Review

Combustion of sulfur-containing fossil fuels such as coal is the major source of SOx.

Gasoline and diesel-powered motor vehicles emit a wide variety of pollutants, CO, NOx, VOCs and particulates (PM10)

NO and unburnt hydrocarbons (VOC) are the primary reactants responsible for photochemical smog formation

\[ \text{VOCs + NO + O}_2 + \text{sunlight} \rightarrow \text{mixture of O}_3, \text{HNO}_3, \text{organics, free radicals} \]
INDOOR AIR POLLUTION

Indoor air quality is important since people spend more times indoors than outdoors.

Source: burn coal & wood; carpet, tobacco smoke

**Formaldehyde: H₂C=O**
Stable intermediate of oxidation product of methane
Can reach up to 1000 ppb (1 ppm) ……as compared to 10 ppb outdoors

**Nitrogen oxides: NOₓ**
Homes that burn of natural gas (stove, heater, furnace) or kerosene have higher level of NOₓ

**Carbon Monoxide: CO**
Colorless, odorless gas whose concentration indoors increases from incomplete burning of carbon based fuels.

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**Are FEMA trailers ‘toxic tin cans’?**
Private testing finds high levels of formaldehyde; residents report illnesses

BAY ST. LOUIS, Miss. — For nearly a year now, the ubiquitous FEMA trailer has sheltered tens of thousands of Gulf Coast residents left homeless by Hurricane Katrina. ……

The gas is formaldehyde, the airborne form of a chemical used in a wide variety of products, including composite wood and plywood panels in the thousands of travel trailers that the Federal Emergency Management Agency purchased after Katrina to house hurricane victims. It also is considered a human carcinogen, or cancer-causing substance, by the International Agency for Research on Cancer and a probable human carcinogen by the U.S. Environmental Protection Agency.

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**Formaldehyde Issues Cause FEMA to Offer Trailer Refunds to Hurricane Survivors**
FRIDAY, JANUARY 18, 2008 (AP News)

NEW ORLEANS — The federal emergency management agency, responding to concerns about formaldehyde in trailers issued to hurricane survivors, said Thursday that it would offer refunds to people who bought them after their initial use.
Carbon Monoxide Can Be Deadly
Carbon monoxide (CO) is produced whenever any fuel such as gas, oil, kerosene, wood, or charcoal is burned. If appliances are not working properly or are used incorrectly, dangerous levels of CO can result. Hundreds of people die accidentally every year from CO poisoning. Even more die from CO produced by idling cars. Fetuses, infants, elderly people, and people with anemia or with a history of heart or respiratory disease can be especially susceptible.

CO Poisoning Symptoms
Know the symptoms of CO poisoning. At moderate levels, you or your family can get severe headaches, become dizzy, mentally confused, nauseated, or faint. You can even die if these levels persist for a long time. Low levels can cause shortness of breath, mild nausea, and mild headaches, and may have longer term effects on your health. Since many of these symptoms are similar to those of the flu, food poisoning, or other illnesses, you may not think that CO poisoning could be the cause.
Watch out when you turn up the heat at your next hotel stay …

Throughout the United States, hotel rooms are heated with individual heating units, many of which do not even have a thermostat on them. While in a perfect world, such heating units might have no greater risk for carbon monoxide poisoning than any other HVAC unit, the logistics of maintaining a hotel make the risk greater. There will be as many as hundreds of such units in a given property, greatly increasing the risk that the maintenance on such units will be sporadic.

Hotel Closed After Carbon Monoxide Leak, 17 Hospitalized

Last Update: 1/21 1:42 pm LOUISVILLE, Ky. (AP) - A carbon monoxide leak at a Jeffersontown hotel has sent least 17 people to the hospital.
Carbon monoxide binds to hemoglobin 320 times more effectively than oxygen does. Continuous exposure of more than 50 ppm CO is accompanied by some observable impairment, 250 ppm results in loss of consciousness and 750 ppm can result in death. A room having the dimension 4 m x 3 m x 8 m is kept at 20°C by a natural gas (CH₄) space heater.

Write the two balanced chemical equations for the combustion of CH₄ to produce (1) CO₂ and water and (2) CO and water.

\[
\begin{align*}
\text{CH}_4 + 2\text{O}_2 & \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \quad (1) \\
\text{CH}_4 + \frac{3}{2}\text{O}_2 & \rightarrow \text{CO} + 2\text{H}_2\text{O} \quad (2)
\end{align*}
\]

The fuel-air mixture of the heater is running slightly rich (CH₄:O₂ ratio of 1.00:1.92) resulting in some incomplete combustion to CO₂. Calculate what percent of the total carbon oxides produced is carbon monoxide.

CH₄:O₂ is 1:1.92
A combination of the two reactions above (Eq. (1) and (2)) occurs. Let \( x \) represent the contribution of Equation (2) and \( 1-x \) the contribution of Equation (1)

\[
1.92 = 2(1-x) + 1.5(x)
\]

\[
x = 0.16
\]

\[
\therefore \text{16\% of the total carbon oxide gases are CO.}
\]

The heater combusts 10.0 g of methane per hour. Assuming all the carbon monoxide from the heater is expelled into the room and there is no ventilation, how long will it take before there is a danger of losing consciousness? (Note: 250 ppm CO results in loss of consciousness)

Hint: convert g \( \rightarrow \) moles of CH₄. Determine moles of CO produced and then convert to ppm/h.

\[
\text{Mole(} \text{CH}_4 \text{)} = \frac{\text{Mass(} \text{CH}_4 \text{)}}{\text{Mwrt(} \text{CH}_4 \text{)}} = \frac{10.0 \text{ g}}{16.042 \text{ g/mol}} = 0.623 \text{ mol}
\]

\[
\text{Mole(CO)} = \text{Mole(} \text{CH}_4 \text{)} \times (0.623 \text{ mol}) \times (0.10) = 9.97 \times 10^{-2} \text{ mol}
\]

\[
\rho(\text{CO}) = \frac{nRT}{V} = \frac{(9.97 \times 10^{-2} \text{ mol}) \times (0.0821 \text{ L atm K}^{-1} \text{ mol}^{-1}) \times (293 \text{ K})}{(9.6 \times 10^{4} \text{ L})} = 2.50 \times 10^{-5} \text{ atm}
\]

At 1 atm.

\[
\text{ppm(} \text{CO} \text{)} = (2.50 \times 10^{-5} \text{ atm}) \times (1 \times 10^6) = 25 \text{ ppm h}^{-1}
\]

\[
\text{Time to reach 250 ppm} = \frac{250 \text{ ppm}}{25 \text{ ppm h}^{-1}} = 10 \text{ h}
\]

\[
\therefore \text{in ten hours there is a danger of an occupant losing consciousness.}
\]
**INDOOR AIR POLLUTION**

**Tobacco Smoke**

http://www.cancer.org/docroot/PED/content/PED_10_2X_Cigarette_Smoking.asp

The 1982 United States Surgeon General's report stated that "Cigarette smoking is the major single cause of cancer mortality (death) in the United States." This statement is as true today as it was in 1982. -Am. Cancer Soc.

- Cigarettes, cigars, and pipe tobacco are made from dried tobacco leaves, as well as ingredients added for flavor and other reasons.
- Manufacturers do not usually give out information to the public about the additives used in cigarettes.
- More than 60 chemicals (carcinogens) are known to cause cancer.

**Asbestos** (See http://www.epa.gov/asbestos/)

Refers to a family of six naturally occurring silicate minerals that are fibrous. .......causes lung cancer

*Contrary to what many people believe, asbestos is not and has never been banned in the United States.
*(Tests are required before demolition or renovation of old buildings)

Read more about indoor pollutants in the textbook p163-171 (old book p127-135)

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**Acid Rain**

First discovered by Angus Smith in mid 1800s .....but forgotten until 1950s

It refers to precipitation that is more acidic than natural ("unpolluted") rain

Natural water has dissolved CO₂ which forms carbonic acid (weak acid)

\[ \text{CO}_2 (g) + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \]

\[ \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \]

Natural rain water has a pH of 5.6. Rain water that is significantly acidic than the natural rain water (pH<5) is referred as acid rain

Two predominant acids responsible for the acid rain are \( \text{H}_2\text{SO}_4 \) and \( \text{HNO}_3 \)

This pollution is not limited by state or country boundaries!
Wet Deposition
The process of removing gases and particles from the atmosphere by rain, snow, sleet, or fog.

Dry Deposition
The process through which gases and particles are removed from the atmosphere in the absence of precipitation.

Gravity
Vegetation

The National Atmospheric Deposition Program (NADP) monitors wet atmospheric deposition at 250 National Trends Network sites throughout the United States. The USGS supports 74 of the roughly 250 active NADP/NTN sites. A fundamental NADP program objective is to provide scientific investigators world-wide with a long-term, high-quality database of atmospheric deposition for research support in the areas of air quality, water quality, agricultural effects, forest productivity, materials effects, ecosystem studies, watershed studies and human health.

http://nadp.sws.uiuc.edu/
Acid Rain: Cross-boundary Pollution

A large portion of SO₂ and NO₂ produced in one country is exported to others by prevailing surface winds. More than half the acid deposition in heavily populated southern Canada originates from seven central and upper Midwestern states-Ohio, Indiana, PA, IL, Missouri, WV, and TN, where coal and oil-burning power and industrial plants are concentrated.

http://nadp.sws.uiuc.edu/

Why don’t we hear about Acid Rain anymore in the news?

Dying lakes, dying crops
- major environmental problem became political issue between US and Canada

Listen to the story from Ottawa, Canada
Source cbc archives

Why don’t we hear about Acid Rain anymore in the news?

Since 1991, significant progress has been made in reducing sulfur dioxide, one of the key pollutants forming acid rain.

Measuring the success of Mulroney’s 1991 acid rain accord

Listen to the story from Ottawa, Canada
Source cbc archives
**SOx**

Sulfur dioxide emissions are highest in regions with many coal-fired electric power plants, steel mills, and other heavy industries that rely on coal.

Allegheny County, in western Pennsylvania, is just such an area, and in 1990 it led the United States in atmospheric SO₂ concentration.

**NOx**

The highest NOx emissions are generally found in states with large urban areas, high population density, and heavy automobile traffic.

Therefore, it is not surprising that the highest levels of atmospheric NO₂ are measured over Los Angeles County, the car capital of the country.
**Figure 4:**

Source: “Acid Rain Revisited”, A Science Links™ Publication of the Hubbard Brook Research Foundation
Effects of acid rain

- Acidification of surface water (lakes, rivers, etc), and subsequent damage to aquatic ecosystems.
  - Kills aquatic plants, fish and microorganisms in lakes and streams by releasing ions of Al, Pb, Hg and Cd from soils and sediments.
- Damage to forests and vegetation
  - Weakens or kills trees, especially conifers at high elevations;
  - Makes trees more susceptible to diseases, insects, drought, and fungi and mosses that thrive under acidic conditions;
  - Stunts growth of crops such as tomatoes, soybeans, spinach, carrots, broccoli and cotton

\[
\text{CaCO}_3(s) + H^+ \rightarrow \text{Ca}^{2+} + \text{HCO}_3^- (aq) \\
\text{HCO}_3^-(aq) + H^+(aq) \rightarrow \text{H}_2\text{CO}_3 (aq) \rightarrow \text{CO}_2 (g) + \text{H}_2\text{O} (aq)
\]
**Ions in pure water**

\[
\text{H}_2\text{O} \quad \overset{\text{autoionization}}{\rightleftharpoons} \quad \text{H}^+ + \text{OH}^- \\
\]

\[
K_{eq} = \frac{[\text{H}^+][\text{OH}^-]}{[\text{H}_2\text{O}]} \quad K_w = K_{eq}[\text{H}_2\text{O}]
\]

\[
= [\text{H}^+][\text{OH}^-] \quad = 10^{-14} M^2
\]

**Review of pH**

The pH of a solution is a measure of the concentration of the H\(^+\) ions present in that solution.

The mathematical expression for pH is a log-based scale and is represented as:

\[
\text{pH} = -\log[\text{H}^+]
\]

So for a solution with a

\[
[\text{H}^+] = 1.0 \times 10^{-3} \text{ M}, \text{ the pH} = -\log (1.0 \times 10^{-3}), \text{ or } (-3.0) = 3.0
\]

Since pH is a log scale based on 10, a pH change of 1 unit represents a power of 10 change in [H\(^+\)].

That is, a solution with a pH of 2 has a [H\(^+\)] ten times that of a solution with a pH of 3.
pH value of pure water

\[ K_w = [H^+][OH^-] \]

\[-\log K_w = -\log[H^+] - \log[OH^-] \]

\[ pK_w = pH + pOH \]

In pure water, autoionization is the only source of ions, therefore:

\[ [H^+] = [OH^-] = 10^{-7} \text{ M} \]

\[ pH = 7 \]

A pH of 7 defines neutrality, pH<7 means acidic and pH>7 is basic.

What is the pH of natural rain water?

pH of natural rain water is determined by acidic and basic species that are naturally present in the atmosphere.

\[ K_{eq} = 10^{-1.5} \text{ and } CO_2: 400 \text{ ppm} \] (At 1 atm air this conc. corresponds to 400x10^{-6} atm)

\[ CO_2(g) + H_2O = H_2CO_3 \]

\[ K_{eq} = \frac{[H_2CO_3]}{CO_2}[H_2O] \]

\[ K_{eq}[H_2O] = \frac{[H_2CO_3]}{p_{CO_2}} \]

\[ 10^{-1.5} = \frac{[H_2CO_3]}{400 \times 10^{-6}} \]

\[ (\log 400 = 2.6 \quad 400 = 10^{2.6}) \]

\[ [H_2CO_3] = 10^{-4.9} \text{ M} \]

\[ [H^+] \approx [HCO_3^-] \]

\[ H_2CO_3 = H^+ + HCO_3^- \quad (K_a = 10^{-6.4}) \]

\[ K_a = \frac{[H^+][HCO_3^-]}{[H_2CO_3]} \]

\[ K_a = \frac{[H^+]^2}{[H_2CO_3]} \]

\[ [H^+]^2 = K_a[H_2CO_3] = 10^{-6.4} \times 10^{-4.9} \]

\[ [H^+] = 10^{-5.65} \]

\[ pH = 5.65 \]
• Rainwater has a pH of 5.7. If CO₂ is the only species that affects its acidity.

• When additional acidic species are present at appreciable levels as a result of man-made activities, pH of rain water becomes lower than 5.7 → Acid rain.

• H₂SO₄ and HNO₃ are the major contributors to acid rain.

• Both substances are formed in the air
  – Precursor to H₂SO₄: SO₂
  – Precursor to HNO₃: NO₂
• Concentrations of the precursors SO₂ and NO₂ are greatly increased by fossil fuel combustion.

Note:
• NO is not very soluble in H₂O.
• H₂SO₃ formed from the dissolution of SO₂ in water is a weak acid.
• Thus primary pollutants themselves do not directly increase the acidity of rain water. However over periods of hours and days these weak acids get converted to strong acids, HNO₃ and H₂SO₄
• Acidification of Lakes and Soils – affecting the delicate balance of nature
The source and the cause of acid rain

Example:

The burning of coal.
Coal contains 1-3% sulfur

\[ S(s) + O_2(g) \rightarrow SO_2(g) \]
\[ 2 \text{SO}_2(g) + O_2(g) \rightarrow 2 \text{SO}_3(g) \]

\[ \text{SO}_2(g) + H_2O(l) \rightarrow H_2\text{SO}_3(aq) \text{ sulfurous acid} \]

\[ \text{SO}_3(g) + H_2O(l) \rightarrow H_2\text{SO}_4(aq) \text{ sulfuric acid} \]

And then: \[ H_2\text{SO}_4(aq) \rightarrow 2 H^+(aq) + \text{SO}_4^{2-}(aq) \]

The Ecological Effects of Acid Rain

Global Pattern of acidity pattern

Major problems in Europe and East Coast.
Ohio Valley pollution is responsible or the acid rain in Ontario
In North America most of the acidity comes from the burning of high sulfur content coal in power plants.

The effect of acid rain on biological life depends upon the composition of soil and bedrock in the area.

Neutralization of Soil by Acid Rain

Neutralization of Acid Rain by soil

\[
\text{CaCO}_3(s) + \text{H}^+ \rightarrow \text{Ca}^{2+} + \text{HCO}_3^- (aq)
\]

\[
\text{HCO}_3^-(aq) + \text{H}^+(aq) \rightarrow \text{H}_2\text{CO}_3 (aq) \rightarrow \text{CO}_2 (g) + \text{H}_2\text{O} (aq)
\]

Acidity from the rain deteriorates soil.

Although SO\textsubscript{2} emissions have decreased over the years, rain acidity remains high (lack of fly ash emission which used to neutralize acidity).
Thousands of lakes have become strongly acidified. The acid rain problem of Northeast now extends to southeast.

Role of NH₃ in acid rain

- **Ammonia dissolved in rainwater neutralizes H⁺:**
  \[ \text{NH}_3 \text{(aq)} + \text{H}^+ = \text{NH}_4^+ \]

- **Ammonia input lowers the acidity in rain.**

<table>
<thead>
<tr>
<th>Ion</th>
<th>Rural New York (μeq/l)</th>
<th>Southwest Minnesota (μeq/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H⁺(pH)</td>
<td>46 (4.34)</td>
<td>0.5 (6.31)</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>45</td>
<td>46</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>8.3</td>
<td>38</td>
</tr>
</tbody>
</table>

The larger input of NH₃ in MN is responsible for the lower rain acidity than in NY.

- Animal waste,
- ammonification of humus followed by emission from soils
- losses of NH₃-based fertilizers from soils
- industrial emissions.
How much ammonia do dairy farms emit?

*by C. Alan Rotz, May 25 issue of Hoard's Dairyman*

<table>
<thead>
<tr>
<th>Farm type</th>
<th>Emission rate lbs./cow/day</th>
<th>Herd size Cows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confinement farms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tie stall barn with daily hauling</td>
<td>0.40</td>
<td>250</td>
</tr>
<tr>
<td>Free stall barn with daily hauling</td>
<td>0.58</td>
<td>170</td>
</tr>
<tr>
<td>Free stall barn with bottom-loaded storage tank</td>
<td>0.82</td>
<td>120</td>
</tr>
<tr>
<td>Free stall barn with top-loaded manure pit</td>
<td>1.00</td>
<td>100</td>
</tr>
<tr>
<td>Open feedlot</td>
<td>0.92</td>
<td>110</td>
</tr>
<tr>
<td>Grazing farms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tie stall barn with daily haul</td>
<td>0.18</td>
<td>550</td>
</tr>
<tr>
<td>Free stall barn with bottom-loaded storage tank</td>
<td>0.45</td>
<td>220</td>
</tr>
</tbody>
</table>

*Maximum number of cows for emitting less than 100 pounds of ammonia per day.*

http://www.prodairyfacilities.cornell.edu/Docs/ammonia.pdf
Farms May Be Exempted From Emission Rules
By Elizabeth Williamson

Under pressure from agriculture industry lobbyists and lawmakers from agricultural states, the Environmental Protection Agency wants to drop requirements that factory farms report their emissions of toxic gases, despite findings by the agency’s scientists that the gases pose a health threat.

The rule change would eliminate ammonia emissions reporting for big animal-feeding operations such as Three mile Canyon Farms in Boardman, Ore., where waste from tens of thousands of dairy cows releases more than 15,000 pounds of ammonia into the atmosphere each day, according to the EPA.

http://www.washingtonpost.com/wp-dyn/content/article/2008/02/25/AR2008022502472.html

Acidified lakes also possess elevated concentrations of $\text{Al}^{3+}$ ions - leached from rocks and soil
Problem 2 (p162). If the pH of the rainfall is 4.0 and half the acidity is due to HNO$_3$ and half due to H$_2$SO$_4$, calculate the mass of the primary pollutants NO and SO$_2$ that are required to acidify 1L of rain.

Since pH is 4.0, $[H^+] = 10^{-4}$ M/L \hspace{1cm} (Recall pH = -log$[H^+]$)

H$^+$ obtained from the dissociation of each of HNO$_3$ and H$_2$SO$_4$ is 5x10$^{-5}$ M/L

$[\text{HNO}_3] = 5x10^{-5}$ M/L and $[\text{H}_2\text{SO}_4] = 2.5x10^{-5}$ M/L \hspace{1cm} (two H$^+$ for 1 H$_2$SO$_4$)

Since 1 mole of HNO$_3$ results from 1 mole of NO

$5x10^{-5}$ moles of NO = 5x10$^{-5}$ mole x(30g/1mole) = 0.0015 g NO

Since 1 mole of H$_2$SO$_4$ results from 1 mole of SO$_2$

$2.5x10^{-5}$ moles of SO$_2$ = 2.5x10$^{-5}$ mole x (64.1g/1mole) = 0.0016 g SO$_2$

Thoughts for Future

Mandatory implementation of catalyst converter in automobiles enabled the control of SOx and NOx emissions. No such requirement exists for home heating systems. What is your thought on recommending only high efficiency (95+%) home furnaces?

How to control CO$_2$ emission?

Do you think using electric cars, Liquefied Natural Gas or Hydrogen fuel cell driven cars can reduce the emission?

With increasing energy demand increased amount of coal and natural as burning will be necessary. Do you think additional treatment of smokestack emissions is necessary?

Should we consider nuclear energy as an alternative source to meet our energy demand?
Are you interested in summer research?

Learn about REU programs at different campuses in the country (Disciplines range from Biology to Engineering)

Application deadline is approaching fast

Contact me if you need to more information

http://www.nsf.gov/crssprgm/reu/reu_search.cfm
The Acid Rain Program (ARP) was created under Title IV of the 1990 Clean Air Act (CAA) Amendments to reduce the adverse effects of acid deposition through reductions in annual emissions of SO2 and NOx primarily from fossil-fuel burning electricity generation.

In 2007, for the first time, SO2 emissions were below the ARP’s long term emission cap of 8.95 million tons -- three years before the 2010 statutory deadline.

http://www.epa.gov/airmarkt/progress/arp07.html
Using a market-based cap and trade mechanism to reduce SO2 emissions allows flexibility for individual combustion units to select their own methods of compliance.

For 2007, EPA allocated over 9.5 million tons SO2 allowances under the ARP. (+ 6.2 million tons unused allowances)

In 2007, SO2 emissions from sources regulated under the ARP fell below 8.95 million tons, thereby reaching the 2010 emission cap three years earlier than required by statute.

A major factor in the SO2 emission decrease was the use of flue gas desulfurization (FGD) systems (also called scrubbers)

2007 SO2 ALLOWANCE MARKET IN BRIEF

<table>
<thead>
<tr>
<th>Allowance Market</th>
<th>$5.1 billion*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Nominal Price</td>
<td>$325 per ton</td>
</tr>
<tr>
<td>Total Allowance Volume (Allowable Emissions)</td>
<td>15,776,130</td>
</tr>
<tr>
<td>2007 Private Transactions</td>
<td>4,700 transactions moving 36.9 million allowances</td>
</tr>
<tr>
<td>54 percent of allowances transferred between economically unrelated parties</td>
<td></td>
</tr>
</tbody>
</table>

*Total value of allowance market is a snapshot based on the average nominal price as of July 1, 2007 ($235 and 2007 total allowance volume.

2007 Acid Rain Report -EPA

Figure 1: Trends in Electricity Generation, Fossil Energy Use, Prices, and Emissions from the Electric Power Industry

Source: Energy Information Administration (electricity generation, retail price). EPA total input and emissions, representing all affected ARP units, 2008

Acid Rain and Related Programs: 2007 Progress Report

On October 19, 1998, federal, provincial, and territorial Energy and Environment Ministers signed *The Canada-wide Acid Rain Strategy for Post-2000.* The Strategy laid the framework for how Canada would manage acid rain in the future. The primary long-term goal of the Strategy is to achieve critical loads (or the threshold level) for acid deposition across Canada.

The Strategy is currently being implemented. Its key commitments are:

- to seek further SO₂ emission reductions in the U.S.;
- to establish new SO₂ emission reduction targets in eastern Canada (Ontario, Quebec, New Brunswick and Nova Scotia);
- to ensure adequate acid rain science and monitoring;
- to prevent pollution;
- to keep clean areas clean; and
- to report annually on emissions and on progress.

**What has Canada done about acid rain?**

On October 19, 1998, federal, provincial, and territorial Energy and Environment Ministers signed *The Canada-wide Acid Rain Strategy for Post-2000.* The Strategy laid the framework for how Canada would manage acid rain in the future. The primary long-term goal of the Strategy is to achieve critical loads (or the threshold level) for acid deposition across Canada.

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- to prevent pollution;
- to keep clean areas clean; and
- to report annually on emissions and on progress.


**Remaining Challenges**

Despite this progress, an acid rain science assessment conducted in the mid-1990s showed that some serious problems remained:

Without further emission reductions beyond those required under the 1991 Air Quality Agreement, scientists estimated that an area of some 800,000 square kilometers, extending from central Ontario through southern Quebec and across much of Atlantic Canada, would still be receiving more sulfate than its natural systems could tolerate.

Canadian ecosystems have been found to be more sensitive to acid rain than scientists had originally thought. Atmospheric modeling conducted as part of the science assessment showed that a further 75% reduction in sulfur dioxide emissions (beyond current commitments) in targeted regions of eastern Canada and the U.S. would be necessary to protect all of the 95,000 lakes in this area.

Some acidified lakes showed signs of recovery, but many more did not. Of 202 lakes that were studied between the early 1980s and the mid-1990s, 33% had reduced levels of acidity while 56% showed no change and 11% actually became more acidic. Atlantic Canada, although lakes in this region were never as highly acidified as those in some parts

If nitrate deposition continued at current levels, its contribution to acidification would eventually erode the benefits gained from the reductions in sulfur dioxide. Because nitrogen oxides also contribute to ground-level ozone, the main ingredient in smog, reducing these emissions would also help to improve air quality.