In its Title I, the Clean Air Act has identified six air pollutants of special concern because of their health and environmental effects.

These six so-called criteria pollutants are:

- Carbon Monoxide (CO)
- Nitrogen Dioxide (NO₂)
- Ozone (O₃)
- Sulfur Dioxide (SO₂)
- Particulate Matter (PM)
  - subdivision: Respirable particulate matter (PM₁₀) [size ≤ 10 µm]
  - Fine particulate (PM₂.₅) [size ≤ 2.5 µm]
- Lead (Pb)

### Criteria Pollutants

(Nazaroff & Alvarez-Cohen, Section 7.A.1)

<table>
<thead>
<tr>
<th>Criteria Pollutant</th>
<th>Primary / Secondary</th>
<th>Sources</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO Carbon Monoxide</td>
<td>P</td>
<td>Incomplete combustion</td>
<td>Impairs oxygen-carrying capacity of blood → Asphyxiation &amp; brain damage</td>
</tr>
<tr>
<td>NO₂ Nitrogen Dioxide</td>
<td>both P and S</td>
<td>From combustion, esp. automobile engines</td>
<td>Respiratory irritant (asthma)</td>
</tr>
<tr>
<td>O₃ Ozone</td>
<td>mostly S</td>
<td>From NO and NO₂</td>
<td>Compromised immunity</td>
</tr>
<tr>
<td>SO₂ Sulfur Dioxide</td>
<td>P</td>
<td>Sulfur in fuels, esp. coal and diesel</td>
<td>Lung, throat and eye irritant</td>
</tr>
<tr>
<td>PM₁₀ and PM₂.₅ Particulate Matter (*)</td>
<td>both P and S</td>
<td>Industrial combustion Other industrial activities</td>
<td>Reduced resistance to infection Damage to vegetation</td>
</tr>
<tr>
<td>Pb Lead</td>
<td>P and S</td>
<td>Industrial processes Lead pipes, solder</td>
<td>Blood poisoning; hypertension Kidney damage; cancer Mental retardation</td>
</tr>
</tbody>
</table>

You need to know this list!

(*) also going by name of “aerosols”

For added information, see
Mihelcic & Zimmerman, pages 531-537.
Problems caused by nitrogen oxides

Excitation: \( \text{NO}_2 \text{ + sunlight} \rightarrow \text{NO} + \text{O} \)

Ozone formation: \( \text{O} + \text{O}_2 \rightarrow \text{O}_3 \)

Relaxation: \( \text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 \)

Sources of and problems caused by sulfur oxides

Sources of sulfur oxides according to the EPA

- Fuel Combustion: Electrical Utilities 67%
- Industrial & Other: 18%
- Nonroad Vehicles & Engines: 5%
- Metal Processing: 3%
- All Others: 7%

Sulfur in fuel

SO\(_x\) in fumes

Respiration irritant

H\(_2\)SO\(_4\)

Acid rain

Acid lakes

Tree damage

Dead fish

Damaged buildings & monuments

Sources: http://www.robl.w1.com/Pixl-900991.htm
The EPA has set National Ambient Air Quality Standards (NAAQS) for these six criteria pollutants.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Standard</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide (CO)</td>
<td>9 ppm (10 mg/m³)</td>
<td>Primary</td>
</tr>
<tr>
<td>8-hour average</td>
<td>35 ppm (40 mg/m³)</td>
<td>Primary</td>
</tr>
<tr>
<td>Nitrogen dioxide (NO₂)</td>
<td>53 ppb (100 µg/m³)</td>
<td>Primary &amp; Secondary</td>
</tr>
<tr>
<td>annual average</td>
<td>100 ppb</td>
<td>Primary</td>
</tr>
<tr>
<td>Ozone (O₃)</td>
<td>70 ppb (157 µg/m³)</td>
<td>Primary &amp; Secondary</td>
</tr>
<tr>
<td>Particulate Matter ≤ 10 µm (PM₁₀)</td>
<td>150 µg/m³</td>
<td>Primary &amp; Secondary</td>
</tr>
<tr>
<td>24-hour average</td>
<td>12 µg/m³</td>
<td>Primary</td>
</tr>
<tr>
<td>Particulate Matter ≤ 2.5 µm (PM₂.₅)</td>
<td>15 µg/m³</td>
<td>Secondary</td>
</tr>
<tr>
<td>annual average</td>
<td>35 µg/m³</td>
<td>Primary &amp; Secondary</td>
</tr>
<tr>
<td>Sulfur dioxide (SO₂)</td>
<td>0.5 ppm</td>
<td>Secondary</td>
</tr>
<tr>
<td>3-hour average</td>
<td>75 ppb</td>
<td>Primary</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>0.15 µg/m³</td>
<td>Primary &amp; Secondary</td>
</tr>
</tbody>
</table>

www.epa.gov/criteria-air-pollutants/naaqs-table
In some U.S. cities...

Los Angeles, CA

Newark, NJ

www.epa.gov/air-trends/air-quality-national-summary

www3.epa.gov/airquality/greenbook/mapnpoll.html
Hazardous Air Pollutants
(Nazaroff & Alvarez-Cohen, Section 7.A.2)

Hazardous air pollutants, also called air toxics, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.

Examples of air toxic pollutants include benzene (from gasoline), mercury (from coal combustion and fluorescent lamps), perchloroethylene (from dry cleaning facilities), methylene chloride (a solvent used in industry).

Some affect humans by direct respiration, others settle and fall in water, affecting people when they drink. On rare occasions, effect is through skin exposure (dermal contact).

Hazardous Air Pollutants (HAPs) are not covered by national ambient air quality standards because they tend not to be uniformly present in the atmosphere but to be in greater concentrations near their sources. Hence, they are not subject to routine monitoring in the air. Instead, emissions are monitored at the source.

Air-Quality Management
(Mihelcic & Zimmerman, Sections 12.2 & 12.

Two-prong strategy:
1. Control emissions, with goal of reduction
   - Command & Control – requiring use of Best-Available Control Technology (BACT)
   - Incentives (cap-n-trade of emissions)

2. Control of ambient concentrations: Six criteria pollutants
   - National Ambient Air Quality Standards (NAAQS)

Distinction:

Primary pollutant: emitted directly from a source
(source can be regulated)

Secondary pollutant: formed in the air by chemical reactions from precursor species
(no source to be regulated – need to go after chemical precursors)
Emission Factor Modeling
(Nazaroff & Alvarez-Cohen, page 424)

Basic idea
A source emitting a pollutant has a certain level $A$ of activity (action per time).
This activity level leads to a certain amount $E$ of emission (amount emitted per time).
The factor of proportionality is called the Emission Factor ($EF$), ratio of amount emitted per action.

Example
An industrial boiler emits 0.6 kg of CO per 1,000 L of oil burned.
$EF = 0.6 \text{ kg CO} / 1,000 \text{ L fuel}$

So, if the activity level of the boiler is 120,000 L of oil consumed per day,
then $A = 120,000 \text{ L/day}$, and
the emission is $E = (0.6 \text{ kg CO} / 1,000 \text{ L})(120,000 \text{ L/day}) = 72 \text{ kg CO per day}$.

Correction
There may be an emission-control device installed that reduces the outgoing emission by an efficiency factor $\eta$ (% of emission captured).

→ Formula
$$E = A \times EF \times (1 - \eta)$$
Emission factors for common fuels

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Bituminous coal (pulverized) (1.8% sulfur)</th>
<th>Diesel oil (#6 'residual') (2% sulfur)</th>
<th>Natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating value:</td>
<td>24.2 kJ/g</td>
<td>41.7 MJ/L</td>
<td>38.3 MJ/m³</td>
</tr>
<tr>
<td>Emission factors:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particulates</td>
<td>31 kg/ton</td>
<td>2.9 kg/m³</td>
<td>16-80 kg/10⁶ m³</td>
</tr>
<tr>
<td>SO₂</td>
<td>35 kg/ton</td>
<td>38 kg/m³</td>
<td>9.6 kg/10⁶ m³</td>
</tr>
<tr>
<td>NOₓ</td>
<td>10.5 kg/ton</td>
<td>8 kg/m³</td>
<td>8800 kg/10⁶ m³</td>
</tr>
<tr>
<td>CO</td>
<td>0.3 kg/ton</td>
<td>0.6 kg/m³</td>
<td>640 kg/10⁶ m³</td>
</tr>
<tr>
<td>Non-methane organics</td>
<td>0.04 kg/ton</td>
<td>0.09 kg/m³</td>
<td>23 kg/10⁶ m³</td>
</tr>
<tr>
<td>Methane</td>
<td>0.015 kg/ton</td>
<td>0.03 kg/m³</td>
<td>4.8 kg/10⁶ m³</td>
</tr>
</tbody>
</table>

(Nazaroff & Alvarez-Cohen, Table 7.B.3)

Example

A coal-fired power plant burns bituminous coal with a 1.8% sulfur content by weight. To produce 1 MW of electricity, this plant burns 12 tons of coal per day. The plant is equipped with a wet scrubber that captures 95% of the SO₂ from combustion. How much SO₂ does the plant release per day when it generates 350 MW of electricity?

Answer

Activity = \( A = (350 \text{ MW}) \times (12 \text{ tons coal / day} \times \text{ MW}) = 4,200 \text{ tons coal / day} \)

Emission Factor = \( EF = 35 \text{ kg SO₂ / ton of coal} \) (from preceding table)

Emission-control efficiency = \( \eta = 95\% = 0.95 \)

Emission = \( \dot{E} = A \times EF \times (1 - \eta) \) = \( (4,200 \text{ tons coal / day}) \times (35 \text{ kg SO₂ / ton coal}) \times (1 - 0.95) \) = 7,350 kg SO₂/day
Best Available Control Technology (BACT)

Most common types of “end-of-pipe” treatment

Particulates: Cyclone
Electrostatic precipitator

Stationary combustion fumes (incl. SO2): Wet scrubber

Mobile exhaust: Catalytic converter

(http://www.aa1car.com/library/p0420_dtc.htm)

(sketches from an earlier http://www.epa.gov/ site)