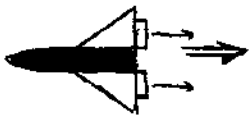
IV. STRATOSPHERIC OZONE DEPLETION

CFCs



Example $NO + O_3 \rightarrow NO_2 + O_2$

$NO_2 + O \rightarrow NO + O_2$

Net $O + O_3 \rightarrow 2O_2$

III. ATMOSPHERIC WARMING

Greenhouse Gases

Concentration × IR Cross-section

CO_2 CFCs

CH_4 N_2O

II. ACID RAIN

$NO + HC + \text{☼} \Rightarrow$

NO_2 + Aerosol +

O_3 + Aldehydes + ...

Photochemical Smog

Particulate Matter

CO SO_2

Toxics

I. GROUND LEVEL

Criteria Pollutants (there are 6)

NO_2 [nitrogen dioxide, a consequence of NO (nitric oxide) and NO_2 emitted into the atmosphere]

SO_2 [sulfur dioxide, the primary emission product of sulfur in the fuel; other sulfur emissions are sulfur trioxide (SO_3), acids of sulfur, sulfate ($SO_4^{=}$) particulate matter, and chemically reduced sulfur species such as H_2S, COS, and CS_2.]

O_3 (ozone)

CO (carbon monoxide)

Pb (lead)

PM_{10} (suspended particular matter of size less than 10 microns)

Criteria pollutants continued:

Proposed: $PM_{2.5}$

Note: VOC's as NMHC's (non-methane hydrocarbons) are no longer considered as a criteria pollutant, since they are now covered under the air toxics list.

Of concern for combustion-fired electrical generating stations are the following:

NOx (i.e., NO + NO_2)

SO_2

SO_3, acids of sulfur, and sulfate particulate (SO_3 leads quickly to acids of sulfur and sulfate particulate, which cause plume visibility; also SO_3 and its products cause corrosion and fouling of the plant equipment.)

O_3 (this is not a stack gas, rather it forms in the atmospheric though photochemical smog reactions)

"Of concern" continued:

CO
TSP (total suspended particulate) and
PM_{10}

VOC's: For most combustion-fired powerplants operating near full load, VOC emissions are very low. VOC emissions can be a problem at reduced load, or if the combustion process is faulty.

Air Toxics
These were developed under the Clean Air Act Amendments of 1990 (signed into US law in 1991). There are 189 air toxics. These are also known as hazardous air pollutants (HAP's). Of the 189 air toxics, 37 have been identified as being of concern to combustion-fired electric

Air toxics continued:

generating stations. The 37 include organic compounds, two acid gases (HCl and HF), and inorganic compounds of Sb, As, Be, Cd, Co, Pb, Mn, Hg, Ni, P, and Se (which are adsorbed onto the surface of tiny particles, except for gas-phase emissions of Hg and some of the Se).

Pollutants which contribute to photochemical smog:

NOx + hydrocarbons + sunlight $\Rightarrow$ strong oxidants such as O_3 + irritants such as aldehydes + aerosol (haze)

Note: each hydrocarbon species has a unique photochemical reactivity.

Table 1: Toxic compounds of concern to utilities

Acetaldehyde
Antimony compounds
Arsenic compounds
Benzo-a-pyrene
Benzene
Beryllium compounds
Biphenyl
Bis-(2-ethylhexyl)-phthalate
Cadmium compounds
Carbon disulfide
Carbon tetrachloride
Carbonyl sulfide
Chlorine
Chlorobenzene
Chloroform
Chromium compounds
Cobalt compounds
Dibenzofurans
1,4-Dichlorobenzene(p)
Formaldehyde
Hexachlorobenzene
Hydrochloric acid
Hydrofluoric acid
Lead compounds
Manganese compounds
Mercury compounds
Naphthalene
Nickel compounds
Pentachlorophenol
Phenol
Phosphorus
Selenium compounds
2,3,7,8-Tetrachlorodibenzo-p-dioxin
Tetrachloroethylene
Toluene
Trichloroethylene
2,4,5-Trichlorophenol

Pollutants which contribute to acid rain – acid rain precursor gases:

SOx (i.e., SO_2 + SO_3)

NOx (i.e., NO + NO_2)

Gases which contribute to stratospheric ozone depletion:

These gases are emitted at ground level and are not destroyed in the troposphere.

N_2O (nitrous oxide), which is oxidized to NO in the stratosphere. (Only known significant powerplant source is coal-fired fluidized bed combustors.)

CFC's (chlorofluorocarbons)

Ozone depletion continued:

$$X(\text{i.e., NO or Cl}) + O_3 \Rightarrow XO + O_2$$
$$O_3 + \text{sunlight } (\lambda < 0.31\mu m) \Rightarrow O_2 + O$$
$$XO + O \Rightarrow X + O_2$$
$$\text{NET: } 2O_3 \Rightarrow 3O_2$$

Gases and Particulate Matter Associated with Global Warming and Cooling:

- CO_2 (warming)
- CH_4 (warming)
- N_2O (warming)
- CFC's (warming)
- Soot particles (warming)
- Sulfate particles (cooling)
- Tropospheric ozone (warming)
- Stratospheric ozone (cooling)