Air Quality Issues and Technologies

(Nazaroff & Alvarez-Cohen, Section 7.A)
(Mihelcic & Zimmerman, Chapter 12)

Quality of the air

- Chemicals that humans breathe
  - Toxic, potentially fatal
  - Harmful to lungs
  - Causing cancer
- Chemicals harmful to non-humans
  - Harmful to breathing animals
  - Harmful to vegetation & habitats
  - Impacting water quality
    - Harmful to aquatic life
  - Affecting buildings & monuments
  - Affecting visibility

Climate issues

- Excessive greenhouse gases
  - Global warming
    - Change in precipitation patterns
    - Change in vegetation
    - Rising sea level (thermal expansion)
  - Other climatic changes
    - Melting of sea ice (climate feedback)
    - Melting of land ice (glaciers)
      - Rising sea level (added water)
    - More extreme weather

A distinction

(Mines & Lackey, Section 11.1)

A distinction needs to be made between indoor and outdoor (personal *vs*. ambient) air quality.

In the United States, indoor, personal air quality is mostly regulated by the Occupational Safety & Health Administration (OSHA) whereas outdoor, ambient air quality is the purview of the Environmental Protection Agency (EPA).

Indoor air quality is addressed, in large parts, at the time of building planning via design of heating and ventilation needs. In industrial settings, air quality is also addressed in relation to the equipment used by workers.

Leaving indoor air quality issues to building planners and ventilation mechanical engineers, the air section of this course is (except for the following slide) exclusively concerned with outdoor, ambient air pollution and its preventative treatment.

Indoor Air Pollutants

(Mihelcic & Zimmerman, Section 12.4.3)

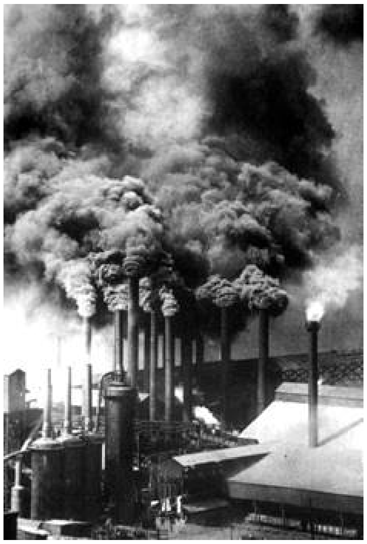
Pollutant	Source	Permissible Exposure Limit	Short-Term Exposure Limit
Carbon monoxide	Stoves, furnaces	50 ppm	400 ppm
Formaldehyde	Carpets, particle board, finishes	0.75 ppm	2 ppm
Particulate Matter	Cooking, carpets, materials processing	5 mg/m^3	
Volatile Organic Compounds (VOCs)	Solvents, cleaning products, personal-care products	Compound specific	
Radon	Diffusion from underground rocks and soil	100 pCi/L	
Ozone	Photocopiers, printers, air-cleaning devices	0.1 ppm	0.3 ppm
Biological agents	Mold, fungi, pets	No exposure	
Tobacco smoke	Cigarettes, cigars, pipes	No exposure	
Asbestos	Wall insulation, floor/ceiling tiles, fireproofing	0.1 $fiber/cm^3$	

Air-quality problems vary with scale

System	Length scale	Time scale	Examples
Indoor environment	10 m	1 hour	Radon in basement Tobacco smoke Airplane cabin air
Industrial plumes	1 km	10 minutes	Toxic organics Mercury and other metals
Urban airshed	10 to 100 km	day-night cycle	Ground-level ozone (smog) Carbon monoxide Particulate matter
Regional / continental	1000 km	several days to a week	Acid deposition
Planetary atmosphere	20,000 km	decades to centuries	Nuclear plant accidents Stratospheric ozone depletion Climate change

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

It used to be worse a century ago…



Sign of prosperity in Pittsburgh in 1906
(*Source*: Carnegie Library of Pittsburgh)

… and still 50 years later …

Riders of a local message delivery company in Los Angeles being outfitted with protective gas masks in the fall of 1955.

At the 1958 Air Pollution Conference,
Dr. James P. Dixon, Health Commissioner of Philadelphia said :

"If gas masks are not to become as common in a hundred years as shoes are today in the civilized world, we should do well to heed our somewhat submerged instincts of self-preservation and remember that – whatever other uses man may devise for it – air is essentially for breathing."

Brief historical review in the United States:

Almost no concern until problems became highly visible and unavoidable.
Initially also, air pollution problems were viewed as local and not a federal matter.

1955: First federal action – Air Pollution Control Act
(funding for research, not control!)

1970: Establishment of the U.S. Environmental Protection Agency (EPA)
(under president Richard Nixon)

1970: Clean Air Act passed by the US Congress

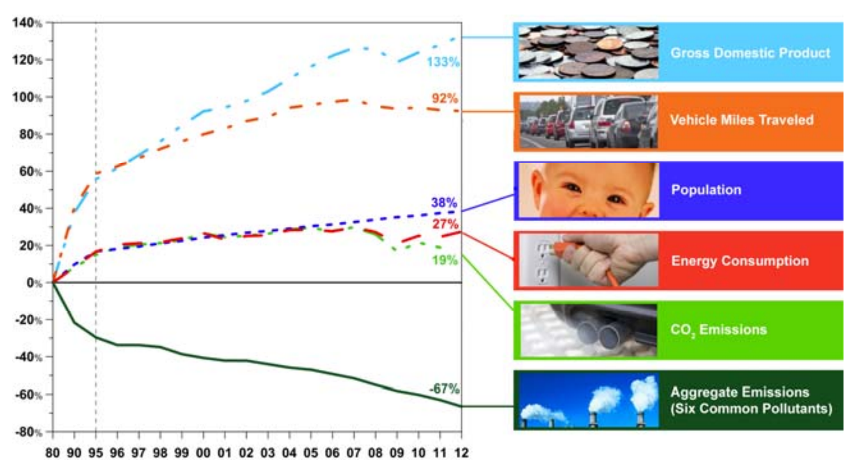
1973-1993: Gradual elimination of lead emission

1980s: Concern over acid rain; regulation of sulfur dioxide
Stratospheric ozone depletion (→ Montreal Protocol in 1989)

1990: Clean Air Act Amendments

1990s to present: Concern over climate change

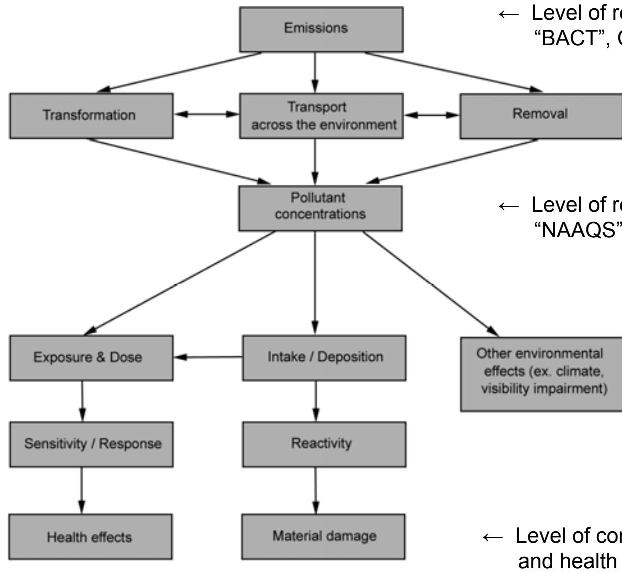
The landmark piece of legislation governing ambient air quality in the U.S. is the **Clean Air Act** (CAA), first enacted in 1970 and subsequently amended several times, with major amendments enacted in 1990.



Great work has been accomplished, especially in the face of a growing population and economy. There is more to be done, however.
For a summary and helpful presentation, see <http://www.epa.gov/oar/caa/>.

Framework for understanding air pollution problems

(Nazaroff & Alvarez-Cohen, Figure 7.A.1, page 390, slightly modified)



← Level of regulations
"BACT", Cap-n-Trade

← Level of regulations
"NAAQS"

← Level of concern
and health studies

The **Clean Air Act** is divided into 9 so-called "Titles", the most important of which deal with either a particular type of problem or source:

Title I – National Ambient Air Quality Standards (NAAQS) for criteria pollutants
Title II – Fuel standards and vehicle tailpipe emissions
Title III – Hazardous air pollutants from specific sources
Title IV – Acid-rain pollution
Title V – Permitting program for stationary sources (ex. power plants)
Title VI – Global issues, such as stratospheric ozone depletion and greenhouse gases
Title VII – Provisions for enforcement
Title VIII – Miscellaneous provisions
Title IX – Clean air research

Terminology:

Primary standards → to protect general population, esp. more vulnerable members
Secondary Standards → to provide public welfare protection (visibility, vegetation, animals) and to protect assets (crops, buildings).

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

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:

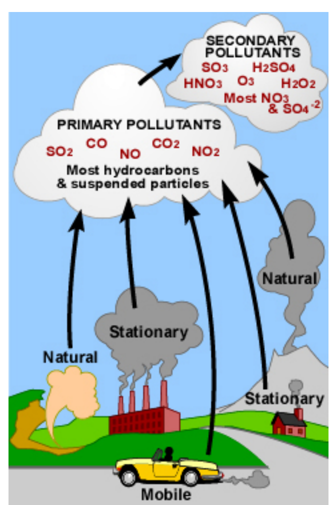
You need to know this list!

- Carbon Monoxide (CO)
- Nitrogen Dioxide (NO_2)
- Ozone (O_3)
- Sulfur Dioxide (SO_2)
- Particulate Matter (PM)
  - subdivision:
    - Respirable particulate matter (PM_{10}) [size ≤ 10 μm]
    - Fine particulate ($PM_{2.5}$) [size ≤ 2.5 μm]
- Lead (Pb)

Distinction: Primary vs. Secondary pollutants
(Nazaroff & Alvarez-Cohen, page 390)

A primary pollutant is one emitted by an identifiable source.

A secondary pollutant is not emitted from a source but formed from precursors through chemical reactions taking place in the atmosphere.



(Formerly found at http://www.epa.gov/apti/course422/ap3.html)

Note:

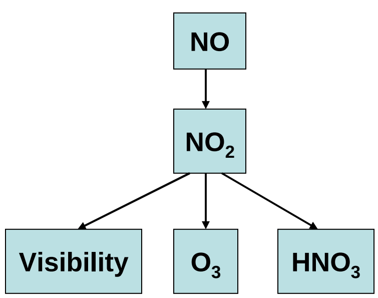
CO_2 is not mentioned here.
It is simply not a pollutant.
It is a greenhouse gas.

Criteria Pollutant	Primary / Secondary	Sources	Effects
CO *Carbon Monoxide*	P	Incomplete combustion	Impairs oxygen-carrying capacity of blood → Asphyxiation & brain damage
NO_2 *Nitrogen Dioxide*	both P and S	From combustion, esp. automobile engines	Respiratory irritant (asthma) Compromised immunity Visibility impairment Acid deposition
O_3 *Ozone*	mostly S	From NO and NO_2	Lung, throat and eye irritant Reduced resistance to infection Damage to vegetation
SO_2 *Sulfur Dioxide*	P	Sulfur in fuels, esp. coal and diesel	Respiratory irritant Heart attack Acid deposition; reduced visibility
PM_{10} and $PM_{2.5}$ *Particulate Matter* (*)	both P and S	Industrial combustion Other industrial activities	Visibility impairment Respiratory impairment
Pb *Lead*	P and S	Industrial processes Lead pipes, solder	Blood poisoning; hypertension Kidney damage; cancer Mental retardation

For added information, see Mihelcic & Zimmerman, pages 531-537.

(*) also going by name of "aerosols"

Problems caused by nitrogen oxides



$$\text{Excitation}: \quad NO_2 + \text{sunlight} \rightarrow NO + O$$
$$\text{Ozone formation}: O + O_2 \rightarrow O_3$$
$$\text{Relaxation}: \quad NO + O_3 \rightarrow NO_2 + O_2$$

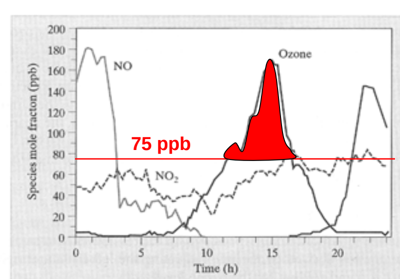
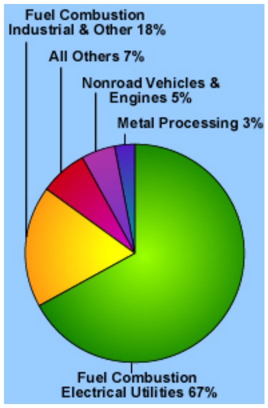
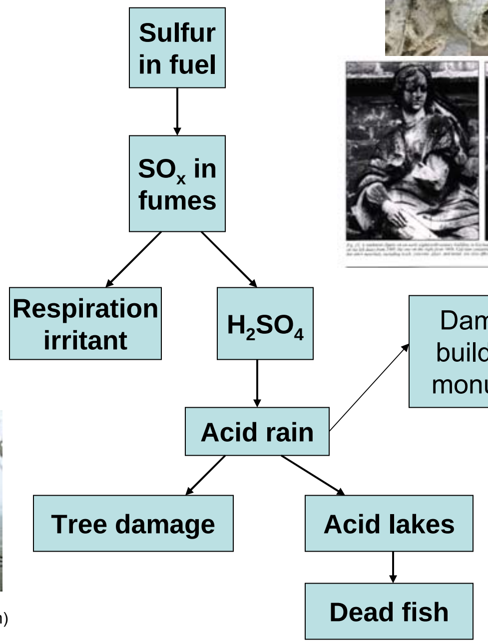


Figure 7.A.4 Ozone, nitric oxide (NO), and nitrogen dioxide (NO_2) mole fractions for a day in the Los Angeles air basin (November 4, 1984). The maximum 8-hour average ozone concentration is 97 ppb, which exceeds the 80 ppb standard. Time 0 corresponds to midnight.

Sources of and problems caused by sulfur oxides

Sources of sulfur oxides according to the EPA

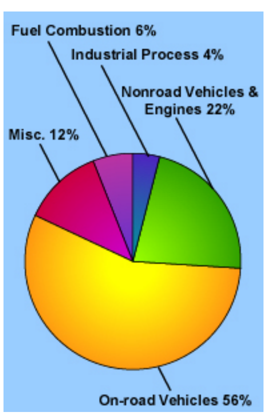




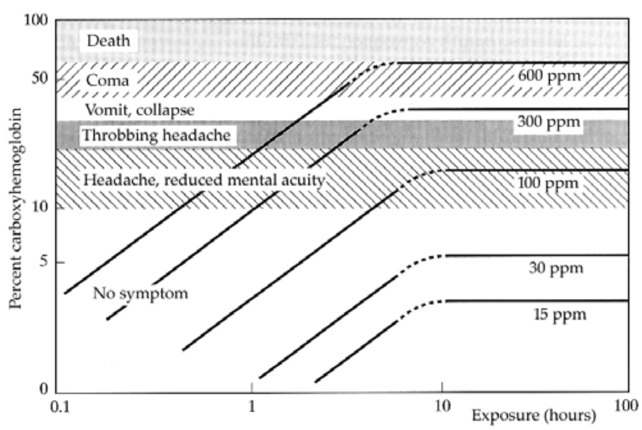
(http://www.merritton.ca/acid55.jpg)

(http://www.robl.w1.com/Pix/I-900991.htm)

Carbon monoxide



Sources of carbon monoxide (CO) according to the EPA



Effects of exposure to carbon monoxide (From Seinfeld, 1986; Masters, 1998)

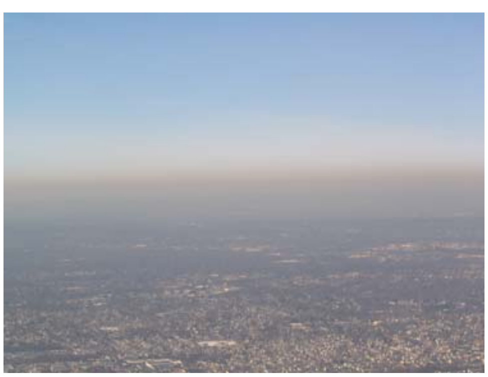
The EPA has set National Ambient Air Quality Standards (NAAQS) for these six criteria pollutants.

Pollutant	Standard	Type
Carbon monoxide (**CO**)		
8-hour average	9 ppm (10 mg/m^3)	Primary
1-hour average	35 ppm (40 mg/m^3)	Primary
Nitrogen dioxide (**NO_2**)		
annual average	53 ppb (100 μg/m^3)	Primary & Secondary
1-hour average	100 ppb	Primary
Ozone (**O_3**)		
8-hour average	75 ppb (157 μg/m^3)	Primary & Secondary
Particulate Matter ≤ 10 μm (**PM_{10}**)		
24-hour average	150 μg/m^3	Primary & Secondary
Particulate Matter ≤ 2.5 μm (**$PM_{2.5}$**)		
annual average	15 μg/m^3	Primary & Secondary
24-hour average	35 μg/m^3	Primary & Secondary
Sulfur dioxide (**SO_2**)		
3-hour average	0.5 ppm	Secondary
1-hour average	75 ppb	Primary
Lead (**Pb**)		
rolling 3-month average	0.15 μg/m^3	Primary & Secondary

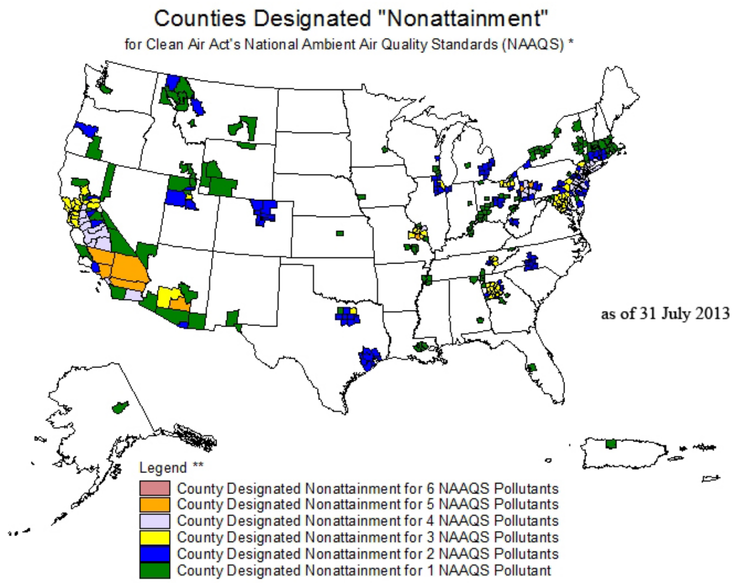
http://www.epa.gov/air/criteria.html

In some U.S. cities…

Los Angeles, CA



Newark, NJ



(*Source*: http://www.epa.gov/oaqps001/greenbk/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.

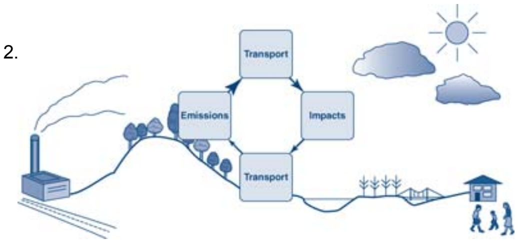
Examples of air toxic pollutants include *benzene* (from gasoline), *mercury* (from coal combustion and fluorescent lamps), *perchloroethylene* (from dry cleaning facilities), *methylene chloride* (a solvent used in industry).

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 ControlTechnology* (BACT)
   - Incentives (cap-n-trade of emissions)

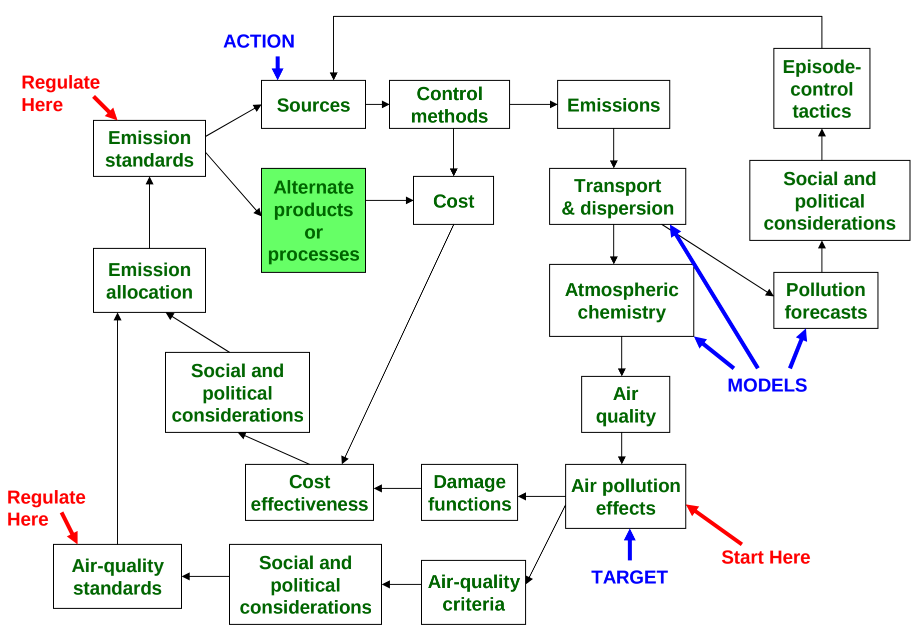
2. Control of ambient concentrations: **Six criteria pollutants**
   - *National Ambient Air Quality Standards* (NAAQS)

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)

Components of an Air-Pollution Management System



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 kg CO/ 1,000 L fuel

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

Correction

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

Rule

$$E = A \times EF \times (1 - \eta)$$

Emission factors for common fuels

Fuel type	Bituminous coal (pulverized) (1.8% sulfur)	Diesel oil (#6 'residual') (2% sulfur)	Natural gas
Heating value:	24.2 kJ/g	41.7 MJ/L	38.3 MJ/m^3
Emission factors:			
Particulates	31 kg/ton	2.9 kg/m^3	16-80 kg/10^6 m^3
SO_2	35 kg/ton	38 kg/m^3	9.6 kg/10^6 m^3
NO_x	10.5 kg/ton	8 kg/m^3	8800 kg/10^6 m^3
CO	0.3 kg/ton	0.6 kg/m^3	640 kg/10^6 m^3
Non-methane organics	0.04 kg/ton	0.09 kg/m^3	23 kg/10^6 m^3
Methane	0.015 kg/ton	0.03 kg/m^3	4.8 kg/10^6 m^3

(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 SO_2 from combustion.

How much SO_2 does the plant release per day when it generates 350 MW of electricity?

<u>Answer</u>

Activity = A = (350 MW) x (12 tons coal / day • MW) = 4,200 tons coal / day

Emission Factor = EF = 35 kg SO_2 / ton of coal (from preceding table)

Emission-control efficiency = η = 95% = 0.95

Emission = E = A x EF x (1 – η)
= (4,200 tons coal / day) x (35 kg SO_2 / ton coal) x (1 – 0.95)
= 7,350 kg SO_2 /day

Best Available Control Technology (BACT)

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

Particulates: Cyclone
Electrostatic precipitator

Stationary combustion fumes (incl. SO_2): Wet scrubber

Mobile exhaust: Catalytic converter

Figure 1. Top-Inlet Large-Diameter Cyclone

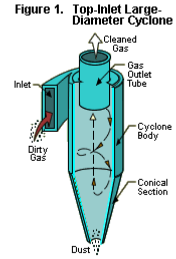


Figure 9. Conventional Electrostatic Precipitator

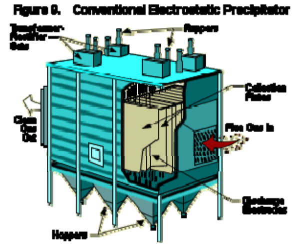
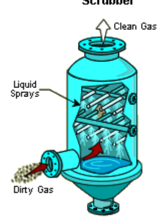
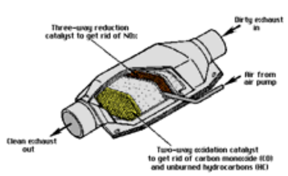


Figure 6. Spray Tower Scrubber





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

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