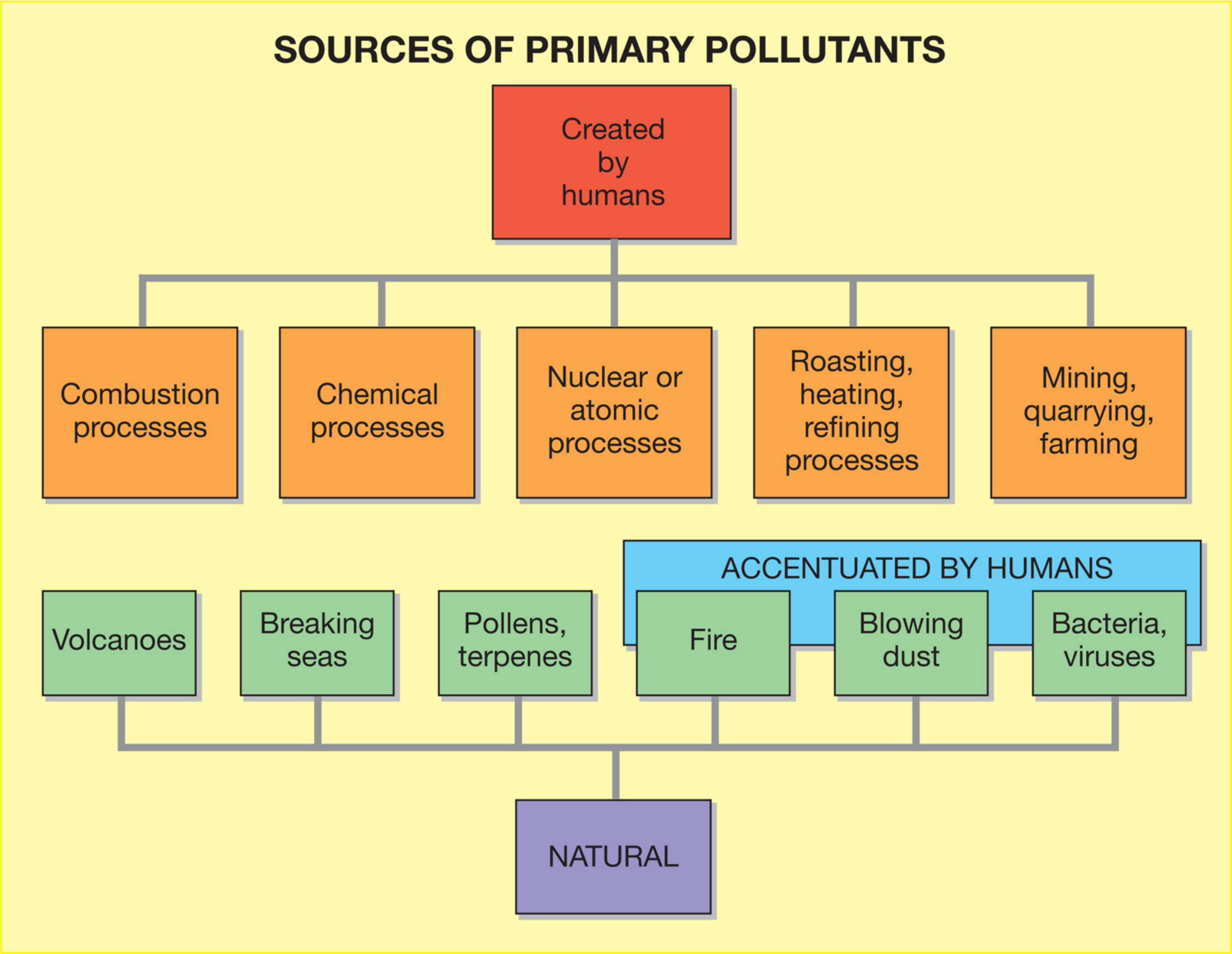
Air Pollution

Kuala Lumpur

Beijing, China, 2008

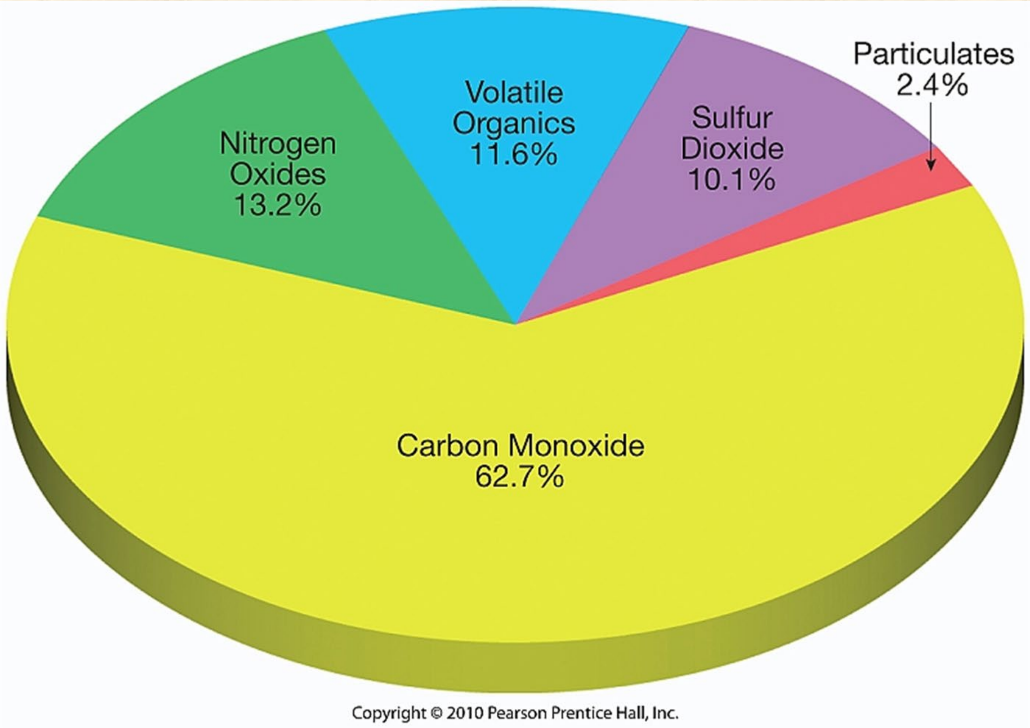
Sources & Types of Air Pollution

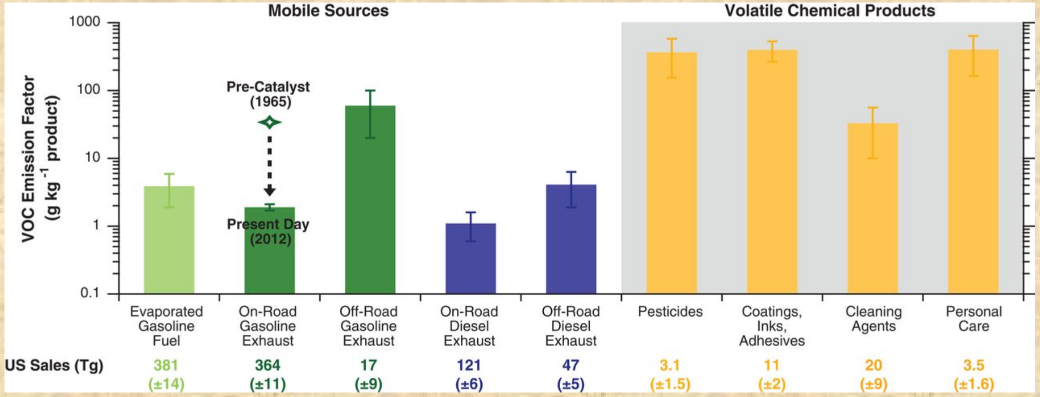
- ***Air pollutants are*** airborne particles and gases that occur in concentrations that endanger the health and well-being of organisms, or disrupt the orderly functioning of the environment
- Pollution is divided into two categories
  1. Primary
  2. Secondary
- ***Aerosols are*** solid or liquid particulates between 0.1 and 100 µm in size.
- ***Primary Pollutants*** are emitted directly from identifiable sources.
- They pollute the air immediately when they are emitted
- ***Secondary Pollutants*** are produced in the atmosphere when certain chemical reactions take place among primary pollutants, and with natural air & water. e.g. smog
- Secondary pollutants have more severe effects on humans than primary pollutants


SOURCES OF PRIMARY POLLUTANTS
Created by humans
Combustion processes
Chemical processes
Nuclear or atomic processes
Roasting, heating, refining processes
Mining, quarrying, farming
ACCENTUATED BY HUMANS
Volcanoes
Breaking seas
Pollens, terpenes
Fire
Blowing dust
Bacteria, viruses
NATURAL

Primary Pollutants

1. Particulates
2. Sulfur oxides
3. Nitrogen oxides (NOx)
4. Volatile organic compounds (VOC)
5. Carbon monoxide
6. Lead





Primary Pollutants

Where do they come from:

1. Transportation
2. Stationary source fuel combustion
3. Industrial processes
4. Solid waste disposal
5. Miscellaneous

Primary Air Pollutants

Pollutant	Description	Primary Sources	Effects
Carbon monoxide (CO)	CO is an odorless, colorless, poisonous gas. It is produced by the incomplete burning of fossil fuels.	Sources of CO are cars, trucks, buses, small engines, and some industrial processes.	CO interferes with the blood's ability to carry oxygen, slowing reflexes and causing drowsiness. In high concentrations, CO can cause death.
Nitrogen oxides (NO_x)	When combustion (burning) temperatures exceed 538°C, nitrogen and oxygen combine to form nitrogen oxides.	NO_x comes from burning fuels in vehicles, power plants, and industrial boilers.	NO_x can make the body vulnerable to respiratory infections, lung diseases, and cancer. NO_x contributes to the brownish haze seen over cities and to acid precipitation.
Sulfur dioxide (SO_2)	SO_2 is produced by chemical interactions between sulfur and oxygen.	SO_2 comes mostly from burning fossil fuels.	SO_2 contributes to acid precipitation as sulfuric acid. Secondary pollutants that result from reactions with SO_2 can harm plant life and irritate the respiratory systems of humans.
Volatile organic compounds (VOCs)	VOCs are organic chemicals that vaporize readily and form toxic fumes.	VOCs come from burning fuels. Vehicles are a major source of VOCs.	VOCs contribute to smog formation and can cause serious health problems, such as cancer. They may also harm plants.
Particulate matter (particulates or PM)	Particulates are tiny particles of liquid or solid matter.	Most particulates come from construction, agriculture, forestry, and fires. Vehicles and industrial processes also contribute particulates.	Particulates can form clouds that reduce visibility and cause a variety of respiratory problems. Particulates have also been linked to cancer. They may also corrode metals and erode buildings and sculptures.

Particulate Matter (PM)

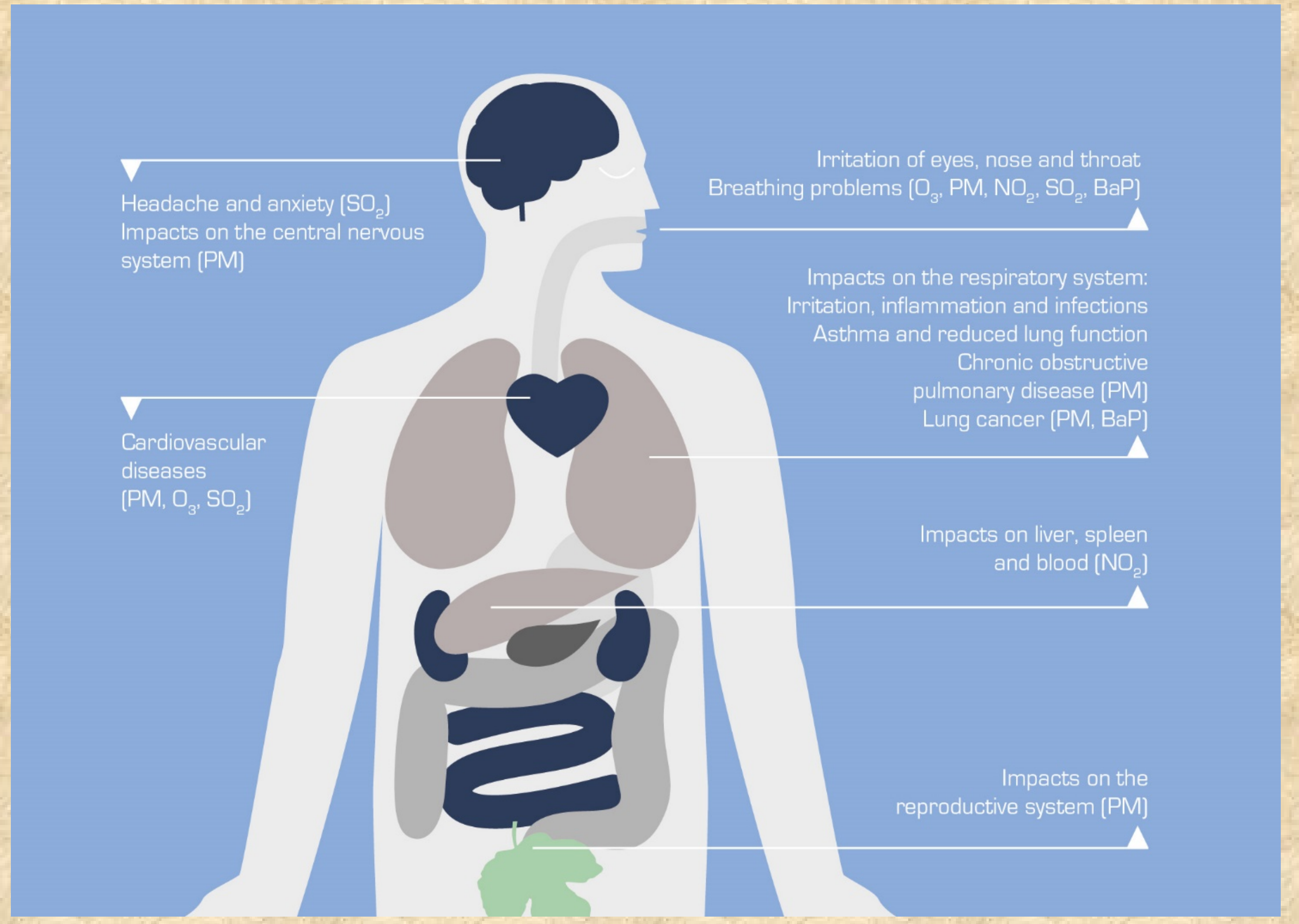
- Mixture of solid particles and liquid droplets found in the air
- Particulates reduce visibility. Leave deposits of dirt on surfaces, and may carry other pollutants dissolved in or on them
- Some are visible to the naked eye, some are not - frequently the most obvious form of air pollution
- Sizes range from fine (<2.5 micrometers in diameter) to coarse (>2.5 micrometers)
- ***Fine particles*** (PM2.5) result from fuel combustion (motor vehicles, power generation, industrial facilities, residential fireplaces & wood stoves)
- ***Coarse particles*** (PM10) result from things such as vehicles travelling on unpaved roads, materials handling, grinding & crushing & wind-blown dust
- EPA standards are defined for PM2.5 and PM10

Particulate Matter

- ***Inhalable particular matter*** includes both coarse & fine particles
- Coarse particles lead to diseases like asthma
- Fine particles are associated with heart & lung diseases, decreased lung function, premature death.
- Sensitive groups include elderly people with cardiopulmonary disease (e.g. asthma) and children.

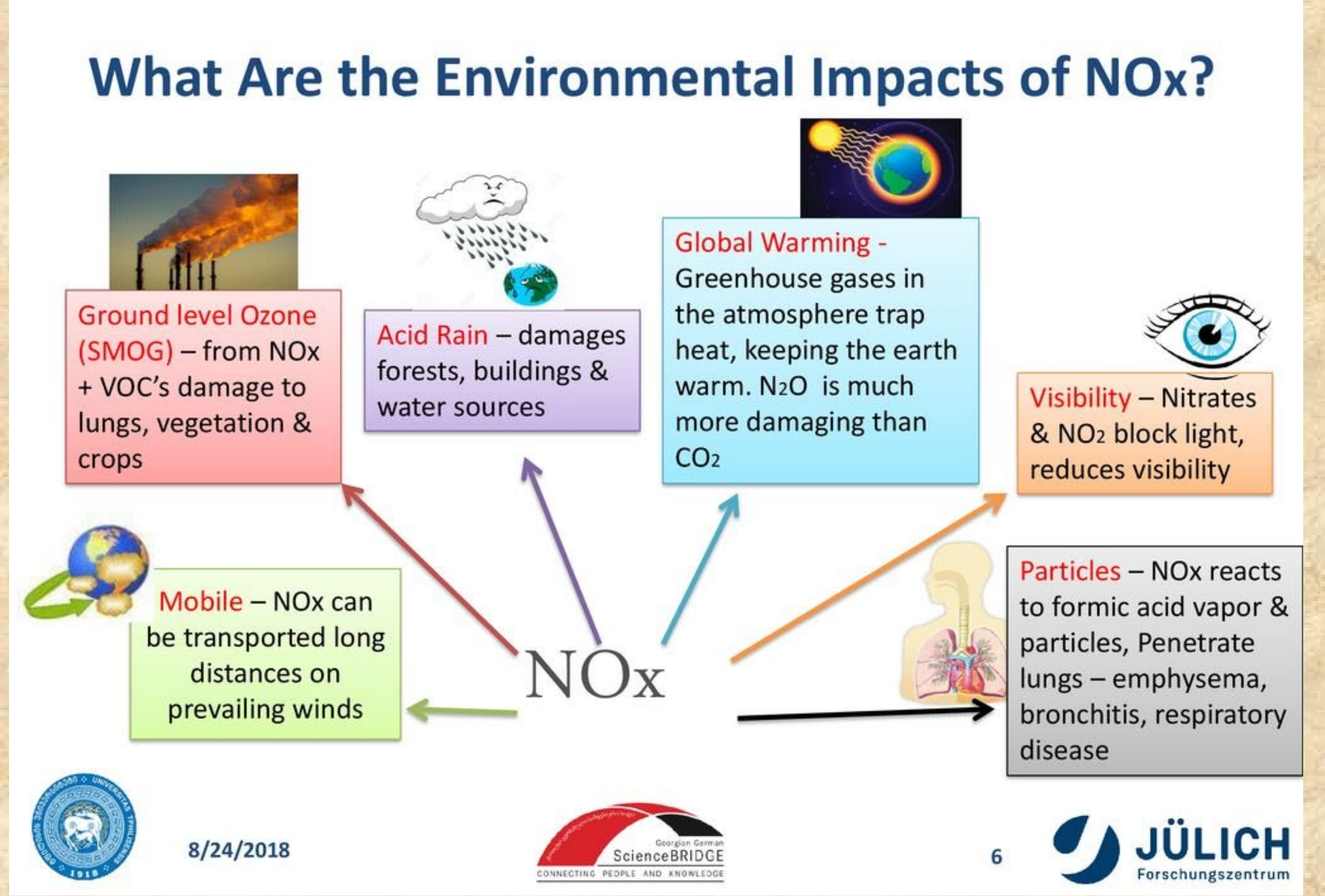
Sulfur Dioxide

- SO_2 is a colorless and corrosive gas that ***originates*** from the combustion of material containing sulfur, e.g., coal and oil.
- Acrid and poisonous.
- Frequently transformed into SO_3. Add water (H_2O), get H_2SO_4 - sulfuric acid
- Leads to acid precipitation (acid rain)



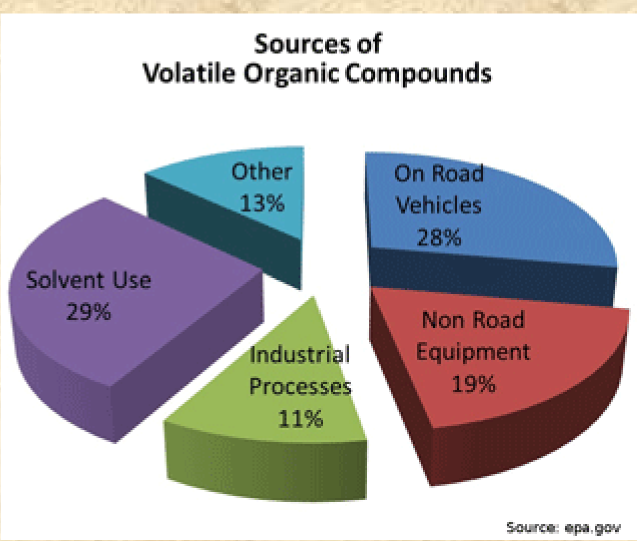
Nitrogen Oxides (NOx)

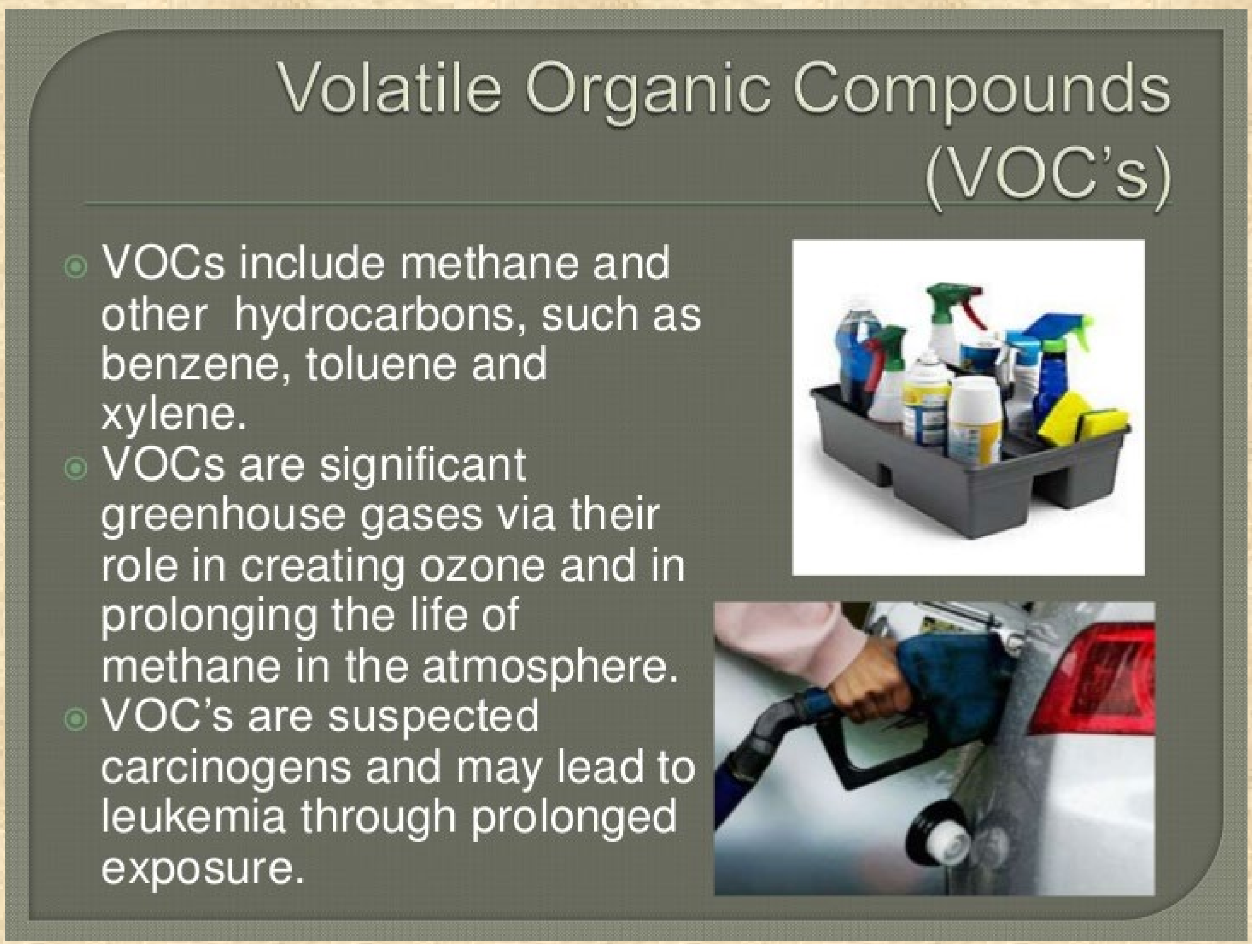
- ***Form*** during the high-temperature combustion of fuel, when nitrogen in the fuel reacts with oxygen.
- ***Primary sources*** are power plants and motor vehicles
  - N + O -> NO + O -> NO_2
  - NO_2 is a reddish-brown gas
  - NOx occur naturally, but in much lower concentrations



Volatile Organic Compounds (VOC)

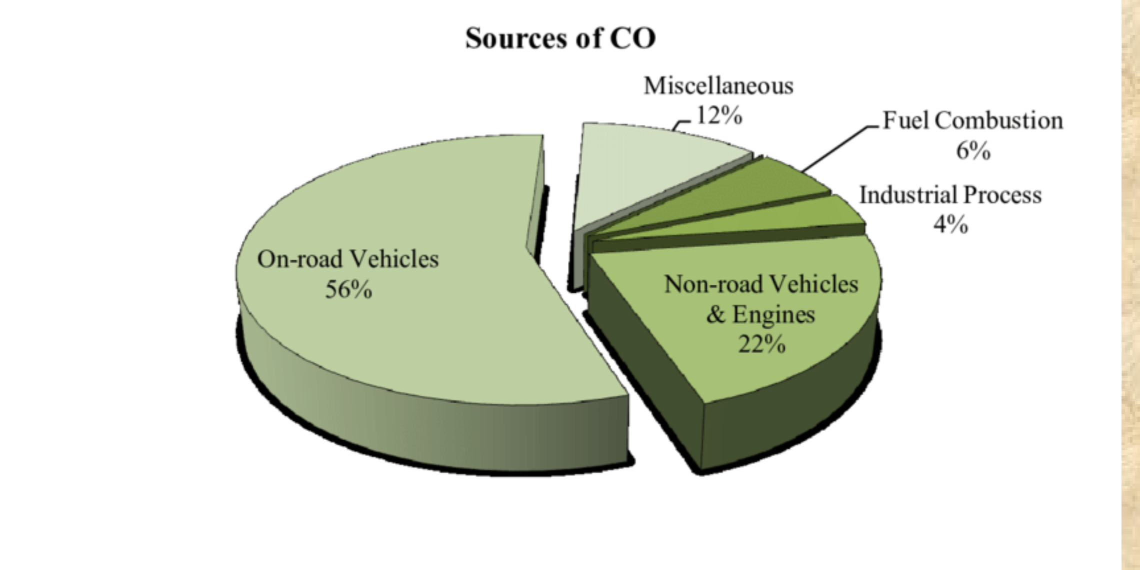
- These are hydrocarbons - hydrogen + carbon
- Can be solid, liquid or gas
- Most abundant is methane (CH_4, greenhouse gas)
- VOCs are important in themselves, but also lead to noxious secondary pollutants

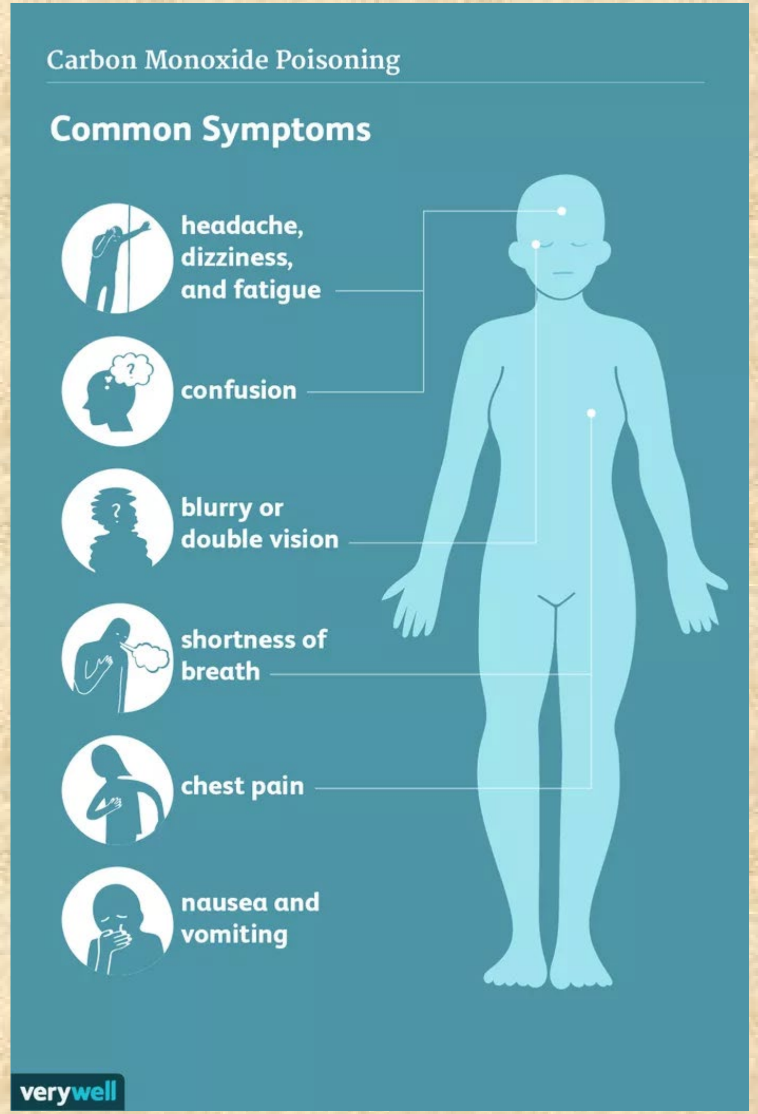




Carbon Monoxide

- CO - colorless, tasteless, odorless and poisonous
- Formed by incomplete combustion of carbon
- The most abundant primary pollutant, caused mostly be transportation industry
- CO enters the blood stream via the lungs, and reduces oxygen delivery to the body's organs and tissues
- Hazardous in high concentrations - e.g. underground parking stations.





Secondary Pollutants

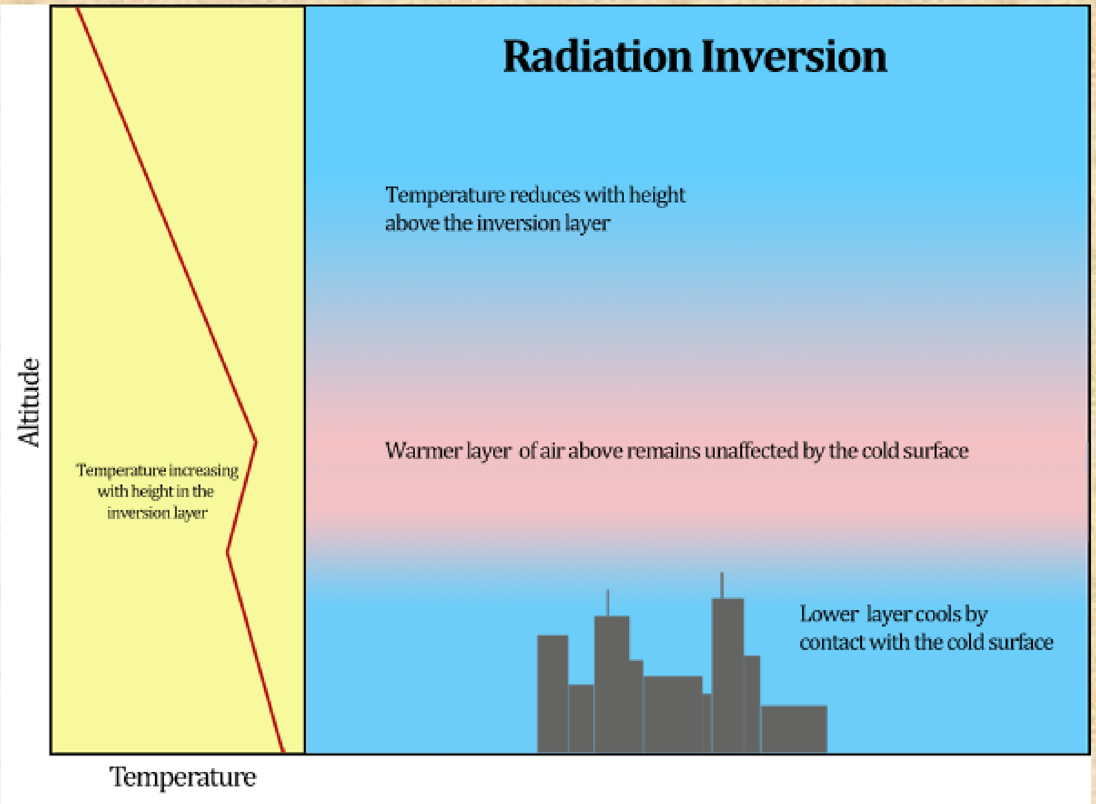
- ***Formed*** by reactions among primary pollutants, and with H_2O and O_2 of the air
- For example, $SO_2 + O \rightarrow SO_3$
- Smog = SMoke + fOG
- Nowadays, used as a general term for air pollution
- Term is usually qualified by a location where that type of smog is/was common, or by descriptions of the cause.
- e.g., London fog; photochemical smog.
- ***Photochemical*** reactions - sunlight reacts with primary pollution, causing a chemical reaction.
- Occur during the day, maximizing in the summer - depends on sun angle.
- ***Photochemical smog*** is a noxious mixture of gases and particles - very reactive, irritating and toxic.

Types of Smog

Characteristic	Classical	Photochemical
First occurrence noted	London	Los Angeles
Principal pollutants	So_x, particulates	O_3, No_x, HC, CO, free radicals
Principal sources	Industrial and household fuel combustion (coal, petroleum)	Motor vehicle fuel combustion (petroleum)
Effects on humans	Lung & throat irritation	Respiratory dysfunction
Effects on compounds	Reducing	Oxidizing
Time of occurrence of worst episodes	Winter months (early mornings)	Summer months (mid-day)

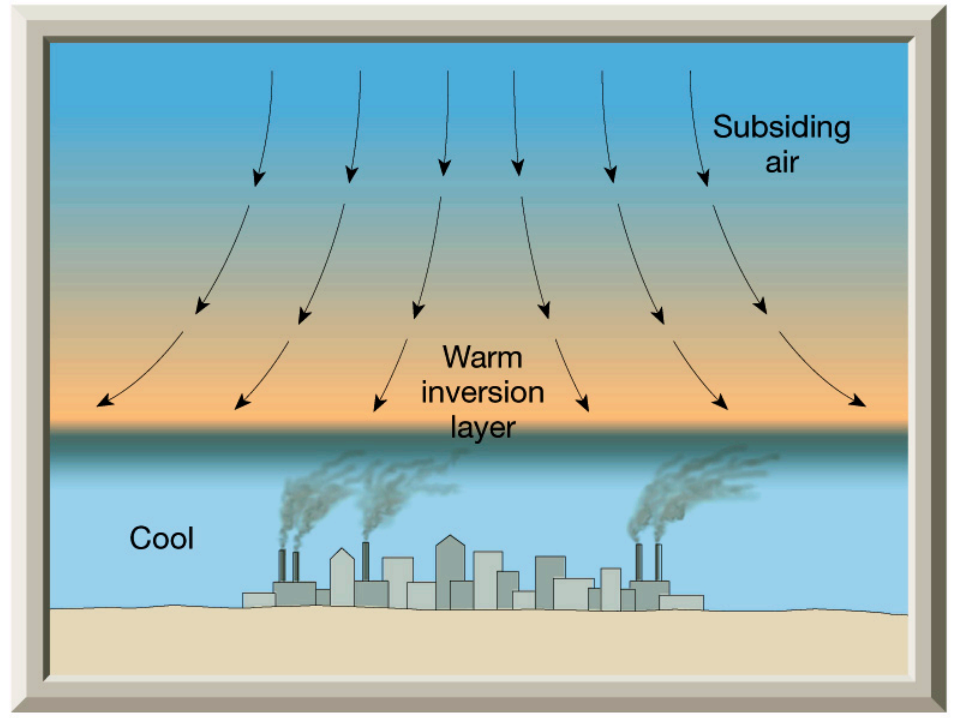
Surface Temperature Inversions

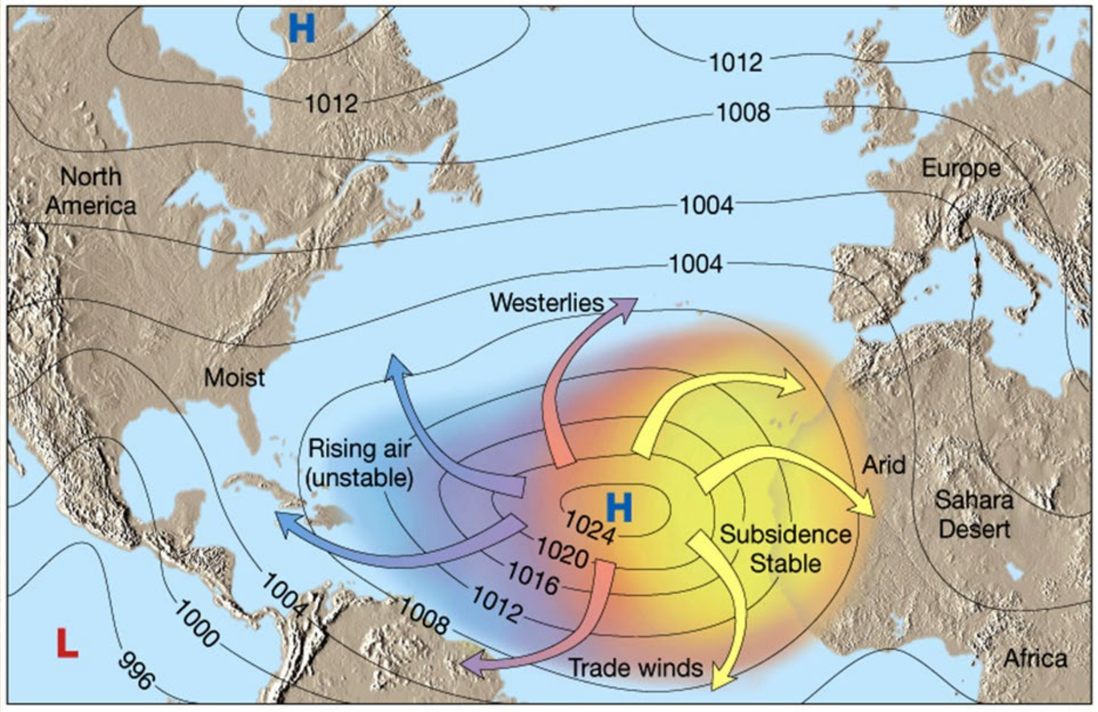
- The temperature usually decreases as the altitude decreases.
- In an inversion, the air at some altitude becomes warmer than on the ground, so the surface air will not rise up through it.



Inversions Aloft

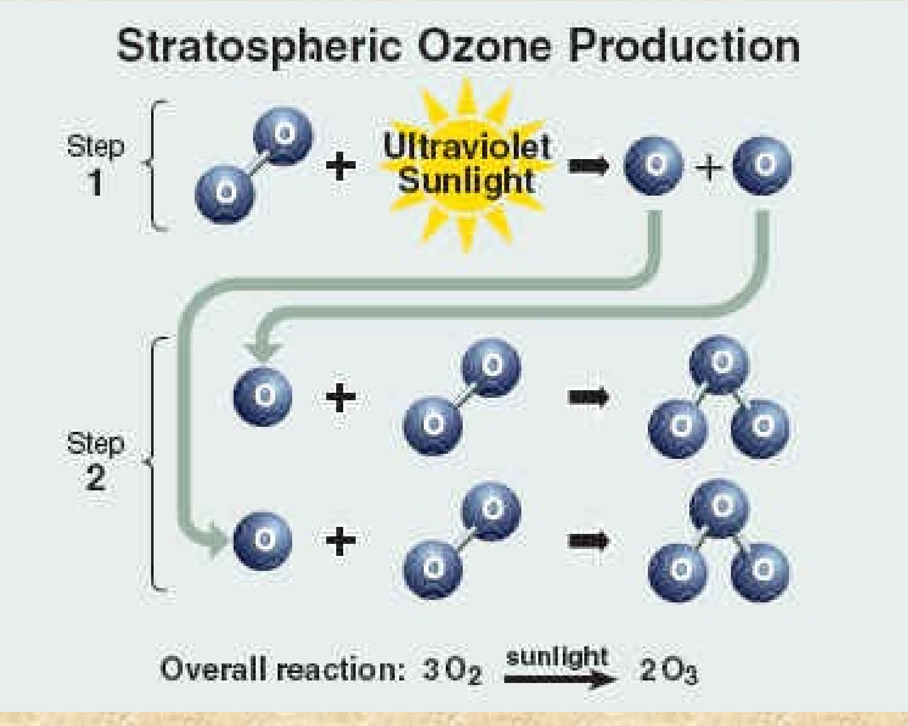
- These are associated with descending air in anticyclones.
- As the air descends, it is compressed, and therefore warms
- Work is done compressing the air. ***Some*** of this work is converted to heat. (First Law of Thermodynamics)
- Turbulence near the surface prevents the descending air from reaching the surface, so we get a warm inversion layer

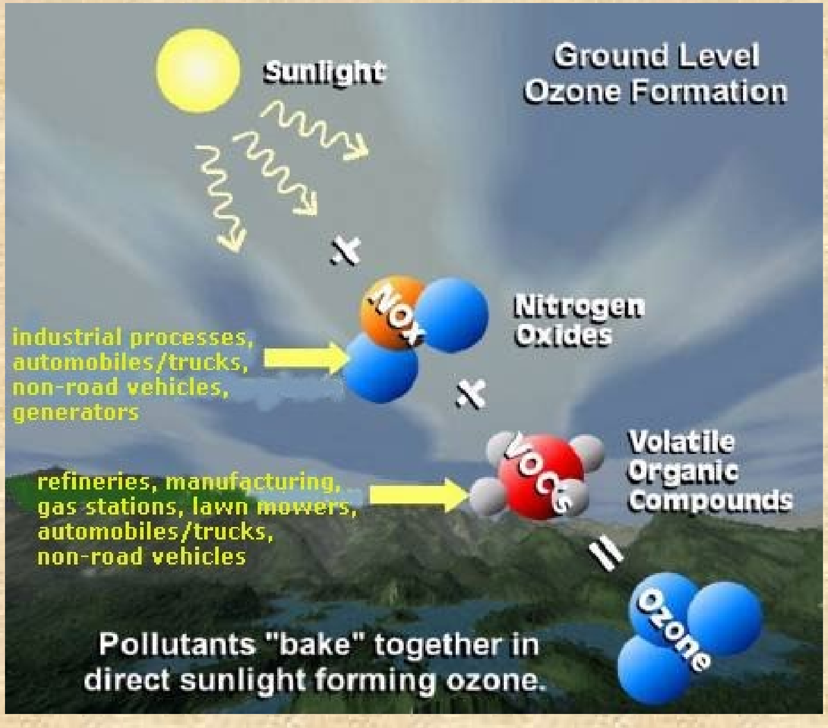




Ozone - Good or Bad?

- Major component of photochemical smog is ozone.
- ***Ozone*** causes eye and lung irritation, lowers crop yields, damages material such as rubber etc.
- Ozone in the upper atmosphere is a good thing (protects us from solar UV)
- Ozone at ground level is a bad thing





Clean Air Act of 1990

1. Tighter controls on air quality
2. Lower acceptable limits on auto emissions
3. Greater restraints on the use of indoor pollutants
4. Reduction of acid rain
5. Limits on and then abolishment of the use of CFCs and other ozone-depleting compounds
6. Data collection on greenhouse gases and anything that contributes to long-term climate change

Trends in Air Quality

- Solution is education, and then action
- Regulations - Clean Air Act of 1970, National Ambient Air Quality Standards
- Acceptable levels are set by what a human being can tolerate without noticeable ill effects - minus 10 to 50% margin of safety

Short-term and long-term levels are set for some contaminants

1. *Acute* - life-threatening within a few days or hours
2. *Chronic* - effects are additive over a period of years

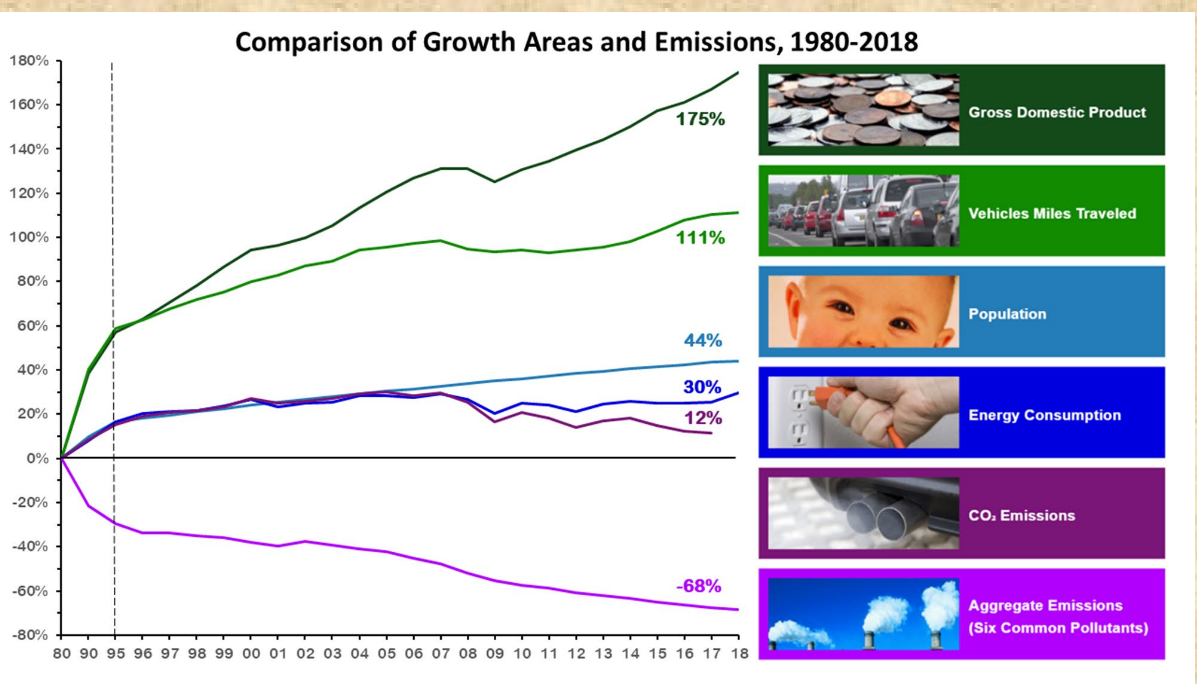
United States Environmental Protection Agency

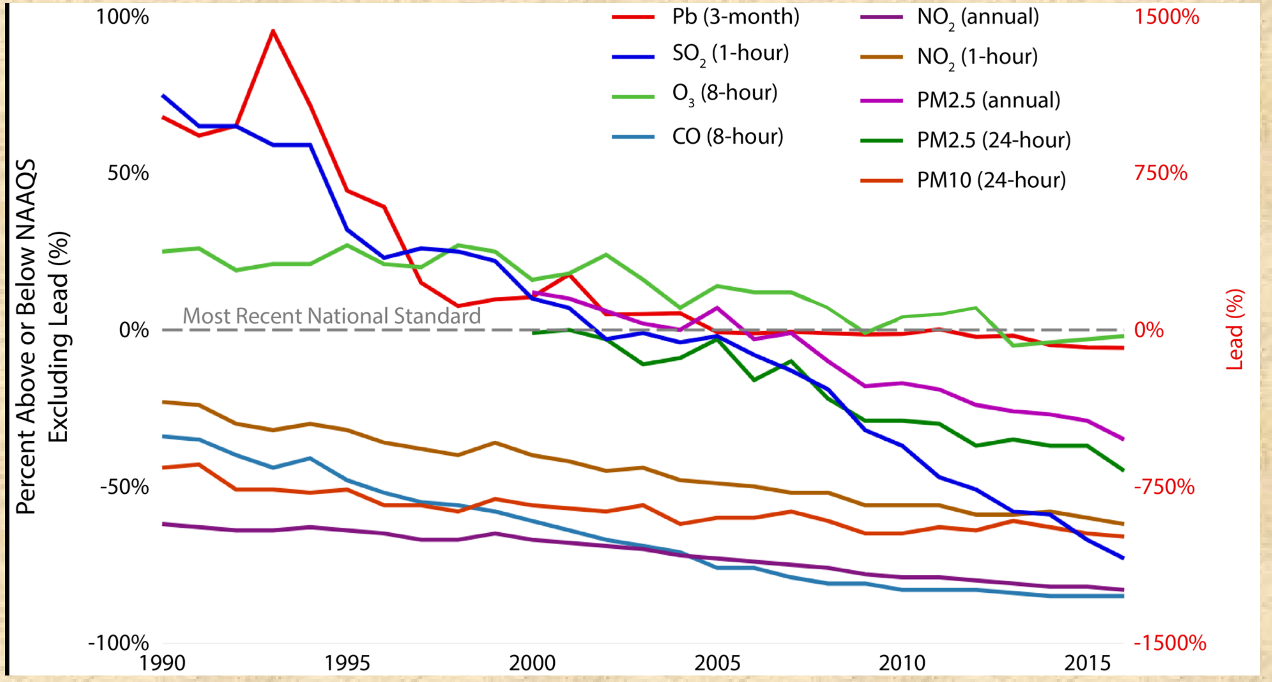
Office of Air Quality Planning and Standards

National Ambient Air Quality Standards

Pollutant	Primary Standards	Averaging Time	Secondary Standards	
Carbon Monoxide	9 ppm (10 mg/m^3)	8-hour	None	
	35 ppm (40 mg/m^3)	1-hour		
Lead	0.15 µg/m^3	Rolling 3-Month Average	Same as Primary	
Nitrogen Dioxide	53 ppb	Annual (Arithmetic Average)	Same as Primary	
	100 ppb	1-hour	None	
Particulate Matter (PM_{10})	150 µg/m^3	24-hour	Same as Primary	
Particulate Matter ($PM_{2.5}$)	15.0 µg/m^3	Annual (Arithmetic Average)	Same as Primary	
	35 µg/m^3	24-hour	Same as Primary	
Ozone	0.075 ppm (2008 std)	8-hour	Same as Primary	
	0.08 ppm (1997 std)	8-hour	Same as Primary	
Sulfur Dioxide	0.03 ppm	Annual (Arithmetic Average)	0.5 ppm	3-hour
	0.14 ppm	24-hour		
	75 ppb	1-hour	None	

Trends in Air Quality





Meteorological Factors Affecting Air Quality

- The solution to pollution is dilution - disperse the contaminants
- Spread the contaminants around, keeping the levels below the toxic levels. (This cannot work forever.)
- Meteorological Factors affecting ***Dispersion***
  1. The strength of the wind
  2. The stability of the air

Meteorological Aspects

Processes that cause air to rise and pollutants to disperse

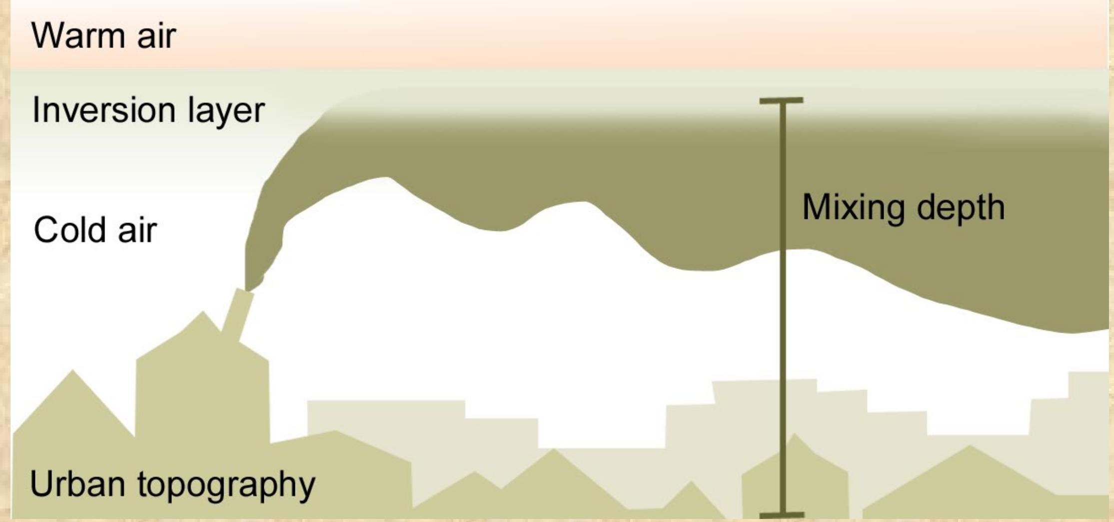
- Convective air flow due to heating of earth's surface
- Orographic ascent
- Air mass lifting due to advection

Turbulence dilutes pollutants by mixing with surrounding air. Types of turbulence –

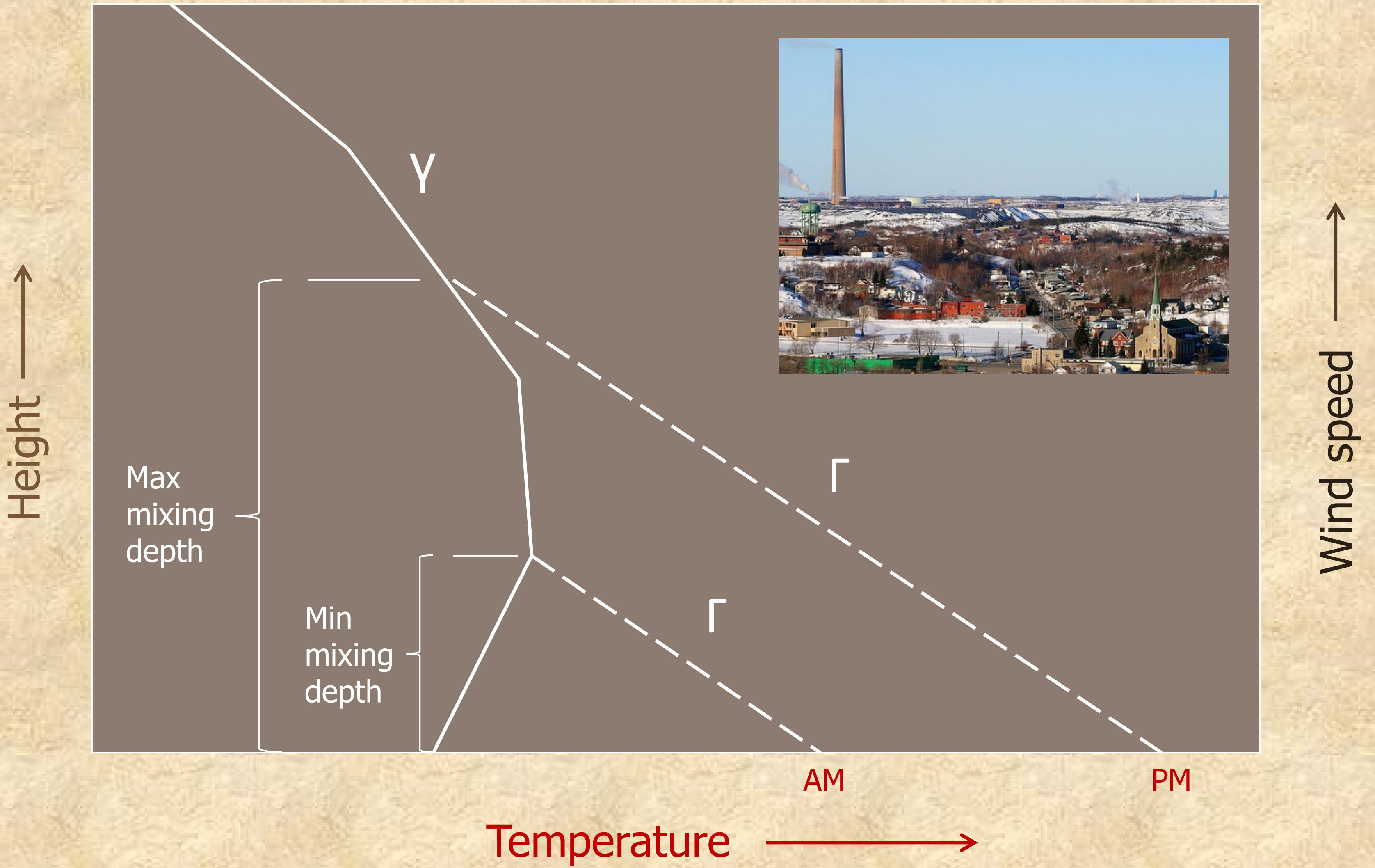
- Mechanical - due to air passing over a rough surface
- Thermal – thermal heating and convectional air flow
- Strong winds blow the pollution away (to someone else's backyard)
- The stronger the wind, the more turbulent the air and the better the mixing of the contaminants with the wind.

Atmospheric Stability

- Atmospheric stability determines the extent to which vertical motions will mix the pollution with the air above (most pollution occurs at the surface)
- The vertical extent to which convection causes mixing is called the ***mixing depth***.
- Greater mixing depths lead to less air pollution.
- Need a mixing depth of several km. Mixing depths are greatest in the afternoon in Summer.
- If the air is stable, convection is limited, and the mixing depths are small.
- Stable air is often associated with a high pressure region (mid-latitude anti-cyclone)
- Temperature inversions will trap the pollution.



Forecasting Air Pollution Potential (FAPP)



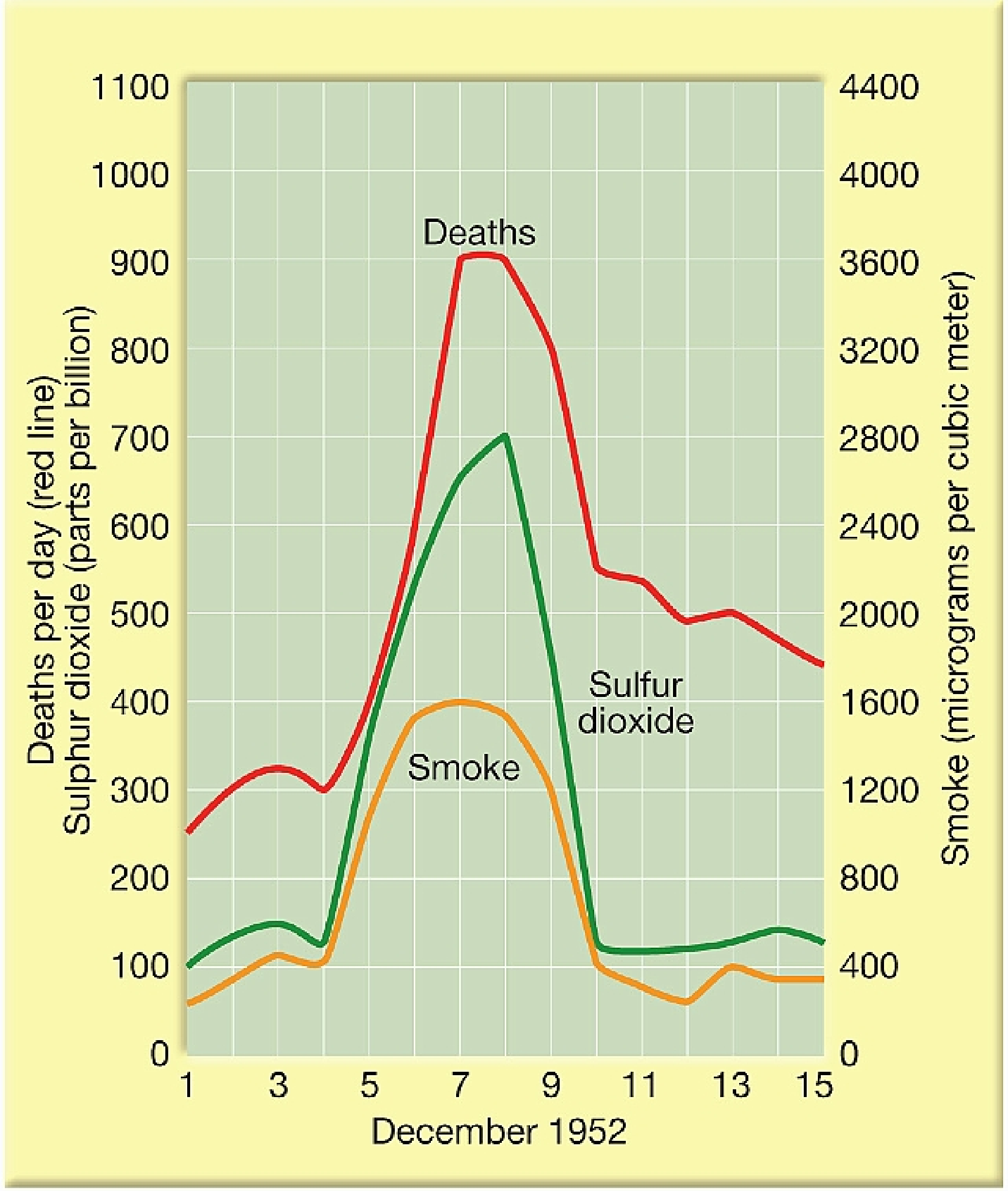
Rate of ventilation = depth of mixing layer x average wind speed mixing layer

Health Aspects of Air Pollution – Air Pollution Episodes

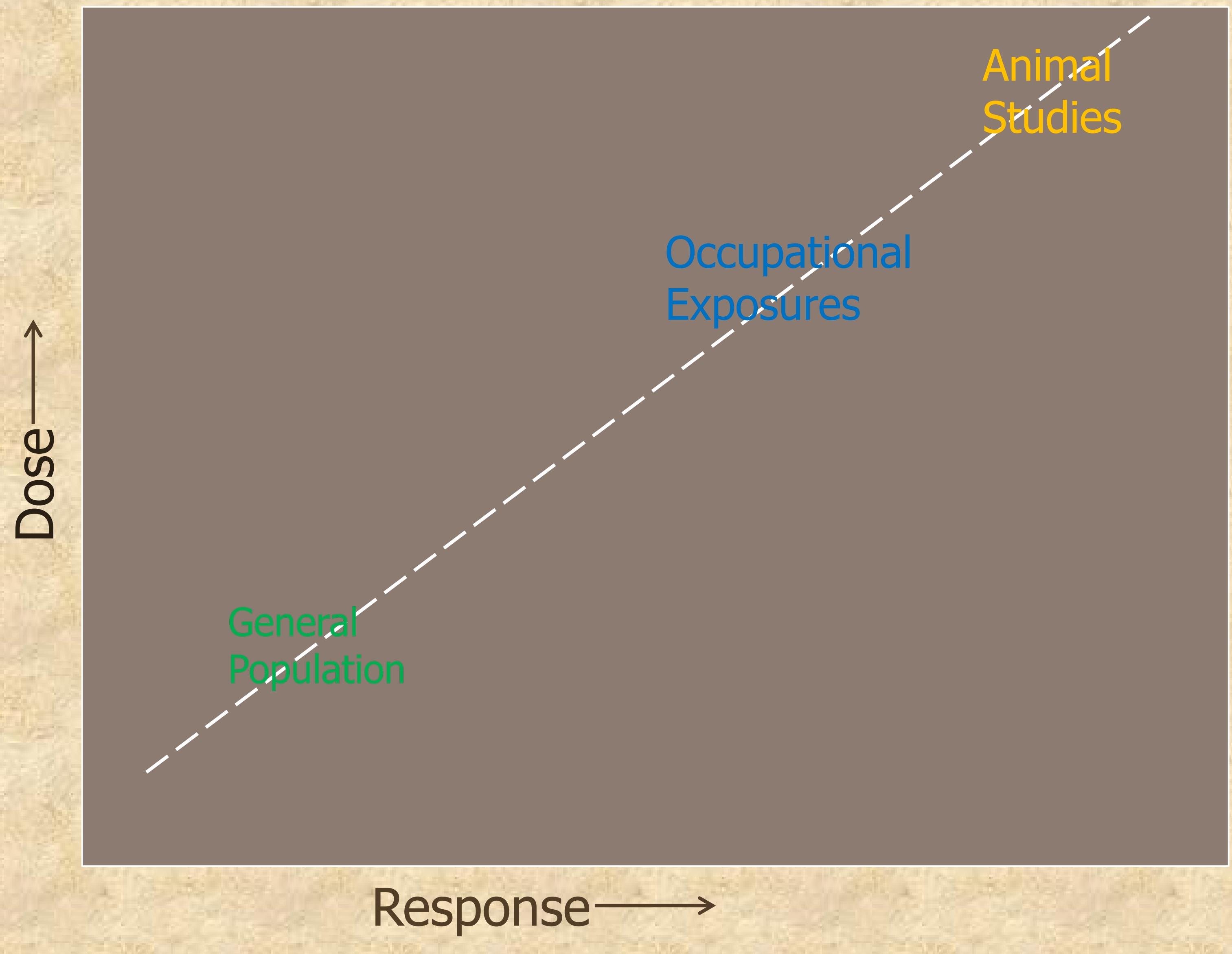
Date	Place	Excess Deaths	Cause
Feb 1930	Meuse Valley, Belgium	63	Inversion, SO_2
Oct 1948	Donora, PA	20	Inversion (valley), SO_2
Dec 1952	London	4,000	Subsidence inversion, SO_2 + particulates
Nov 1953	New York	250	Inversion, high SO_2
Jan 1956	London	1,000	Subsidence inversion, SO_2 + particulates
Jan 1957	London	800	Subsidence inversion, SO_2 + particulates
Jan 1962	London	700	Subsidence inversion, SO_2 + particulates
Jan 1963	New York	400	Inversion, high SO_2
Nov 1966	New York	168	Inversion, high SO_2

London 1952

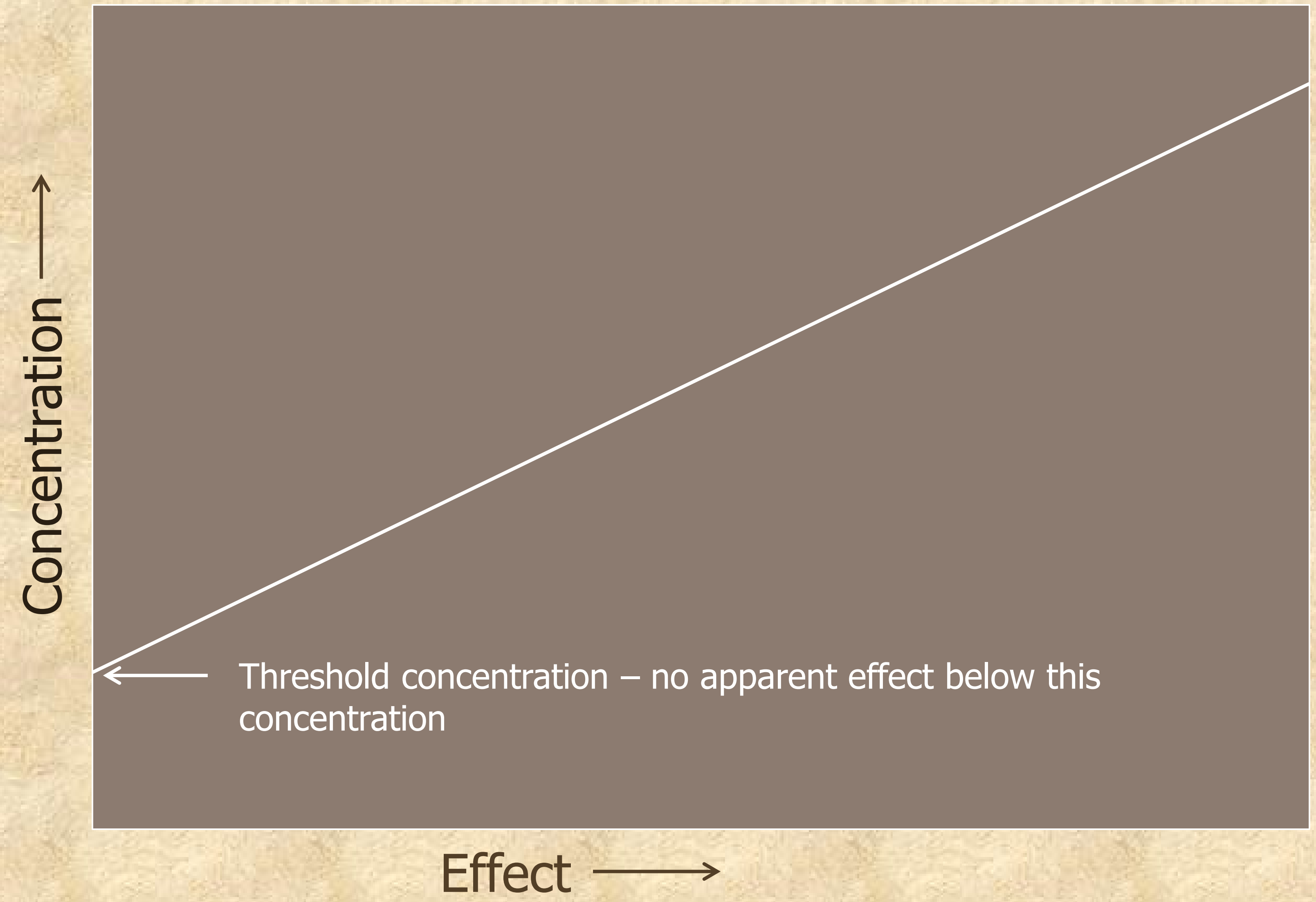

COPE'S
Great New
SHORT STORIES
EVENING
NEWS
Chronicle


Deaths per day (red line)
Sulphur dioxide (parts per billion)
Smoke (micrograms per cubic meter)
December 1952
Deaths
Sulfur dioxide
Smoke
0
100
200
300
400
500
600
700
800
900
1000
1100
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
4400
1
3
5
7
9
11
13
15

Determining "Cause and Effect"

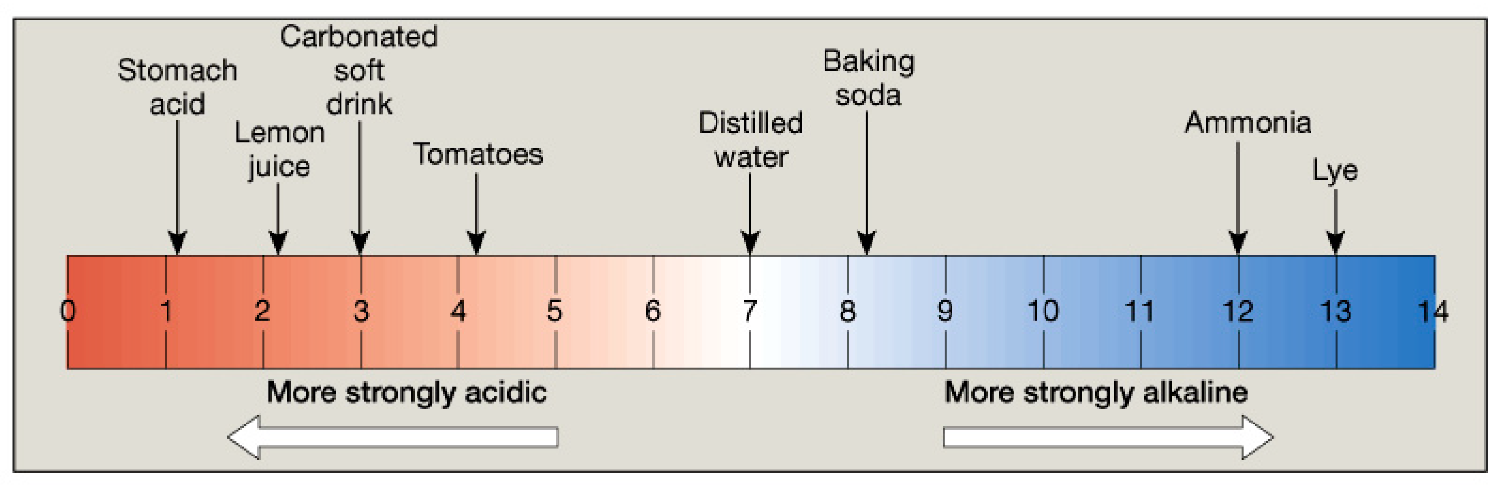


The “Threshold” concept

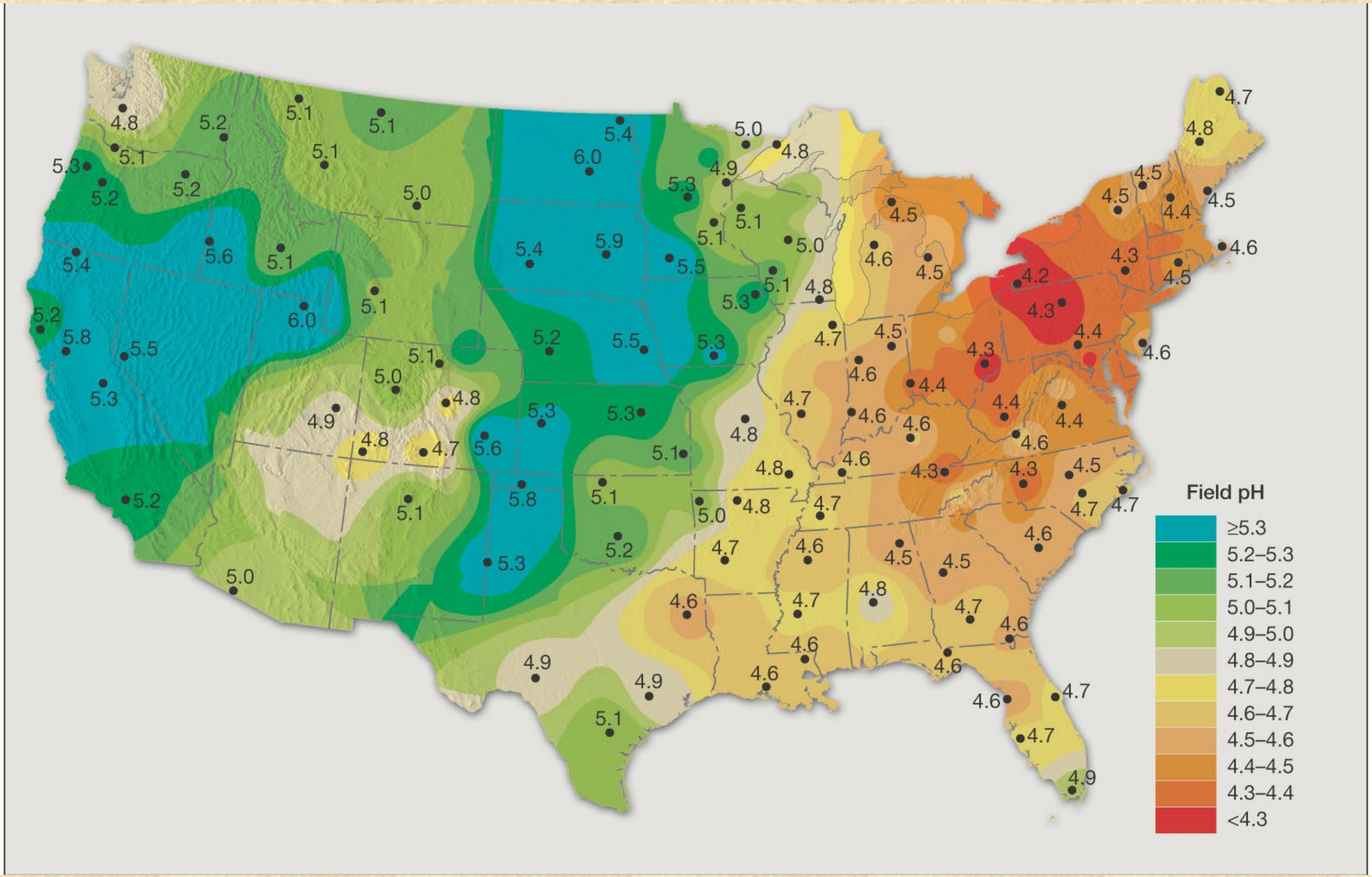


Acid Precipitation

- Some pollutants end up as acids e.g. $SO_2 + O + H_2O$ gives H_2SO_4 - sulfuric acid.
- Also get nitric acid from NOx + water.
- Some acids fall to Earth as acid rain or snow (acid precipitation)
- Water is naturally somewhat acidic (ph ~ 5.6) - $CO_2 + H_2O$ gives carbonic acid (appears in aerated drinks)



Precipitation [pH 5.6 is good]



Effects of Acid Precipitation

1. Low pH in lakes and streams lead to more leaching of aluminum from the soils, and aluminum is toxic to fish. Calcium carbonate helps (acid breaks it down to CO_2 & H_2O)
2. Reduces crop yields
3. Impairs the productivity of forests - damages leaves & roots, and leaches out the trace minerals
4. Corrodes metals and damages stone structures

London
1973

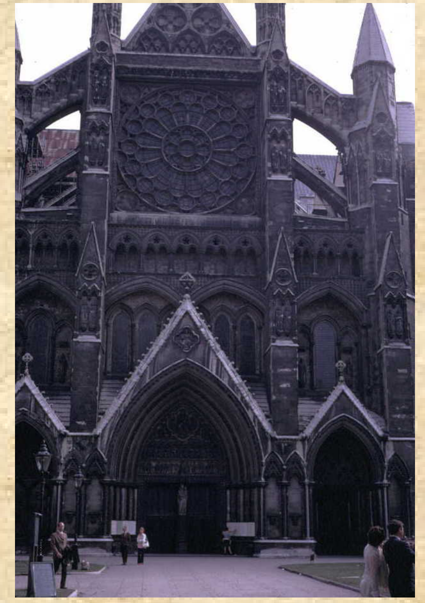
Houses of Parliament

London
2011

Westminster Abbey

London
2011

London
1973

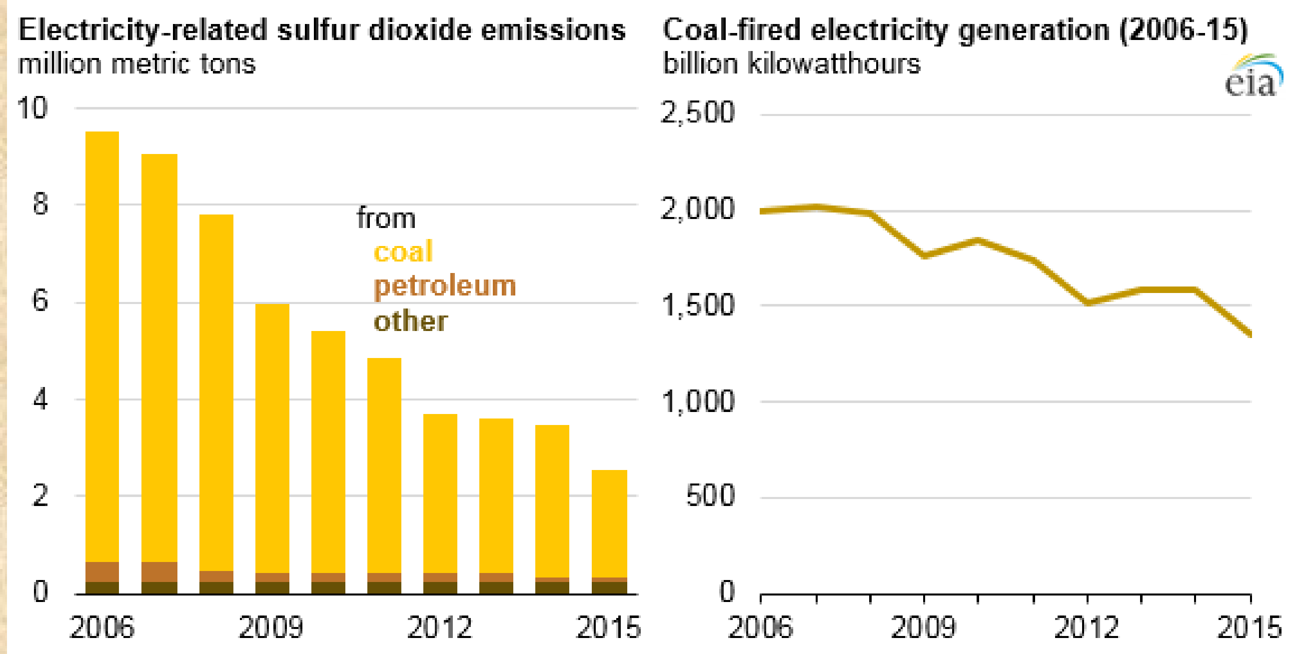


Air Pollution Abatement

- Disperse pollutants → dilution = solution
- Change in process
- Fuel substitution
- Removal of pollutants
  - Electrostatic precipitators →
  - Bubblers and Scrubbers

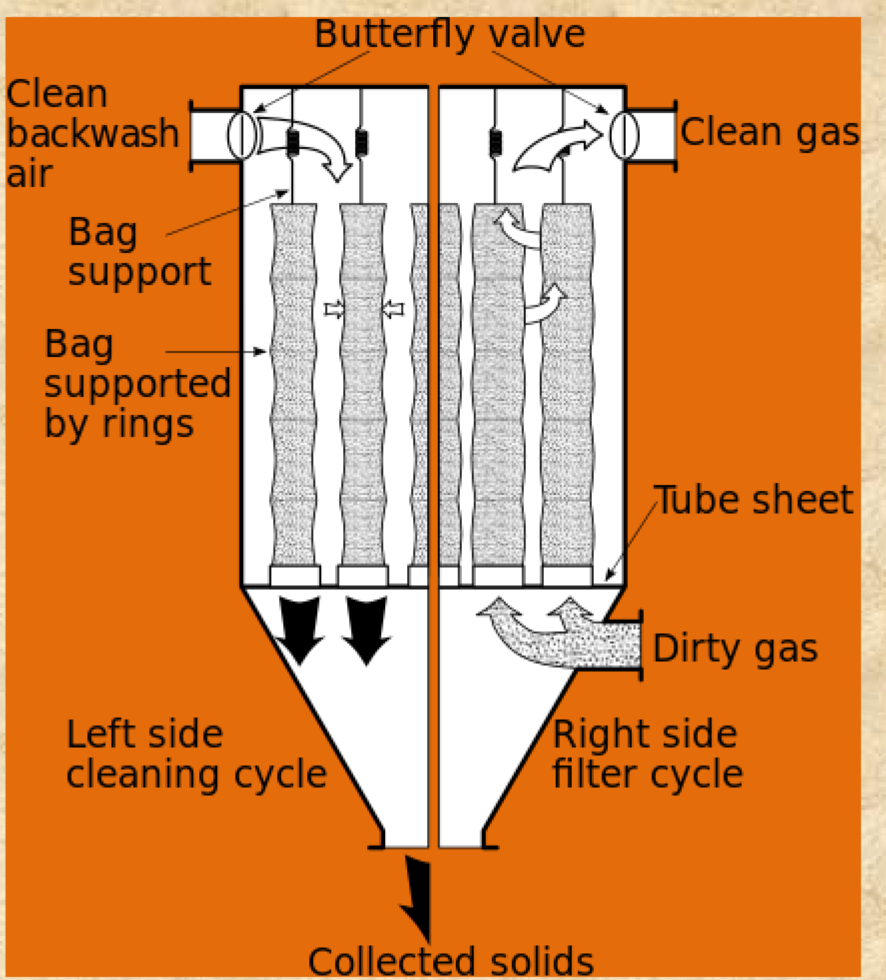
Emission Control

- Products of incomplete combustion (PIC) and CO – lean mixture
- Control of particles – Electrostatic precipitators and bag houses
- Sulfur control – before (coal washing, coal gasification, oil desulfurization) or after combustion (sorbent injection, wet scrubber, dry scrubber)
- Nitrogen oxide – during (low-No_x burner) or after (selective catalytic reduction, selective noncatalytic reduction) combustion.
- Mercury
- Toxic metals
- Waste disposal



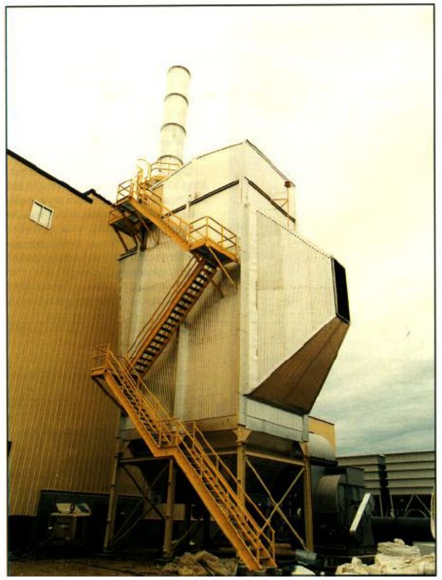
Removal of Particulates

Bag House



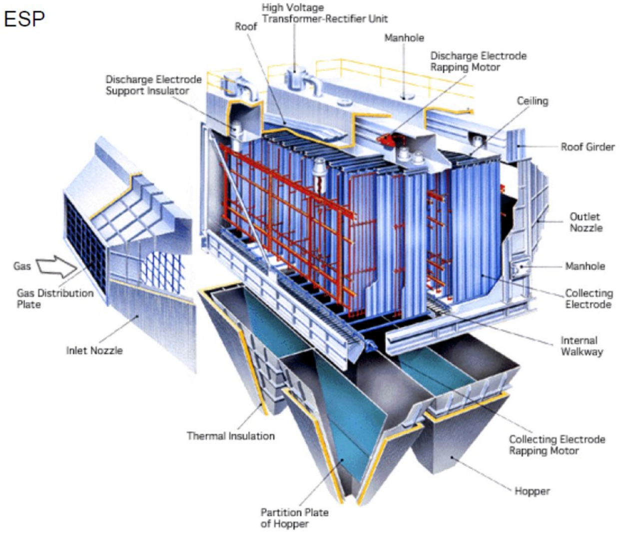
(www.dom.com/)

Electrostatic precipitators (ESPs) are major pieces of equipment and are expensive.



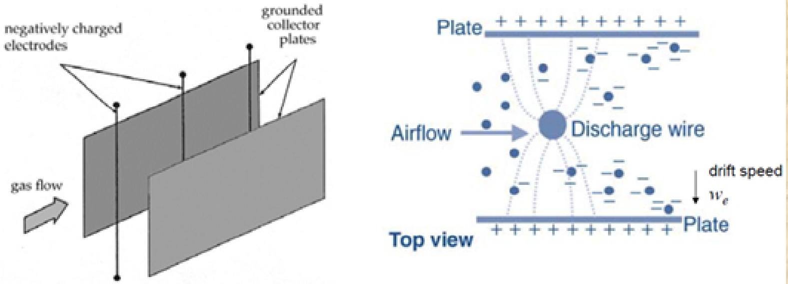
(http://www.ppcesp.com/ppcart.html)

Inside an ESP



(http://www.qrbiz.com/product/1472881/Electrostatic-Precipitator.html)

At the core of the apparatus



Principle: Electrodes at high voltage create a corona effect (ionized atmosphere) surrounding them. This charges the passing particles. Once charged, particles are subject to a transverse electrostatic force that pulls them toward the collecting plates. Plates are periodically "rapped" (vibrated) to make the collected particles fall down into a receiver basket in the bottom of the apparatus.

Efficiency of an electrostatic precipitator (Deutsch equation)

$\eta = 1 - \exp(-wA/Q)$

w = drift velocity ≈ $0.05 d_p$ m s^{-1}

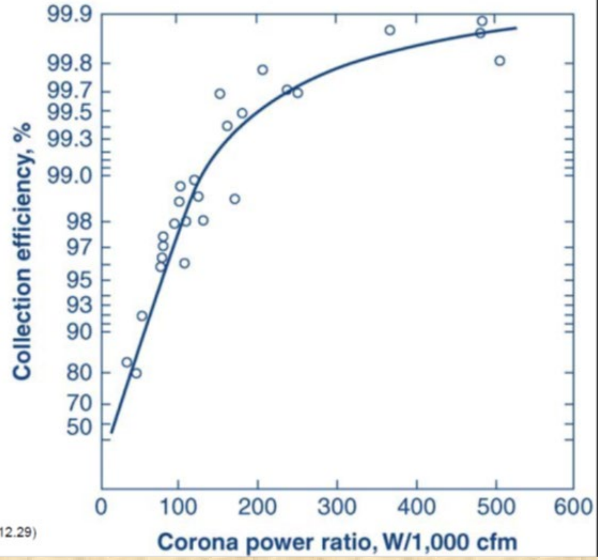
d_p = particle diameter in microns

A = total area of plates

Q = volumetric flow rate

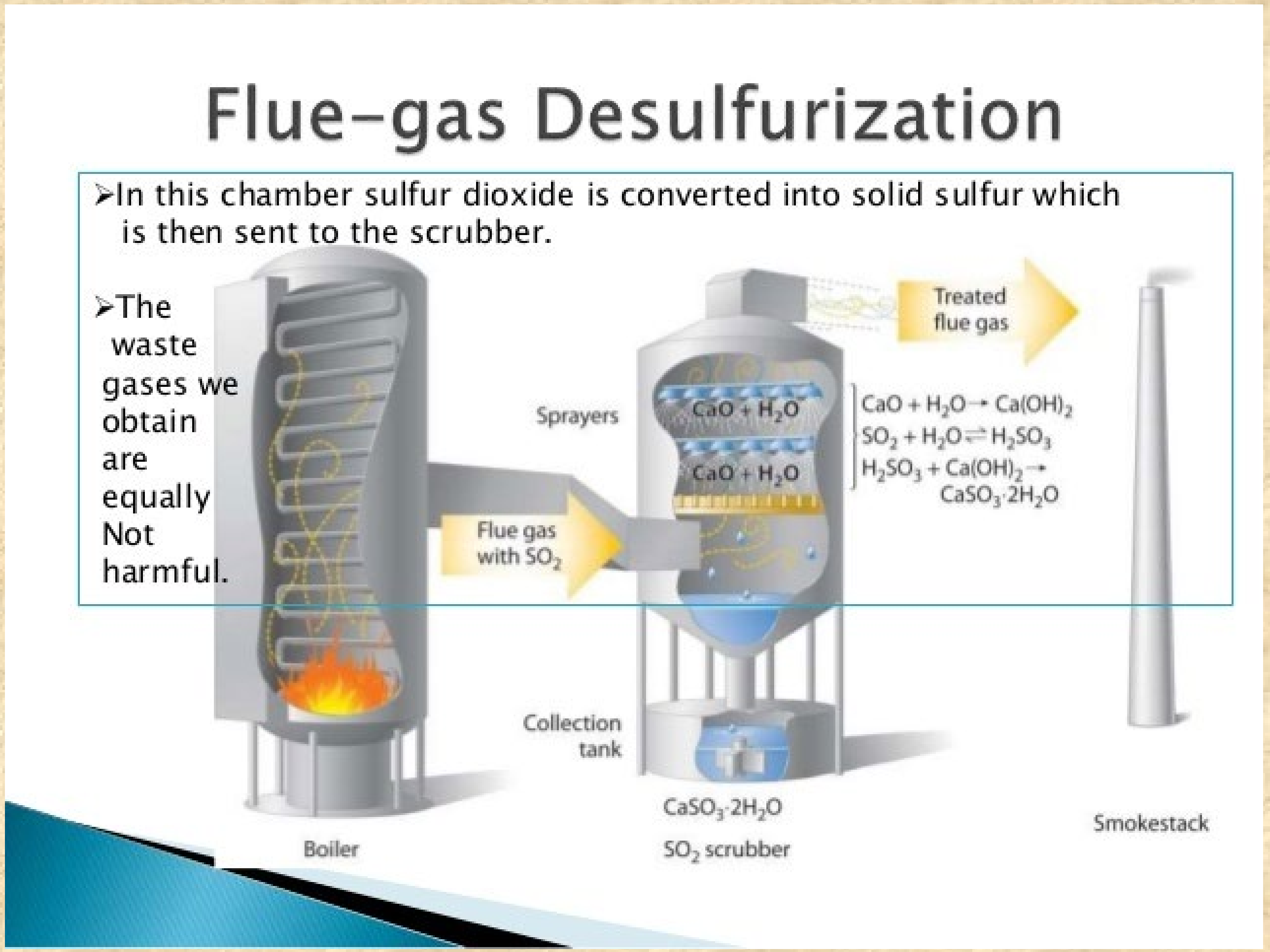
Typical efficiency of an electrostatic precipitator as a function of the corona power ratio, which is power consumed (in Watts) divided by the airflow in cubic feet per minute (cfm).

Note the extremely high efficiencies, nearing 100%.



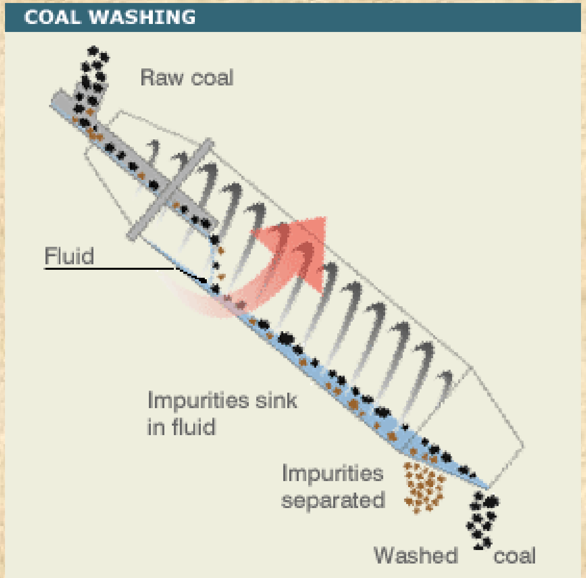
(*Source*: Mihelcic & Zimmerman, Figure 12.29)

Removal of Sulfur Dioxide from Effluent Stream - Scrubber



Removal of sulfur before combustion

1) Coal washing – remove mineral components which sink while coal floats. In terms of sulfur emissions the removal of pyrite (FeS_2) is most important. Sulfur that occurs in the organic molecules is not removed by this process. Post-combustion clean-up may be required.



2) Coal gasification

3) Oil desulfurization

$$RS + H_{2(g)} \rightarrow H_2S_{(g)} + R \quad (R = \text{organic radical, catalyst present})$$

$$H_2S_{(g)} + 0.5O_2 \rightarrow H_2O + S$$

Coal gasification is the process of producing syngas–a mixture consisting primarily of carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2), natural gas (CH_4) , and water vapour (H_2O)–from **coal** and water, air and/or oxygen.