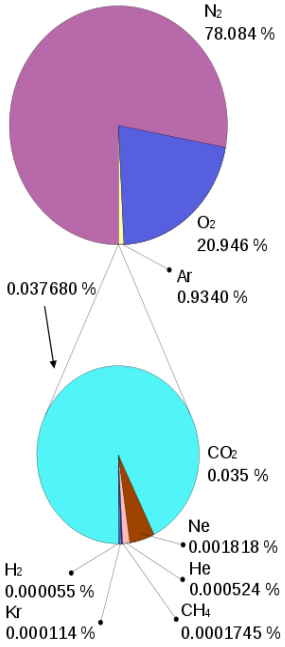
Unit 7: the Atmosphere & Air Quality

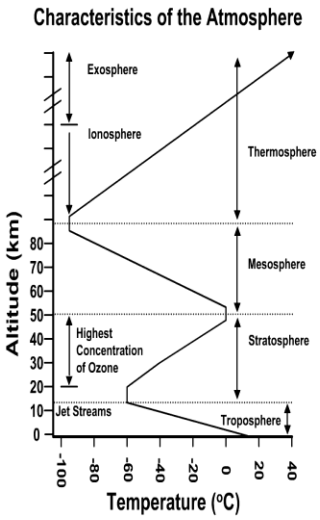
I. Earth Systems & Resources:

B. The Atmosphere

1. **Composition:** Current composition: see figure to the right.
   Historic Composition: See activity, "The Atmosphere & Living Things"



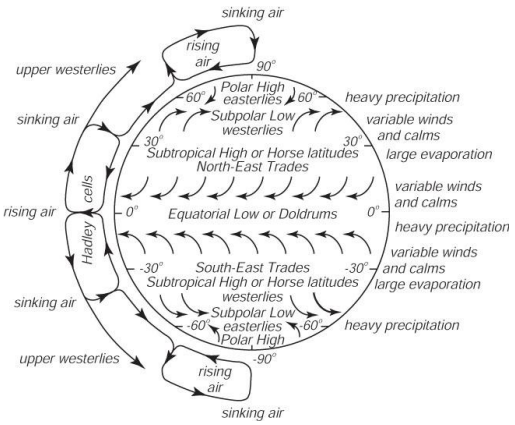
2. **structure;**
   - **a.** More dense near surface of earth –gravity holds molecules down
   - **b.** Divided into layers based on changes in temperature



   - **i.** Troposphere
     1. Closest to Earth's surface.
     2. Weather takes place
     3. Colder as altitude increases
     4. Top = "tropopause"
     5. Highest concentration of particles
   - **ii.** Stratosphere
     1. Jet airplanes fly here
     2. Ozone Layer – O_3 absorbs UV rays→ layer gets hotter as altitude increases
     3. Uppermost portion called "stratopause"
   - **iii.** Mesosphere
     1. Coldest layer
   - **iv.** Thermosphere
     1. Highest layer
     2. Hottest layer – photons from the sun are slowed as they hit the molecules in the upper atmosphere (friction)
     3. Ionosphere – layer where Northern Lights takes place; meteor showers
     4. Exosphere – Space. (sometimes considered its own layer)

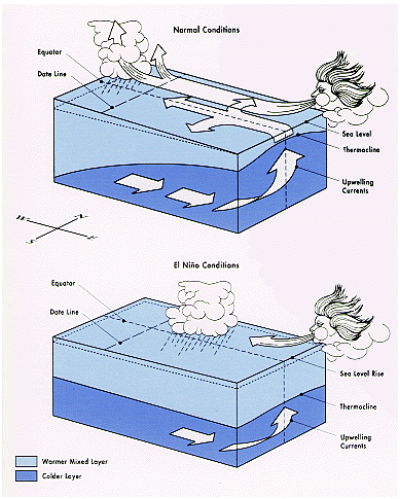
3. **weather & climate;**
   - **a.** Weather = short-term patterns (rain, snow, sunny, hail, sleet, cloudy, etc)
   - **b.** Climate = long-term weather conditions (based on temperature & precipitation)

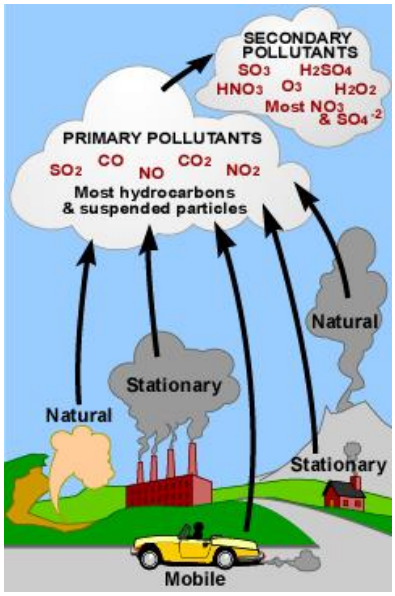
4. **atmospheric circulation & the Coriolis Effect**
   - **a.** Air over Earth is fluid – moves as a result of the Earth's rotation
   - **b.** Air rises at 0° & 60° N & S latitude; sinks at 30° & 90° N & S latitude. Called "convection cells / currents"
   - **c.** Winds are named based on the direction of origin:
     - **i.** North East Tradewinds – 0° → 30° N – winds originate in the northeast & move southwest.
     - **ii.** South-East Tradewinds - 0° → 30° S – winds originate in the southeast & move northwest.
     - **iii.** Westerlies: 30° N (or S) → 60° N (or S) – winds originate in the west & move east.
     - **iv.** Polar Easterlies: 60° N (or S) → 90° N (or S) – winds originate at the poles & move west



   - **d.** Northern Hemisphere = clockwise rotation; Southern Hemisphere = counterclockwise rotation (related to ocean currents)
   - **e.** Coriolis Effect: apparent curvature of winds – reason missiles will "bend" as they travel. Helps meteorologists predict weather movelemtn (hurricanes/tornadoes).

5. **atmosphere-ocean interactions**: winds create surface currents on the ocean.
6. **ENSO**: El-Nino Southern Oscillation
   - **a.** SE tradewinds off the western coast of S. America weaken, causing the Pacific Current to weaken.
   - **b.** Warm waters usually pushed toward Indonesia are not pushed, resulting in warm water throughout the region.
   - **c.** Occurs every 3-5 years
   - **d.** No clear reason why this occurs.
   - **e.** Impact on weather:
     - **i.** Western S. America = wetter than usual
       1. Weakening upwellings off coast; fishing is more common
     - **ii.** SW US & Midwest = heavy rains & intense storms. (La Nina = extremeb heat & dry weather)
     - **iii.** NW US = warmer & drier.
     - **iv.** Australia & Indonesia = droughts





VI. Pollution (25-30%)

A. Pollution Types

1. Air pollution

a. Sources-primary and secondary;

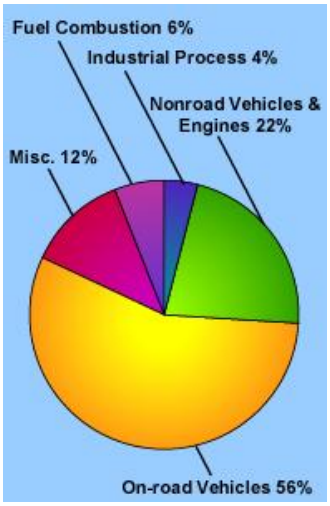
1. Primary: pollutants that are emitted into the atmosphere directly from the source of the pollutant & retains the same chemical form.

Examples: particulates (soot, pollen, SO_x, CO_2, etc)

2. Secondary: pollutants formed by atmospheric reactions of precursors or primary emissions – they undergo a chemical change once they reach the atmosphere.

Examples: ozone (NO_x + VOCs, in the presence of sunlight, → ozone), smog.

3. Other Notes: secondary are often more problematic to regulate because mitigation of secondary pollutants requires the identification of the precursor compounds & their sources as well as an understanding of the specific chemical reactions that result in their formation



b. major air pollutants;

1. Biogenic sources: natural sources (volcanoes spew particulate matter & SO_x; swamps emit H_2S; lightning strikes set forest fires – smoke, CO_2; VOCs – naturally from plants; pollen; wind storms generate dust)
2. Anthropogenic sources: man-made sources.
    1. Mobile sources –transportation (cars, airplanes, motorcycles, tractors, etc) Account for more than 50% of the air pollution in the US. (which is 70-90% less than it was in 1970 per mile driven)
        1. Perfect combustion: C_xH_y (fuel – hydrocarbon) + $O_{2\ (air)}$ → $CO_{2(g)}$ + $H_2O_{(g/l)}$ + unaffected nitrogen
        2. Typical engine combustion: C_xH_y (fuel – hydrocarbon) + $O_{2\ (air)}$ → unburned C_xH_y+ NO_x + CO + $CO_{2(g)}$ + $H_2O_{(g/l)}$
    2. Stationary sources
        1. Power generating: coal, oil, natural gas power plants.
        2. industrial facilities: oil refineries, chemical manufacturing plants, smelters
    3. Point Source (aka. Emission point) – a fixed point (smokestack, storage tank) – you can "point" to the source.
    4. Nonpoint (area) source – a series of small sources that together cause a problem (community of homes that burn their trash)
3. Two basic physical forms of air pollutants:
    1. Particulate matter (small solid & liquid particles including dust, smoke, sand, pollen, mist & fly ash (ash given off while burning))
    2. Gases (CO, SO_2, NO_2, VOCs, etc)
4. The EPA has classified ambient air pollutants for regulatory purposes as hazardous air pollutants (HAPs) & criteria pollutants (ambient air is air to which the general public has access) Criteria pollutants include:

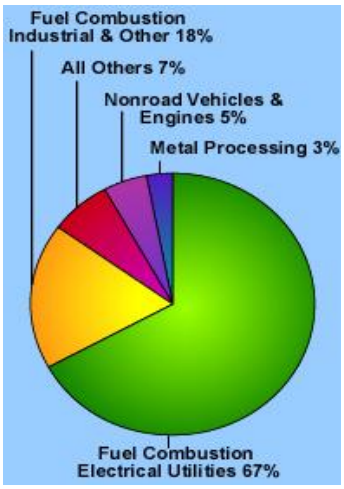


Table 1: Sources, Health and Welfare Effects for Criteria Pollutants.

Pollutant	Description	Sources	Health Effects	Welfare Effects
Carbon Monoxide (CO)	Colorless, odorless gas	Motor vehicle exhaust, indoor sources include kerosene or wood burning stoves.	Headaches, reduced mental alertness, heart attack, cardiovascular diseases, impaired fetal development, death.	Contribute to the formation of smog.
Sulfur Dioxide (SO_2)	Colorless gas that dissolves in water vapor to form acid, and interact with other gases and particles in the air.	Coal-fired power plants, petroleum refineries, manufacture of sulfuric acid and smelting of ores containing sulfur.	Eye irritation, wheezing, chest tightness, shortness of breath, lung damage.	Contribute to the formation of acid rain, visibility impairment, plant and water damage, aesthetic damage.

Nitrogen Dioxide (NO_2)	Reddish brown, highly reactive gas.	Motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels.	Susceptibility to respiratory infections, irritation of the lung and respiratory symptoms (e.g., cough, chest pain, difficulty breathing).	Contribute to the formation of smog, acid rain, water quality deterioration, global warming, and visibility impairment.
Ozone (O_3)	Gaseous pollutant when it is formed in the troposphere.	Vehicle exhaust and certain other fumes. Formed from other air pollutants in the presence of sunlight.	Eye and throat irritation, coughing, respiratory tract problems, asthma, lung damage.	Plant and ecosystem damage.
Lead (Pb)	Metallic element	Metal refineries, lead smelters, battery manufacturers, iron and steel producers.	Anemia, high blood pressure, brain and kidney damage, neurological disorders, cancer, lowered IQ.	Affects animals and plants, affects aquatic ecosystems.
Particulate Matter (PM)	Very small particles of soot, dust, or other matter, including tiny droplets of liquids.	Diesel engines, power plants, industries, windblown dust, wood stoves.	Eye irritation, asthma, bronchitis, lung damage, cancer, heavy metal poisoning, cardiovascular effects.	Visibility impairment, atmospheric deposition, aesthetic damage.

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c. measurement units:

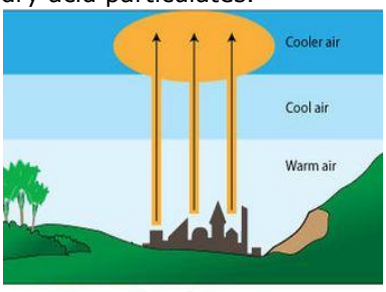
1. micrograms per cubic meter ($\mu g/m^3$)
2. parts per million (ppm) - # of molecules that are pollutants per million molecules of a sample.
3. Parts per billion (ppb) - # of molecules that are pollutants per billion molecules of a sample.
4. PM-10 – measures diameter of particulate matter in microns (micrometers = $1x10^{-6}m$). PM-10 = diameter of particulate is less than 10 μm. (Also, PM-5, PM-2.5, etc. smaller # = finer particle)

d. smog; Two types.

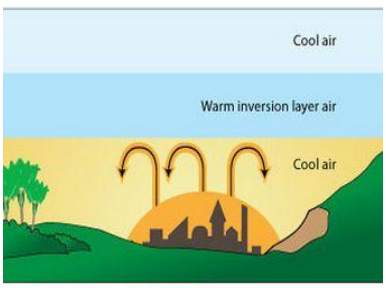
1. Industrial Smog: smoke + SO_2 from industrial processes (i.e. burning coal – 70% of SO_2) combine with fog. Yellowish-black in color.
2. Photochemical Smog: NO_x + VOCs (from burning fossil fuels – specifically in cars) interact in the presence of sunlight. Creates ground-level ozone. Brownish haze, especially a problem in cities in the summer (many cars, lots of sunlight).
3. Negative effects: makes it hard for people to breathe – esp. sensitive groups. Interferes with plants' ability to produce & store food and makes them more susceptible to weather, disease & pests. Increases global temperatures.
4. Ways to reduce impact: reduce the need for fossil fuels. How? Reduce the products needed to be generated; reduce oil use (carpool, combine trips, tune-up cars, fuel efficient cars, catalytic converters); better scrubbers on coal-burning power plants (reduces SO_2)
5. Factors that affect severity: dense population; topography of land & climate; types & amounts of fuels used by industry, heating, transportation; amount of industry

e. acid deposition-causes and effects; Includes acid rain, snow, sleet, etc & dry acid particulates.

1. Causes: emissions of SO_2 & NO_x react with water, O_2, & oxidants to form acids.
2. Effects: acidification of soil & surface water.
    1. Lower pH kills microorganisms & fish.
    2. Reacts with marble on buildings causing building damage.
    3. Leaches toxic metals (Pb & Cu) from water pipes
    4. Leaches heavy metals (Hg, Al, Cd) from underlying rock
    5. Leaches essential nutrients (Ca & Mg) from soil, reducing productivity
    6. Weakens trees & plants (more susceptible to disease)
3. General Notes: Because it takes so long for the reaction to occur, acid deposition spreads over hundreds of miles.
4. How it's measured: pH scale. Natural rainwater's pH = 5.6 (b/c of N, S & C in the air naturally – volcanoes, decomposition, etc)
5. pH = 4.2-4.7 = acid deposition
6. How to reduce effects: natural buffers (limestone keeps pH up); tall smokestacks (pollutants are released above wind inversions
7. Things that increase effects of acid deposition: geography = downwind of industrial coal burning plant or large city; mountain ranges have thinner soil (no buffering)



Normal pattern



Thermal inversion

f. heat islands and temperature inversions;

1. Heat Islands: Because of the lack of plants (which absorb heat) and the increase of hardscapes that tend to be dark in color (roof tops, asphalt, roads, etc) cities tend to absorb heat more than rural areas. Also, tends to be an increase in greenhouse gases (because of burning fossil fuels in transportation & for energy production) which absorbs heat.
2. Temp / Thermal Inversions: Found in areas surrounded by mountains where it doesn't rain much & the air doesn't have much of an opportunity to turn over. Usually warm air is found at the surface of earth with a cooler air mass positioned above. In some instances, the air masses are inverted – the warm air sits on top of the cooler air, causing the air close to the surface of earth not to move. This holds in pollutants because air does not get carried away & pollutants do not wash out.
    1. Notable examples: Los Angeles in the 1980's (led to CA Emissions Standards on passenger vehicles); Salt Lake City, Utah 2013 (air quality is so bad it's like smoking a pack of cigarettes/day for otherwise healthy people – has resulted in reproductive problems)

g. indoor air pollution;

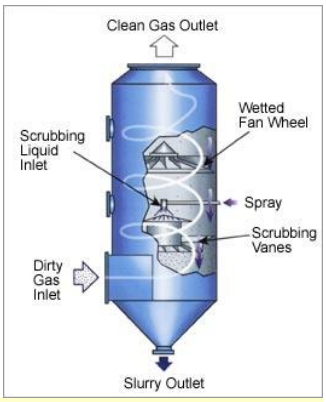
1. Worse than in the past due to improved insulation (air pollutants get into house & don't escape)
2. "Sick Building Syndrome" – indoor pollutants reach a level that makes people sick.

Pollutant	Source	Effect on Humans	Methods of Prevention or Clean-Up
Asbestos	Insulation, floor & ceiling tiles, spray-on fire retardant, roof shingles	Lung cancer, lung disease, mesothelioma, asbestosis	Removal, encapsulation
CO & CO_2	*See Table 1*		
Tobacco Smoke	Cigarettes, cigars, pipe smoking, etc	Cancer (lung, mouth, throat, bladder), respiratory problems, heart disease, emphysema	Stop smoking, ban indoor smoking; improved ventilation
Formaldehyde	Furniture stuffing, paneling, particle board, foam insulation, new furniture, plywood, carpeting	Irritation of eyes, nose, throat, skin, & lungs, nasal & lung cancer, nausea, asthma	Improved ventilation, alternative building materials
Radon	Radioactive soil, rock, foundations & building materials; U deposits	Lung cancer	Improved ventilation; fix cracks in foundation
Arsenic	Smoking, pesticides	Toxic, Carcinogen	Improved ventilation; stop smoking; alternative pesticides
Bacteria	Air-handling systems; damp building materials, furnishings	Bacterial diseases & infections (Legionnaires, strep, etc)	Improved ventilation; humidity control; maintenance of filter systems
Fungi (mold spores)	Air-handling systems; damp building materials, furnishings	Respiratory irritant; aggravates asthma; allergic reactions	IV; humidity control, maintenance of filter systems
Lead Particulates	Pb paint particulates (dust); smelters; contaminated soil; exhaust from leaded gasoline (banned in US)	Impaired mental & physical development; fatigue, headache; muscular tremor; clumsiness; memory loss; convulsions; miscarriage/premature birth; anemia	IV; alternate paints; indoor filtering systems; sealing old paints; smelter filter systems; alternative gasoline source
Mercury	Fungicides; fossil fuel combustion, thermometers, thermostats	Nervous system damage; carcinogen	IV; alternate fungicides; alternate energy source
Methane / Propane	Leaking natural gas lines & appliances; leakage from underground tanks or landfills; anaerobic sewer backup	O_2 deficiencies (headaches, drowsiness, irregular heartbeat, fatigue, impaired vision, confusion, nausea)	IV; sealing leaks; sealing foundations, maintenance of sewer lines/drains
NO_2	**See Table 1**		
Ozone	Photocopiers; electrostatic air cleaners (Ionic Breeze); outdoor air; electrical equipment	Respiratory irritant, fatigue; asthma; mucous membrane irritant	IV; reduce NO_x & VOCs

Particulates	*See Table 1*		
Volatile Organic Compounds	Tobacco combustion; burned food; paints; solvents; cleaning products; carpets; draperies; clothing; furniture; varnishes	Respiratory & mucous membrane irritant, possible carcinogen	IV; reduce tobacco use; alternate products; air filtering

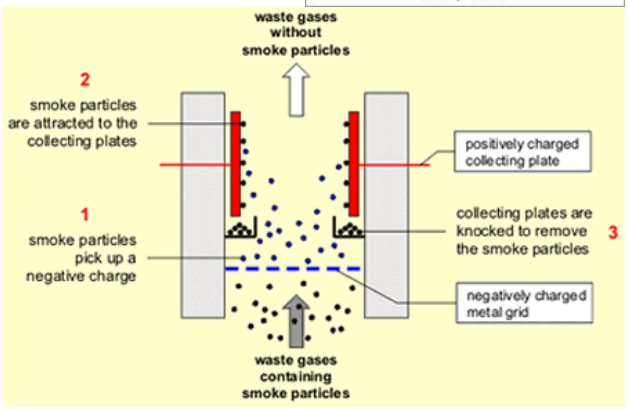
h. remediation and reduction strategies – see tables above

1. Coal – cleaning before burning
2. Taller smokestacks
3. Scrubbers – washes the air with limestone slurry as it leaves the smokestacks
4. Precipitators – electric charges attract particulate matter



i. Clean Air Act

1. 1970: Established national primary & secondary air quality standards; required states to develop implementation plans.
    1. Requires states to identify, monitor & reduce air contaminants
    2. Seven major "criteria pollutants" identified (SO_x, Pb, CO, NO_x, particulates, VOCs & metals & Halogens (i.e. Hg & Br-compounds))
    3. 1990 revision included CO_2 & SO_2 emission reduction
    4. Problems with CAA:
        1. Continued reliance on cleanup instead of prevention
        2. Doesn't regulate two-cycle gasoline engines (lawn mowers, leaf blowers, etc)
        3. Allows emission trading (Cap & Trade) which allows the most polluting companies to buy & sell pollution rights



j. other relevant laws:

1. National Environmental Policy Act (NEPA): 1) authorizes Council on Environmental Quality; 2) directs federal agencies to take environmental consequences into account in decision making; and 3) requires an environmental impact statement (EIS) be published for every major federal project likely to have an impact on environmental quality

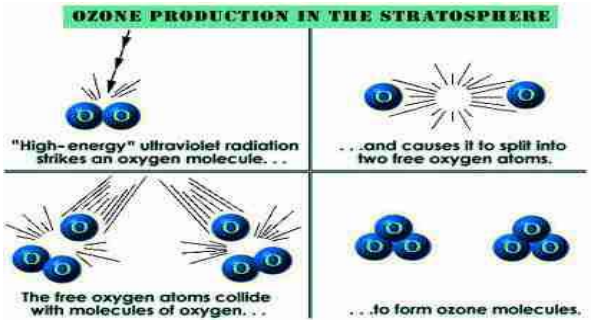
2. Noise pollution

a. Sources; engines (cars, trains, airplane engines); loud stereos; factory equipment
b. effects; general annoyance; high blood pressure; lack of sleep
c. control measures: laws in place to reduce noise; fines for breaking noise threshold

VII. Global Change (10-15%)

A. **Stratospheric Ozone**: ozone layer – large concentration of O_3 molecules (good ozone). Necessary for life on Earth.

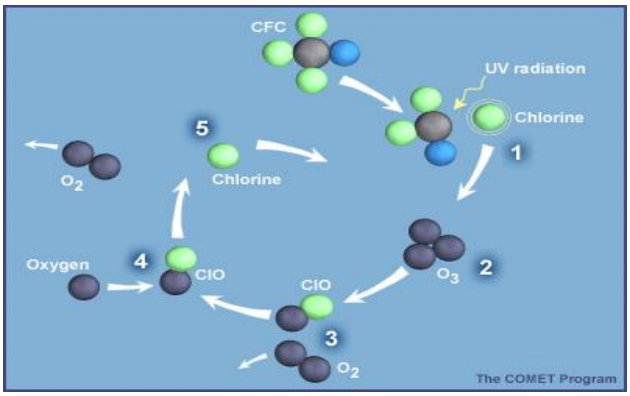
a. **Formation of stratospheric ozone**;
    i. when hit with UV radiation: $O_3 \rightarrow O_2 + O$ OR $O_2 \rightarrow 2O$
    ii. $O + O_2 \rightarrow O_3$ (O does not like to exist alone; very quickly reacts to form either O_2 or O_3 molecules)
    iii. Most O_3 production happens near equator
    iv. Measured in Dobson Units (1 DU = 0.01 mm thick layer of O_3 → 300 DU is typical value (3mm))



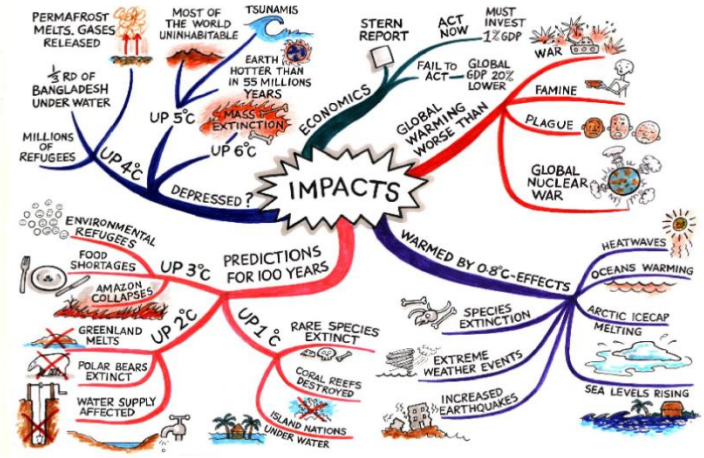
b. **ultraviolet radiation**;
    i. Source: the sun
    ii. Damages skin & plant tissue (high levels over Antarctica could kill plankton)

c. **causes of ozone depletion**;
    i. Chlorine-based aerosols (esp CFCs) reacted with O_3 molecules in the ozone layer to break them down into O_2 molecules
    ii. Cl free radicals are persistent – one Cl could "kill" thousands of O_3 molecules.
    iii. "Hole" in the ozone layer discovered in 1985 over the south pole (indicators of a problem had been in place since the 1960s, but were ignored)

d. **effects of ozone depletion**;
   i. skin cancer, cataracts, kills plant tissue
   ii. Big problem in areas near the hole in the ozone layer (Australia)
e. **strategies for reducing ozone depletion**;
   i. Banned CFCs
   ii. Replaced CFCs with HCFCs which still release Cl, but only half as much
   iii. Slowly recovering – should be back to normal by 2049
f. relevant laws and treaties
   i. Montreal Protocol (1987) banned use of most CFCs by 2000.



B. Global Warming: Heating of the Earth's average temperature; leads to global climate change
a. **Greenhouse gases** : heat is trapped & stored within the molecule's bonds
   i. Carbon Dioxide (CO_2)
      1. Most abundant
      2. Source: incomplete combustion of gasoline
   ii. Nitrogen Oxides (NO_x)
      1. Absorbs more heat than other GHGs / molecule
      2. Source: combustion of gasoline (vehicle emissions)
      3. Generates ozone which also absorbs heat
   iii. Methane (CH_4)
      1. Source: anaerobic respiration (particularly a problem with cattle raising & dairy production)
   iv. Chloroflurocarbons (CFC's or CCl_2F_2)
      1. Solely anthropogenic source
      2. Source: aerosol containers, refrigerants, air conditioners, styrofoam inflation
      3. Led to the depletion of the ozone layer (NOT b/c it's a GHG!)
   v. Water (H_2O)
      1. #1 greenhouse gas – life on earth wouldn't exist without it
      2. Regulates climate
      3. Not always considered a GHG
   vi. Ozone – sometimes considered a GHG (not always) **NOT the same as O_3 in the ozone layer!
      1. Source: secondary pollutant from reactions with NO_x + VOCs + sunlight
b. **the greenhouse effect**: the atmosphere traps heat close to the earth the way a greenhouse traps heat (the fact that the Earth gets hotter is called Global Warming)
c. **impacts and consequences of global warming**;
   i. Acidification of soil / water
   ii. Changes in weather patterns
   iii. Displacement of people
   iv. Ecological productivity reduced
   v. Forest fires worsened
   vi. Glacier melting
   vii. Increased health & behavioral effects
   viii. Increase in disease
   ix. Increased property loss
   x. Loss of economic development
   xi. Loss of biodiversity
   xii. Released methane bubbles as ice melts
   xiii. Rise in sea level
   xiv. Slowing of Thermohaline Circulation (THC) – ocean current recirculation



d. **reducing climate change**;
   i. Reduce GHGs – personal use; laws; alternative energy sources
e. relevant laws and treaties: Kyoto Protocol (1997) agreement among industrialized nations to reduce GHG Emissions by 5.2% compared to 1990 readings (compared to the emissions levels that would be expected by 2010 w/out the Protocol, this target represents a 29% cut). Goal: Lower GHG emissions from 6 GHGs (CO_2, CH_4, NO_x, SF_6, HFCs, PFCs) between 2008-2012. US signed w/ Clinton, but didn't ratify under GW Bush.