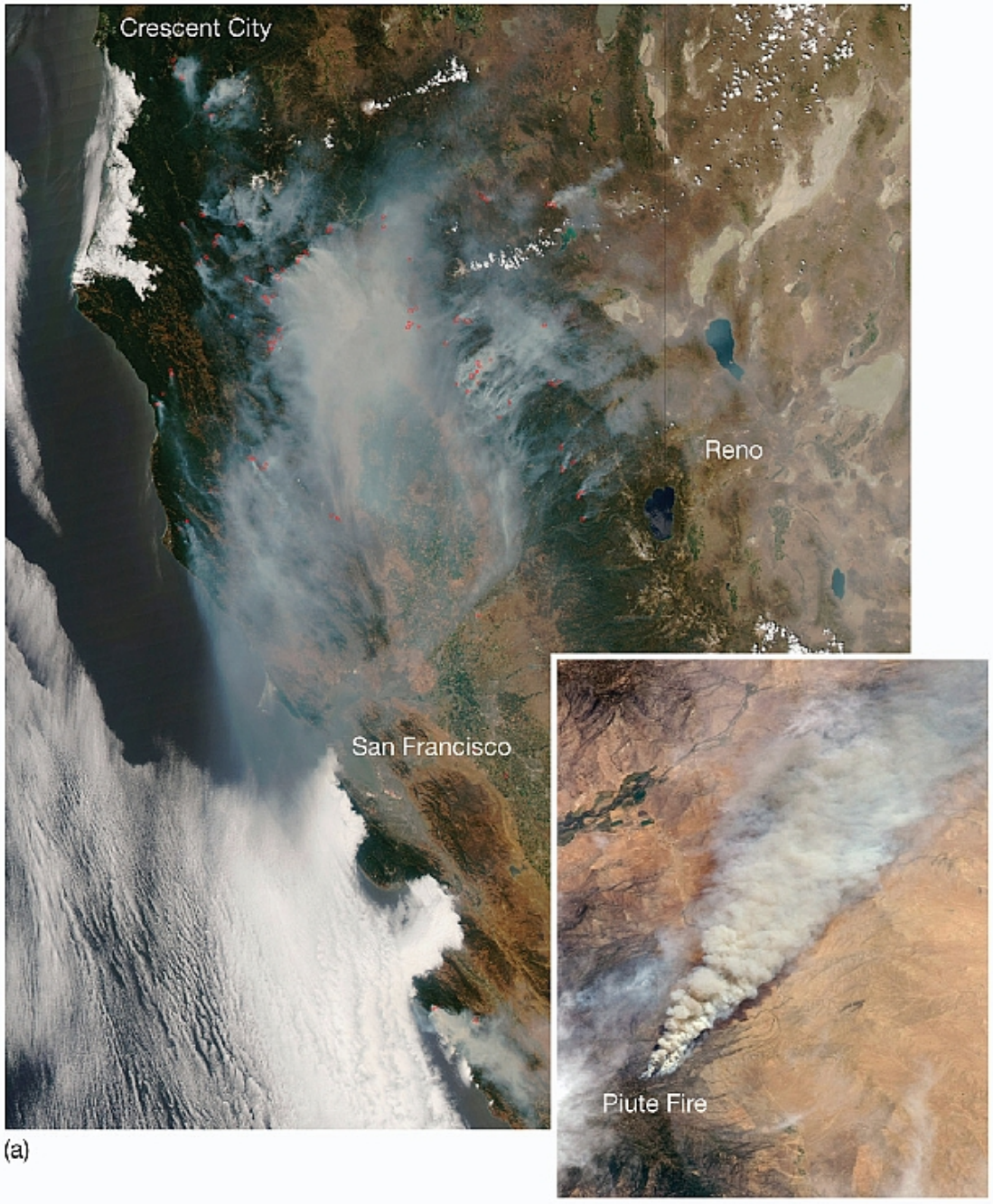
Air Pollution

Kuala Lumpur

Beijing, China, 2008

Perspective

- Air pollution is not a new problem
- Pollution sources can be divided into two main classes
  1. Created by Humans
  2. Natural
- Pollution by humans has increased to an unacceptable level
- We have polluted the air, the water, the land



(a)

(b)

Drought + Forest Fire

Dust storm Kansas 1937

Chicago ca. 1950

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.

TABLE 13-1 Air-Pollution Source Categories

Category	Comments
Point sources	Includes factories and electric power plants
Mobile sources	Not only includes cars and trucks but also lawn mowers, airplanes, and anything else that moves and pollutes the air
Biogenic sources	This category includes all nonanthropogenic (not human-generated) sources. Examples include trees and other vegetation, microbial activity, oil and gas seeps, etc.
Area sources	Small and individual sources such as dry cleaners and degreasing operations

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

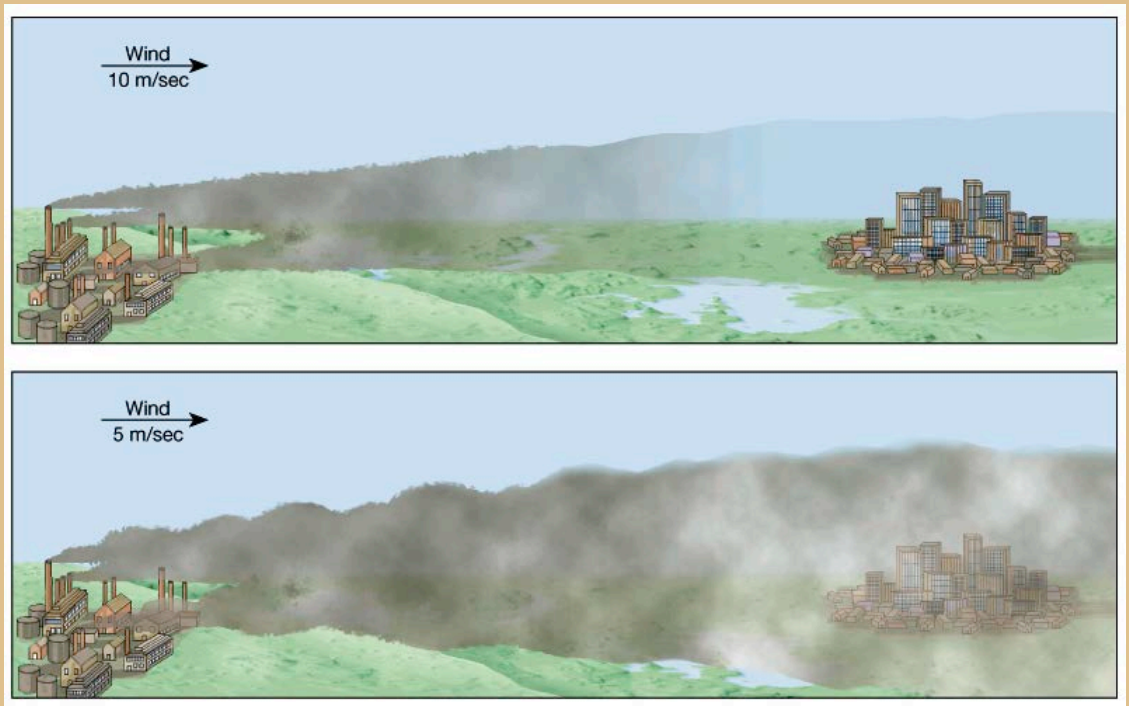
- Convective air flow due to heating of earth's surface
- Orographic ascent
- Air mass lifting due to advection

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

Wind as a Factor

- 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.



The Role of 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.

Atmospheric Stability

- 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)

Height

Wind speed

Max mixing depth

Min mixing depth

AM

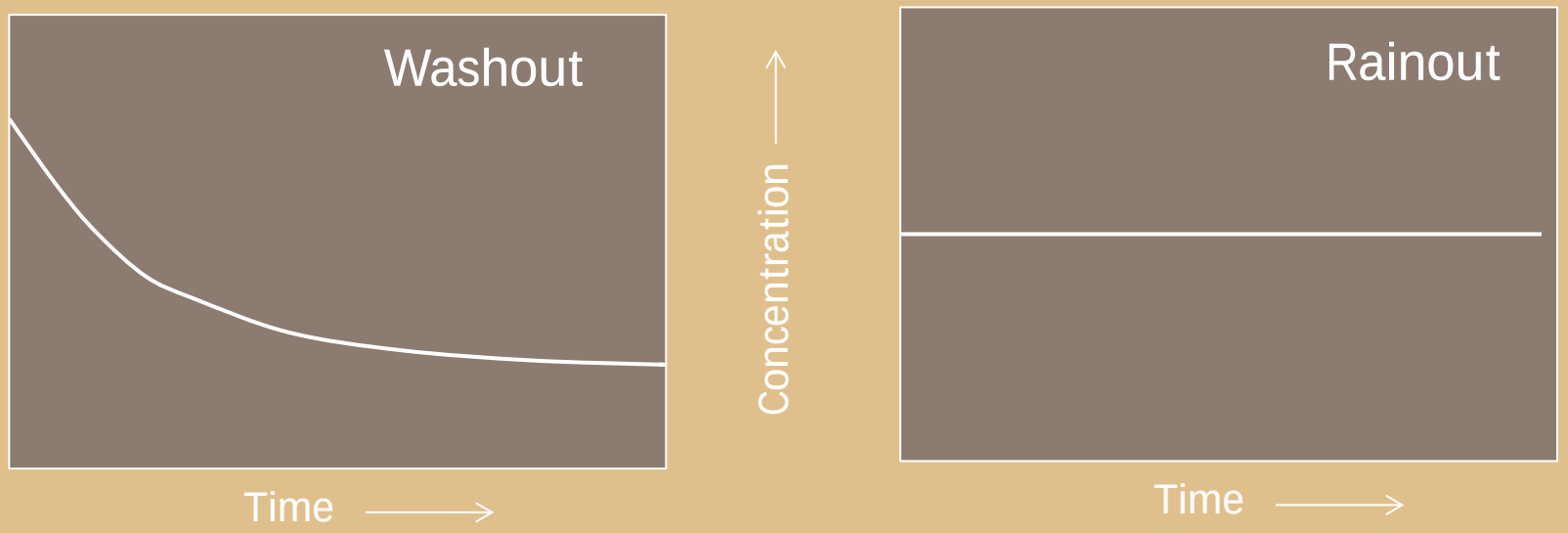
PM

Temperature

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

Removal of particulates from air

- >10 μm removed by gravitational settling
- 0.1 to 10 μm act as condensation nuclei
- >2 μm removed by precipitation
    1. Washout – particles intercepted by falling raindrops
    2. Rainout – serve as condensation nuclei and come out with precipitation



Air Pollution and Climate of Cities

- Air pollution contributes to city "heat islands"
- Air pollution may provide condensation nuclei
- Blanket of particulates over a city reduces the amount of solar energy reaching the surface.
- Particulates have the most effect when the sun angle is low - longer path through the pollution

Cities continued...

- Relative humidity in cities is 2 to 8% lower than in surrounding rural areas.
  1. Cities are hotter
  2. Less water vapor provided by evaporation of surface water
- Cities have more clouds and fogs than rural areas - particulates act as condensation nuclei

Shenyang, China

Air Pollution and Global Climate

Bryson's heat budget equation: $ScA = KeT^4(4c)$

- S = incoming solar radiation (solar constant)
- c = cross-sectional area of the Earth
- A = amount of radiation absorbed
- K = constant
- e = effective emissivity of the Earth
- T = average global T (K)
- (4c) = area over which heat radiation occurs

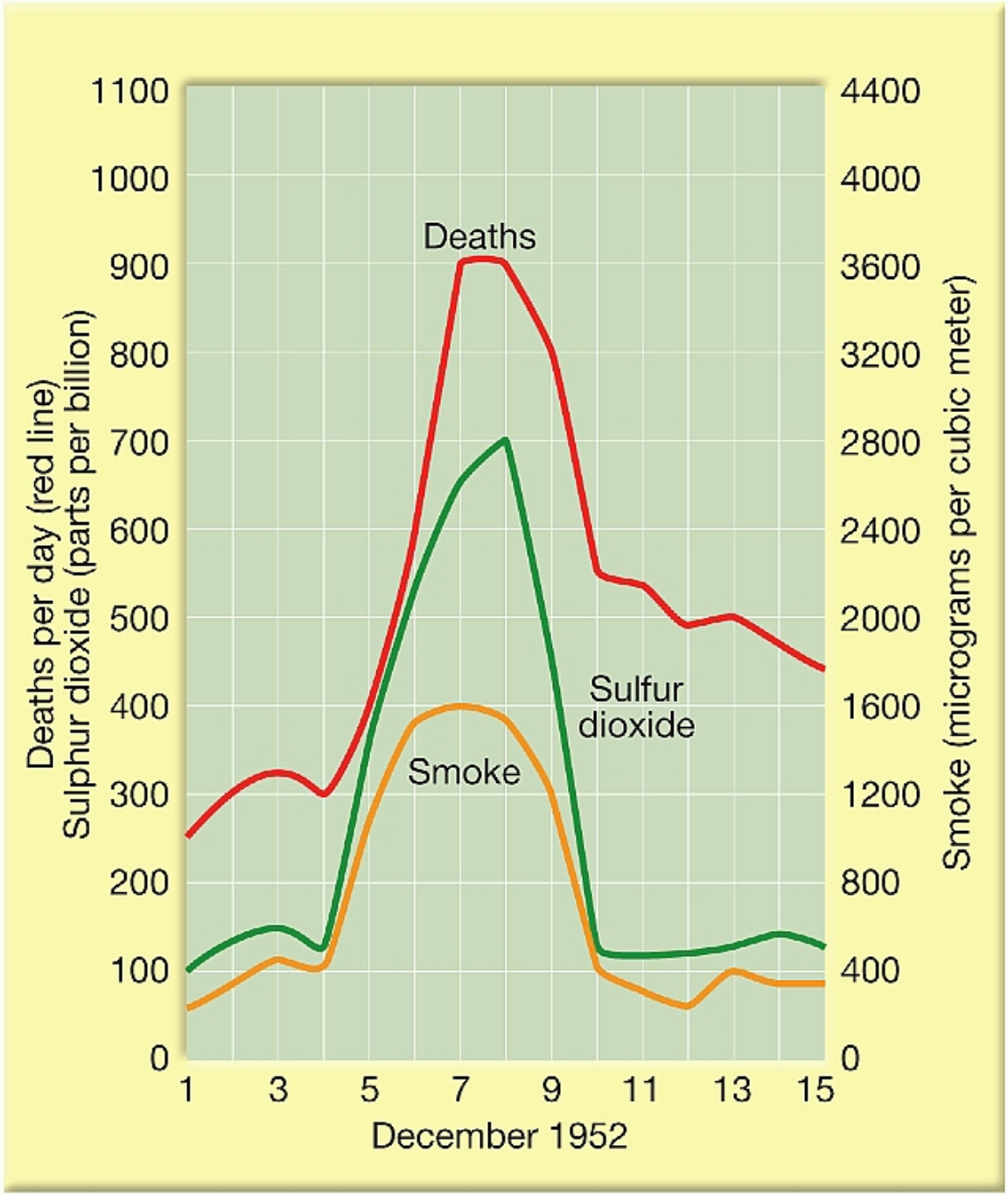
How do changes in these variables affect the Earth's temperature?

$T \rightarrow f(S, A, 1/e)$

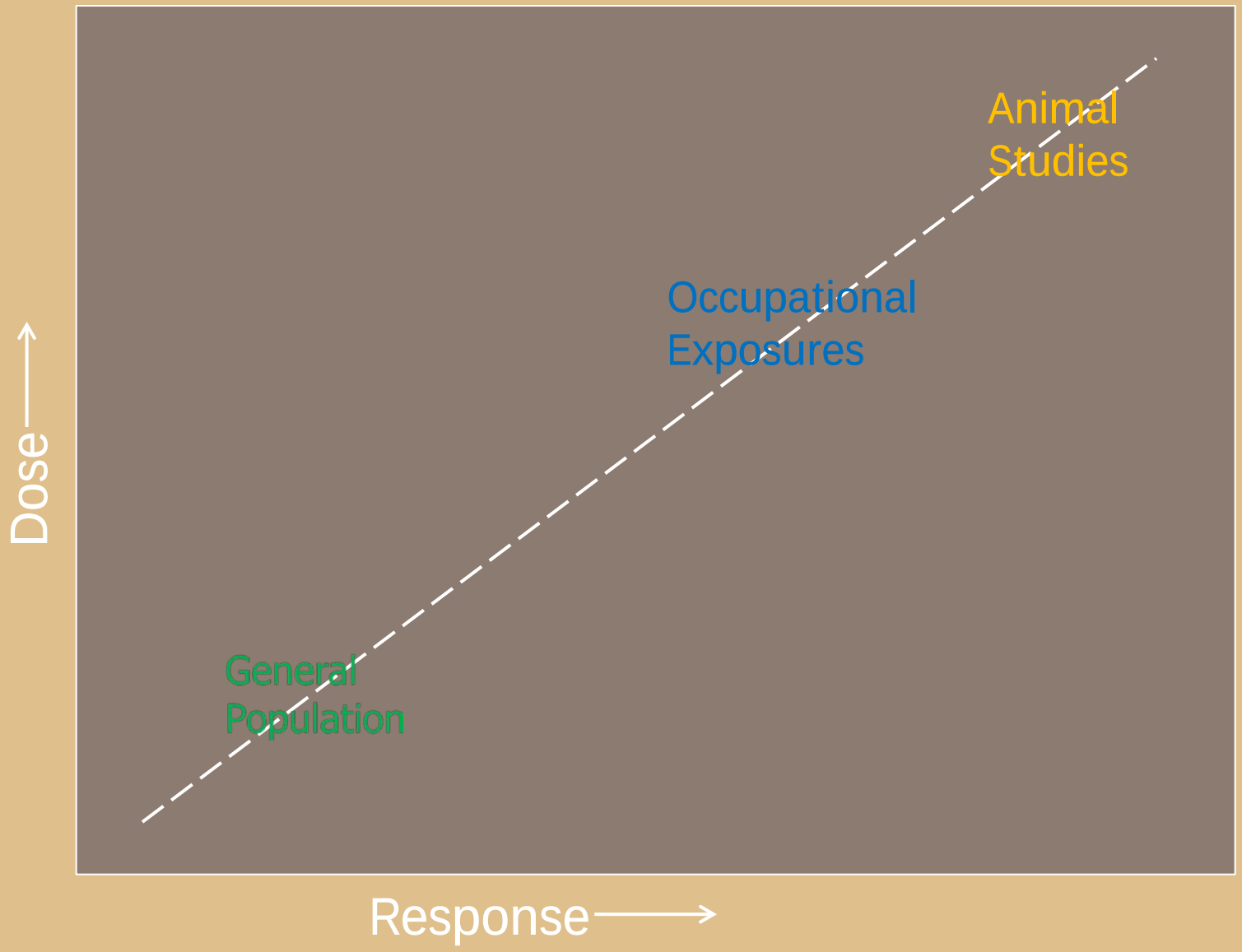
Health Aspects of Air Pollution – Air Pollution Episodes

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

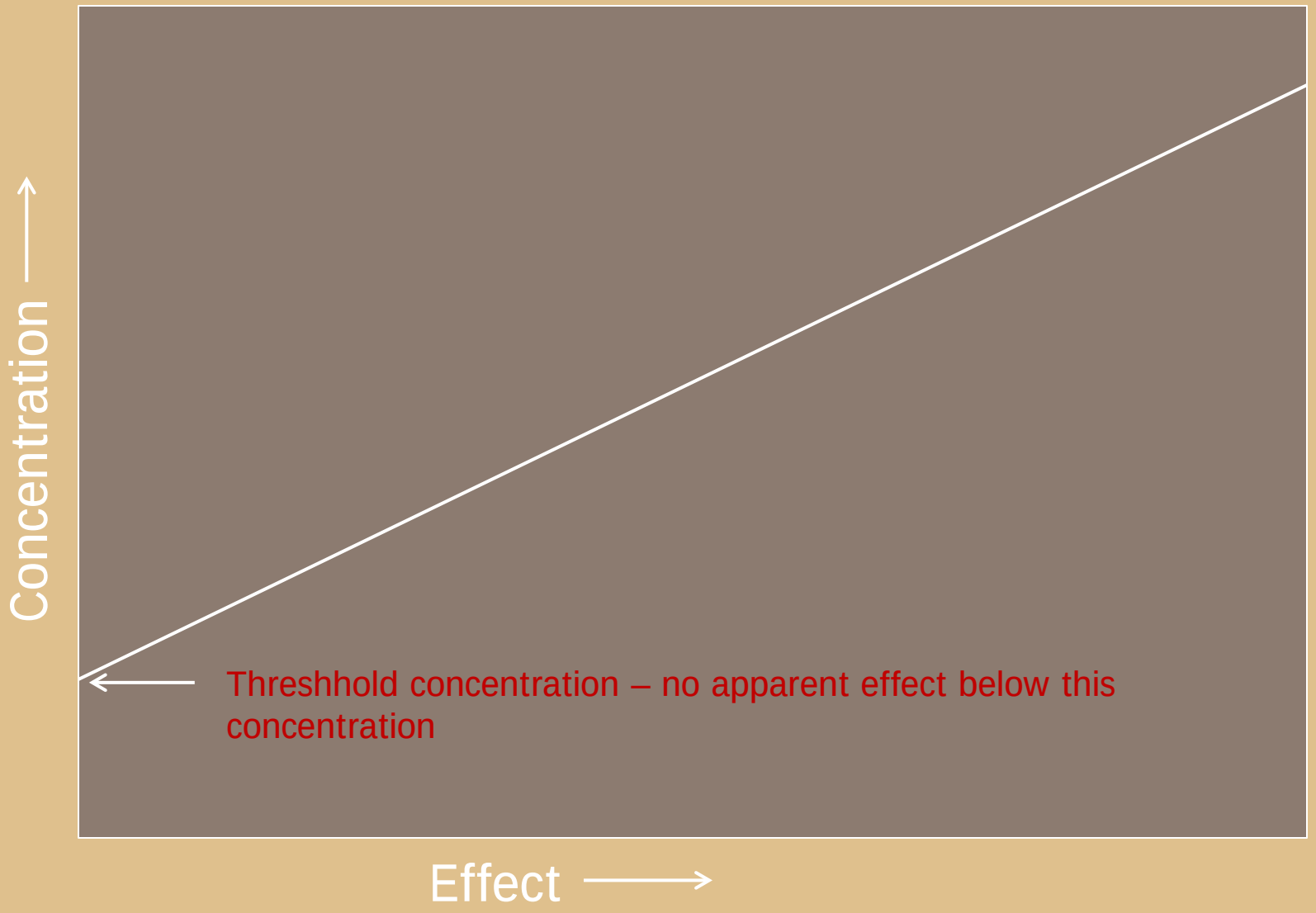
London 1952



Determining “Cause and Effect”



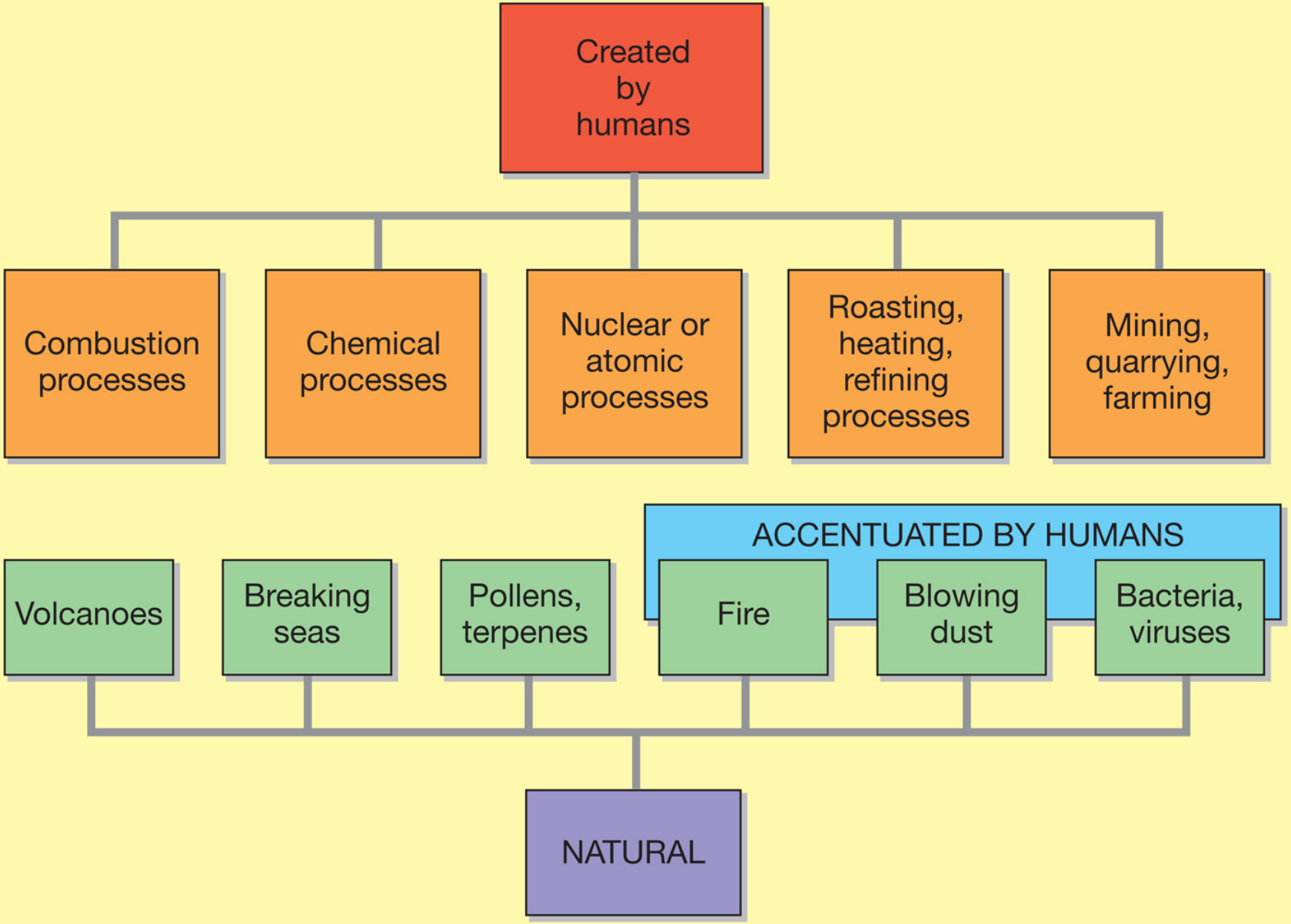
The “Threshhold” concept



Types of Air Pollution

- ***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

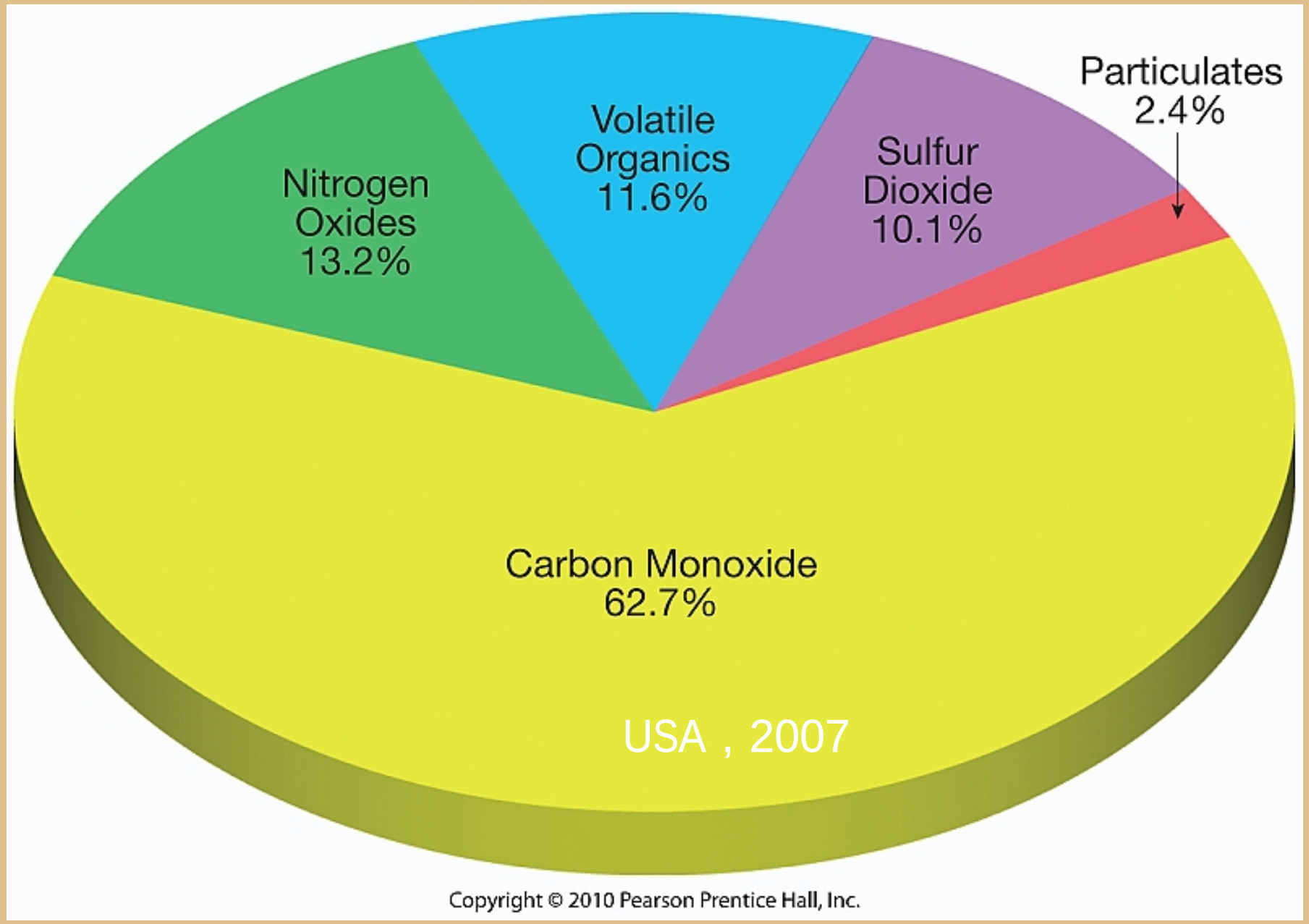
SOURCES OF PRIMARY POLLUTANTS



Primary Pollutants

What they are:

1. Carbon Monoxide
2. Sulphur oxides
3. Nitrogen Oxides
4. Volatile organics
5. Particulates


Particulates
2.4%
Volatile
Organics
11.6%
Sulfur
Dioxide
10.1%
Nitrogen
Oxides
13.2%
Carbon Monoxide
62.7%
USA , 2007
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Primary Pollutants

Where they come from:

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

TABLE 13–2 Sources of Primary Pollutants in the United States, 2002

Source	Emissions (tons)	Percent
On-road Vehicles	76,361,265	38.49%
Nonroad Equipment	30,702,485	15.48%
Fires	29,303,986	14.78%
Electricity generation	16,899,351	8.51%
Road Dust	11,108,355	5.60%
Industrial Processes	8,181,573	4.12%
Miscellaneous	6,993,504	3.52%
Fossil Fuel Combustion	6,645,307	3.35%
Residential Wood Combustion	4,673,512	2.36%
Solvent Use	4,296,662	2.16%
Waste Disposal	3,199,427	1.61%
Fertilizer and Livestock	48,918	0.02%
TOTAL	198,414,345	100%

Source: U.S. Environmental Protection Agency

Major primary pollutants

1. Particulate matter
2. Sulfur dioxide
3. Nitrogen Oxides (NOx)
4. Volatile organic compounds (VOC)
5. Carbon Monoxide
6. Lead

Particulate Matter (PM)

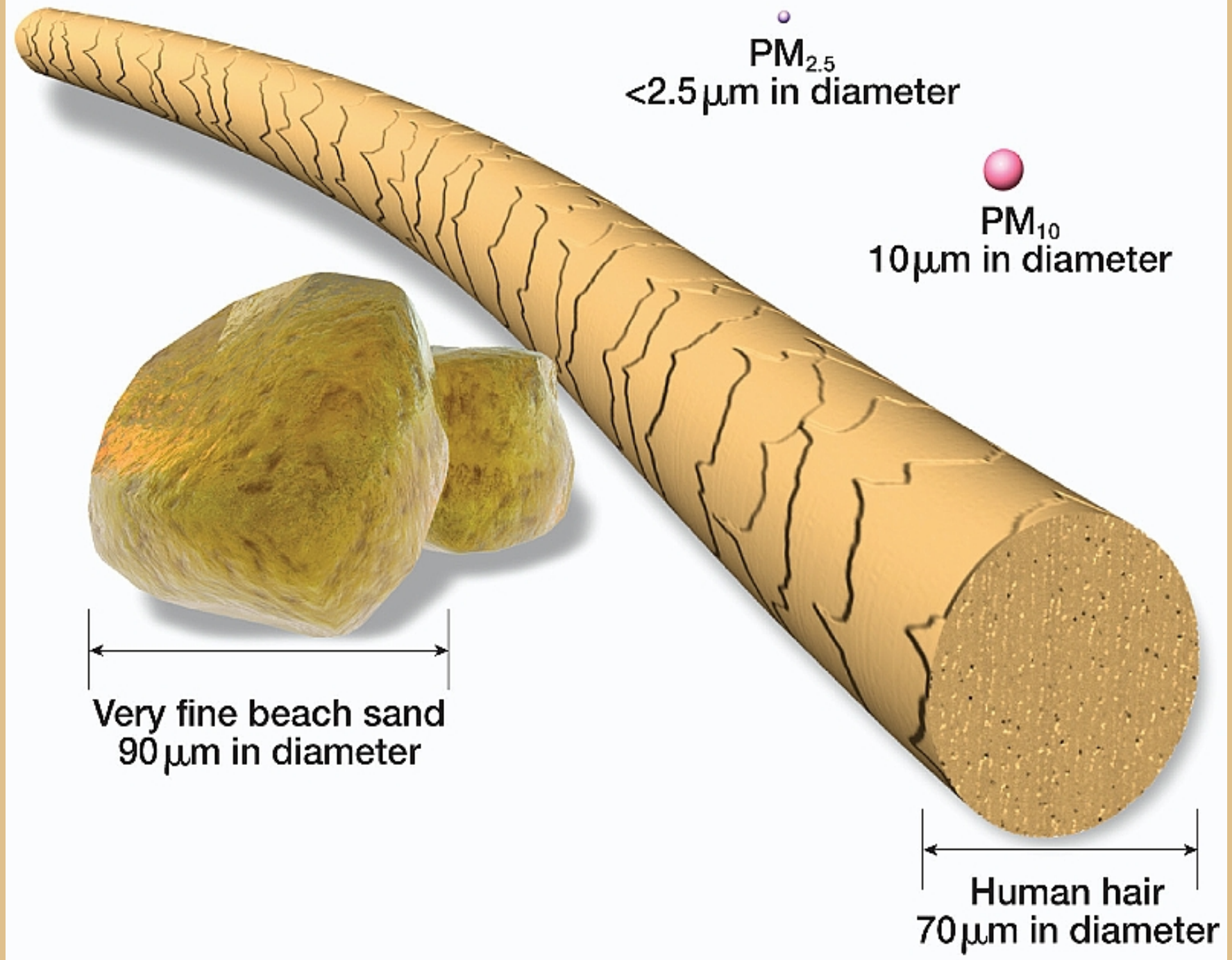
- Mixture of solid particles and liquid droplets found in the air
- Particulates reduce visibility. Leave deposits of dirt on surfaces, and may carry other pollutants dissolved in or on them
- Some are visible to the naked eye, some are not - frequently the most obvious form of air pollution
- Sizes range from fine (<2.5 micrometers in diameter) to coarse (>2.5 micrometers)

Particulate Matter

- ***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

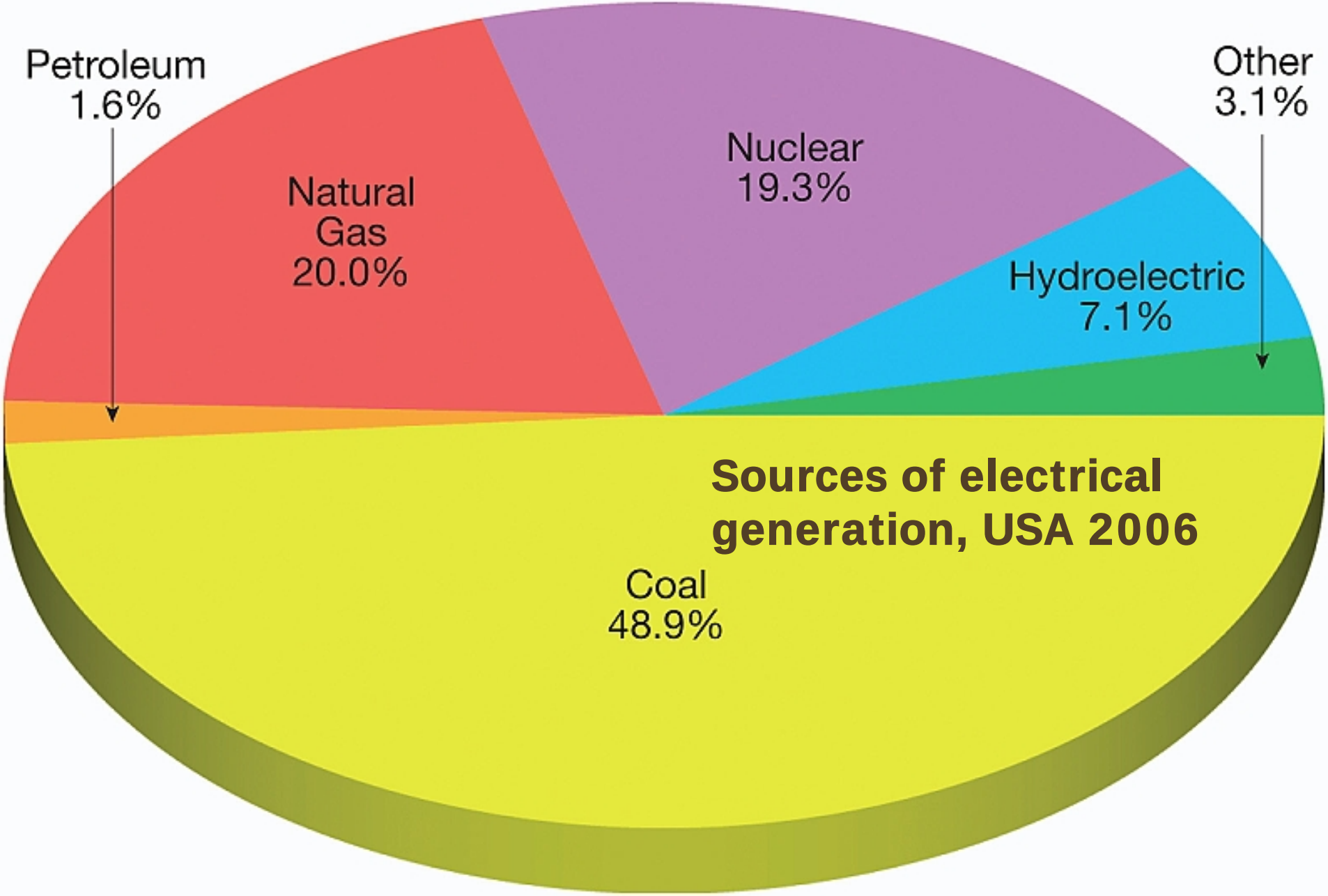
Particulate Matter

- ***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.



Sulphur Dioxide

- SO_2 is a colorless and corrosive gas that ***originates*** from the combustion of material containing sulphur, 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 - q.v.)



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

Nitrogen Oxides (NOx)

- Can contribute to heart & lung problems
- Also contribute to acid rain
- Because they are highly reactive, they play an important role in the ***formation of smog***

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 (face turns blue)
- Hazardous in concentrations - e.g. underground parking stations.

Lead (Pb)

- Can accumulate in bones and tissues
- Can cause damage to nervous system, especially in children
- Major source - automobiles
- Now use lead-free gas, and lead concentrations have dropped dramatically

TABLE 13–3 Air Quality and Emissions Trends

	Percent change in concentrations	
	1980–2007	1990–2007
NO_2	–46	–35
O_3 8-hour	–21	–9
SO_2	–68	–56
PM_{10} 24-hour	—*	–28
$PM_{2.5}$ annual	—*	–11
CO	–77	–67
Pb	–94	–78
	Percent change in emissions	
	1980–2007	1990–2007
NO_x	–39	–34
VOC	–50	–35
SO_2	–49	–43
PM_{10}	–65	–34
$PM_{2.5}$	—*	–52
CO	–55	–44
Pb	–99	–60

*Data not available.

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.

Secondary Pollutants - 2

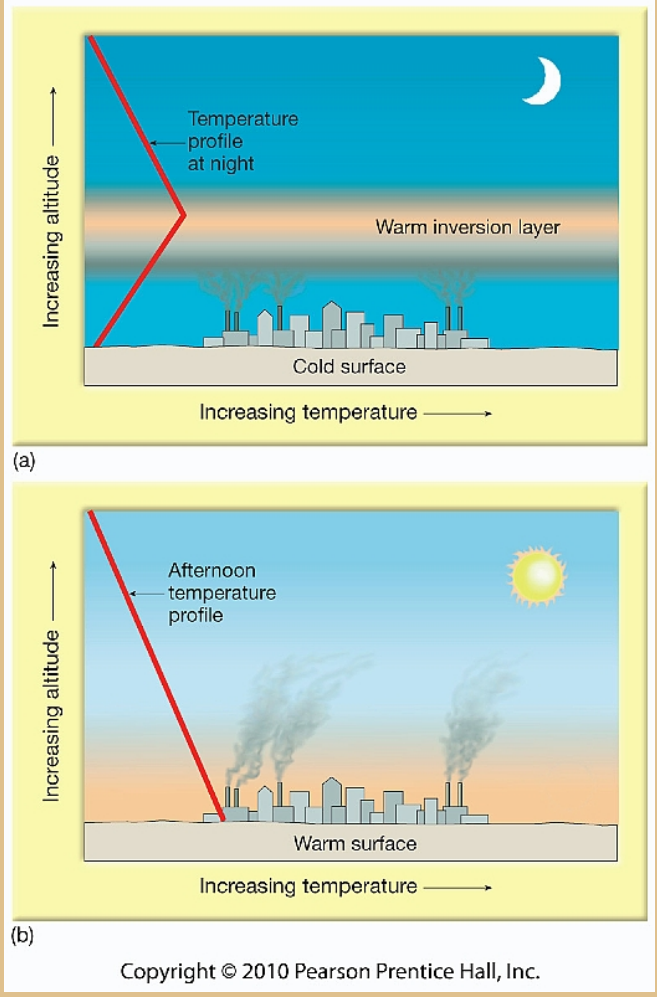
- ***Photochemical*** reactions - sunlight reacts with primary pollution, causing a chemical reaction.
- Occur during the day, maximizing in the summer - depends on sun angle.
- ***Photochemical smog*** is a noxious mixture of gases and particles - very reactive, irritating and toxic.

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)

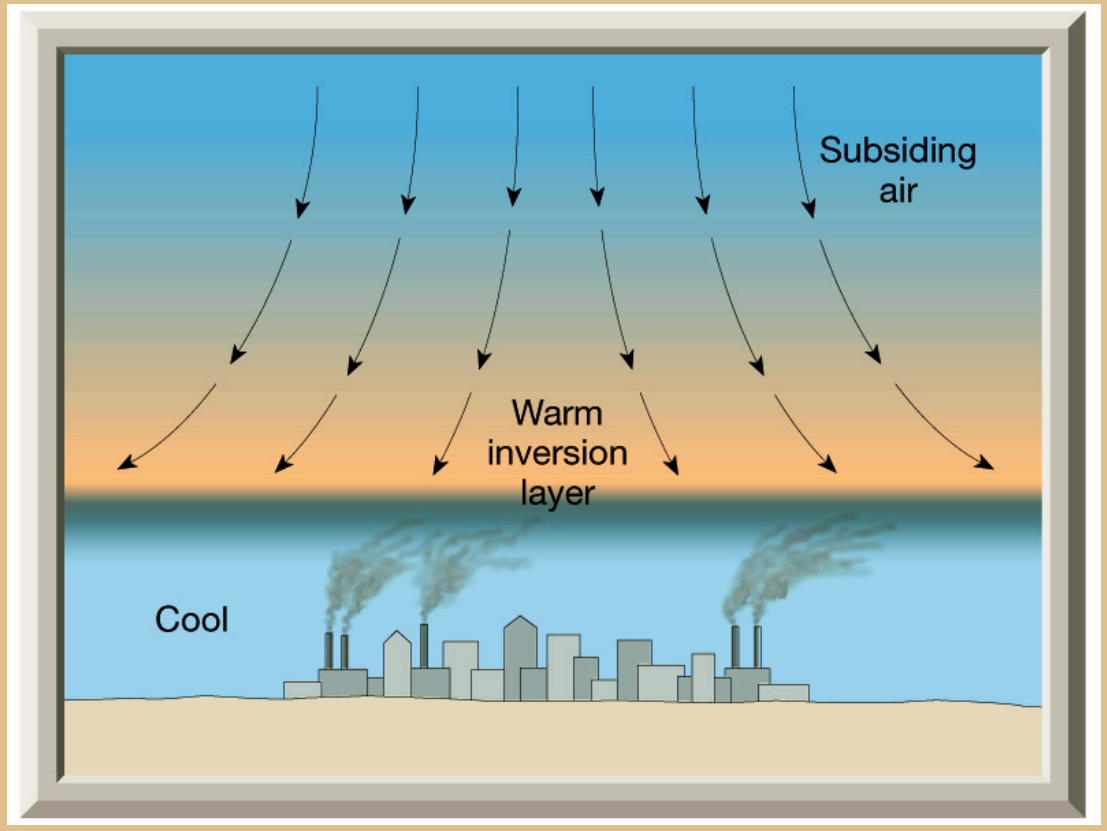
Surface Temperature Inversions

- 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

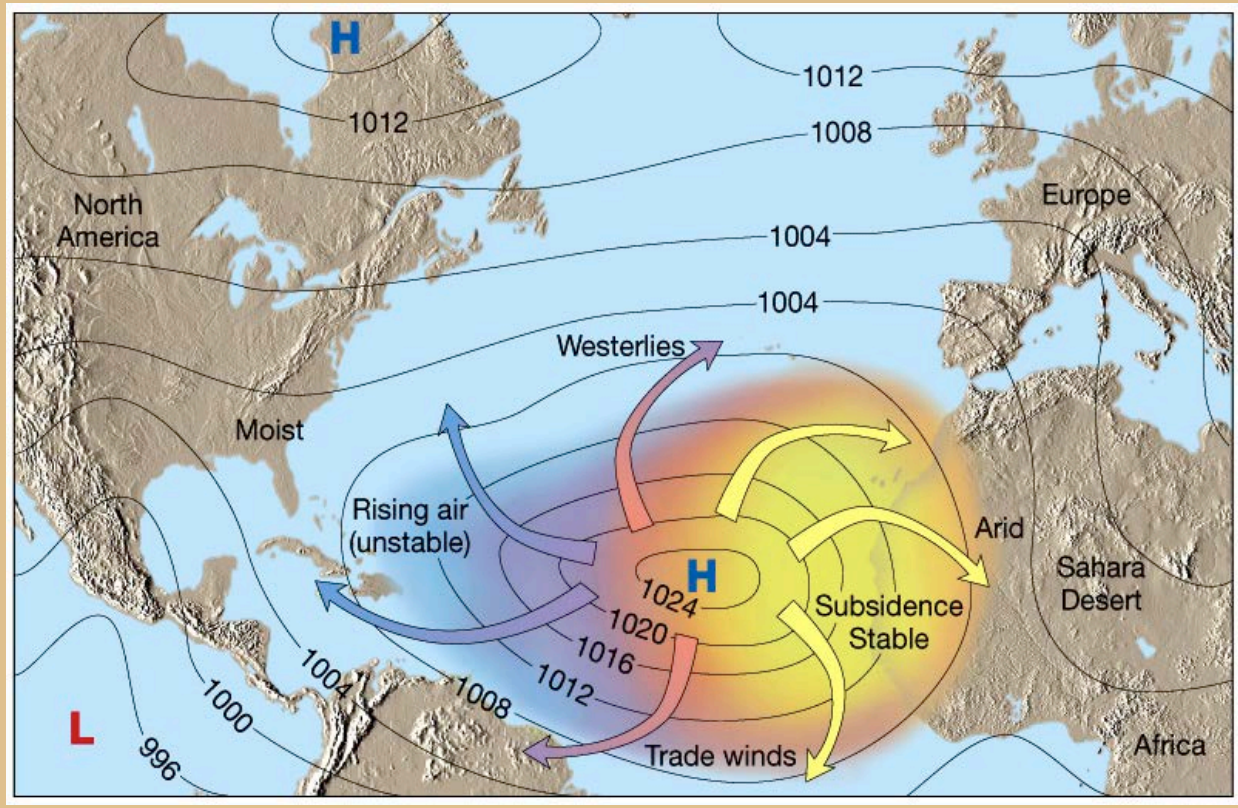
- These are associated with descending air in anticyclones.
- As the air descends, it is compressed, and therefore warms
- Work is done compressing the air. ***Some*** of this work is converted to heat. (First Law of Thermodynamics)
- Turbulence near the surface prevents the descending air from reaching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



Downtown Los Angeles

Los Angeles Pollution

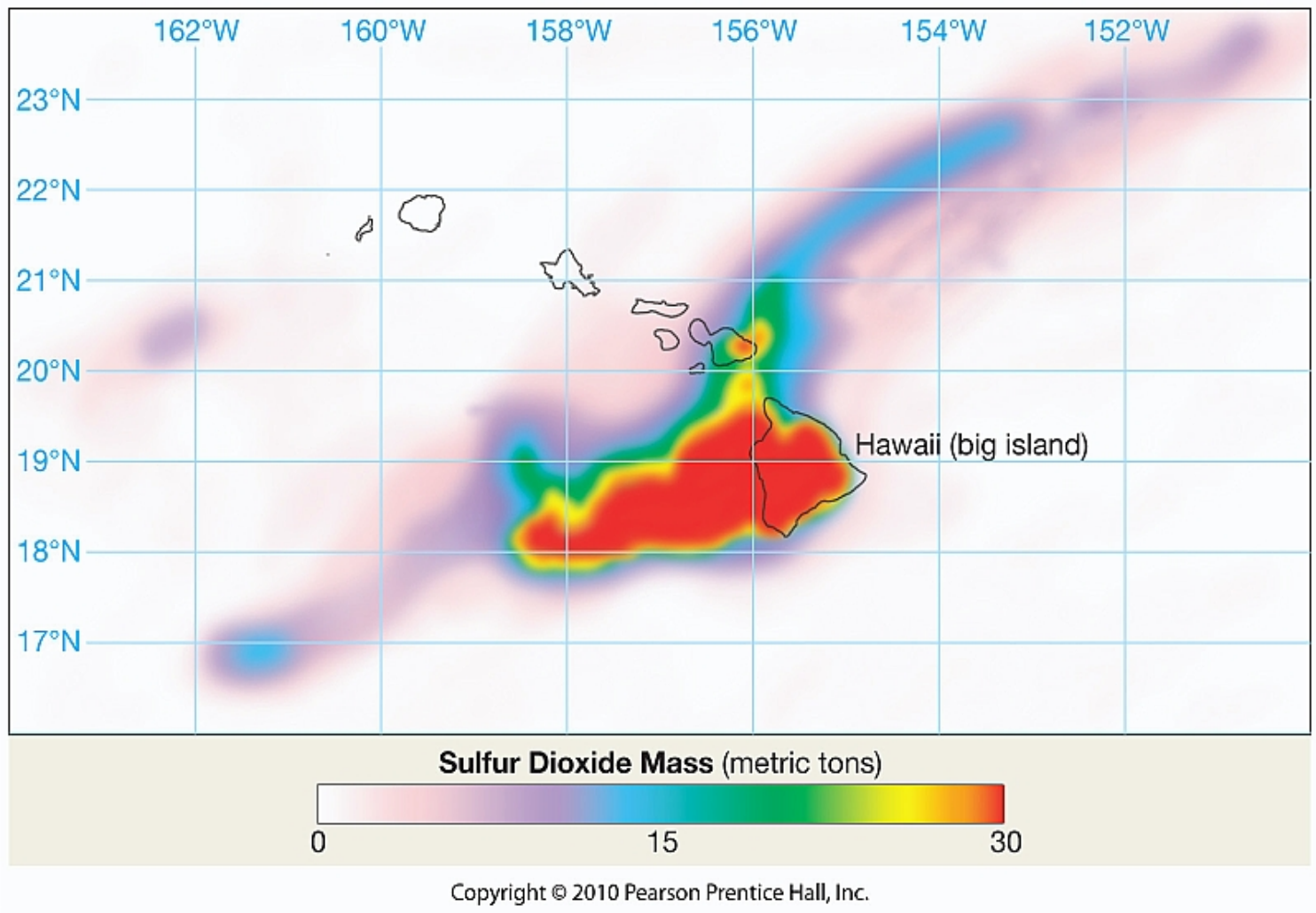
- Related to temperature inversions associated with the eastern portion of the subtropical high
- What causes most of the pollution?
- The temperature difference is exacerbated by the cool air coming inland off the cold ocean currents.



Ozone - Good or Bad?

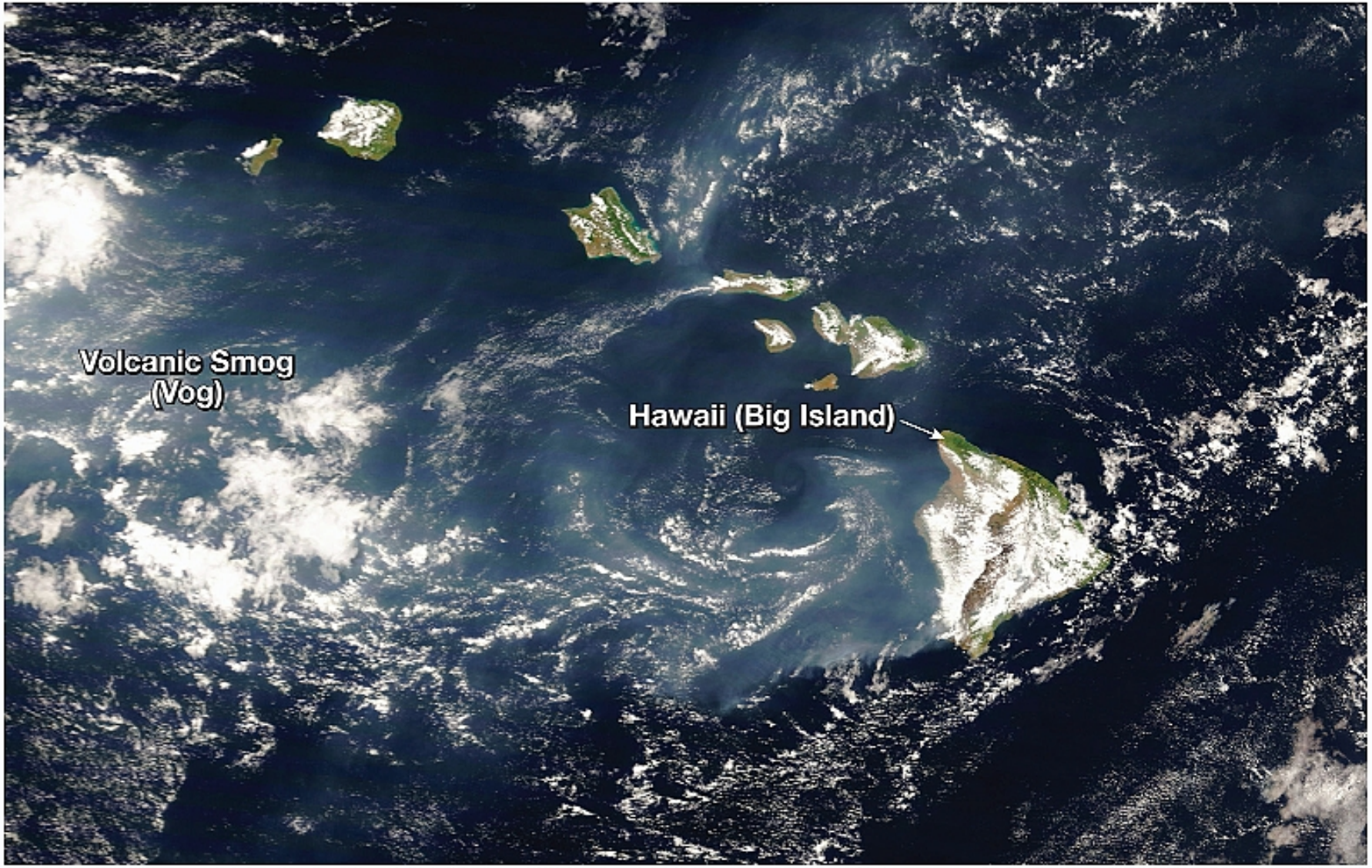
- Major component of photochemical smog is ozone.
- ***Ozone*** causes eye and lung irritation, lowers crop yields, damages material such as rubber etc.
- Ozone in the upper atmosphere is a good thing (protects us from solar UV)
- Ozone at ground level is a bad thing

Volcanic Smog (Vog)



Satellite measurements of SO_2 concentration

Satellite Visible Imagery



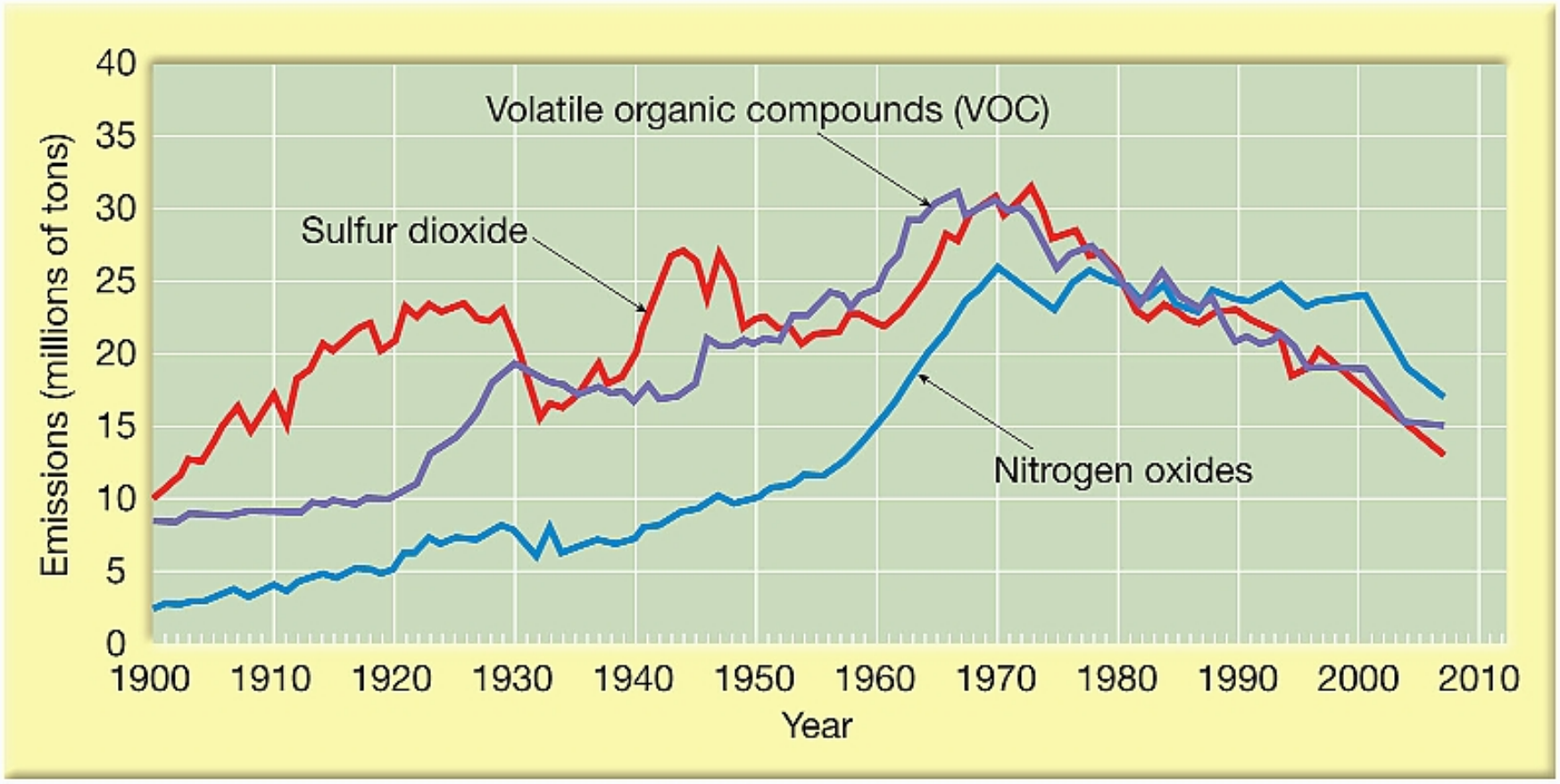
Clean Air Act of 1990

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

Clean Air Act

For example, EPA set reduced levels of sulfur in gasoline. Sulfur reduces the efficiency of catalytic converters, and leads to greater pollution.

Trends in national emissions



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

TABLE 13–4 National Ambient Air-Quality Standards

Pollutant	Standard value	
Carbon monoxide (CO)		
8-hour average	9 ppm*	(10 mg/m^3)
1-hour average	35 ppm	(40 mg/m^3)**
Nitrogen dioxide (NO_2)		
Annual arithmetic mean	0.053 ppm	(100 $\mu g/m^3$)***
Ozone (O_3)		
1-hour average	0.12 ppm	(235 $\mu g/m^3$)
8-hour average	0.08 ppm	(157 $\mu g/m^3$)
Lead (Pb)		
Quarterly average		1.5 $\mu g/m^3$
Particulate < 10 micrometers (PM_{10})		
24-hour average		150 $\mu g/m^3$
Particulate < 2.5 micrometers ($PM_{2.5}$)		
Annual arithmetic mean		15 $\mu g/m^3$
24-hour average		35 $\mu g/m^3$
Sulfur dioxide (SO_2)		
Annual arithmetic mean	0.03 ppm	(80 $\mu g/m^3$)
24-hour average	0.14 ppm	(365 $\mu g/m^3$)
3-hour average	0.50 ppm	(1300 $\mu g/m^3$)

*ppm, parts per million.
**mg/m^3, milligrams per cubic meter of air. A milligram is one-thousandth of a gram.
***$\mu g/m^3$ micrograms per cubic meter. A microgram is one-millionth of a gram.
Source: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards.

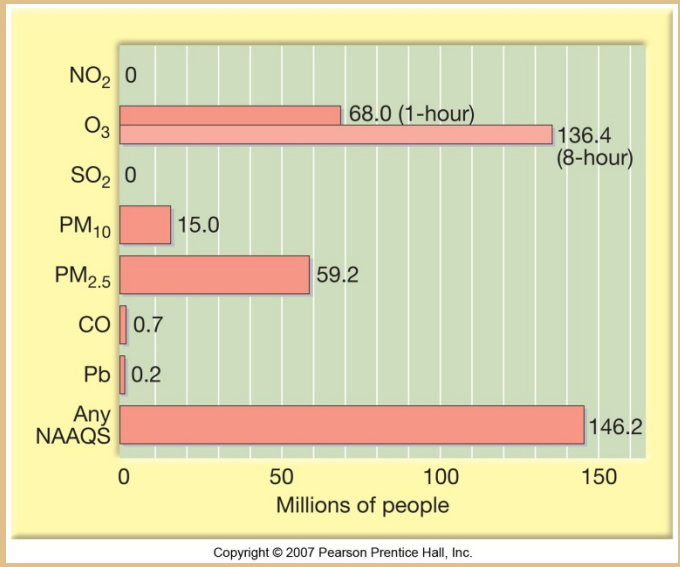
Trends in Air Quality

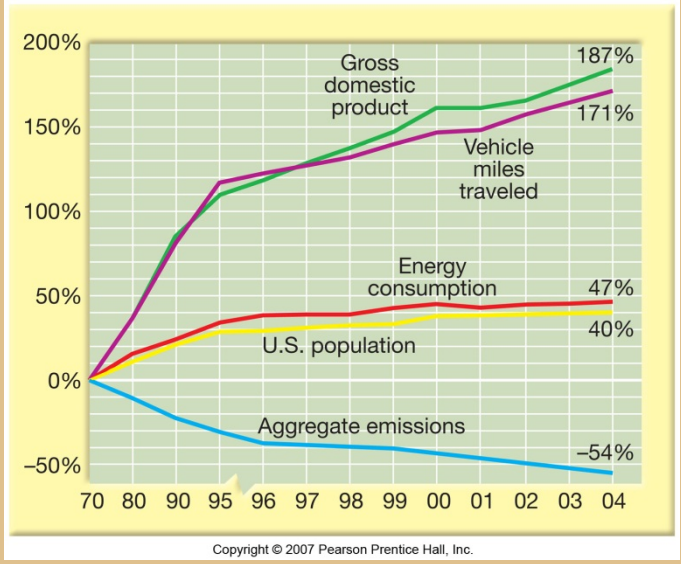
Short-term and long-term levels are set for some contaminants

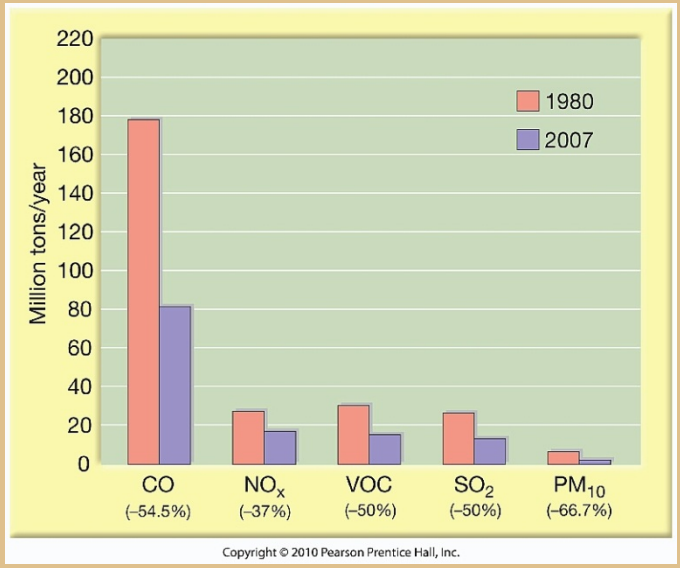
1. ***Acute*** - life-threatening within a few days or hours
2. ***Chronic*** - effects are additive over a period of years

Trends in Air Quality

- Number of people living in countries with low air quality
- 1980 and 2007 emissions of the five major primary pollutants
- Downwards trends in pollution have occurred for 4 of the 5 major primary pollutants
- On a per-car basis, emissions of primary pollutions have been dramatically reduced
- The number of motor vehicles has increased at a greater rate, so the net effect is not great







Most dangerous indoor pollutants

1. Cigarette smoke
2. (Radioactive) radon gas
3. Formaldehyde

Indoor air pollution

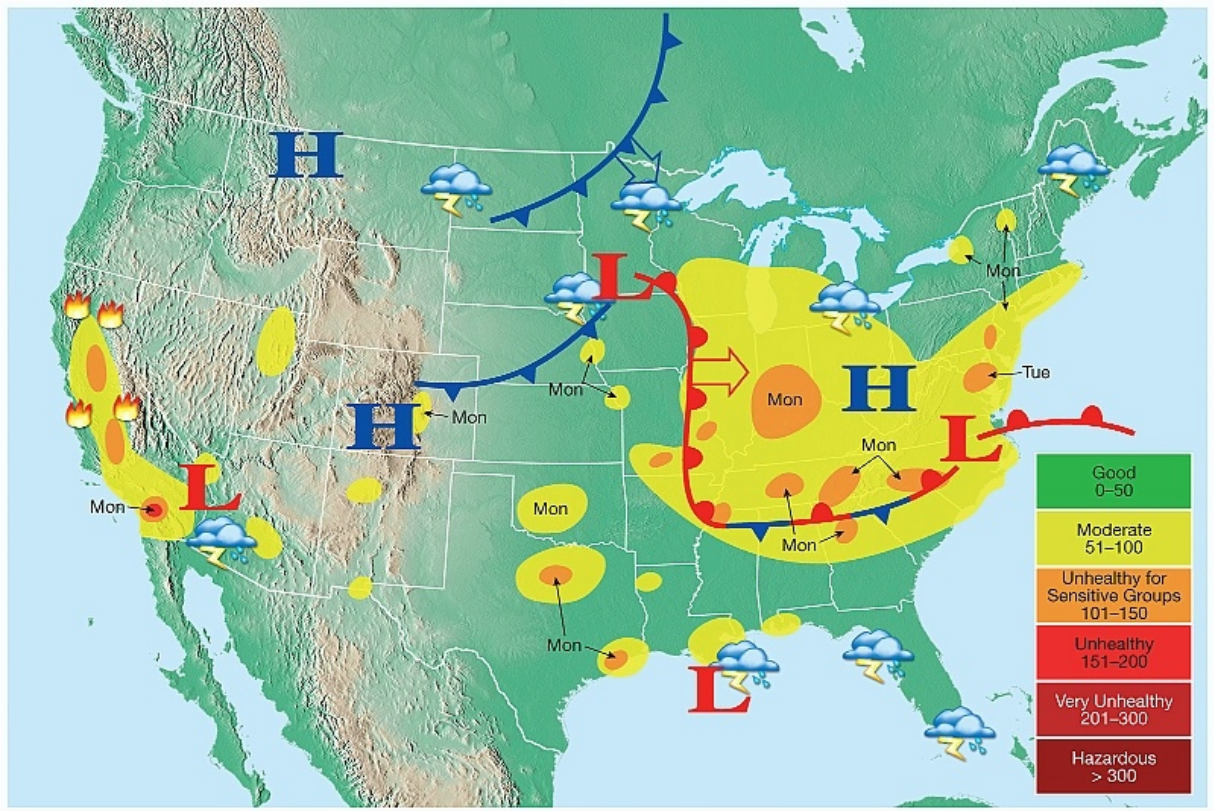
- More than 100 dangerous substances occur in much greater concentrations indoor than outdoors
- Substances get trapped in houses & offices etc.
- Give rise to " ***sick building syndrome*** "
- Buildings are becoming more airtight in a move to cut energy costs
- People spend 70 to 90% of their time indoors

Indoor air pollution

- Problems caused by ***cigarette smoke*** are well documented
- ***Radon gas*** is a natural by-product of the decay of uranium - causes lung cancer
- ***Formaldehyde*** is part of many building materials - causes breathing problems, rashes, headaches etc.
- ***Cleaning products*** also contaminate the air - cleaning products, carpet adhesive, aerosol sprays, mothballs

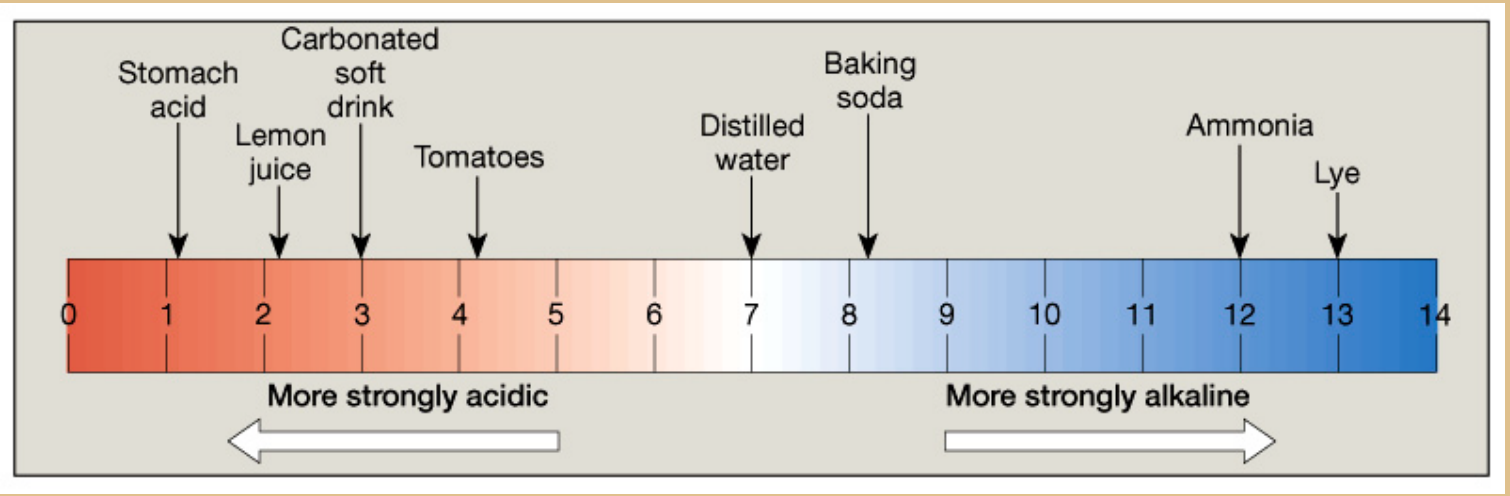
Air Quality Index

- Air Quality Index (AQI)
- How clean or polluted is the air today?
- Meteorological factors are important.

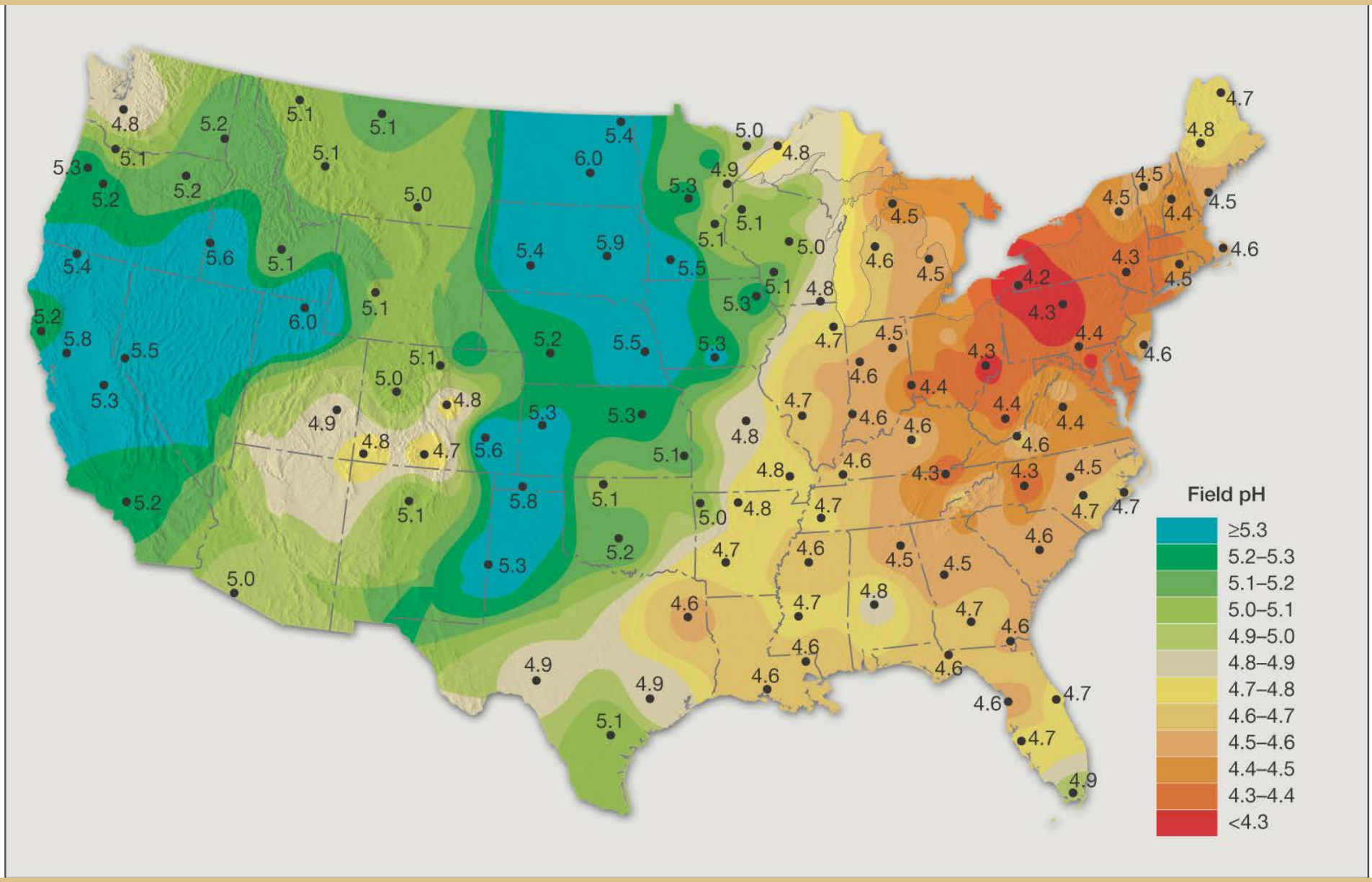


Acid Precipitation

- 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]



Acid Precipitation

- Swimming pools should be operated at pH levels between 7.2 and 7.6 - rain water is not a good thing.
- Acid rain in one country may be caused by pollution emitted by another country upstream of it.
- Taller chimney stacks can help spread the pollution, to solve local problems. However, they just move the problem down-wind.

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

How acid rain effects stone work.
Statute in 1908 (l), Statute in 1968 (r)

London
1973

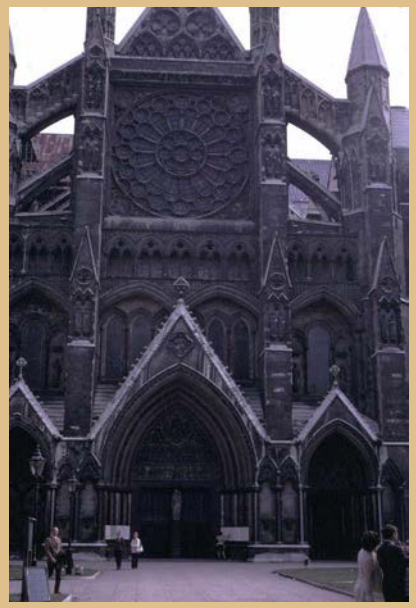
Houses of Parliament

London
2011

Westminster Abbey

London
2011

London
1973



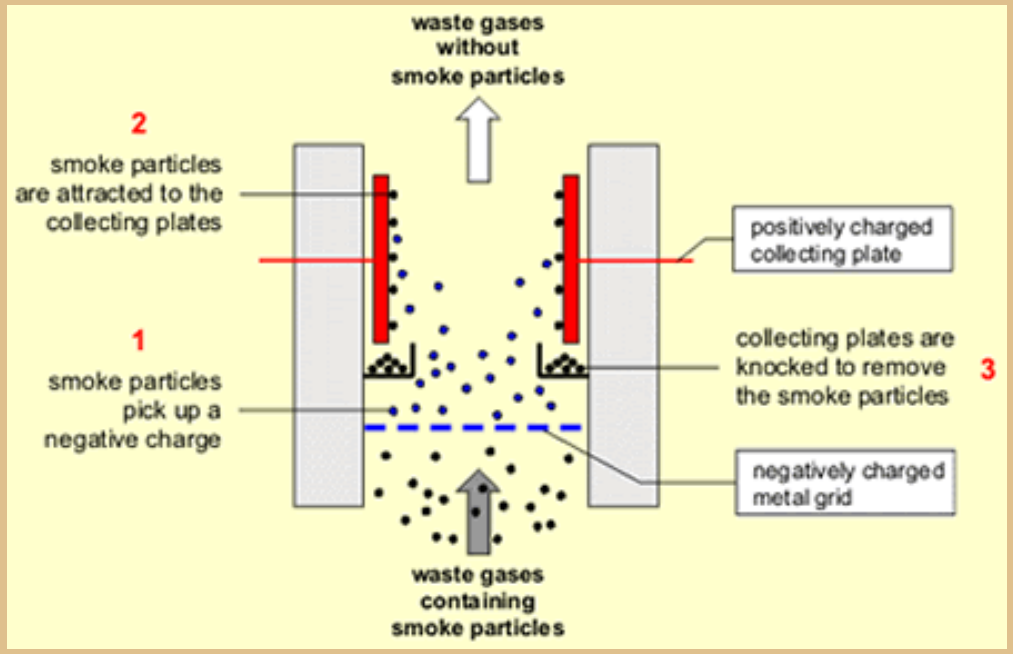
Notre Dame, Paris. Left, restored stone work (white). Right, unrestored stone work (gray).

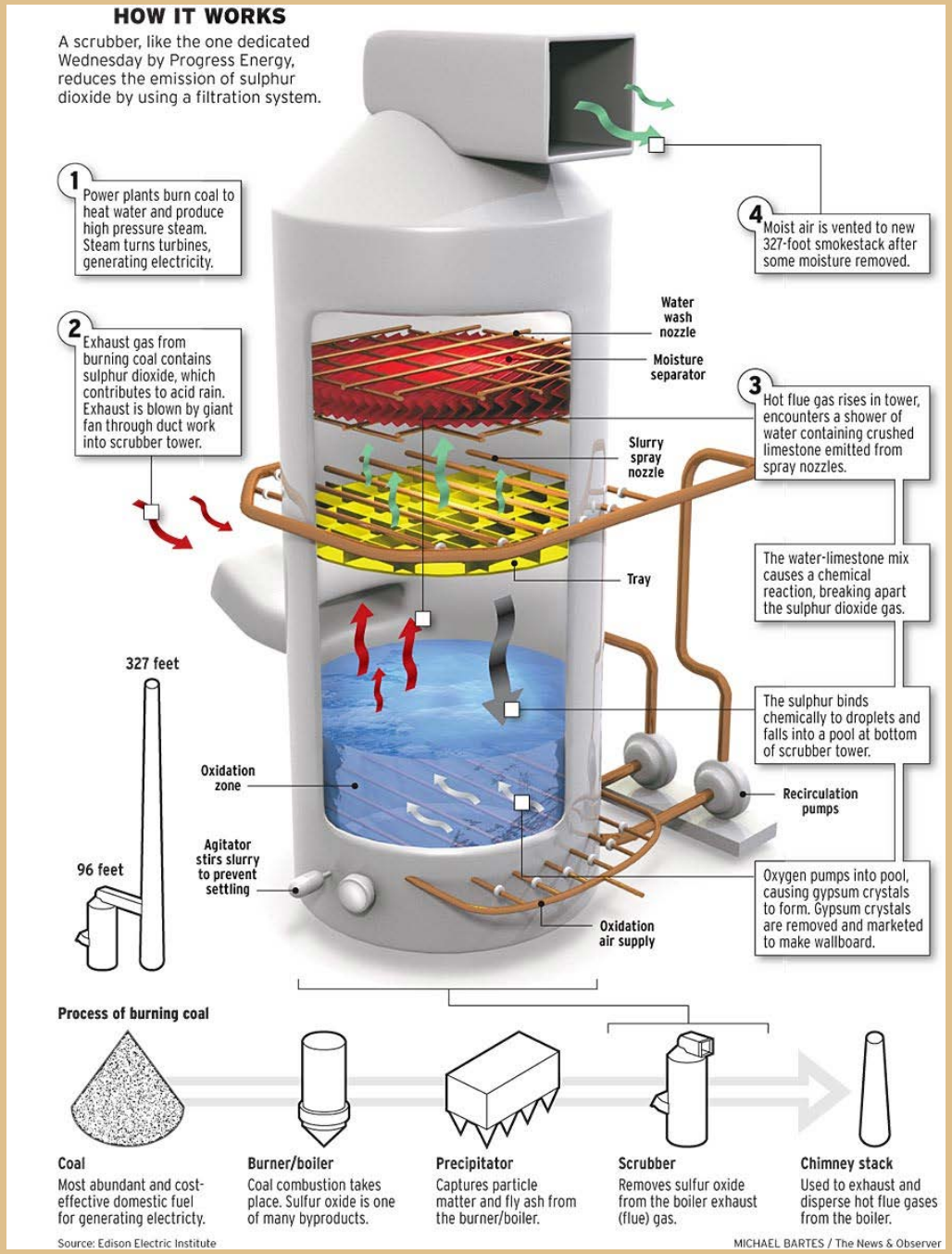
Sand blasting statuary to remove damaged stone work.

Air Pollution Abatement

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

Electrostatic precipitators





Bubblers and Scrubbers