relatively large chambers. Sedimentation is most effective for larger particles. **Inertial mechanisms** operate by spinning a gas in a round chamber such that particles impinge upon the container walls by centrifugal force. Fabric filters contained in **baghouses** act to filter particles from air or stack gas (Figure 7.6.4.1). The mechanism employed provides for periodic shaking of the fabric filters to collect particles held on their walls, thus restoring gas flow through the fabric. Numerous factors including moisture levels, particle abrasion, particle size, and acidity or alkalinity of the gas and particles must be considered in choosing filter fabrics. **Scrubbers** that spray water or solutions into stack gas are employed to literally wash particles out of gas. In some cases these are operated with a minimal amount of water, which evaporates, so that a solid material is collected. One of the most effective means of particle control consists of **electrostatic precipitators**. These devices use a very high voltage to impart a negative charge onto particles, and the particles are attracted to and collect on the positively charged walls of the precipitator.

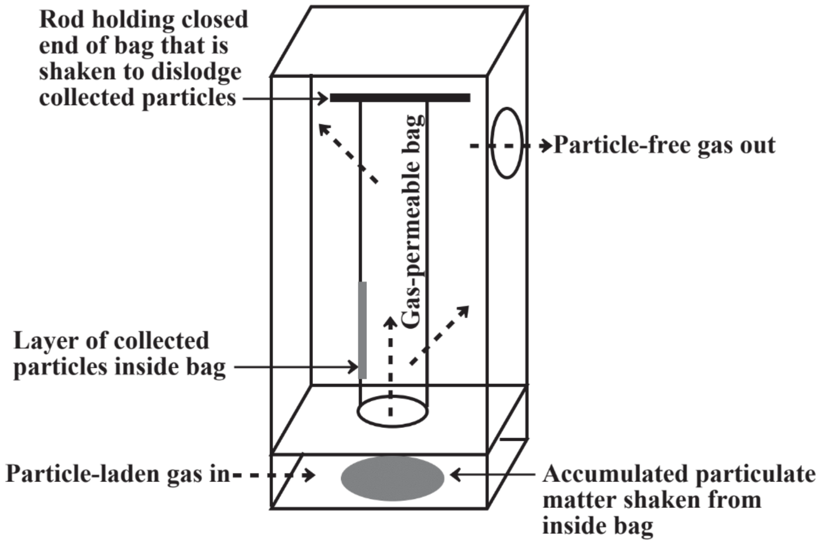

Figure 7.6.4.1. Illustration of a unit of a single bag in a baghouse for removal of particulate matter from a gas stream. The flow of gas is illustrated by the dashed lines. A bag is mounted on an opening in a plate such that particle-laden gas is forced up through the inside of the cylindrical bag and is filtered through the bag walls, then flows out as filtered gas. The particulate matter accumulates on the inside of the bag. Periodically, the gas flow through the bag is stopped and the rod suspending the closed upper end of the bag is shaken to dislodge particulate matter from the bag walls, which is collected at the bottom of the apparatus.

In keeping with the practice of sustainability, the particulate matter such as that collected by a fabric filter in a baghouse may be used for various purposes. Typically, particulate matter from lead or zinc smelting operations is recycled back into the metal recovery process. Lime kiln dust is often used as agricultural lime. Some kinds of coal fly ash could be used as a source of aluminum if aluminum ore (bauxite) becomes scarce. Sulfur is a valuable raw material required in the manufacture of sulfuric acid, one of the largest volume chemicals made. Hydrogen sulfide, H_2S, occurs in large quantities in natural gas, such as that produced in the Canadian province of Alberta. This hydrogen sulfide must be removed from the natural gas. Rather than presenting a pollution problem, it is converted to elemental sulfur, then used to make sulfuric acid. Another green chemistry approach to the reclamation of waste sulfur is practiced in Kalundborg, Denmark. The huge coal-fired power plant in Kalundborg uses lime scrubbing to remove sulfur dioxide from stack gas. The calcium sulfite product of this process is oxidized

$$\mathrm{CaSO_3} + \frac{1}{2}\,\mathrm{O_2} + 2\,\mathrm{H_2O} \rightarrow \mathrm{CaSO_4 \cdot 2H_2O}$$

to generate gypsum, $\mathrm{CaSO_4 \cdot 2H_2O}$. This mineral is then used to make wallboard, thus solving a pollution problem from the production of spent lime and a raw materials problem arising from the need for gypsum to make wallboard needed for building construction.

Controlling Photochemical Smog

As described in the previous section, smog is basically a chemical problem which would indicate that it should be amenable to chemical solutions. Indeed, the practice of green chemistry and the application of the principles of industrial ecology have helped to reduce smog. This is due in large part to the fact that a basic premise of green chemistry is to avoid the generation and release of chemical species with the potential to harm the environment. The best way to prevent smog formation is to avoid the release of nitrogen oxides and organic vapors that enable smog to form. At an even more fundamental level, measures can be taken to avoid the use of technologies likely to release such substances, for example, by using alternatives to polluting automobiles for transportation.

Initially, serious efforts to control pollution were based on a **command and control** approach, which specifies maximum concentration guideline levels of substances that can be allowed in the atmosphere (or water) and places limits on the amounts or concentrations of pollutants that can be discharged in waste streams. Command and control efforts to diminish pollution have resulted in implementation of various technologies to remove or neutralize pollutants in potential waste streams and stack gases. These are so-called "end-of-pipe" measures. As a result, numerous techniques, such as chemical precipitation of water pollutants, neutralization of acidic pollutants, stack gas scrubbing, and waste immobilization have been developed and refined to deal with pollutants after they are produced.

The evolution of automotive pollution control devices to reduce smog provides an example of how green chemistry can be used to reduce pollution. The first measures taken to reduce hydrocarbon and nitrogen oxide emissions from automobiles were very much command-and-control measures. These primitive measures implemented in the early 1970's did reduce emissions, but with a steep penalty in fuel consumption and in driving performance of vehicles. However, over the last three decades, the internal combustion automobile engine has evolved into a highly sophisticated, computer-controlled machine that generally performs well, emits few air pollutants, and is highly efficient. This change has required an integrated approach involving reformulation of gasoline. The first major change was elimination from gasoline of tetraethyllead, an organometallic compound that poisoned automotive exhaust catalysts (and certainly was not good for people). Gasoline was also reformulated to eliminate excessively volatile hydrocarbons and unsaturated hydrocarbons (those with double bonds between carbon atoms) that are especially reactive in forming photochemical smog. Many scientists have suggested that pumping gas at night could further reduce photochemical ozone formation by limiting the amount of exposure VOCs have with sunlight.

In addition to the reformulation of gasoline, every new vehicle sold in the United States must include a catalytic converter to reduce photochemical emissions. Catalytic converters force CO and incompletely combusted hydrocarbons to react with a metal catalyst, typically platinum, to produce CO_2 and H_2O. Additionally, catalytic converters reduce nitrogen oxides from exhaust gases into O_2 and N_2, eliminating the cycle of ozone formation.

An even more drastic approach to eliminating smog-forming emissions is the use of electric automobiles that do not burn gasoline. These vehicles certainly do not pollute as they are being driven, but they suffer from the problem of a very limited range between charges and the need for relatively heavy batteries that utilize rare metals. However, hybrid automobiles using a small gasoline or diesel engine that provides electricity to drive electric motors propelling the automobile and to recharge relatively smaller batteries can largely remedy the emission and fuel economy problems with automobiles. The internal combustion engine on these vehicles runs only as it is needed to provide power and, in so doing, can run at a relatively uniform speed that provides maximum economy with minimum emissions. Additionally, scientists are looking at new ways of producing batteries that are lighter, last longer, and use components that are more environmentally friendly to obtain.

Another approach that is being used on vehicles as large as buses, that have convenient and frequent access to refueling stations, is the use of fuel cells that can generate electricity directly from the catalytic combination of elemental hydrogen and oxygen, producing only harmless water as a product. There are also catalytic processes that can generate hydrogen from liquid fuels, such as methanol, so that vehicles carrying such a fuel can be powered by electricity generated in fuel cells.

Clean Air Acts

Much of the driving force for reducing particulate emissions and the components of photochemical smog has been due to the Clean Air Act of 1970 and its amendments in 1977 and 1990. These acts have set emission limits for different industries and motor vehicles in the United States and allow for their enforcement. Although much maligned, various pollution control measures implemented in response to these acts have reduced wastes and improved environmental quality (Figure 7.6.4.2). Regulation-based pollution control has clearly been a success and well worth the expense and effort. However, it is much better to prevent the production of pollutants rather than having to deal with them after they are made. This was recognized in United States with the passage of the 1990 Pollution Prevention Act, which recognized that source reduction is fundamentally different and more desirable than waste management and pollution control. This act explicitly states that, wherever possible, wastes are not to be generated and their quantities are to be minimized. The means for accomplishing this objective can range from very simple measures, such as careful inventory control and reduction of solvent losses due to evaporation, to much more sophisticated and drastic approaches including complete redesign of manufacturing processes with waste minimization as a top priority.

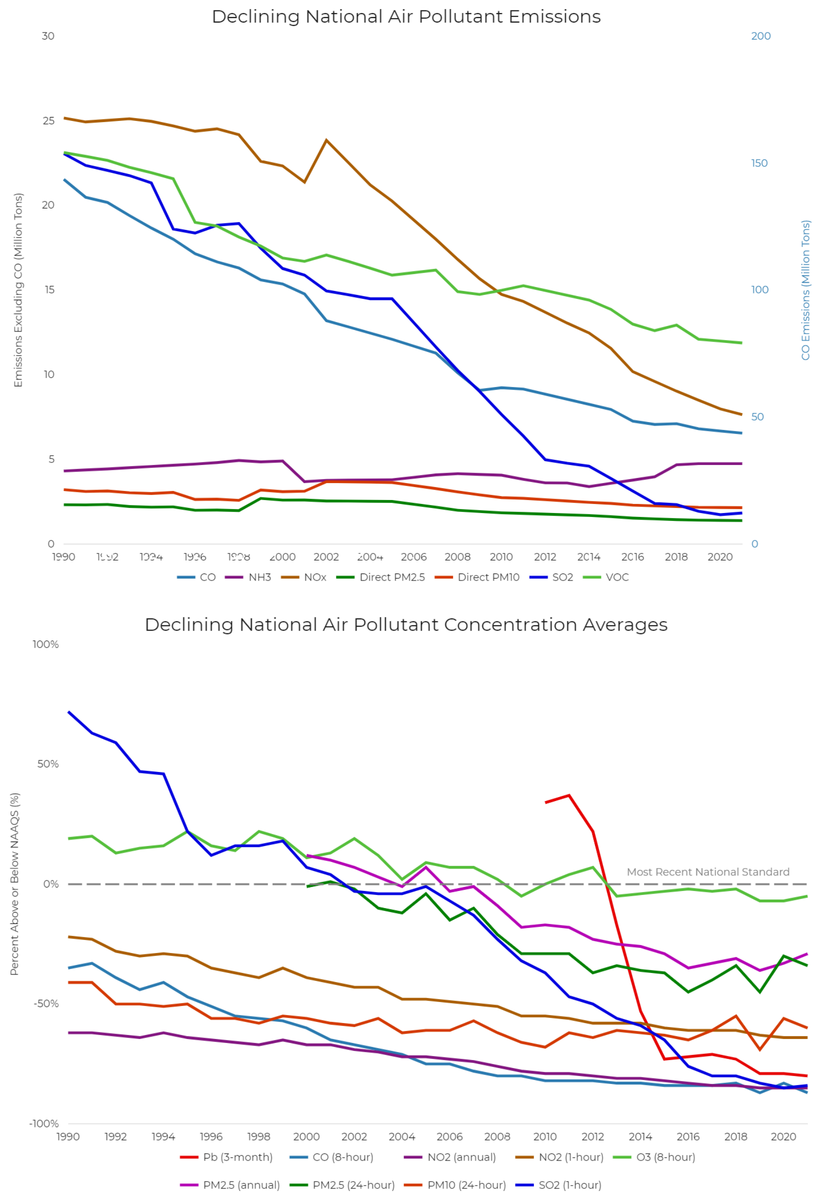

Figure 7.6.4.2: Declining air pollutant emissions and the resultant air pollutant concentrations since the passage of the 1990 Amendments to the Clean Air Act of 1970 and the 1990 Pollution Prevention Act. NAAQS are National Ambient Air Quality Standards. (US Environmental Protection Agency, www.epa.gov)

The net result of these legislations has been a 78 percent drop in the six common pollutants between 1970 and 2020. The emission reductions have led to dramatic improvements in the quality of the air that we breathe and have enabled many areas of the country to meet national air quality standards set to protect public health and the environment. This means that we breathe less pollution and face lower risks of premature death and other serious health effects. In addition, environmental damage has been reduced resulting in the improved health of plants, soils, and aquatic life and increased crop and timber yields. New technologies have been developed which have helped to control costs in addition to reducing emissions. The increased health and new technologies have resulted in increasing gross domestic product while the pollutants have decreased (Figure 7.6.4.3). Studies have estimated that the benefits of reducing pollution exceed the costs by a factor of more than 30-to-1.

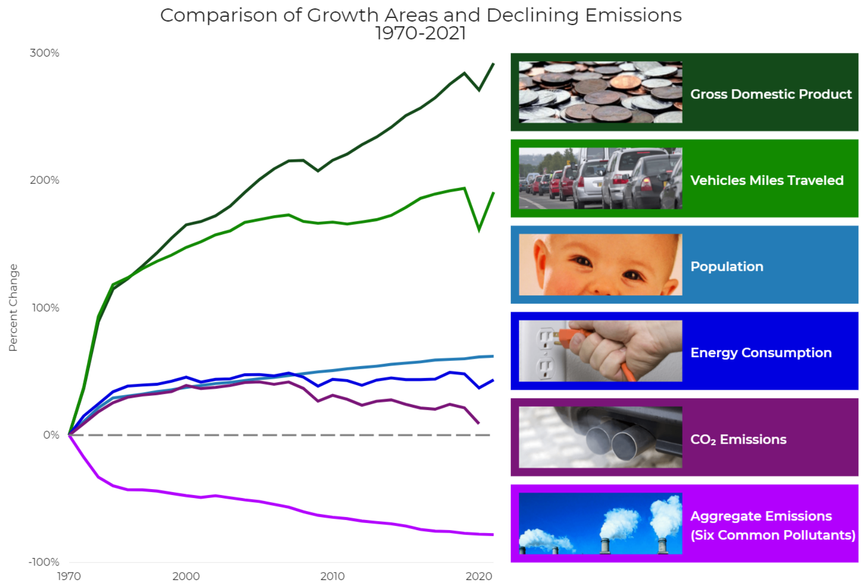

Figure 7.6.4.3: Some of the benefits that have increased as a result of pollution reduction since the implementation of Clean Air Acts. (US Environmental Protection Agency, www.epa.gov)

Summary

- The first efforts to limit air pollution focused on controlling particle emissions. There are a number of different methodologies which have proven effective at preventing particulates from being released to the atmosphere.
- Particulate matter that is removed from gas emissions may be used in other areas, providing a secondary benefit to the effort required to clean the gases.
- A major contributor to the lowering of emissions is the advancements made in the internal combustion engine in cars and gasoline reformulation. These have resulted in cleaner burning vehicles with better gas mileage. The development of hybrid and electric vehicles will help to lower emissions even more.
- The Clean Air Acts have required many industries to take a close look at how they produce and dispose of potential pollutants and minimize their generation and release. This has resulted in a 78% drop in the six common pollutants from 1970 to 2020 while overall productivity has increased over the same time period.

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