CLASSIFICATION OF THE MAIN POLLUTANTS. EMISSIONS SOURCES

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Saulius Vasarevicius, VGTU

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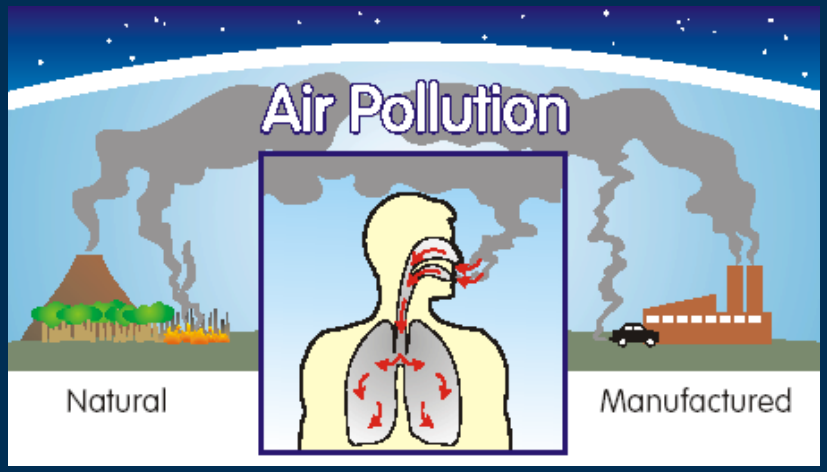
- Air pollution is the human introduction of chemicals, particulate matter, or biological materials that cause harm or discomfort to humans or other living things.
- Air pollution can also cause damages to the natural environment and to the atmosphere.



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Air pollution may be defined as any atmospheric condition in which *substances* are present at concentrations high enough above their normal ambient levels to produce a *measurable effect* on man, animals, vegetation, or materials.

Substances mean any natural or anthropogenic (man-made) chemical compounds capable of being airborne. They may exist in the atmosphere as gases, liquid drops, or solid particles.

- Measurable effects on humans and environment due to:
- 'indoor' air pollutants ,
- air toxics, radioactivity
- urban photochemical smog,
- acid rain, visibility reduction,
- greenhouse warming,
- depletion of the ozone layer,
- climate forcing due to anthropogenic atmospheric aerosols.

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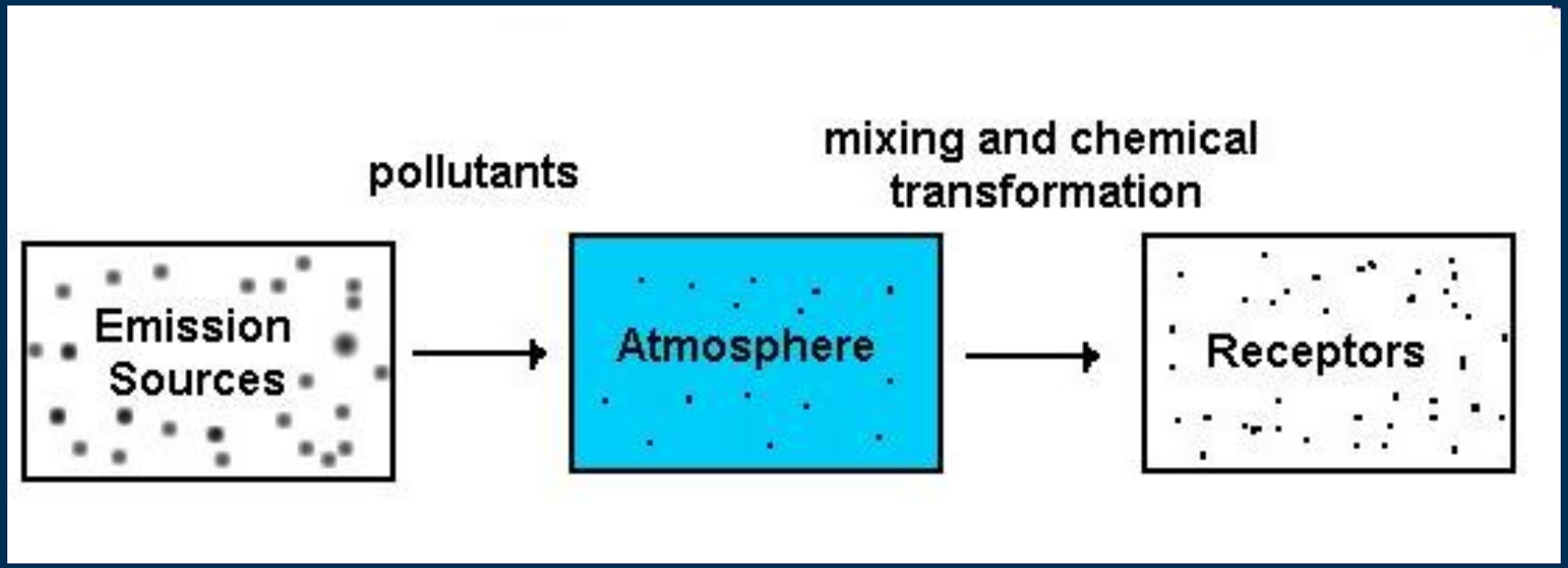
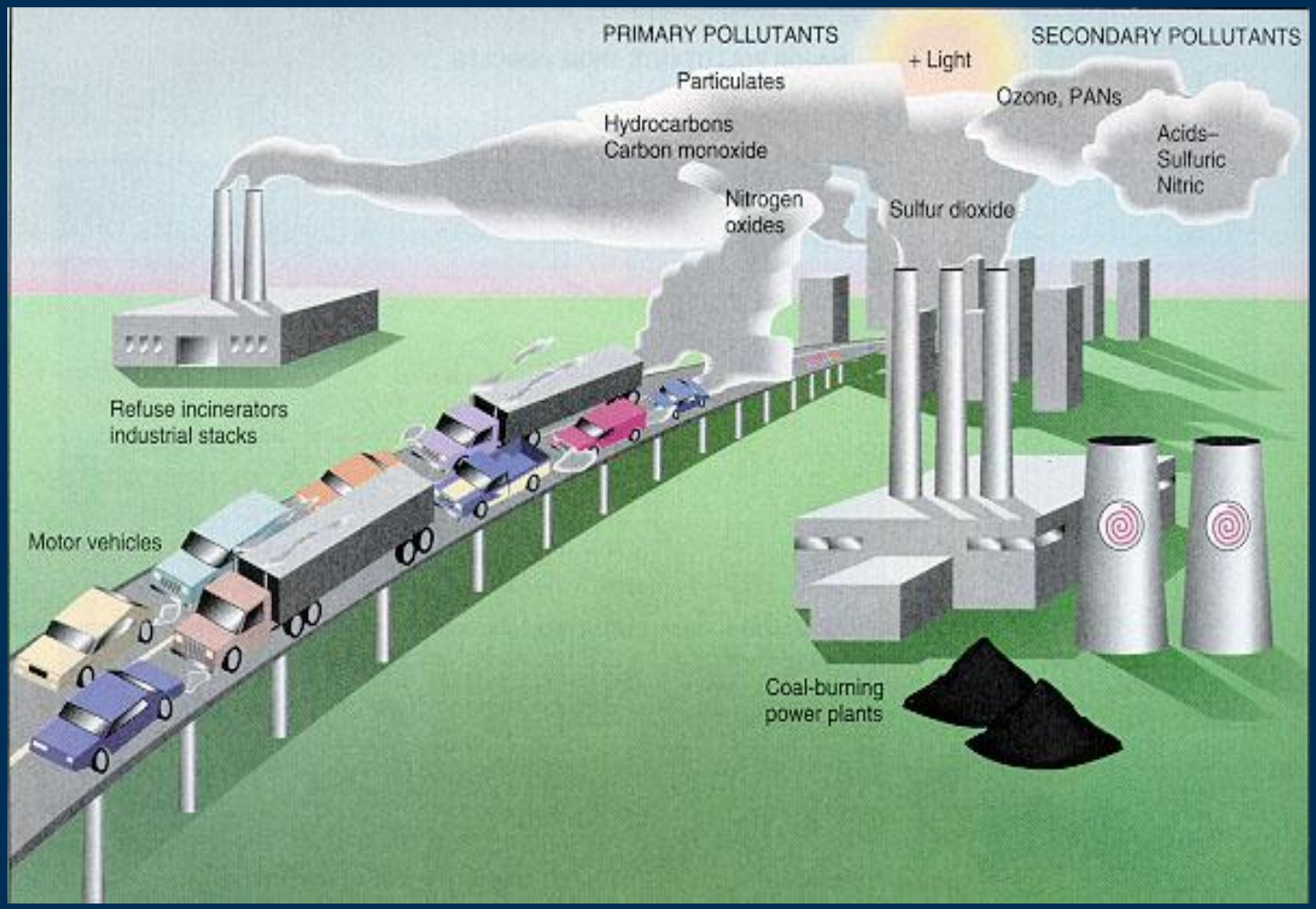
The air pollution problem can be schematically presented as a system consisting of three basic components:



- **Major emission sources:**
- Transportation;
- Industrial and domestic fuel burning;
- Industrial processes.
- **Receptors:**
- Humans;
- Animals;
- Plants;
- Materials.
- **Atmosphere**
- acts as a medium for transport and dispersion,
- physical and chemical transformations

Air Pollution System



AVERAGE COMPOSITION OF THE ATMOSPHERE

Element	Parts per Million
Nitrogen	780,800
Oxygen	209,500
Argon	9,300
Carbon Dioxide	300
Neon	18.2
Helium	5.2
Krypton	1.1
Hydrogen	0.5
Nitrous Oxide	0.5

Air pollution classification.

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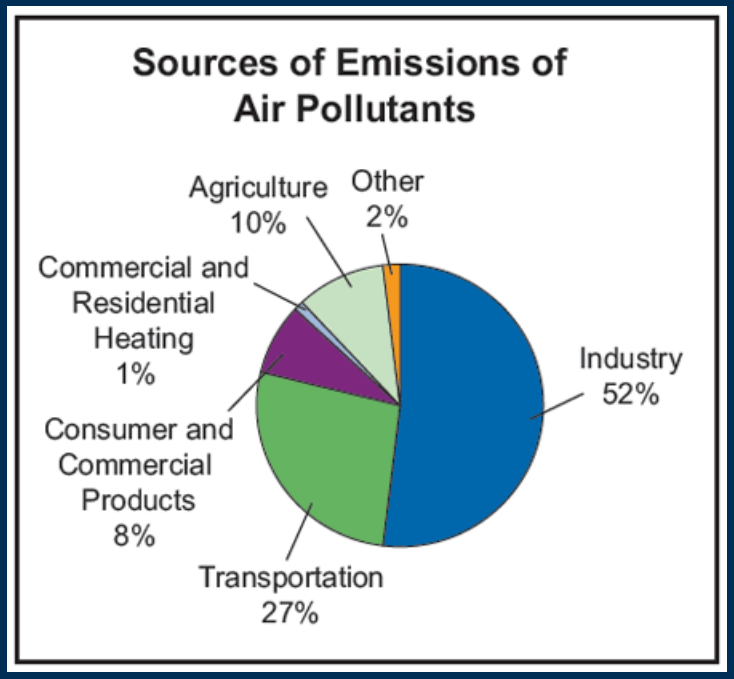
according to chemical composition:

- Sulfur-containing compounds.
- Nitrogen-containing compounds.
- Carbon-containing compounds.
- Halogen-containing compounds.
- Toxic substances (any of about).
- Radiative compounds.

according to physical state:

- Gaseous.
- Liquid (aqueous).
- Solid.



- Air pollution can come from a variety of sources including natural sources and manufactured sources.
- Natural sources include forest fires and volcanoes, while cars, trucks, trains, planes, boats, factories, and power plants contribute to air pollution through manufactured sources.
- Air pollution can even come from smaller, everyday activities such as dry cleaning, filling your car with gas, and painting.

- **<u>according to the manner in which they reach the atmosphere:</u>**
- Primary pollutants (those emitted directly from the sources).
- Secondary pollutants (those formed in the atmosphere by chemical interactions among primary pollutants and normal atmospheric conditions).

- **<u>according to the space scales of their effects:</u>**
- Local (or indoor).
- Regional.
- Global.

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The main pollutants for which ambient air standards have been set to protect human health and welfare:

- Ozone, O3.
- Carbon monoxide, CO.
- Sulfur dioxide, SO2.
- Nitrogen oxides, NOx.
- VOCs.
- H. Metals.
- PM.

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- **Major halogen- containing compounds**
- Chlorofluorocarbons, CFCs, are artificial gases, used as the coolants in refrigerators and air conditioners,; they are neither toxic nor flammable. The most abundant CFCs are CFC-11 (or CFCl3), and CFC-12 (or CF2Cl2).
- CFCs are artificial halocarbons, therefor they are not biodegradable. CFCs are not water-soluble, therefore they are not washed from the atmosphere by rain. In the stratosphere, UV radiation destroys CFCs breaking them down to a few chemicals (including atomic chlorine and atomic bromine which efficiently destroy ozone).
- CFCs effects: they are the key greenhouse compounds they lead to reduction of stratospheric "good" ozone

Where do these pollutants come from?

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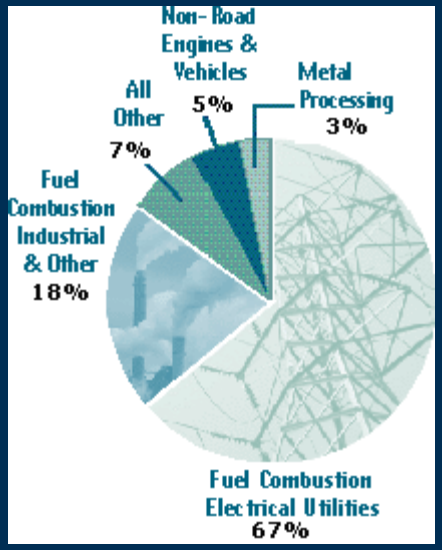
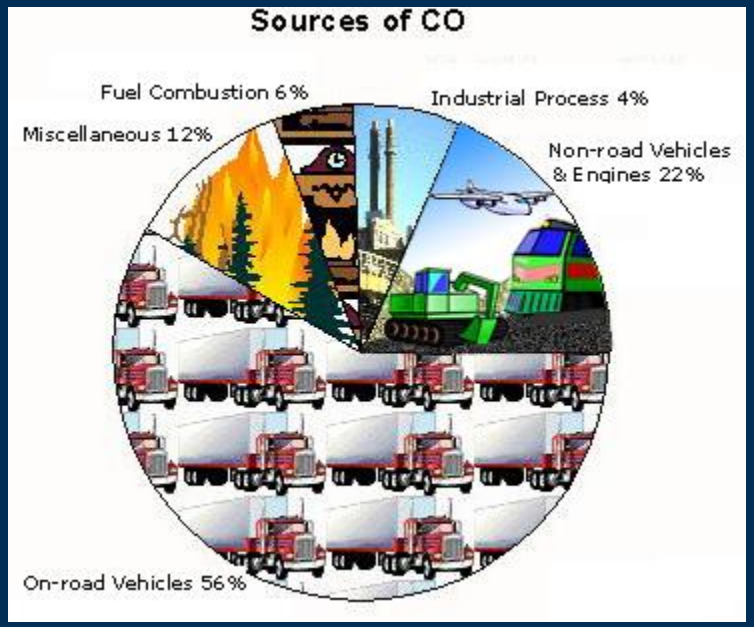
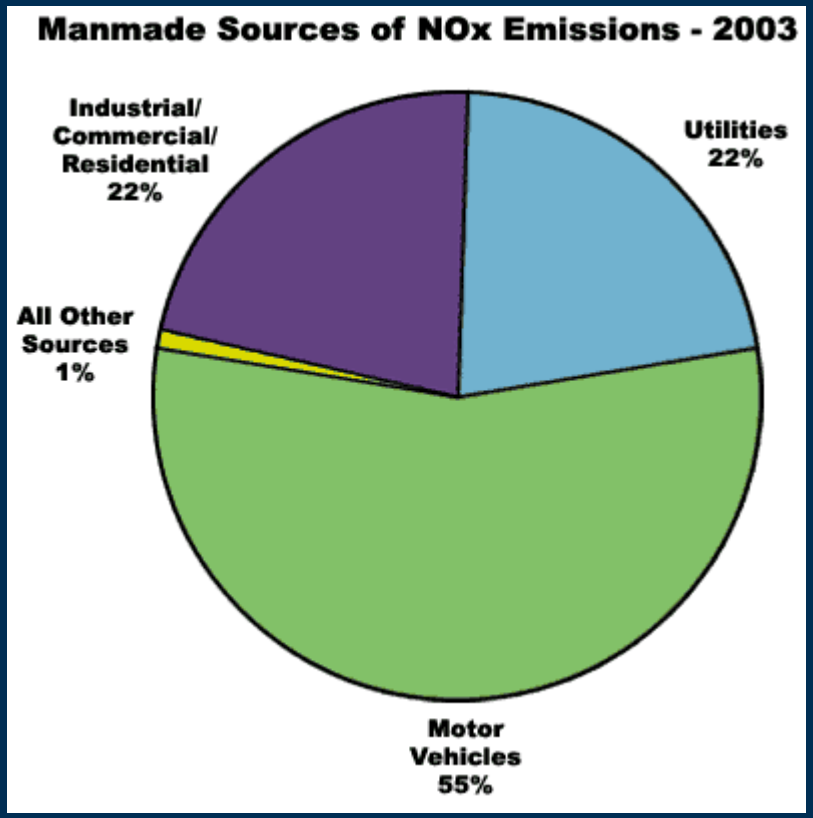
Sulphur dioxide



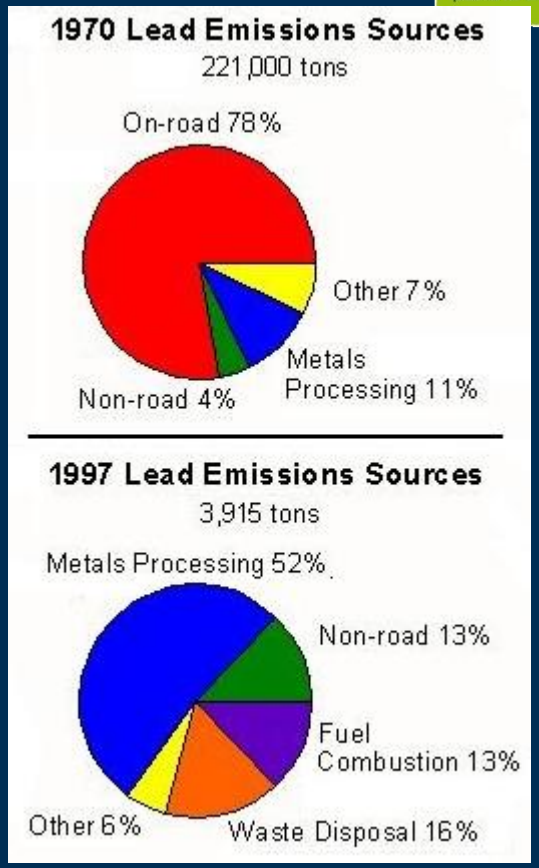
Carbon monoxide



Nitrogen oxides



Lead



Synthetic chemicals deplete stratospheric ozone

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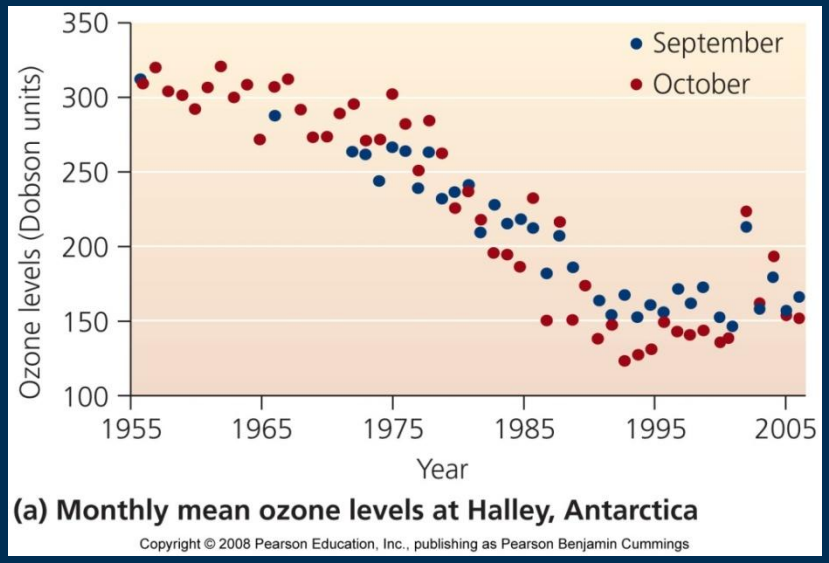
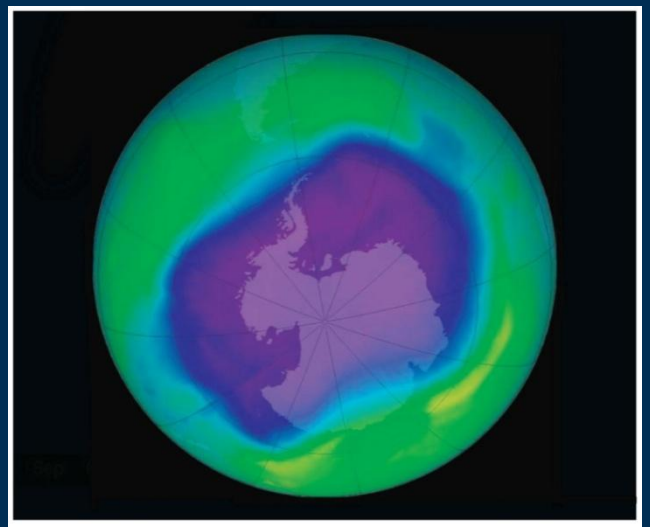
- **Ozone layer** = ozone in the lower stratosphere
- 12 ppm concentrations effectively block incoming damaging ultraviolet radiation
- **Chlorofluorocarbons (CFCs)** = chemicals that attack ozone
- 1 million metric tons/year were produced
- Releases chlorine atoms that split ozone

The hole in the ozone

- **Ozone hole** = ozone levels over Antarctica had declined by 40-60%
- Depletion also in the Arctic and globally
- Causes skin cancer, harms crops and decreases ocean roductivity



(a) Monthly mean ozone levels at Halley, Antarctica

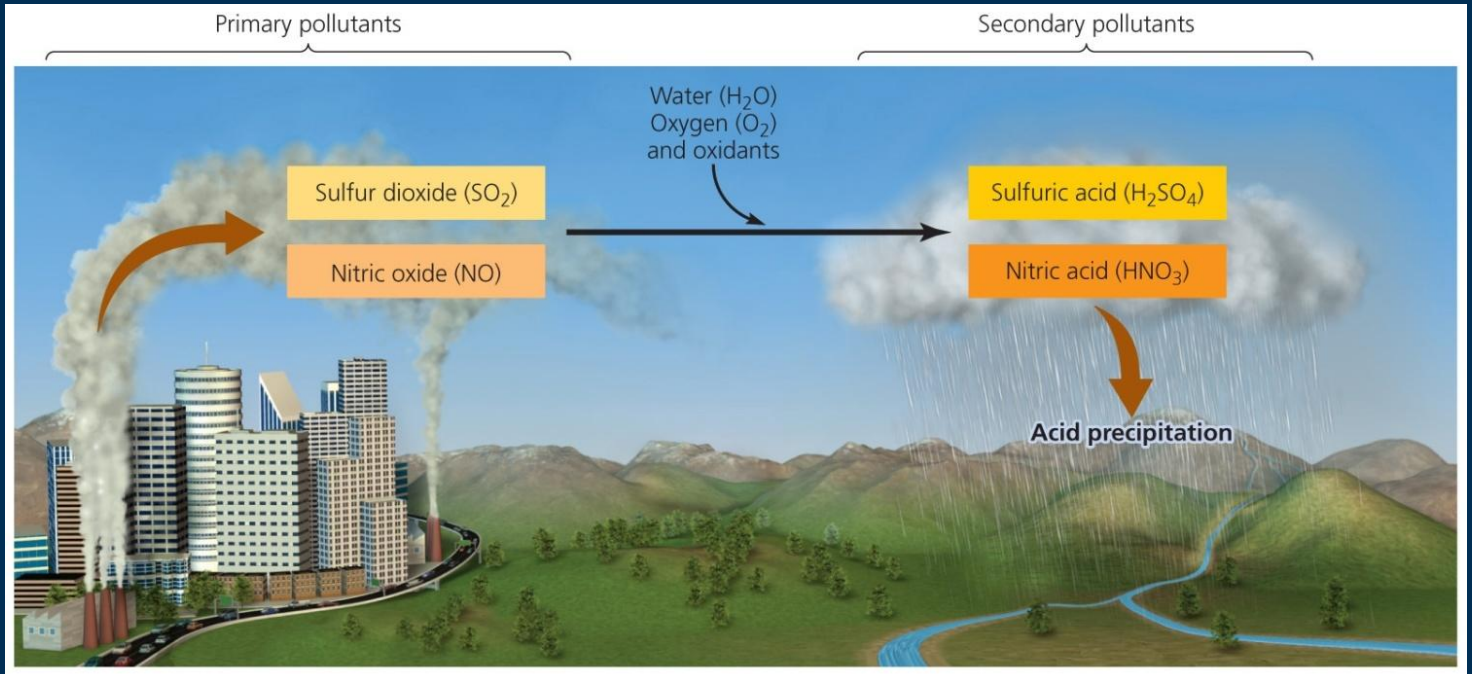


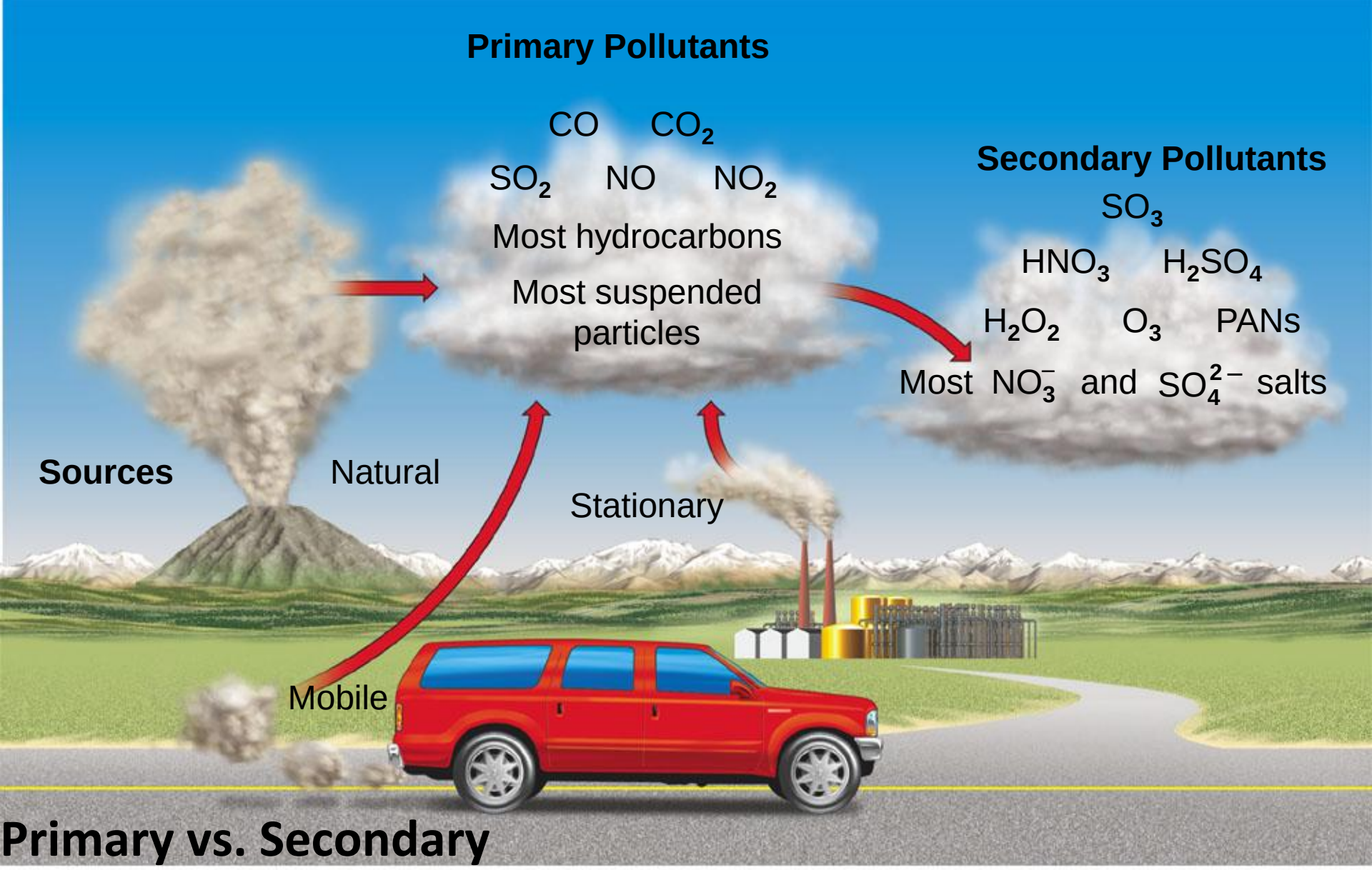
(b) The "ozone hole" over Antarctica, September 24, 2006

- **Acidic deposition** = the deposition of acid, or acid-forming pollutants, from the atmosphere onto Earth's surface
- **Acid rain** = precipitation of acid
- **Atmospheric deposition** = the wet or dry deposition on land of pollutants

Sources of acid deposition

- Originates from burning fossil fuels that release sulfur dioxide and nitrogen oxides
- These compounds react with water to form sulfuric and nitric acids





WHAT ARE EMISSIONS?

- The amount of pollutant(s) a source puts into the air during a fixed time.
- Units: mass/time
- Emissions vary – making air quality management a challenge!

Emissions vary over:
- Time
- Location
- Pollutant

These influence source emissions:
- Source activity
- Economic health
- Population
- Climate
- Controls
- Traffic

Emissions classification

- By pollutant

- By source type

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Classification – by Pollutant

Some general **pollutant** categories include

- **Criteria air** pollutants
- **Criteria Pre-cursor air** pollutants
- **Hazardous Air Pollutants** (HAPs)

Classification – by Source Type

Stationary - sources with a fixed location

- **Point:** usually a large source, often a stack
- **Area:** sources that are considered as a group

Mobile - sources that move

- **On-road:** highway vehicles
- **Non-road:**

  non-highway vehicles

Classification – by Source Type

- Emissions from **source types** modeled differently

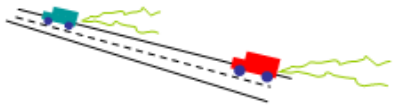
Point source	Gaussian plume model (e.g. ISC-AERMOD)
Mobile source	Roadway models (e.g. CALINE, CAL3QHC)
Area source	Flexible source models (e.g. CALPUFF)

Classification – by Source Type

- Stationary sources
- Mobile sources

Mobile

Mobile source



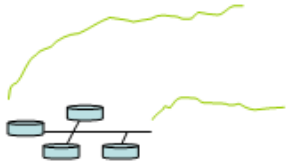
Examples: on-road: gas, diesel; off-road: marine, air, agricultural

Stationary

Point source

Examples: power plant, chemical plant, etc.

Area source

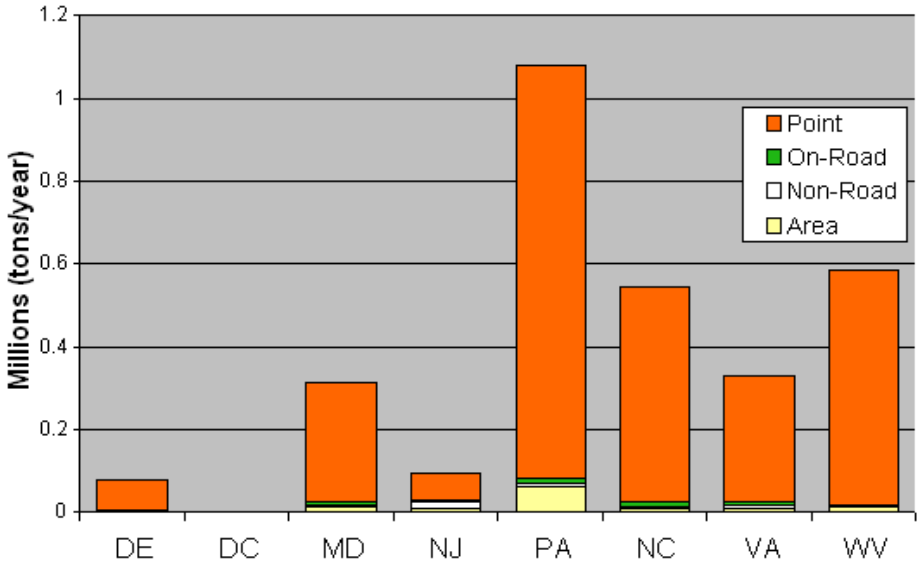


Examples: gas stations, dry cleaners, fireplaces, lawn mowers, tanks farms, etc.

Emission Classification Sulfur Dioxide (SO_2)

Power plants are major sources of (SO_2)

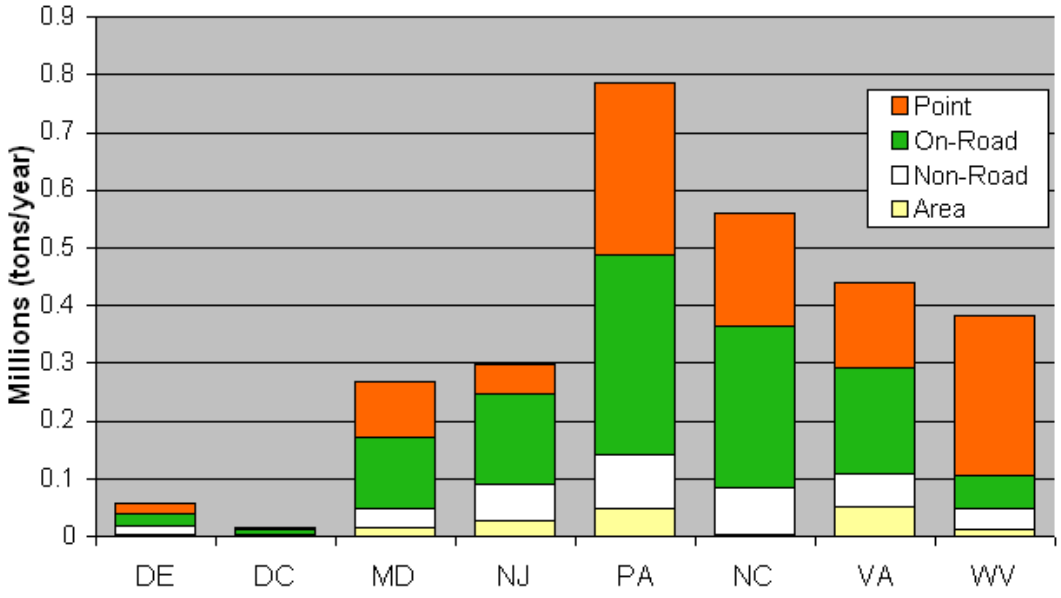
They are stationary (point) sources

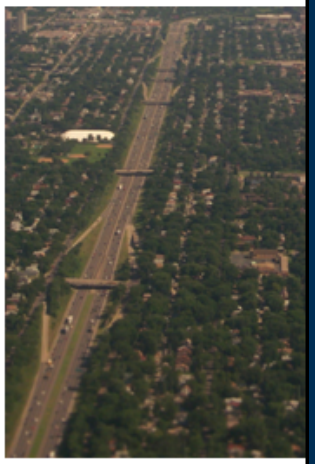


(2002 data)

Emission Classification Nitrogen Oxides (NO_x)

- Passenger vehicles are a major source of NO_x.
- These are **mobile** (**on-road**) sources.

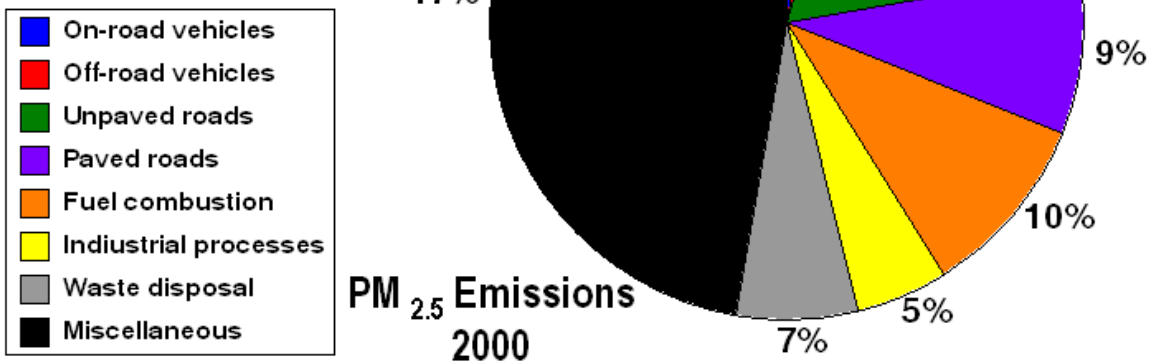




(2002 data)

Emission Classification - Miscellaneous

- Fugitive sources that often contribute to ambient particulate matter:
  - Construction sites
  - Agriculture
  - Unpaved roads



Source: Bureau of Transportation Statistics
http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_04_44.html

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- **Air pollutants** can present a real danger to living organisms as well as the wider environment.
- **Air pollutants** come in the form of ***gases*** and finely divided ***solid*** and ***liquid*** aerosols.
- *Aerosols* are loosely defined as “any solid or liquid particles suspended in the **air**” .
- **Air pollutants** can also be of *primary* or *secondary* nature.
- *Primary **air pollutants*** are the ones that are emitted directly into the atmosphere by the sources (such as power-generating plants).
- *Secondary **air pollutants*** are the ones that are formed as a result of reactions between primary **pollutants** and other elements in the atmosphere, such as ozone.
- Possibly one of the most important characteristics of **air pollutants** is their transboundary nature - they can easily travel and affect the areas far away from their points of origination.

Gaseous Air Pollutants

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- Renowned author Jeremy Colls identifies the following three **main** types of *gaseous* **air pollutants**:
- Sulfur dioxide (SO2)
- Oxides of nitrogen (NOx = NO + NO2)
- Ozone (O3)
- Sulfur dioxide and nitric oxide (NO) are the *primary* **air pollutants**, and ozone is a *secondary* pollutant (though there are negligible direct emissions of the gas itself).
- Nitrogen dioxide (NO2) is both a primary and secondary **air** pollutant.
- Other important gaseous **pollutants** are: ammonia, carbon monoxide, volatile organic compounds (VOCs) and persistent organic **pollutants** (POPs) which we discuss below.

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- **Air Pollutants: Sulfur Dioxide (SO2)**
- Sulfur dioxide is a colorless gas with a pungent, suffocating odor. It is a dangerous **air** pollutant because it is corrosive to organic materials and it irritates the eyes, nose and lungs. (3)
- ***Anthropogenic Sources of Sulfur Dioxide Emissions***
- Sulfur is contained within all fossil fuels, and is released in the form of *sulfur dioxide* (SO2) during fossil fuel combustion. Fossil fuel combustion accounts for almost all anthropogenic (human-caused) sulfur emissions.
- Sulfur contents in fossil fuels range between 0.1% and 4% in oil, oil by-products and coal, and up to 40% in natural gas (when immediately extracted from the well; however, the sulfur is efficiently removed during the processing of gas before distribution ; therefore, combustion of natural gas is not a major source of sulfur emissions .
- Historically, the use of coal in domestic heating was a major source of sulfur dioxide emissions but it has declined substantially over time.

- This trend is possibly true for other industrialized countries as well, though the US as the most important economy in the world is still a large consumer of energy derived from coal.
- Below is a breakdown of all the significant sources of sulfur dioxide emissions :
- Energy Production
- Electric power generation
- Petroleum refining
- Other combustion
- Commercial and residential use
- Combustion for industry use
- Production processes
- Extraction and distribution of fossil fuels
- Transport

- Road transport
- Other Transport (such as aviation, ships, trains).

- Currently, the most important sources of sulfur dioxide emissions (as a result of fossil fuel combustion) are **electric power generating plants**.
- For example, as of 1998, 66% of all sulfur dioxide emissions in the UK came from power plants. In contrast, transport contributions of sulfur dioxide emissions are among the smallest ones.
- The biggest sulfur dioxide emitters: US, China and Russia.
- In fact, you may be surprised to learn that just one Siberian city in Russia – Norilsk – produces 1% of the total global emissions of sulfur dioxide. In 2007, Norilsk was considered to be one of the most polluted places on Earth.

Natural Sources of Sulfur Dioxide Emissions

There are also significant sulfur emissions generated by natural sources.

The **main** natural sulfur emissions come in the reduced forms of sulfur compounds such as :

- hydrogen sulfide (H_2S)
- carbon disulfide (CS_2)
- carbonyl sulfide (COS)
- and in the organic forms of:
- methyl mercaptan (CH_3SH)
- dimethyl sulfide (DMS) (CH_3SCH_3)
- dimethyl disulfide (DMDS) (CH_3SSCH_3)

Most of these compounds get oxidized to sulfur dioxide or to sulfate aerosols in the atmosphere. Marine phytoplankton produce dimethyl sulfide (DMS) which is then oxidized to SO_2 in the atmosphere; decay processes in soil and vegetation produce H_2S (as one of sulfur compounds); and SO_2 is emitted into the atmosphere by volcanoes.

- Around 90% of all natural sulfur emissions come in the form of DMS.
- Most recently the natural sources have been by far surpassed by anthropogenic sources. Natural sources have been estimated to produce around 24% of all sulfur dioxide emissions, whereas human-caused emissions made up around 76%.

- ***Effects of Sulfur Dioxide Emissions***
- Sulfur dioxide found in the **air** produces following effects:
- Irritates eyes, nose, throat
- Damages lungs when inhaled
- As part of acid rain:
- acidifies lakes and streams
- destroys plant and fish life in lakes and streams
- may deplete mineral nutrients in the soil
- may cause reduction of forest and agricultural yields
- corrodes metals
- damages surfaces of buildings.

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- Sulfur dioxide is just one by-product of fossil fuel combustion
- There are many other **air pollutants** produced by the use of fossil fuels.
- Green investing may offer real opportunities for developing clean technologies and finally bringing fossil fuel pollution under complete control.

Air Pollutants: Nitrogen Oxides

Author Andrew Farmer points out that oxides of nitrogen are prod combustion of all fossil fuels including coal- and gas-fired power stations and motor vehicles. Whereas fuel itself can produce some nitrogen (for example, oil and coal contain around 0.5 – 1.5% of nitrogen, and natural gas contains less than that, most of nitrogen oxides' production comes from the reaction of atmospheric nitrogen and oxygen within the combustion chamber.

- The two **main** nitrogen oxides are nitric oxide (NO), or nitrogen monoxide, and nitrogen dioxide (NO2) the sum of which is equal to NOx.
- Nitric oxide (NO) is a colorless gas.
- Nitrogen dioxide (NO2) is a gas of reddish-brown color with a distinct sharp, biting odor.
- Combustion of fuels always produces both NO2 and NO.
- But almost 90% of the NOX combustion product is in the form of NO which is then oxidized to nitrogen dioxide (NO2) in the **air** .

Therefore, only a small percentage of NO2 found in the atmosphere is directly emitted there in this form. The rest has been formed as a result of chemical reactions in the atmosphere itself.

Anthropogenic Sources of Nitrogen Oxide Emissions

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- Road transport (motor vehicles) is by far the largest contributor of nitrogen emissions (in contrast, it contributes a very small proportion to sulfur dioxide emissions, as discussed above).
- **Bus Pollution in Guatemala**
  Photo: Doron Laor
- For example, based on 1998 UK figures, **road transport** contributed nearly half of all nitrogen emissions, followed by contributions from electric power generating plants which only contributed around 20% of total nitrogen emissions.

- Below is a breakdown of the significant sources of emissions of nitrogen oxides :
- Road transport
- Other Transport
- Energy Production
- Electric power generation
- Petroleum refining
- Other combustion: Combustion for industry use; Production processes; Extraction and distribution of fossil fuels.

Natural Sources of Nitrogen Oxide Emissions

- Nitric oxide (NO) is also emitted by soils but there is very little d[illegible]e for the proper assessment of this area.
- Some estimates suggest that the soil production of NO in the UK may be around 2 – 5% of its production from fossil fuel combustion.

Effects of Nitrogen Dioxide (NO2) Emissions

- When inhaled, nitrogen dioxide becomes a serious **air** pollutant which may:
- Cause pulmonary edema (accumulation of excessive fluid in the lungs)
- Be part of acid rain (destroying fish and plant life in lakes, damaging surfaces of buildings etc)
- Contribute to photochemical smog.

Air Pollutants: Ammonia

- Ammonia is a colorless, pungent, hazardous caustic gas composed of n hydrogen. Ammonia emissions are also grouped as NHy which is a sum of NH3 and NH4.

Sources of Ammonia Emissions

- **Agriculture** is by far the biggest source of ammonia emissions.
- Livestock farming and animal waste account for the biggest percentage of total ammonia emissions which are due to the decomposition of urea from large animal wastes and uric acid from poultry wastes.
- Based on Jeremy Colls' table of global ammonia emissions, below is a breakdown of their major sources:
- Livestock – contributes more than 50% of all emissions
- Fertilizer application
- Oceans
- Vegetation
- Biomass burning

Effects of Ammonia Emissions

- Exposure to very high concentrations of gaseous ammonia in the **air** may result in lung damage and even death.

Air Pollutants: Carbon monoxide (CO)

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- Carbon monoxide is a colorless, odorless gas which is highly toxic to humans.
- The combustion of carbon-based fuels produces carbon dioxide (CO2).
- But not all such combustion is complete, and this leads to the production of carbon monoxide (CO).
- Motor vehicles and industry are among the largest anthropogenic sources of carbon monoxide emissions.

Effects of Carbon Monoxide Emissions

- Carbon monoxide is the most common type of fatal poisoning in many countries around the world.
- Exposures to carbon monoxide may lead to:
- Toxicity of the central nervous system and heart
- Severe effects on the baby of a pregnant woman
- Headaches and dizziness
- Problems with getting oxygen supplied to some body parts which may be life-threatening.

Air Pollutants: Volatile Organic Compounds (VOCs)

- Volatile organic compounds (VOCs) are defined as organic compounds which evaporate and enter the atmosphere.
- VOCs may include a wide range of organic **air pollutants**, from pure hydrocarbons to partially oxidized hydrocarbons to organic compounds containing chlorine, sulfur, or nitrogen.
- Historically, the definition of VOCs did not include methane compounds (non-methane VOCs: NMVOCs) since the atmospheric concentration of methane was considered to be a stable natural background. But it was ultimately recognized that methane is also an anthropogenic **air** pollutant that comes from intensive animal and rice production.
- Though some of these compounds can have direct toxic effects, they have been grouped together because of their role in ozone formation.

Anthropogenic Sources of Volatile Organic Compounds

- The major anthropogenic sources of VOCs include:
- Solvent Use (including paints, adhesives, aerosols, metal cleaning and printing)
- Road transport (emissions from fuel / petroleum use)
- Production processes
- Extraction and distribution of fossil fuels
- For example, in the UK the biggest emissions of NMVOCs are due to solvent use and road transport.

Substantial NMVOC emissions occur during the following processes :

- Painting (evaporation of solvents)
- Oil production (flaring and venting of gas)
- Oil refining (flaring and fugitive emissions)
- Distribution of oil or refinery products (evaporation from storage, displacement losses when venting tanks)
- Dry cleaning (final drying of clothes)
- Production of alcoholic drinks (breweries and distilleries)
- Arable farming (crop growing, silage manufacture, sludge spreading)

Natural Sources of Volatile Organic Compounds

- Not a lot is known about the natural emissions of VOCs.
- But we know that forests are the primary natural sources of VOC emissions. And tropical forests are estimated to produce about half of all global natural non-methane VOC emissions.
- Plants synthesize many organic molecules and release some VOCs (including a range of terpenes) into the atmosphere.
- In total, around 1000 different compounds (with some of which themselves being families with thousands of their own members) are known to be emitted by natural sources.

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Effects of Volatile Organic Compounds

- VOCs may produce the following effects:
- Some aromatic compounds such as benzene, toluene and xylene are potential carcinogens and may cause leukemia
- Contribute to *sick building syndrome* indoors
- As facilitators in ozone formation, VOCs may indirectly contribute to respiratory problems and other ozone-related problems

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Air Pollutants: Ozone (O3)

- Ozone (O3) is a colorless, poisonous gas with a sharp, cold, irritating odor.
- Ozone can be found in :

- the stratosphere, one of the upper layers of the atmosphere, where it occurs naturally, and
- the troposphere, the lowest layer of the atmosphere, where it occurs both naturally **and** as a result of human-generated emissions.

- The natural stratospheric ozone is considered to be of beneficial nature – it keeps harmful excessive ultraviolet sunlight from reaching the surface of the Earth.
- Ozone which is formed in the troposphere as a result of anthropogenic emissions of primary **pollutants**, has negative effects on humans and the natural environment. And from this point of view it is an **air** pollutant.
- This human-caused ozone in the troposphere is a secondary pollutant because it is produced by the reaction of primary **pollutants**, nitrogen oxides and hydrocarbons [including VOCs], in the presence of **sunlight**.
- The tropospheric ozone is the **main** component of the photochemical smog.

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Smog in Los Angeles

- A photochemical smog (of brown-yellow color) is a product of the chemical reaction between sunlight, nitrogen oxides and VOCs, which results in the formation of ozone and airborne particles.
- The process of ozone formation may take several days to complete, and ozone itself may turn out to be far from the sources of original primary pollutant emissions.
-

Effects of Ozone as an Air Pollutant

- Ozone in the troposphere can have the following negative effects on animals (including humans) and the natural environment:
- Irritation of the respiratory system causing coughing, throat irritation and an uncomfortable sensation in the chest
- Susceptibility to respiratory infections
- Compromised lung function harming the breathing process which may become more rapid and more shallow than normal
- Inflammation and damage to the lining of the lungs
- Aggravation of asthma
- Reduction in agricultural yields
- Interference with photosynthesis and suppression of growth of some plant species

- At ground level, ozone is a hazard (‘bad’ ozone) - it is a major constituent of photochemical smog. However, in the stratosphere, it serves to absorb some of the potentially harmful UV radiation from the sun, which is believed to cause skin cancer, among other things (‘good’ ozone).
- Sources: ozone is not emitted into the atmosphere; ozone is formed from the ozone precursors, VOCs, and nitrogen oxides (will be discussed in several Lectures).
- "Bad" ozone effects:
- diverse effects on human health
- ecological effects: damage vegetable and trees,

Air Pollutants: Persistent Organic Pollutants (POPs)

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- Persistent organic **pollutants** are compounds which are resistant to degradation and persistent in the environment, with half lives of years in the soil or sediment and days in the atmosphere.
- Such compounds may include dioxins, furans, polychlorinated biphenyls (PCBs) and organochlorine pesticides such as DDT.
- They enter the food chains via the process of biomagnification, get accumulated in human and animal tissue, and are capable of long range transport through being attached to airborne particles.

Sources of Persistent Organic Pollutants

- Some POPs are used as pesticides.
- Others are used in industrial processes as well as in the production of goods such as solvents, polyvinyl chloride and medicines.

Effects of Persistent Organic Pollutants

- Exposure to persistent organic **pollutants** takes place through diet (specifically, consumption of animal fats), environmental exposure or accidents.
- POPs may lead to:
- Death and illness including disruption of endocrine, reproductive and immune systems
- Neurobehavioral disorders
- Cancers

Please note that when POPs are present in the atmosphere in the form of aerosols, they may be classified as airborne particles (see below) rather than gaseous **pollutants**.

Airborne Particles as Air Pollutants

- Airborne particles present one more type of **air pollutants**.
- They are tiny fragments of solid or liquid nature suspended in the **air** (aerosols).
- Particles may be *primary* – when emitted directly into the atmosphere by sources, or *secondary* – when particles are formed in the atmosphere through the interaction of primary emissions.
- Solid particles between 1 and 100 µm (micrometres) in diameter are called ***dust*** particles, while solid particles less than 1 µm in diameter are called ***fumes***, or ***smoke***.

Anthropogenic Sources of Airborne Particles

- Anthropogenic particles account for around 10% of the total amount of particles in the atmosphere.
- Fossil fuel combustion is one of the **main** processes which causes vast amounts of particles to be emitted into the atmosphere.
- The major anthropogenic sources of airborne particles are :
- Road transport
- Power generating plants
- Production processes (such as dust blown away by winds from construction sites)

Natural Sources of Airborne Particles

- **Main** natural sources of particles are :
- Erosion of soil by wind which generates *dust* particles that travel around the globe
- Evaporation of droplets of sea water resulting in sea *salt crystals* being suspended in the **air**
- Volcanoes
- Forest fires
- Living vegetation

Sources of PM and PM Precursors

Mobile Sources
(vehicles)
VOCs, NO_2, PM

Stationary Sources
(power plants, factories)
NO_2, SO_2, PM

Area Sources
(drycleaners, gas stations)
VOCs

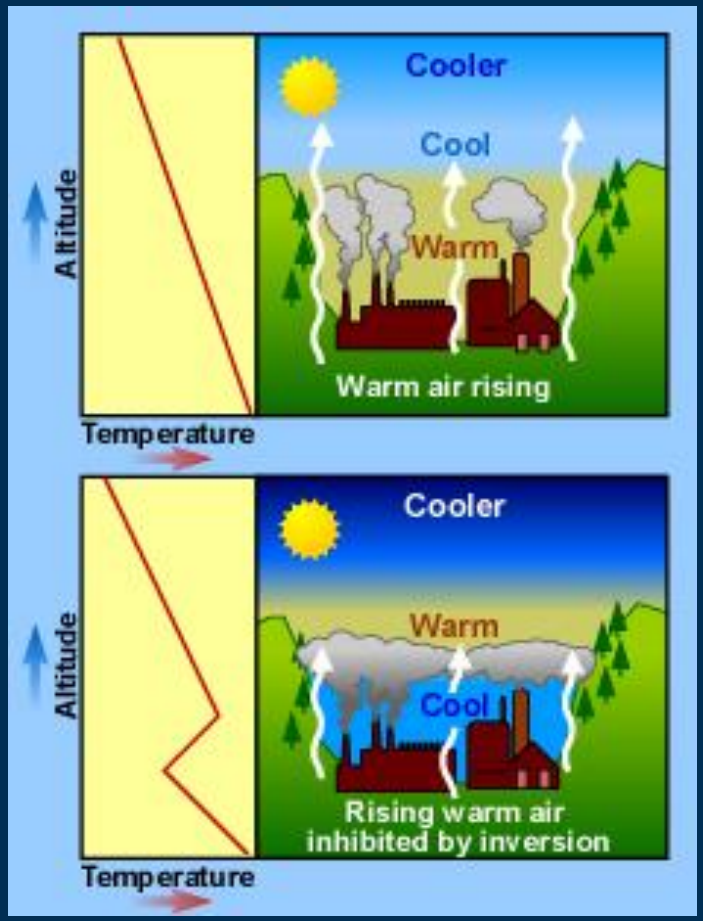
Natural Sources
(forest fires, volcanoes)
PM

Determinants of PM Concentration

- Weather patterns
- Wind
- Stability (vertical movement of air)
- Turbulence
- Precipitation
- Topography
- Smokestack height and temperature of gases

Nearby natural and built structures may lead to downward moving currents causing **aerodynamic or building downwash** of smokestack emissions.

The Role of Inversions



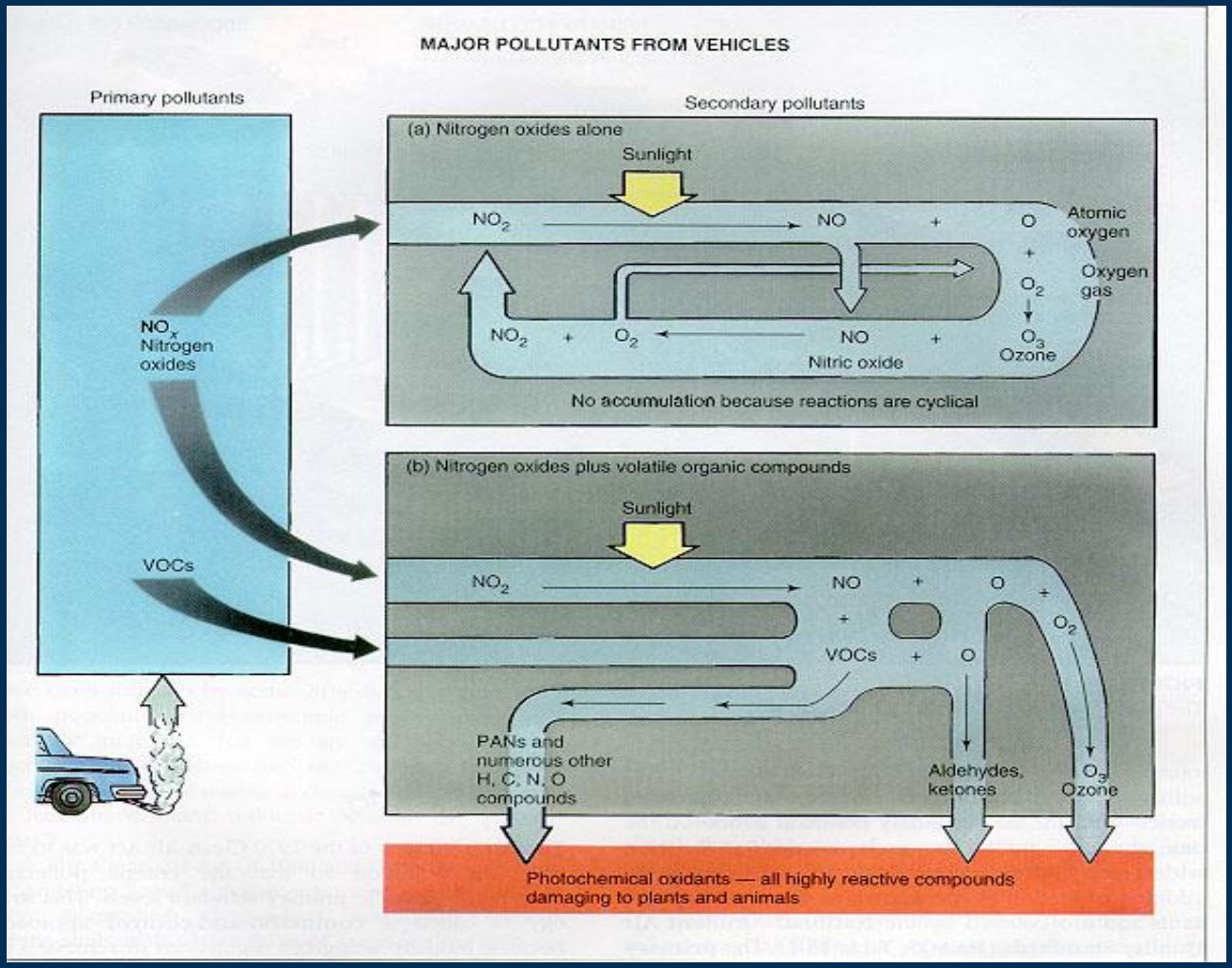
Source: http://www.epa.gov/apti/ course422/ce1.html

An inversion is an extremely stable layer of the atmosphere that forms over areas.

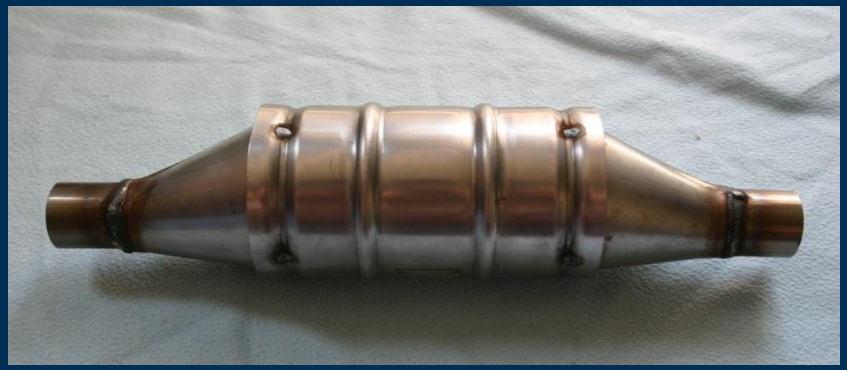
Temperature inversions trap pollutants close to the ground. These inversions involve layers of hot air sitting above cooler air near ground level. When particles accumulate in the air layer, they are unable to rise into the atmosphere where winds will disperse them.

How to reduce atmosphere pollution?

- 1. to install filters in industrial plants in chimneys to clean the exhaust gases.
  2. Instead of oil and coal use gas or other less harmful fuels, alternative energy sources.


MAJOR POLLUTANTS FROM VEHICLES
Primary pollutants
Secondary pollutants
(a) Nitrogen oxides alone
Sunlight
NO_2
NO
+
O
Atomic oxygen
+
O_2
Oxygen gas
NO_2
+
O_2
NO
+
O_3
Ozone
Nitric oxide
No accumulation because reactions are cyclical
NO_x
Nitrogen oxides
VOCs
(b) Nitrogen oxides plus volatile organic compounds
Sunlight
NO_2
NO
+
O
+
O_2
+
VOCs
+
O
PANs and numerous other H, C, N, O compounds
Aldehydes, ketones
O_3
Ozone
Photochemical oxidants — all highly reactive compounds damaging to plants and animals

3. Increase the amount of air fuel and air mixture to burn more fuel.
4. Cars equipped with catalytic reactor tubes, which oxidizes CO to CO2.



5. To reduce the sulfur content of fuels, before being released into the air in the combustion gas cleaning.
6. Prohibit the use of freon.
7. Carry out the Kyoto Protocol.
8. Increasing the forest area.
9. Replanting of deforested areas.

Acid deposition has not been greatly reduced

- New technologies such as scrubbers have helped
- SO_2 emissions are lower
- But, NO_x emissions are higher
- Acid deposition's effects are worse than predicted

- The Clean Air Act cannot restore ecosystems
- More must be done to control acid deposition

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- Indoor air contains higher concentrations of pollutants than outdoor air
  - 6,000 people die per day from indoor air pollution
- The average U.S. citizen spends 90% of the time indoors
  - Exposed to synthetic materials that have not been comprehensively tested
  - To reduce heat loss and improve energy efficiency, building ventilation systems were sealed off ventilation and windows put in that did not open, trapping pollutants inside

Indoor air pollution in the developing world

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- Stems from burning
- Wood, charcoal, dung, crop waste
- Little to no ventilation
- Fuel burning pollution causes an estimated 1.6 million deaths per year
- Soot and carbon monoxide
- Causes pneumonia, bronchitis, allergies, cataracts, asthma, heart disease, cancer and death

Tobacco smoke and radon

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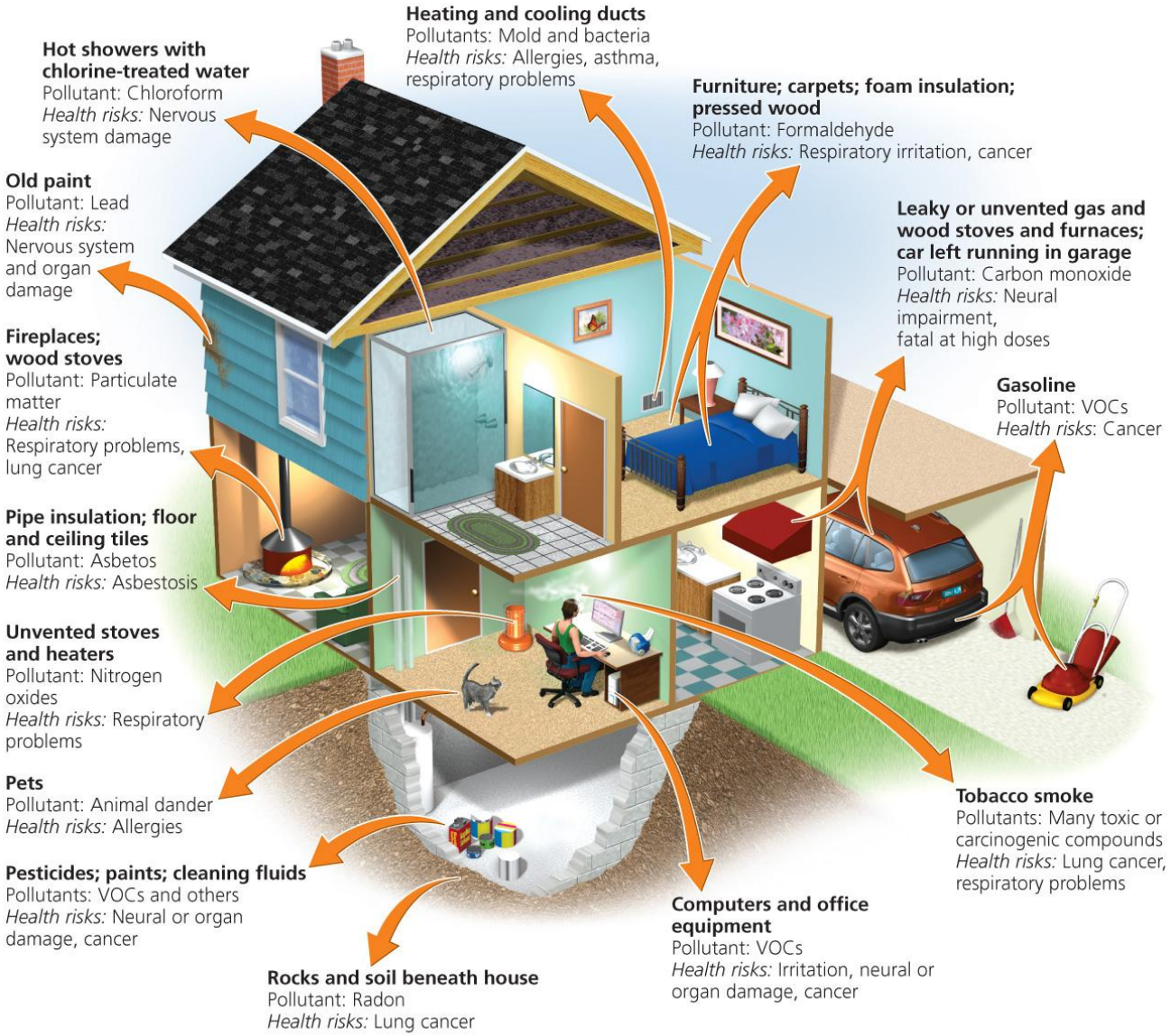
- The most dangerous indoor pollutants in the developed world
- Secondhand smoke from cigarettes is especially dangerous
- Containing over 4000 dangerous chemicals
- Causes eye, nose, and throat irritation
- Smoking has declined in developed nations
- Radon causes 20,000 deaths a year in the U.S.
- A radioactive gas resulting from natural decay of rock; soil; or water, which can seep into buildings
- Most homes are now radon resistant

Volatile Organic Compounds (VOCs)

- The most diverse group of indoor air pollutants
- Released by everything from plastics and oils to perfumes and paints
- Most VOCs are released in very small amounts
- Unclear health implications due to low concentrations
- Also include pesticides, which are found indoors more often than outdoors due to seepage
- Formaldehyde, which leaks from pressed wood and insulation, irritates mucous membranes and induces skin allergies

Sources of indoor air pollution



Living organisms can pollute indoors

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- Tiny living organisms can also pollute
- Includes dust mites and animal dander worsen asthma
- Fungi, mold, mildew, airborne bacteria cause severe allergies, asthma, and other respiratory ailments
- **Sick building syndrome** = a sickness produced by indoor pollution with general and nonspecific symptoms
- Solved by using low-toxicity building materials and good ventilation

We can reduce indoor air pollution

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In developed countries:

- Use low-toxicity material
- Monitor air quality
- Keep rooms clean
- Limit exposure to chemicals

In developing countries:

- Dry wood before burning
- Cook outside
- Use less-polluting fuels (natural gas)

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Thank You for Your attention!