21.6 Acid Rain

Topics

Acid Rain

21.6 Acid Rain (1)

Acid Rain

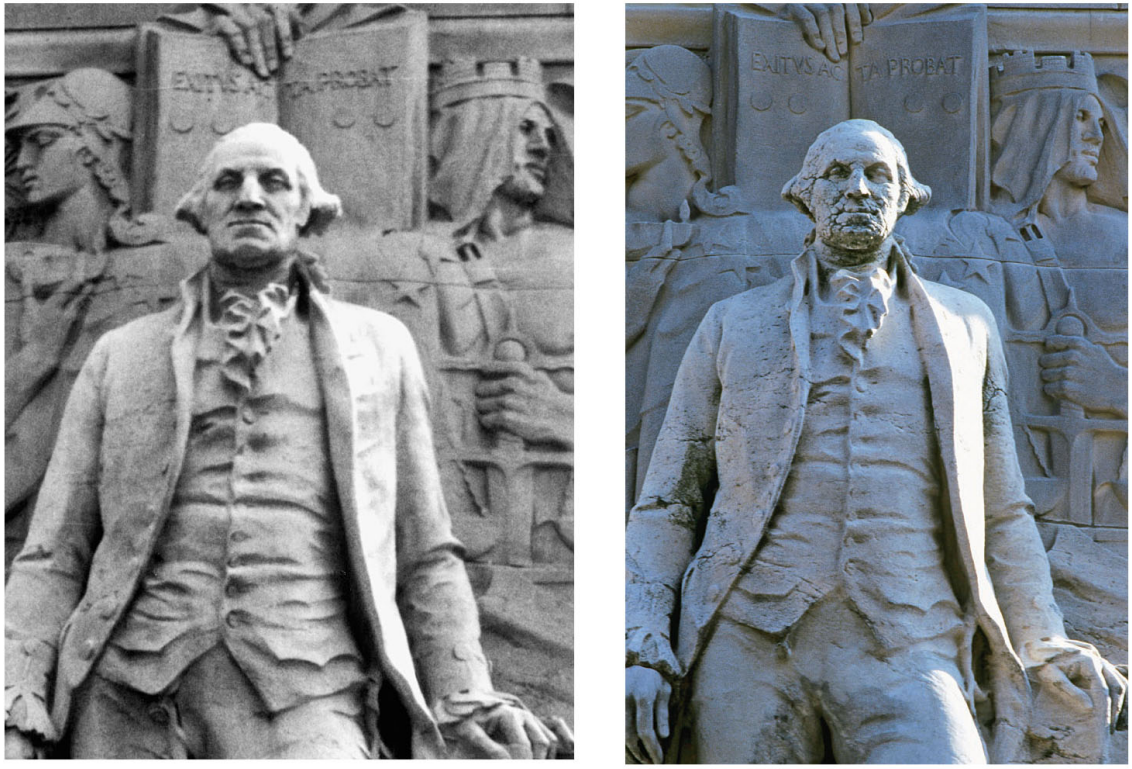
Every year acid rain causes hundreds of millions of dollars' worth of damage to stone buildings and statues throughout the world.

The term *stone leprosy* is used by some environmental chemists to describe the corrosion of stone by acid rain.

Acid rain is also toxic to vegetation and aquatic life.

21.6 Acid Rain (2)

Acid Rain



(first): © NYC Parks Photo Archive/Fundamental Photographs;
(second): © Kristen Brochmann/ Fundamental Photographs

Table 6.2 Effects of Acid Rain and Recovery Benefits

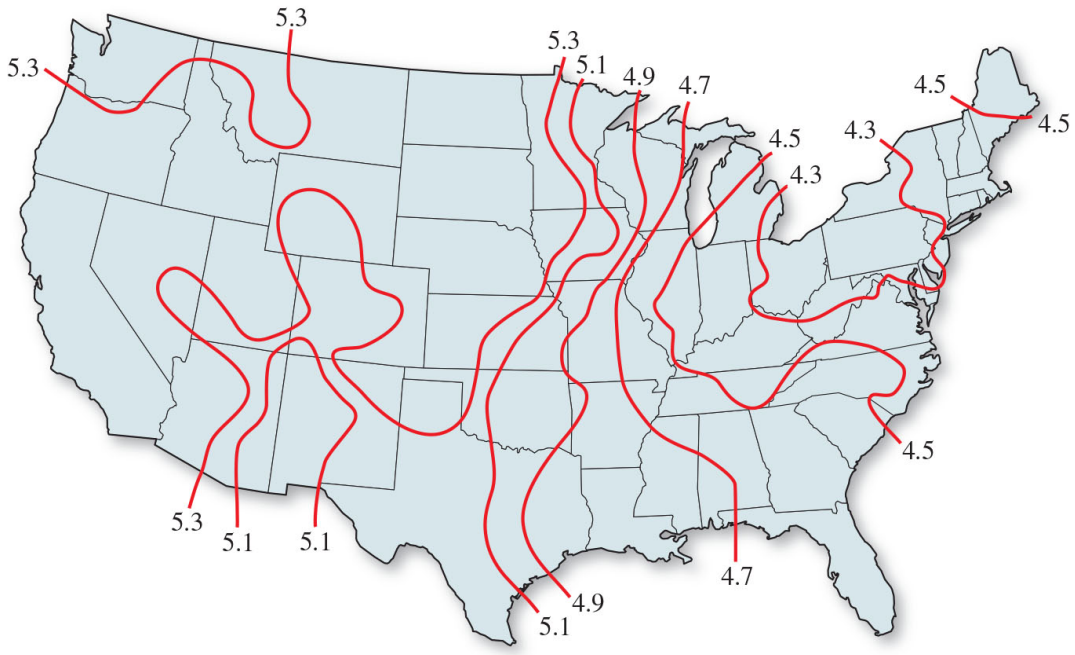
Effects	Recovery Benefits
Materials Acid deposition contributes to the corrosion and deterioration of buildings, cultural objects, and cars. This decreases their value and increases the cost of correcting and repairing damage.	Less damage to buildings, cultural objects, and cars, thus lowering the future costs of correcting and repairing such damage. See Section 6.10.
Human Health Sulfur dioxide and nitrogen oxides in the air increase deaths from asthma and bronchitis and impair the cardiovascular system.	Fewer visits to the emergency room, fewer hospital admissions, and fewer deaths. See Section 6.11.
Visibility In the atmosphere, sulfur dioxide and nitrogen oxides form sulfate and nitrate aerosols that impair visibility and affect enjoyment of national parks and other scenic views.	Reduced haze, therefore the ability to view scenery at a greater distance and with greater clarity. See Section 6.11.
Surface Waters Acidic surface waters decrease the survivability of animal life in lakes and streams. In more severe instances, acidity eliminates some or all types of fish and organisms.	Lower levels of acidity in the surface waters and a restoration of animal life in the more severely damaged lakes and streams. See Section 6.13.
Forests Acid deposition contributes to forest degradation by impairing the growth of trees and increasing their susceptibility to winter injury, insect infestation, and drought. It also causes leaching and depletion of natural nutrients in forest soil.	Less stress on trees, thereby reducing the effects of winter injury, insect infestation, and drought. Less leaching of nutrients from soil, thereby improving the overall forest health.

Source: Adapted from *Emission Trends and Effects in the Eastern U.S.*, United States General Accounting Office, Report to Congressional Requesters, March, 2000.

21.6 Acid Rain (3)

Acid Rain

Precipitation in the northeastern United States has an average pH of about 4.3:



21.6 *Acid Rain (4)*

Acid Rain

Sulfur dioxide (SO_2) and, to a lesser extent, nitrogen oxides from auto emissions are believed to be responsible for the high acidity of rainwater.

Acidic oxides, such as SO_2, react with water to give the corresponding acids.

There are several sources of atmospheric SO_2, including volcanic eruptions.

21.6 *Acid Rain (5)*

Acid Rain

Many metals exist combined with sulfur in nature.

Extracting the metals often entails *smelting,* or *roasting,* the ores—that is, heating the metal sulfide in air to form the metal oxide and SO_2. For example,

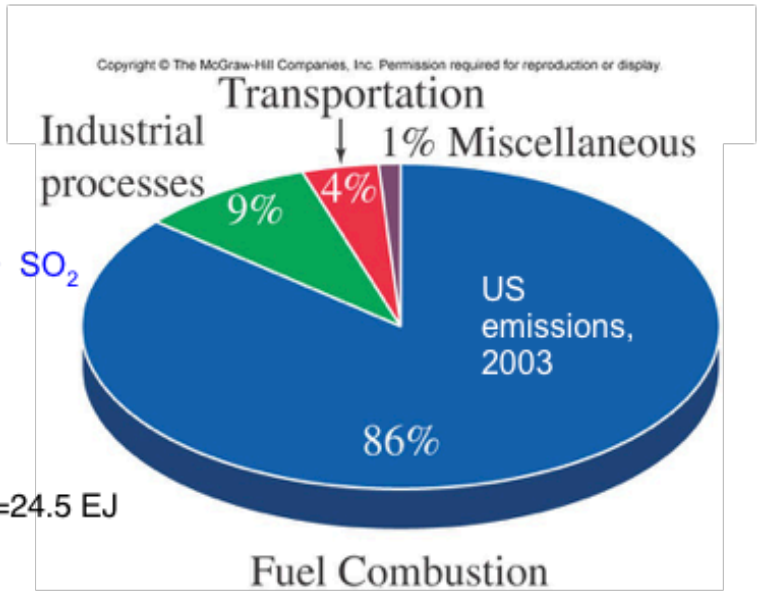
$$2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$$

The metal oxide can be reduced more easily than the sulfide to the free metal.

How Much SO_2 is Produced?

Smelting ore

$NiS + O_2 \rightarrow Ni + SO_2$



burning coal

US consumption of coal:

$$1.15\times10^{9}\ \text{short tons} \times \frac{2.13\times10^{10}\ \text{J}}{1\ \text{short ton}} = 2.45\times10^{19}\ \text{J} = 24.5\ \text{EJ}$$

SO_2 generation from coal combustion (assumes no mitigation):

$$2C_{135}H_{96}O_9NS + 313O_2 \rightarrow 270CO_2 + 96H_2O + 2NO_2 + 2SO_2$$

Molar mass: $C_{135}H_{96}O_9NS$: 135x12.0 +96x1.0+9x16.0+14.0+32.1=1906.1 g/mol

$$1.15\times10^{9}\ \text{short ton} \times \frac{907.2\ \text{kg}}{1\ \text{short ton}} \times \frac{1000\ \text{g}}{1\ \text{kg}} \times \frac{1\ \text{mole Coal}}{1906.1\ \text{g Coal}} \times \frac{1\ \text{mole } SO_2}{1\ \text{mole Coal}} \times \frac{64.1\ \text{g } SO_2}{1\ \text{mole } SO_2} = 3.51\times10^{13}\ \text{g } SO_2$$

$= 3.9\times10^{7}$ short ton

assumes no mitigation

21.6 *Acid Rain (6)*

Acid Rain

The burning of fossil fuels in industry, in power plants, and in homes accounts for most of the SO_2 emitted to the atmosphere.

50 million to 60 million tons of SO_2 are released into the atmosphere each year!

Almost all oxidized to H_2SO_4 in the form of aerosol, which ends up in acid rain.

© Larry Lee Photography/Corbis

21.6 *Acid Rain (7)*

Acid Rain

The mechanism for the conversion of SO_2 to H_2SO_4 is quite complex and not fully understood.

The reaction is believed to be initiated by the hydroxyl radical (OH•):

$$OH + SO_2 \rightarrow HOSO_2$$

The $HOSO_2$ radical is further oxidized to SO_3:

$$HOSO_3 + O_2 \rightarrow HO_2 + SO_3$$

21.6 *Acid Rain (8)*

Acid Rain

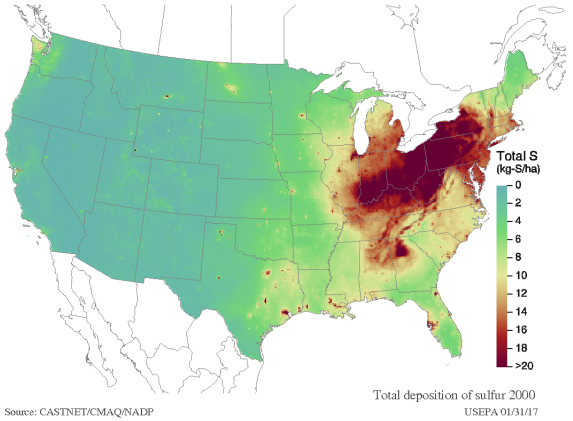
The sulfur trioxide formed would then rapidly react with water to form sulfuric acid:

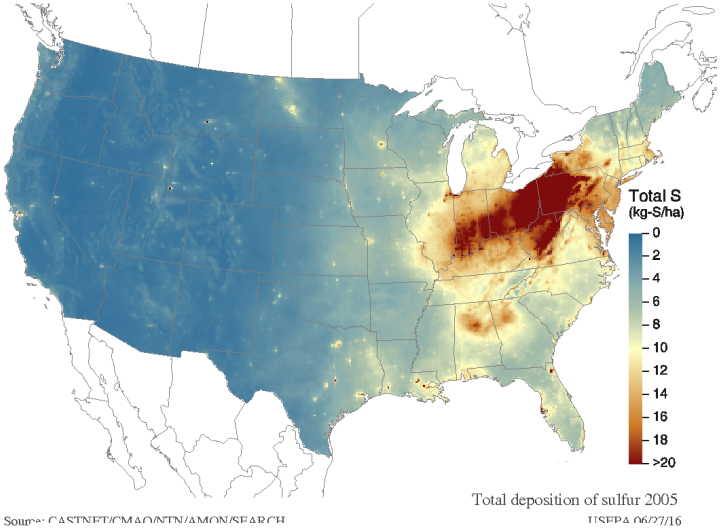
$$SO_3 + H_2O \rightarrow H_2SO_4$$

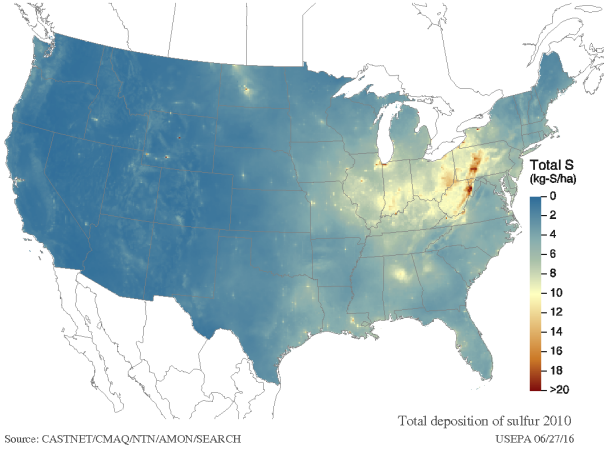
Eventually, the acid rain can corrode limestone and marble.

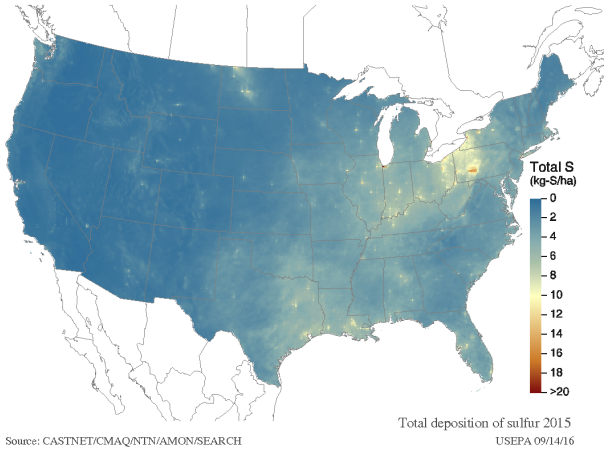
$$CaCO_3(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + H_2O(l) + CO_2(g)$$

Acid Rain – Progress 2000-2015









21.6 *Acid Rain (9)*

Acid Rain

There are two ways to minimize the effects of SO_2 pollution:

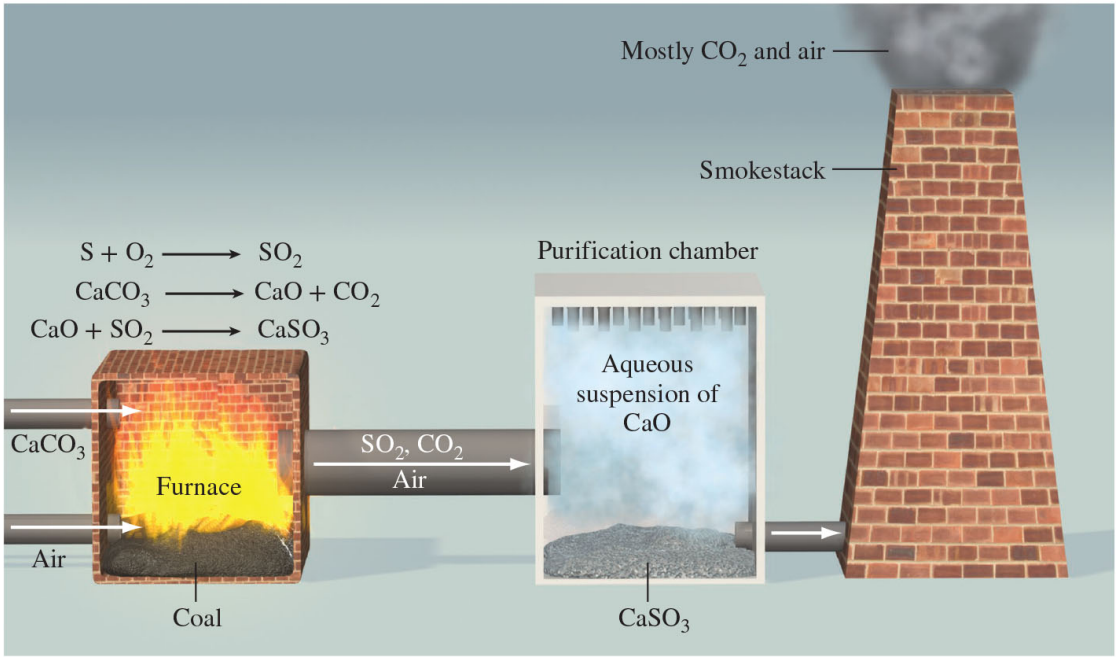
1. remove sulfur from fossil fuels before combustion (difficult)

2. remove SO_2 as it is formed (limestone)

21.6 *Acid Rain (10)*

Acid Rain

Limestone is injected into the power plant boiler or furnace along with the coal.



21.6 *Acid Rain (11)*

Acid Rain

At high temperatures, the following decomposition occurs:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

limestone quicklime

The quicklime reacts with SO_2 to form calcium sulfite and some calcium sulfate:

$$CaO(s) + SO_2(g) \rightarrow CaSO_3(s)$$

$$2CaO(s) + 2SO_2(g) + O_2(g) \rightarrow 2CaSO_4(s)$$

21.6 *Acid Rain (12)*

Acid Rain

Quicklime is also added to lakes and soils in a process called *liming* to reduce their acidity.