

EWCE 105

ENVIRONMENTAL CHEMISTRY
Lecture – 7

Lecture Outlines

- Particulates/Particulate Matter (PM)/ Aerosols
- Carbon Monoxide (CO)
- Nitrogen Oxides (NO_x)
- Sulphur Oxides (SO_x)
- Photochemical Smog

Primary Pollutants



- Five primary pollutants together contribute more than 90% of global air pollution:
  - Particulates/Particulate Matter (PM)/ Aerosols
  - Carbon Monoxide (CO)
  - Nitrogen Oxides (NO_x)
  - Sulphur Oxides (SO_x)
  - Photochemical Smog

Particulate/Particulate Matter (PM)/Aerosol

It consists of any dispersed matter in the air, solid or liquid (except pure water), with size ranging from molecular clusters of 0.005 μm to coarse particles of up to 100 μm.

Primary Aerosols: emitted directly from sources (e.g. vehicles, smokestacks); yields all size of particles.

Secondary Aerosols: particles produced in the atmosphere, e.g., from gas phase chemical reactions that generate condensate species; produce mainly sub-micron size particles.

Terms Used to Describe PM

Condensation aerosol : Formed by condensation of vapors or reactions of gases.

Aerosol: Colloidal-sized atmospheric particles.

Dispersion aerosol : Formed by grinding of solids, atomization of liquids, or dispersion of dusts.

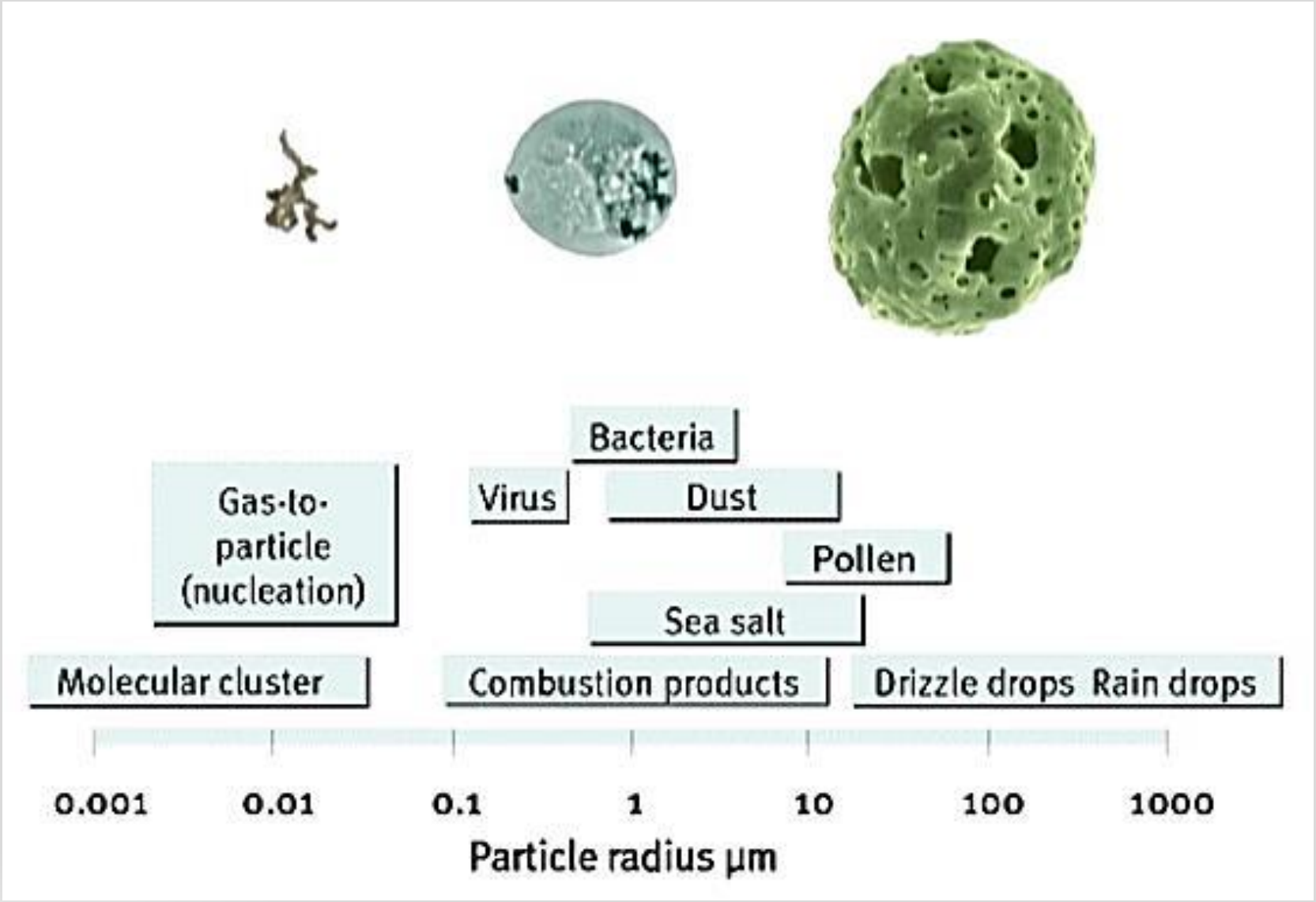
Fog/Mist : Denotes high level of water droplets / liquid particulates.

Haze: Decreased visibility due to particles.

Terms Used to Describe PM

- **Dust:** solid particles are called dust if they are caused by grinding and crushing operations.
- **Fumes:** solid particles are called fumes if they are formed when vapors condenses.
- **Smoke, Soot, Black Carbon (BC):** composed primarily of carbon that results from incomplete combustion.
- **Smog:** derived from smoke and fog (not to be confused with "photochemical smog").

Sizes of Common Airborne Particles



Classification of PM based on Size

Two categories :

- **Fine particles : ≤ 2.5 µm**
- **Coarse particles : >2.5 µm**

Fine fraction: Major components are sulfate, ammonium, nitrate, carbon-containing material including BC/soot and condensed organic matter. Some studies showed that toxic species e.g., PAH compounds, As, Se, Cd, Zn are more concentrated in fine particle fraction.

Coarse Fraction : Consists mainly of crustal materials, e.g., Fe, Ca and Si. Major sources are wind erosion products, primary emissions, sea spray and volcanic eruptions.

Fine particles (Black Carbon/Soot)

Black carbon (BC) is the most strongly light-absorbing component of particulate matter (PM), and is formed by the incomplete combustion of fossil fuels, biofuels, and biomass.

BC is emitted directly into the atmosphere in the form of fine particles ($PM_{2.5}$). BC is the most effective form of PM in the atmosphere.

BC can absorb a million times more solar energy than carbon dioxide (CO_2). BC is a major component of "soot", a complex light-absorbing mixture that also contains some organic carbon (OC).

Major sources of BC -

Transportation Sector – BC typically constitutes 75 % of PM emitted from older diesel engines.
Residential Cooking (traditional stove/ fuel),
Industrial Sectors – Brick kilns, and
Agricultural Burning.

Sources of PM - Natural Sources

- Soil and Rock Debris
- Forest Fires
- Sea Salt
- Volcanic Debris
- Particles formed from Gaseous Emissions of H_2S, NH_3, NO_x, and HC.

Sources of PM – Anthropogenic Sources

* About 90% of respirable particulate in Earth's atmosphere are natural and only about 10% anthropogenic. However, non-uniform distribution and chemical composition of anthropogenic particles make them very dangerous.

- Fuel Combustion
- Industrial Processes (Fugitive Emissions)
- Non-industrial Processes (Fugitive Emissions)
- Transportation

* Fugitive emissions are emissions of gases or vapors from pressurized equipment due to leaks or irregular releases.

Health Effects of PM

- PM suspended in the air enter our body when we breath. The particles include :

  Natural Particles (e.g. bacteria, virus, pollen, sea salt)
  Anthropogenic emissions (e.g., vehicle exhaust)

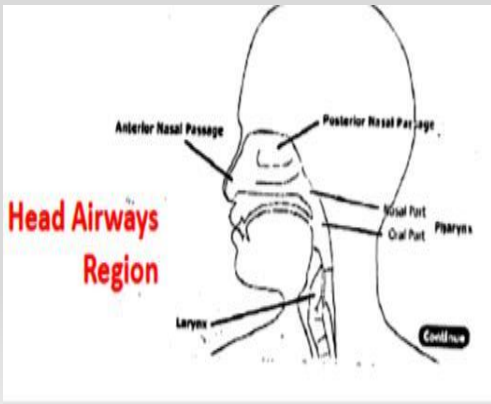
- **Hazard** posed by these particles depends on their "**chemical composition**" as well as "**where they deposit**" with in respiratory system.
- Though the extent of health effects depends on **size**, **composition** and **concentration** of PM, **length of exposure** and **where they deposit**" with in respiratory system.

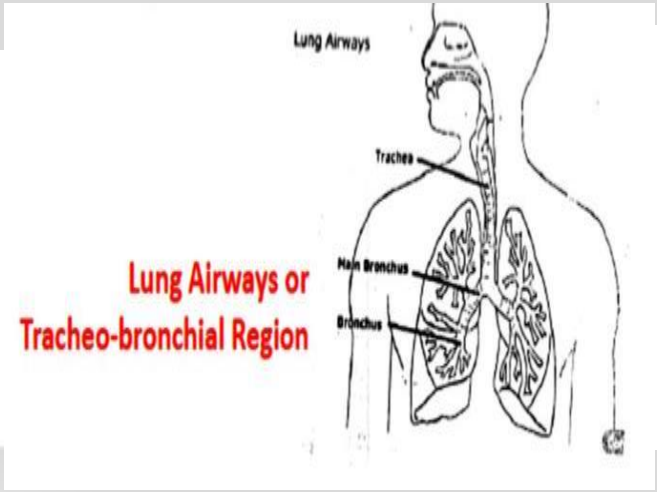
Exposure to PM (**especially $PM_{2.5}$**) is associated with **respiratory illness**, **chronic bronchitis**, **bronco-constriction** and **increased mortality rate**. Adverse effects of **short term exposure** in **asthma** attack.

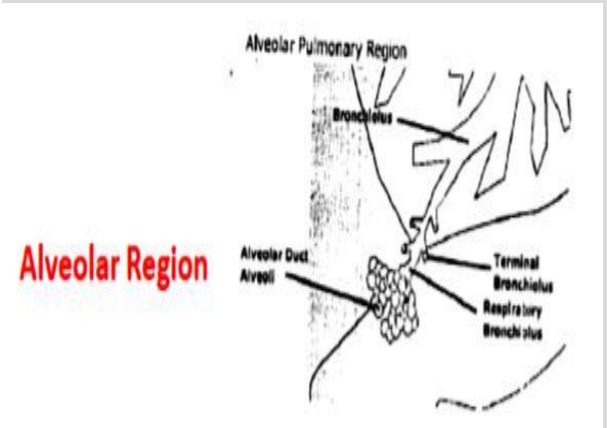
Deposition of PM in Respiratory System

- The respiratory system can be divided into 3 regions (according to respiratory deposition of PM):

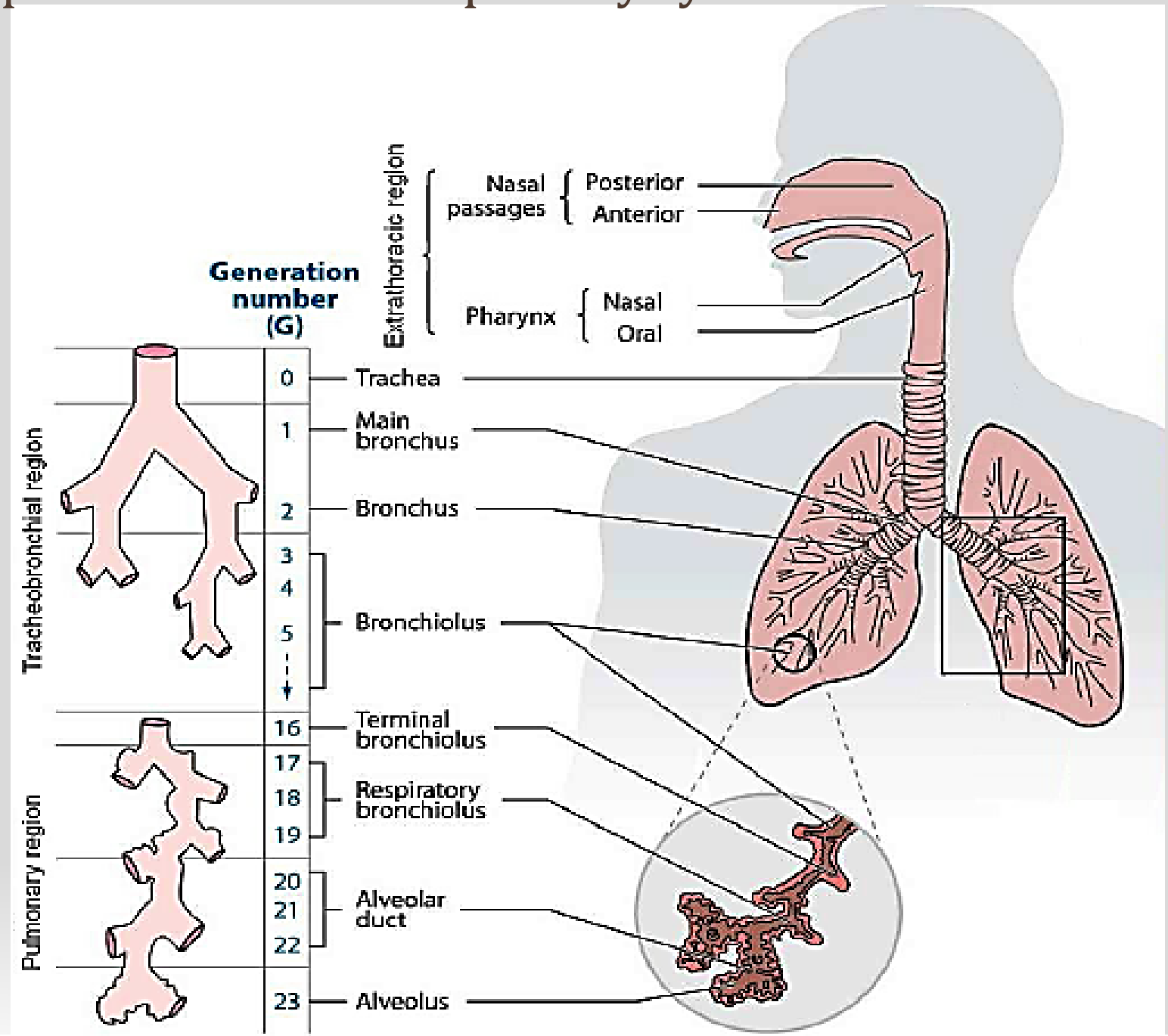
1. Head Airways Region: Nasal airway & Oral airway
2. Lung Airways Region (Tracheo-bronchial Region) : 23 airway branching
2. Pulmonary Region (Alveolar Region) : Across the alveolar membrane O_2 and CO_2 counter-diffuse.







Deposition of PM in Respiratory System



Deposition of PM in Respiratory System

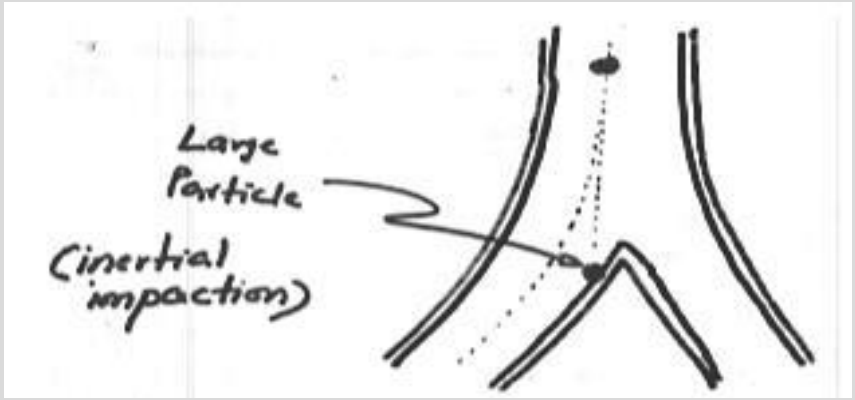
- Head Airways - Large PM are trapped by hairs and linings of nose and are driven out by sneeze. The particles with diameter > 10 μm deposits in the head regions.

- Lung Airways - Small PM are captured by mucus, worked back to throat by the tiny hair like cilia and removed by swallowing or spitting.

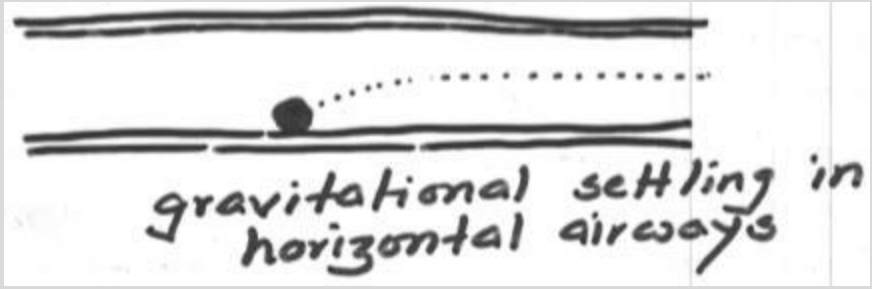
- Pulmonary Region (Alveolar Region) – It is designed as gas exchange compartment. It takes months/years to clear insoluble PM deposited here. Soluble materials pass through alveolar membrane and transported to other parts of the body. It is the region where viruses invade.

PM Deposition Mechanism in Respiratory System

- Impaction – Collection of particles due to a particles inertia that makes the particles deviate from the stream when air stream make a turn.



- Settling – when the flow velocity is small, settling then becomes an important role for large particles (especially horizontally oriented airways.



PM Deposition Mechanism in Respiratory System

- Diffusion/Brownian Motion – In a small airway, where distance is short and residence time is long, diffusion is an important mechanism for small particles (<0.5 μm). The excepted movement of particles from high concentration (center of air stream) to a lower concentration (airway wall).



- Interception – when a particle comes in contact with airway surface because of its physical size (long fibers).



Carbon Monoxide (CO)

Formation of CO :

- Incomplete combustion of Carbon/Carbon containing fuel:

$$2C + O_2 \rightarrow 2CO$$
$$2CO + O_2 \rightarrow 2CO_2$$

- Incomplete combustion results when any of the following 4 variables are not kept sufficiently high:

1. Oxygen Supply;
2. Combustion Temperature;
3. Gas Residence Time at High Temperature;
4. Combustion Chamber Turbulence.

- Industrial production of CO: by high temperature reaction between CO2 and Carbon containing material.

$$CO_2 + C \rightarrow 2CO$$

Carbon Monoxide (CO)

Sources of Carbon Monoxide (CO Pollution)

- Transportation -64% (Most significant and key contributor)
- Forest Fires and Agricultural Burning- 16.9% - 2nd Contributor
- Industrial Processes (mainly iron and steel industries and petroleum and paper industries)- 9.6% -3rd Contributor
- Natural (e.g., Volcanic activity)

Sinks of Carbon Monoxide (CO Pollution)

Major CO sink is some soil microorganisms- include some Fungi- Peniccillium and Aspergillus .

Carbon Monoxide (CO)

Health Effects of Carbon Monoxide (CO)

- The effects of CO exposure are reflected in the O_2 carrying capacity of blood.
- CO diffuses through the alveolar wall and competes with O_2 for one of the major sites in hemoglobin (Hb) molecule. When a Hb molecule acquires a CO, it is called "Carboxy-hemoglobin". It consequences in bloodstream carrying less O_2, which hampers brain function and heart rate increase in an attempt to offset O_2 deficit.

People who are consistently exposed to high levels of CO, like heavy smokers or women in rural kitchen, often adjust to compensate for lower levels of oxygen in bloodstream; but they still risk developing chronic health effects.

Control of CO Pollution

Transportation sources responsible for 74% of all CO emissions and gasoline-fed internal combustion (IC) are primarily accountable for it.

- Focus directed on automobiles to produce no CO.

A low air/fuel ratio reduces NO_x emission remarkably, but increases CO and HC emissions.

Air-fuel ratio should be stoichiometric to avoid emission and complete combustion of fuel.

- Development of alternative fuels for gasoline/ renewable sources- CNG, LNG.
- Development of pollution-free power sources to replace IC engines-Steam with electric engines (hybrid).
- Use a catalytic converter to convert the polluting exhaust gases of burned lead-free gasoline into harmless gases. Platinum (Pt) is the catalysts used. Only a small amount is needed.

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The End