CE102: Environmental Studies

By:

Dr. Subrata Hait

Environmental Pollution Control

Water Purification System

- **Drinking water treatment for both surface as well as groundwater as source**
- **Wastewater treatment for both domestic and industrial wastewater**

- **Water purification can be achieved by:**
  - ***Natural Systems:*** **Water quality/characteristics improvement by processes occurring in nature itself**
  - ***Engineered Systems:*** **Engineered treatment system designed to achieve water quality improvements by maximizing processes that occur in natural systems**

Water Purification System

Drinking Water Treatment

Raw Water Source:

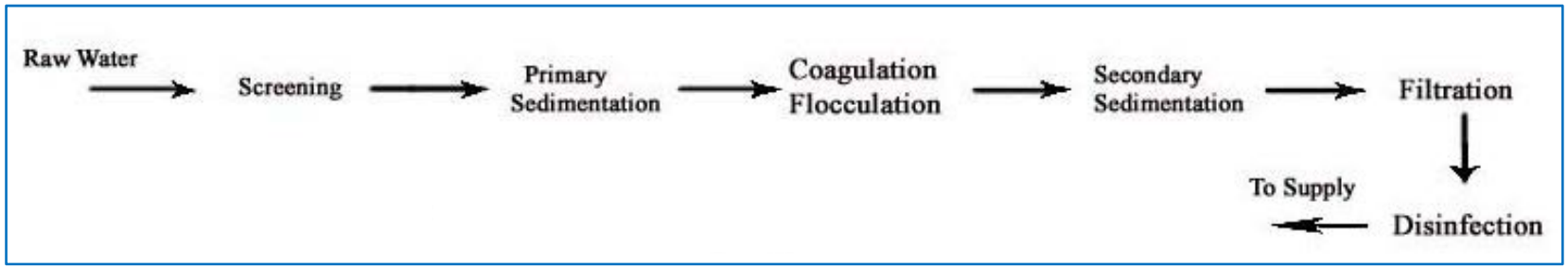
The various sources of water can be classified into two categories:

- ***Surface sources*** **such as Ponds and lakes; Streams and rivers; Storage reservoirs; and Oceans (generally not used for water supplies at present)**
- ***Sub-surface sources or underground sources*** **such as Springs; Infiltration wells; and Wells and Tube-wells.**

Water Purification System

Drinking Water Treatment

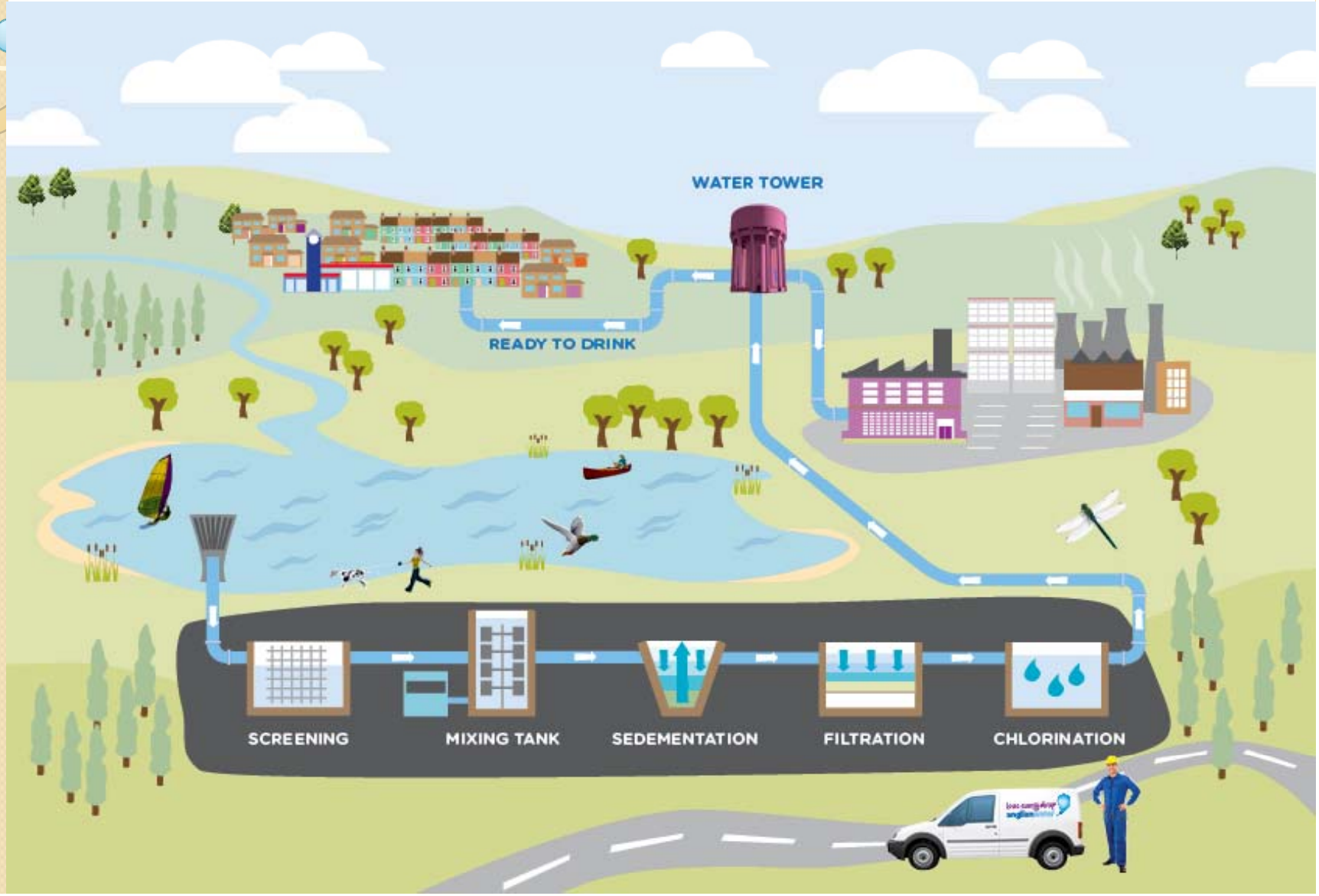
- The available raw waters must be treated and purified before they can be supplied to the public for their domestic, industrial or any other uses
- The extent of treatment required to be given to the particular water depends upon the source as well as the characteristics and quality of the available water, and also upon the quality requirements for the intended use
- The layout of conventional water treatment plant is as follows:



- Depending upon the magnitude of treatment required, proper unit operations are selected and arranged in the proper sequential order for the purpose of modifying the quality or characteristics of raw water to meet the desired standards

Water Purification System

Flow Diagram/Schematic of Drinking Water Treatment Plant



Water Purification System

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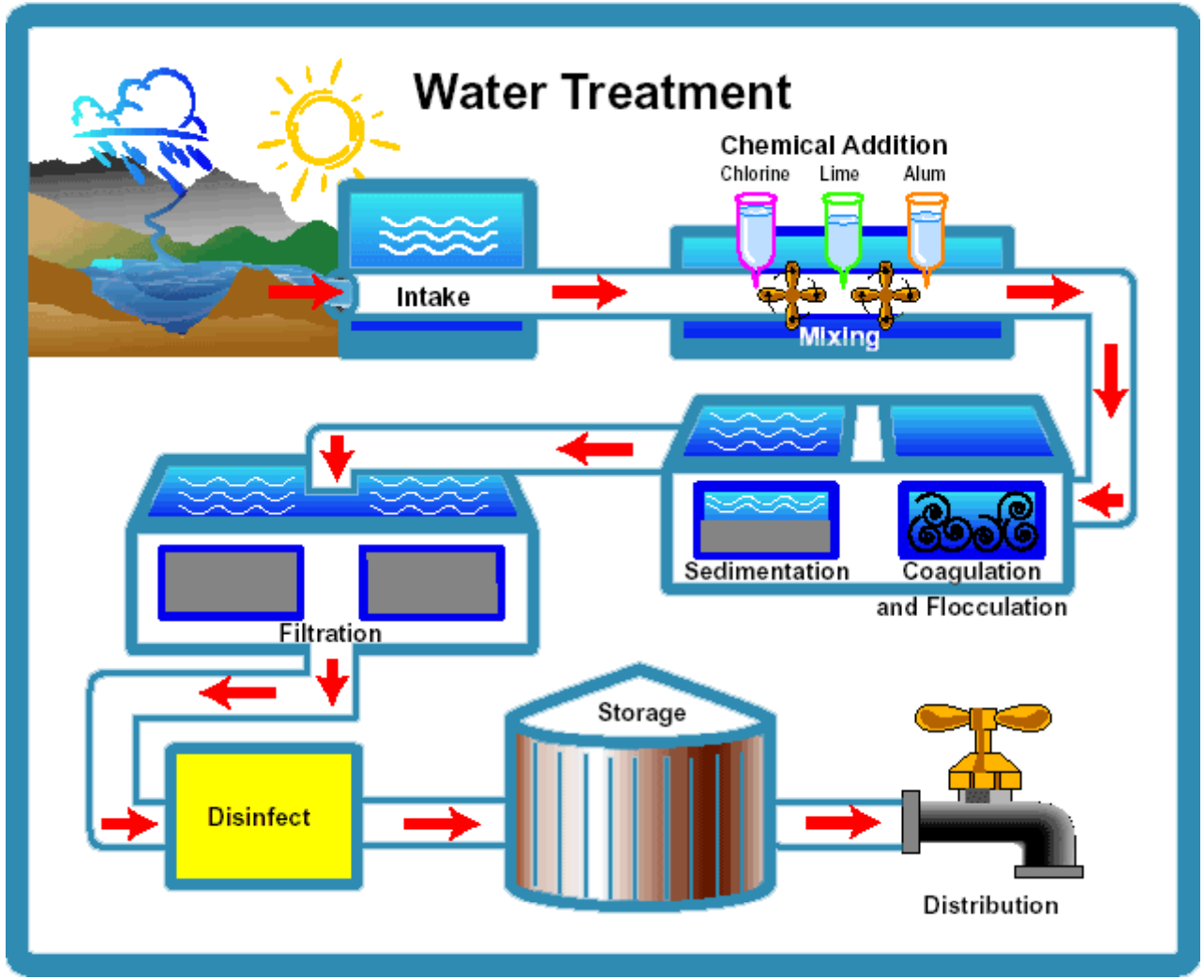

Water Purification System

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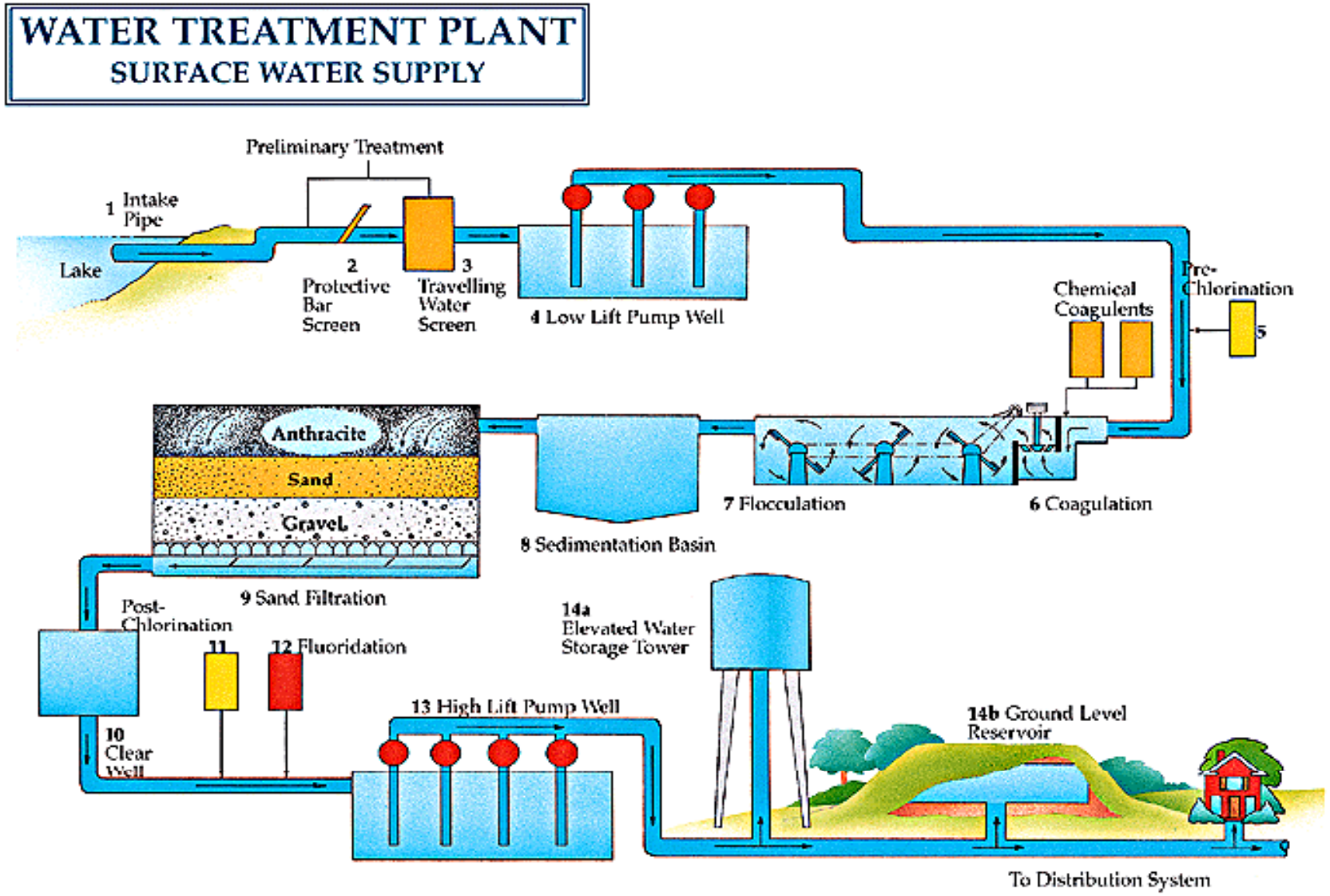


Water Purification System

Drinking Water Treatment

- **The typical functions of each unit operations are given in the following table:**

Unit treatment	Function (removal)
Aeration, chemicals use	Color, Odor, Taste, Iron, Manganese
Screening	Floating matter
Chemical methods	Iron, Manganese, etc.
Softening	Hardness
Sedimentation	Suspended matter
Coagulation	Suspended matter, a part of colloidal matter and bacteria
Filtration	Remaining colloidal and dissolved matter, bacteria
Disinfection	Pathogenic bacteria, Organic matter

Water Purification System

Drinking Water Treatment

- **The types of treatment required for different sources are given in the following table:**

Source of Raw Water	Treatment
1. Ground water and spring water fairly free from contamination	No treatment or Chlorination
2. Ground water with chemicals, minerals and gases	Aeration, coagulation (if necessary), filtration and disinfection
3. Lakes, surface water reservoirs with less amount of pollution	Disinfection
4. Other surface waters such as rivers, canals and impounded reservoirs with a considerable amount of pollution	Complete treatment

Water Purification System

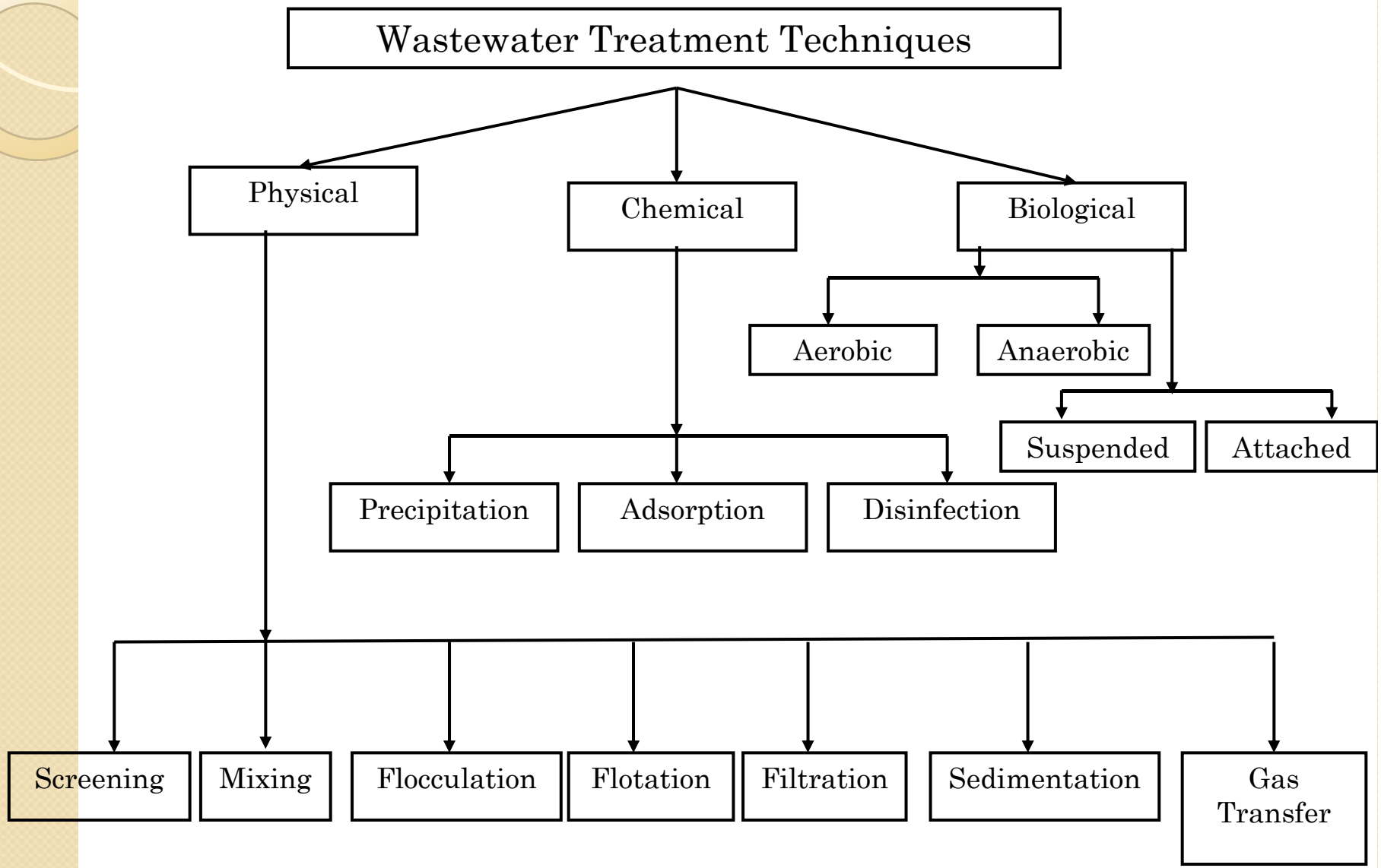
Wastewater Treatment

Major objectives of wastewater treatment:

- The principal objective of wastewater treatment is generally to allow domestic wastewater (sewage) / industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment
- Reduction of organic and nutrients load of the wastewater effluent to limit dissolved oxygen depletion and eutrophication
- Reduction of microbiological contamination/pathogens that may transmit infectious disease

Water Purification System

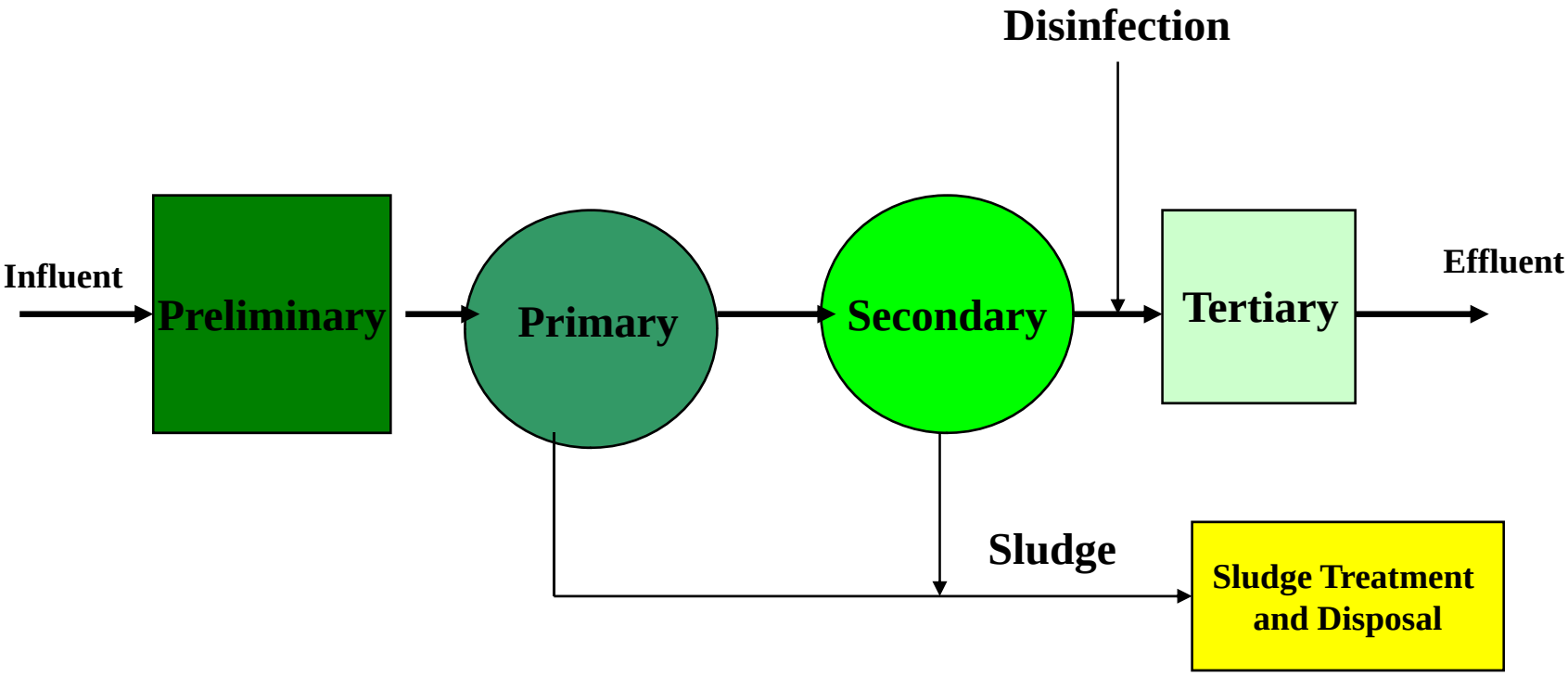
Wastewater Treatment



Water Purification System

Wastewater Treatment

Treatment Scheme



Water Purification System

Wastewater Treatment

Treatment Level:

- Preliminary treatment is a physical process that removes large solids, rags, paper, etc.
- Primary treatment involves physical sedimentation/settling of particulates
- Secondary treatment involves chemical and biological treatment to reduce organic load of wastewater
- Tertiary or advanced treatments include mostly physical or chemical treatments

Water Purification System

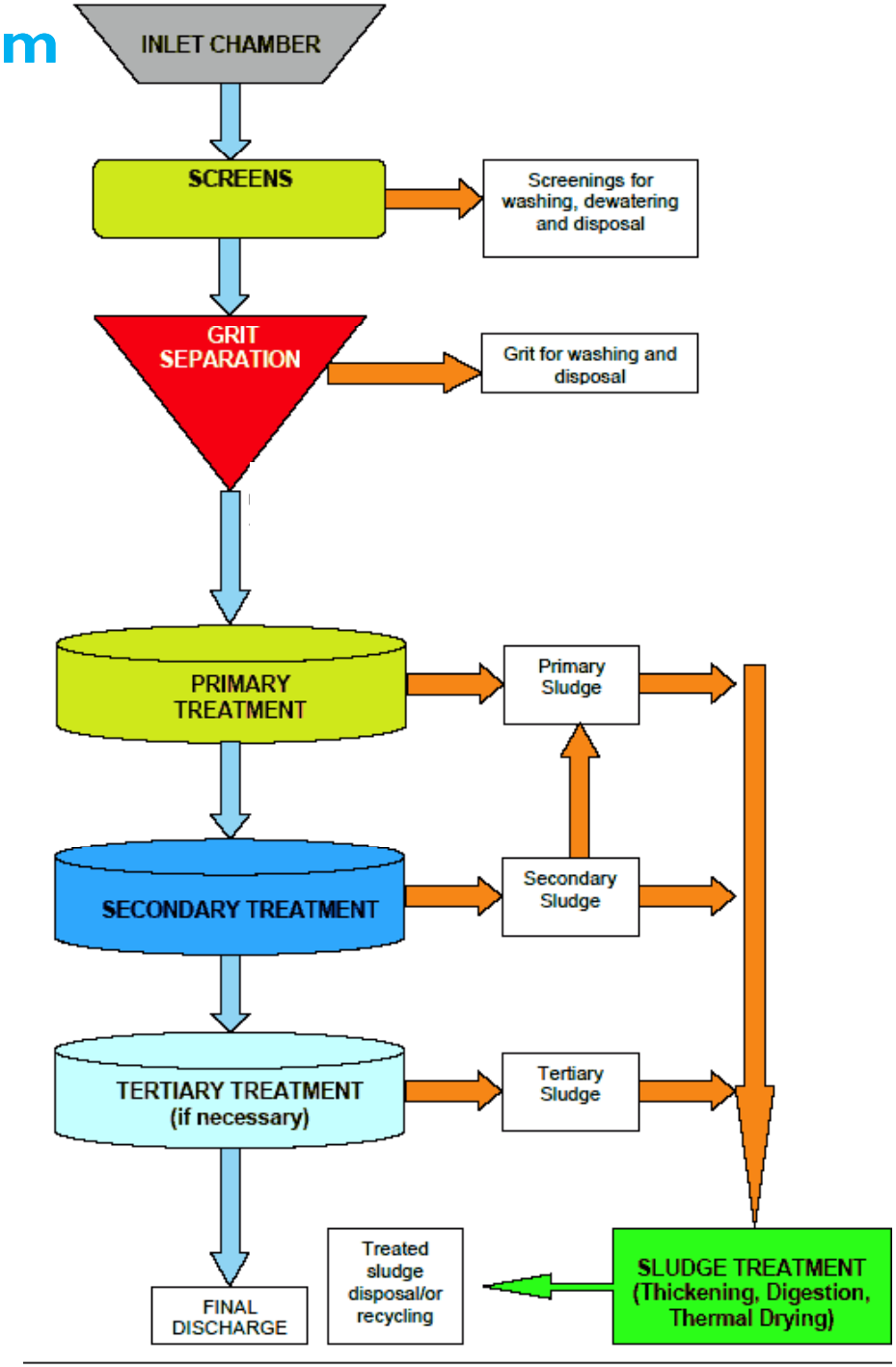
Wastewater Treatment

Treatment Level:

Treatment level	Description
Preliminary	Removal of wastewater constituents such like debris (rags, sticks, floatables etc.), grit and grease, that may cause disturbances as maintenance and/or operational problems to the treatment operations, processes and ancillary systems
Primary	Removal of a part of suspended solids and organic matter from the wastewater
Advanced primary	Enhanced removal of suspended solids and organic matter from the wastewater, typically achieved through chemical addition or filtration
Secondary	Removal of biodegradable (dissolved or suspended) organic matter and suspended solids. Disinfection is also included normally in conventional secondary treatment scope
Secondary with nutrient removal	Removal of biodegradable organics, suspended solids, and nutrients; nitrogen, phosphorus or both nitrogen and phosphorus
Tertiary	Removal of residual suspended solids consequent after secondary treatment, often by granular medium filtration or microscreens. Disinfection as well as nutrient removal are also inclusive of this stage
Advanced	Removal of left-over dissolved and suspended materials after normal biological treatment; when the wastewater treated is required to be used for different water reuse applications

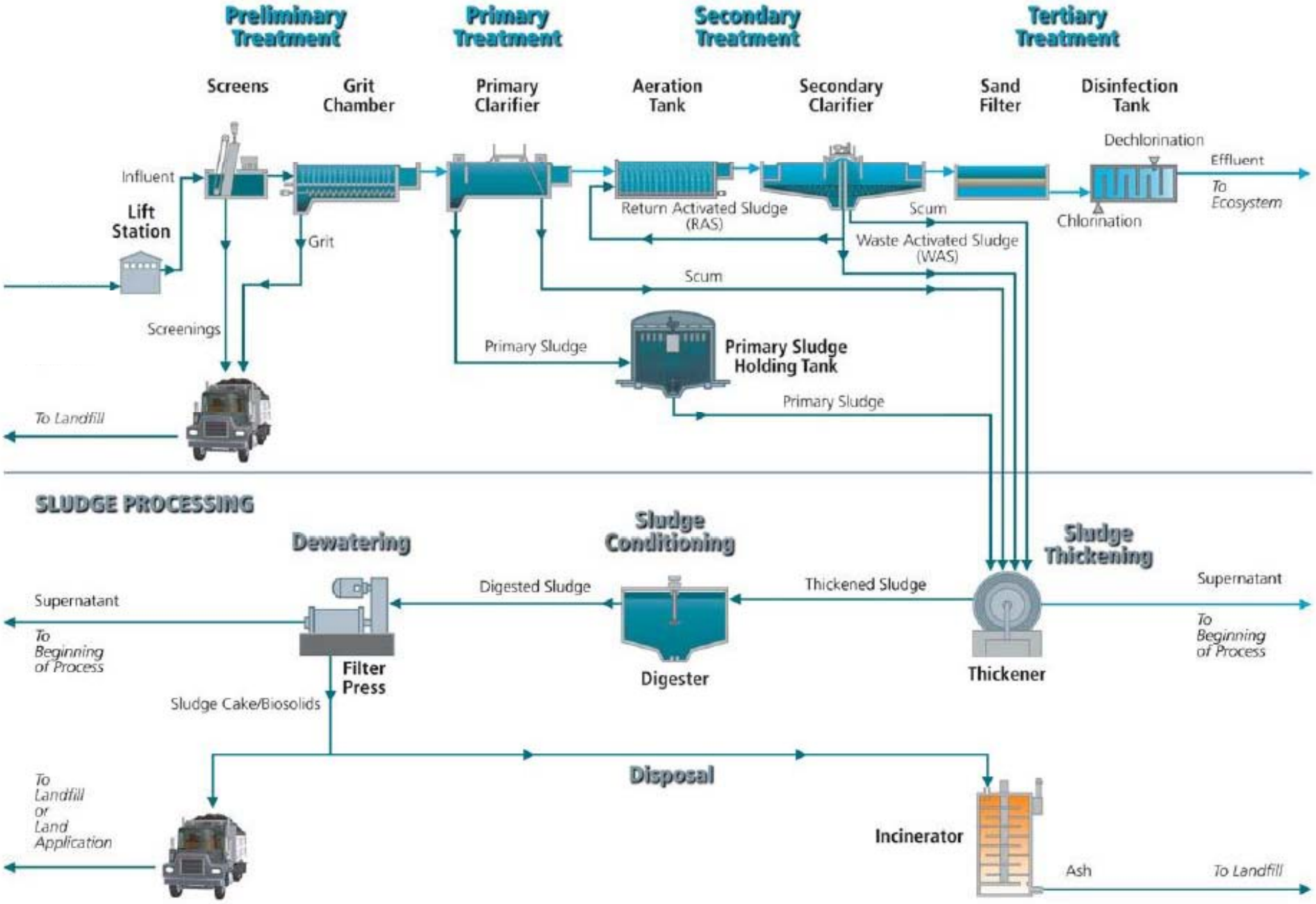
Water Purification System

Wastewater Treatment Plant - Flow Diagram / Schematic



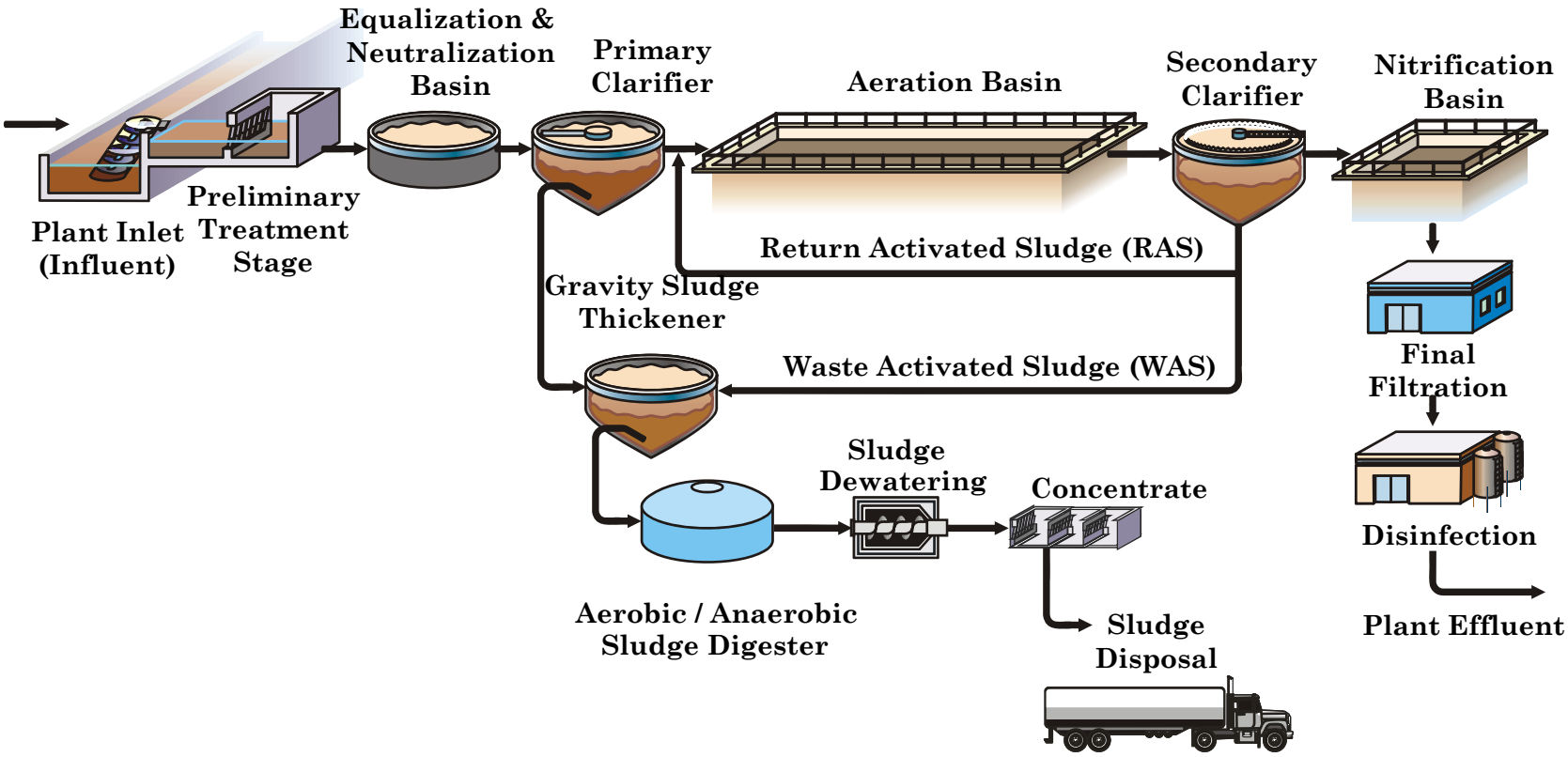
Water Purification System

Wastewater Treatment Plant - Flow Diagram / Schematic



Water Purification System

Wastewater Treatment Chain



Wastewater Treatment

Summary of Unit Operations, Unit Processes and Systems for Wastewater Treatment

S. No.	Contaminants	Unit Operation/Process
1	Suspended solids	Screening, Grit removal, Sedimentation, Coagulation, Floatation, Filtration variations
2	Biodegradable organics	Activated sludge process (ASP), Trickling filter (TF), Upflow anaerobic sludge blanket (UASB) process, Membrane bioreactor (MBR), Physico-chemical systems
3	Nitrogen	Suspended- and attached-growth nitrification and denitrification systems, Ammonia stripping, Ion exchange
4	Phosphorous	Chemical precipitation, Lime coagulation-sedimentation, Biological-chemical phosphorous removal
5	Pathogens	Chlorination, Ozonation, UV treatment
6	Refractory organics	Carbon adsorption, Advanced oxidation process (AOP) including Tertiary ozonation
7	Heavy metals	Chemical precipitation, Adsorption, Ion exchange
8	Dissolved inorganic solids	Adsorption, Ion exchange, Reverse osmosis

Wastewater Treatment

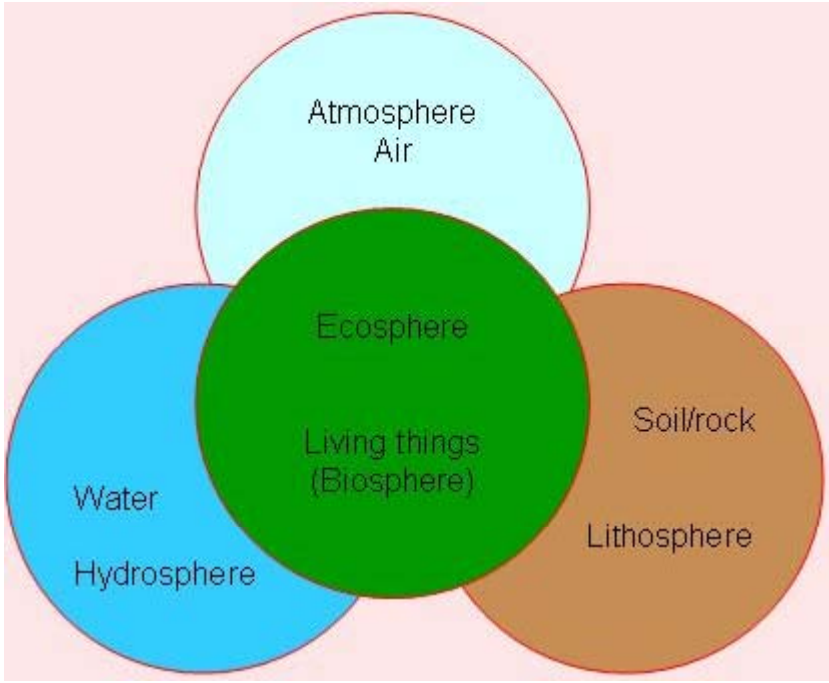
Wastewater Treatment Units

S. No.	Treatment Level	Treatment Units
1	Preliminary	Screening
		Grit Removal
		Flow Equalization
		Neutralization
2	Primary	Primary Sedimentation, Coagulation and Flocculation, Floatation
3	Secondary	Biological *(Aerobic/Anaerobic) (Suspended-/Attached-growth)*: Activated Sludge Process (ASP), Trickling Filter (TF), Upflow Anaerobic Sludge Blanket (UASB) Process, Membrane Bioreactor (MBR)
4	Tertiary	Nutrient Removal Unit, Filtration, Adsorption and Ion Exchange, Chemical Oxidation and Precipitation, Advanced Oxidation Process (AOP), Heavy Metals Removal Unit, Gas Transfer, etc.

Air Pollution and Its Control

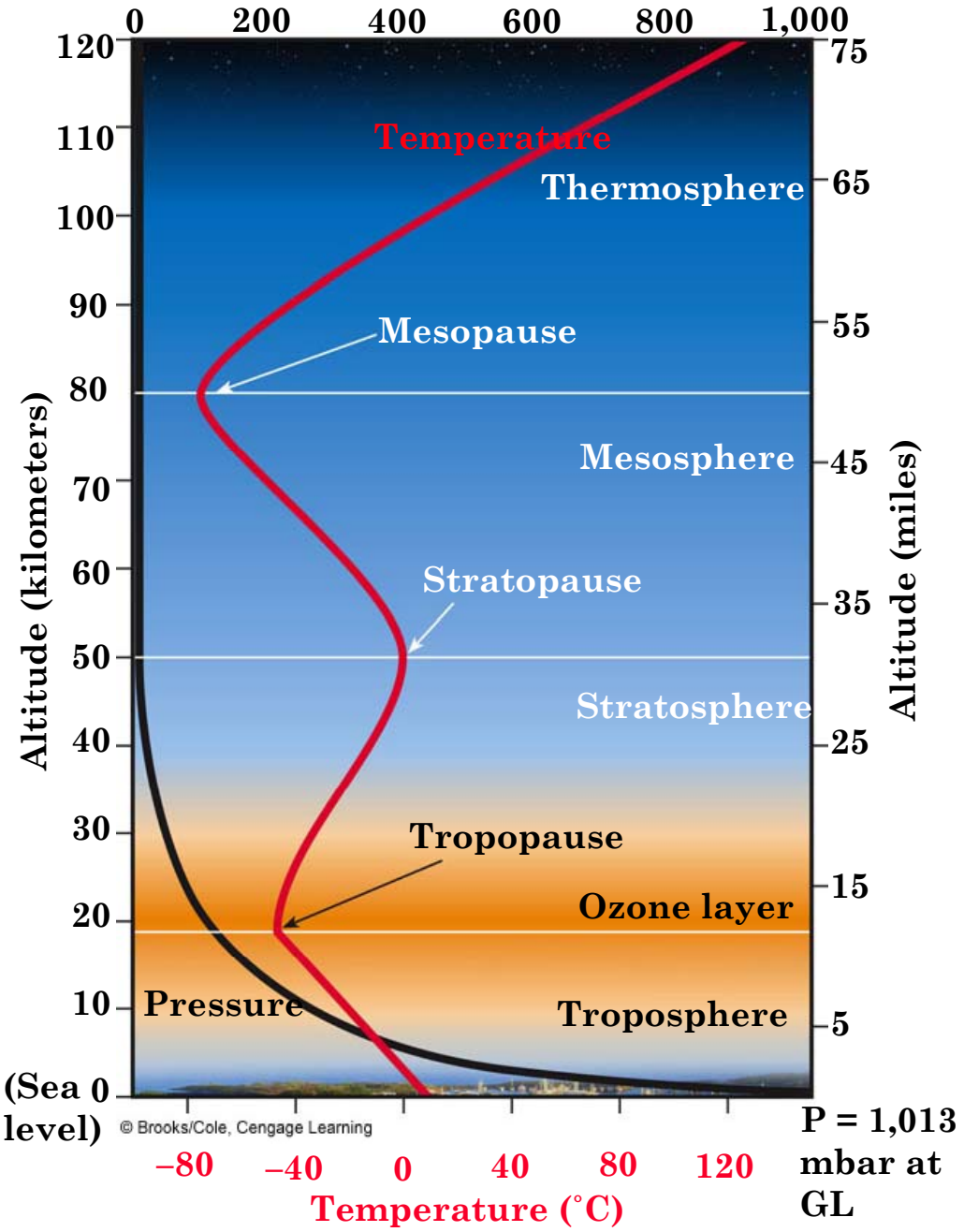
EARTH'S GREAT SPHERES

- **Lithosphere:** The lithosphere contains all of the cold, hard solid land of the planet's crust (surface), the semi-solid land underneath the crust, and the liquid land near the centre of the planet
- **Hydrosphere:** The hydrosphere contains all the solid, liquid, and gaseous water of the planet
- **Biosphere:** The biosphere contains all the planet's living things. This sphere includes all of the microorganisms, plants, and animals of Earth
- **Atmosphere:** The atmosphere contains all the air in Earth's system



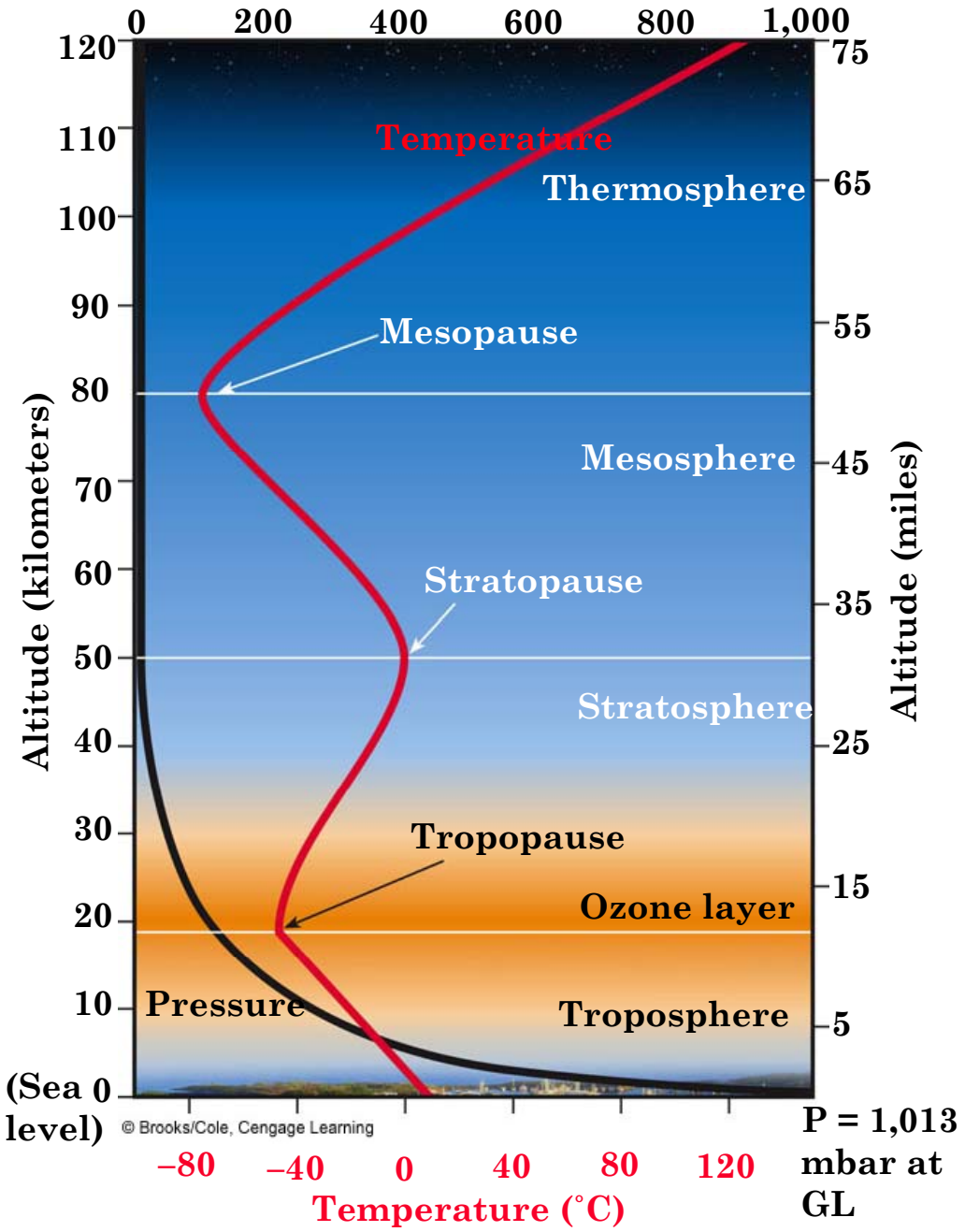
ATMOSPHERE

- Atmosphere consists of several layers: *Troposphere, Stratosphere, Mesosphere, Thermosphere*
- Bottom 10-15 km (Troposphere) is most important part in terms of *weather* and *biogeochemical cycles*
- The lowest 600 meters of Troposphere: *Air Quality Studies*
- Atmosphere varies in density, pressure and temperature



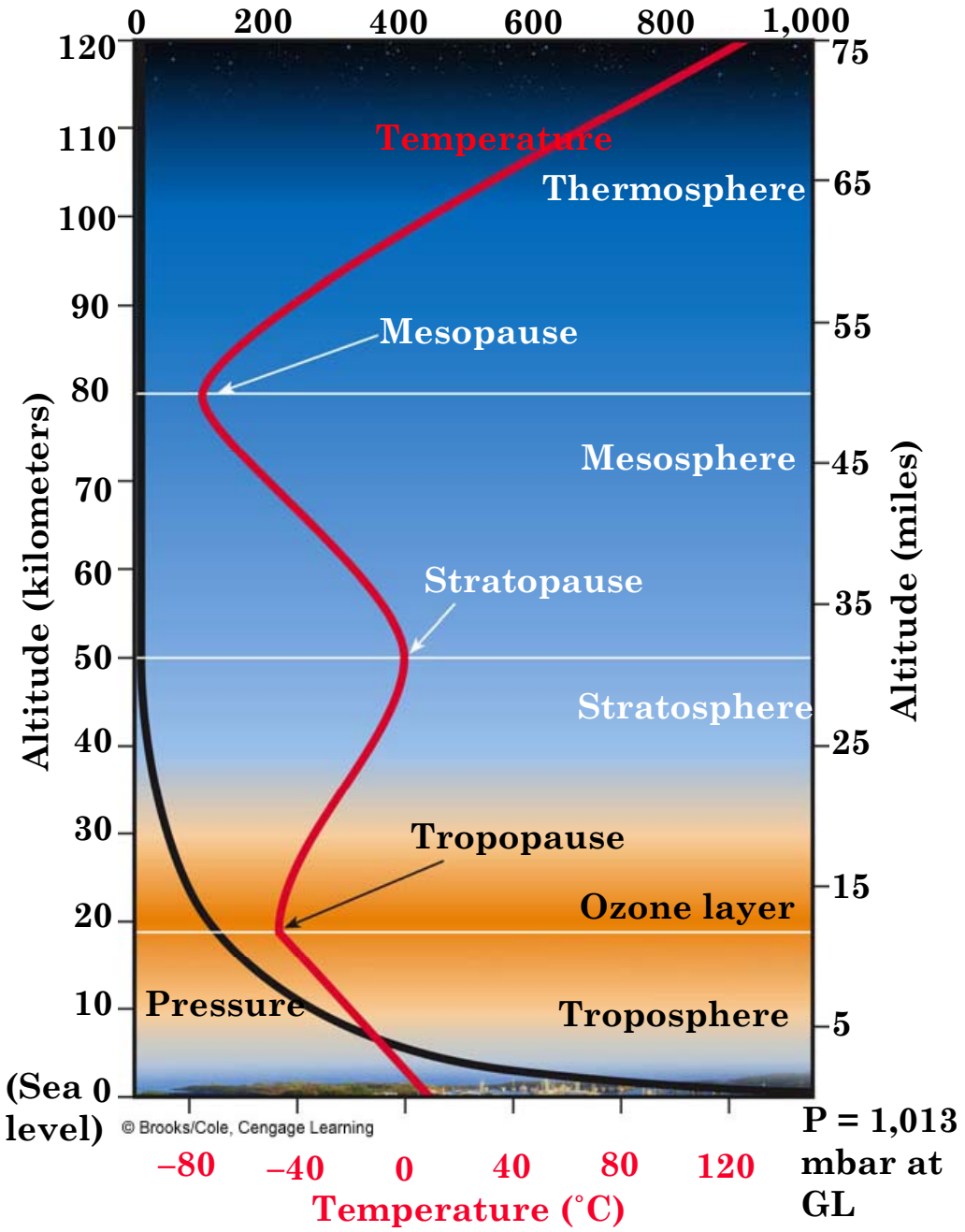
TROPOSPHERE

- 75–80% of the earth's air mass
- Closest to the earth's surface
- Varying chemical composition of air
- Rising and falling air currents: weather and climate
- Involved in chemical cycling



STRATOSPHERE

- Similar composition to the troposphere with 2 exceptions:
  - Much less water
  - Ozone layer filters harmful UV radiation



Composition of Air

Gas	% by volume	
N_2	78.08	Dry air
O_2	20.95	
Ar	0.93	
CO_2	0.03	
All other gases (H_2, Ne, He, Kr, Xe, etc)	0.01	
Water Vapor	Variable	

AIR POLLUTION

- Air is never perfectly clean
- Transfer of harmful and/or of natural/synthetic materials into the atmosphere as a direct/indirect consequences of natural and human activity
- The result of emission into the air of hazardous substances at a rate that exceeds the capacity of natural processes in the atmosphere to convert, deposit, or dilute them
- Presence in the outdoor atmosphere of one or more contaminants or combinations thereof in such quantities and of such duration as may be or may tend to be injurious to receptors (i.e. human, plant, or animal life, or property) or which unreasonably interferes with the comfortable enjoyment of life or the conduct of activities

TYPES OF AIR POLLUTION

- *Personal air exposure:* It refers to exposure to dust, fumes and gases to which an individual exposes herself/himself
- *Occupational air exposure:* It represents the type of exposure of individuals to potentially harmful concentration of aerosols, vapors, and gases in their working environment
- *Community air exposure:* This is most serious, complex, consists of varieties of assortment of pollution sources, meteorological factors, and wide variety of adverse social, economical, and health effects

SOURCES OF AIR POLLUTION

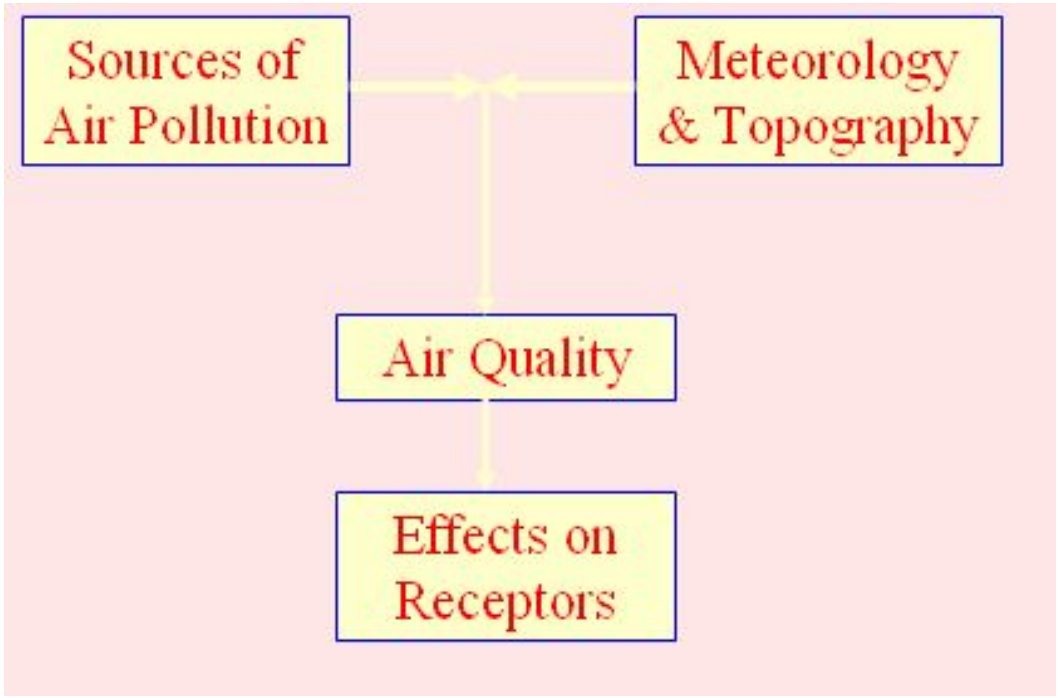
- **Natural Sources:** Volcano, forest fire, dust storms, etc.
- **Anthropogenic Sources:** created by human beings or man-made activities
  - *Stationary sources:*

    - Point sources (industrial processing, power plants, fuels combustion, etc.)

    - Area sources (Residential heating coal gas oil, on site incineration, open burning etc.)

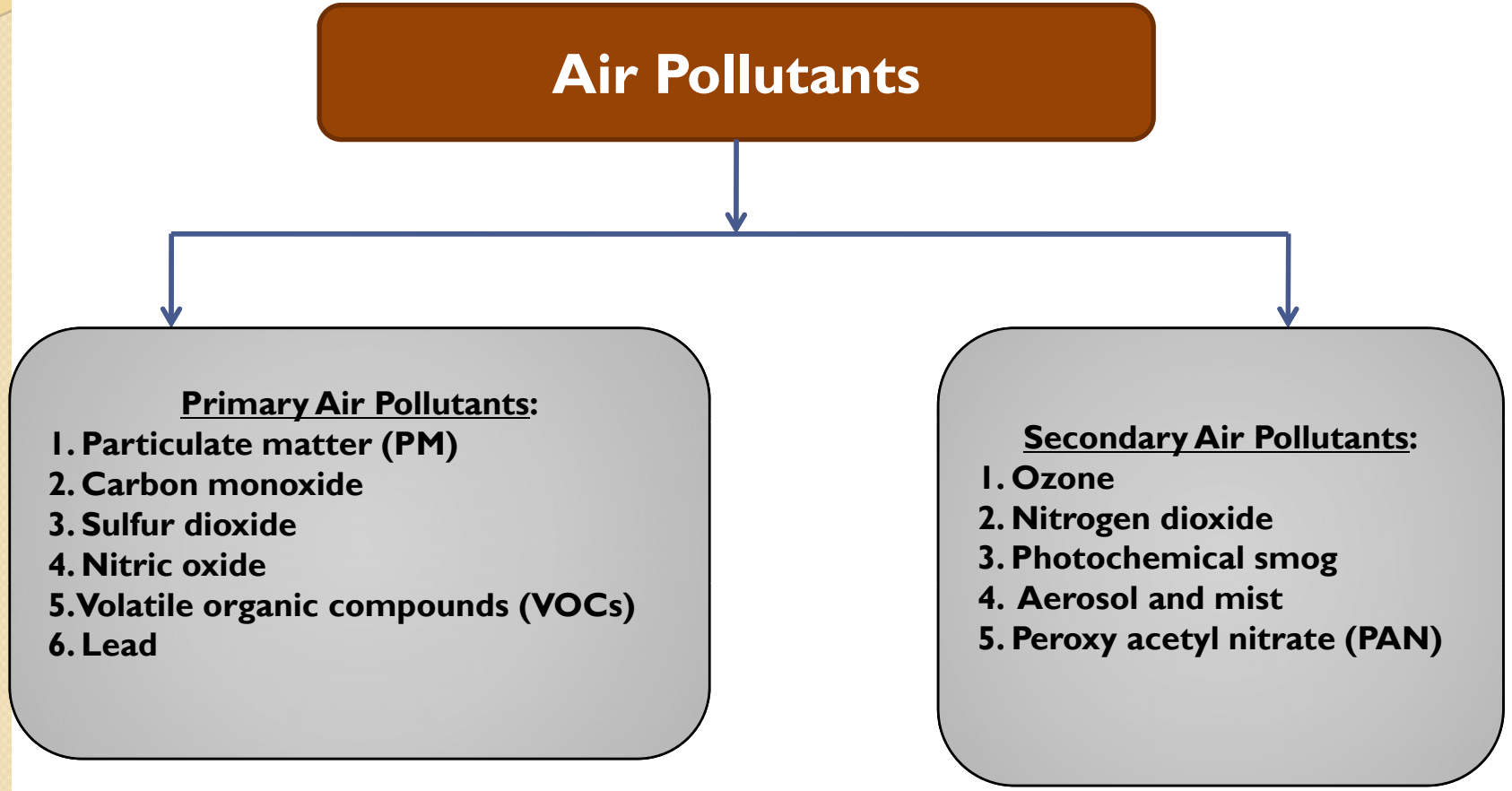
  - *Mobile sources:* Line sources (Highway vehicles, railroad locomotives, etc.)

AIR POLLUTION SYSTEM APPROACH



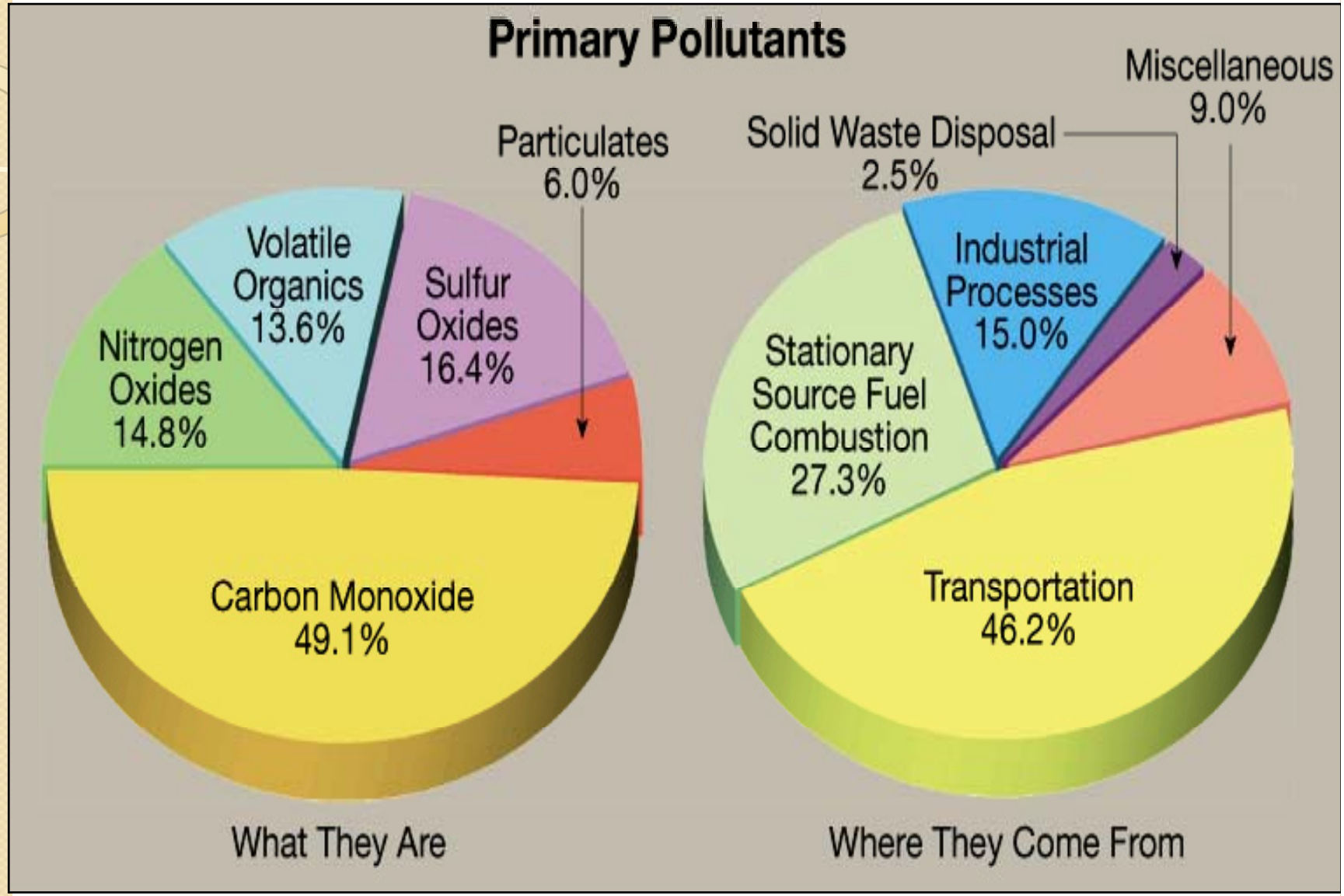
AIR POLLUTANTS

- *Primary air pollutants:* Materials those emitted directly from identifiable sources or when released pose health risks in their unmodified forms
- *Secondary air pollutants:* Primary pollutants interact with one another, sunlight, or natural gases to produce new, harmful compounds

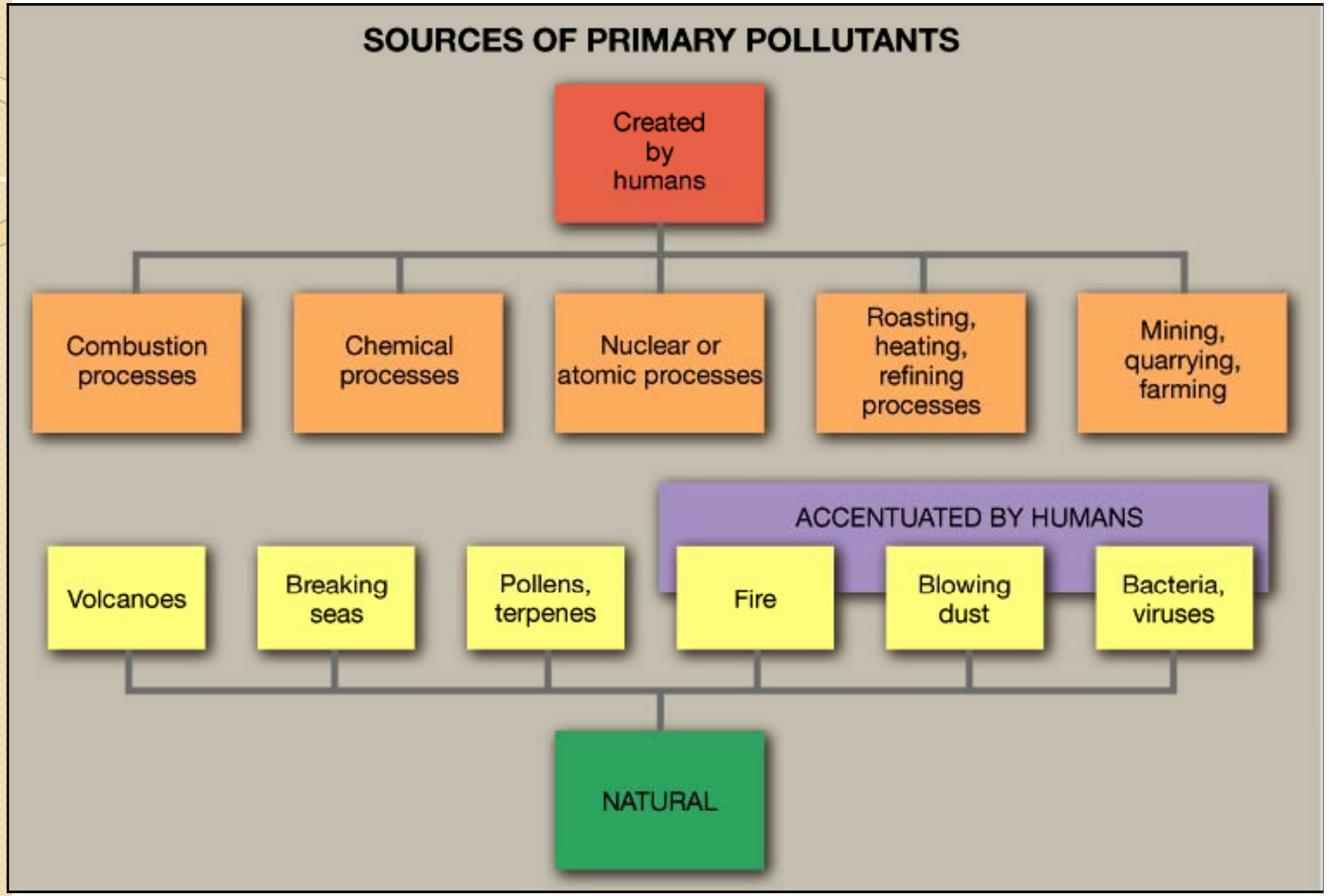


- Concentration of air pollutants is generally expressed in parts per million (by volume) (ppm or ppmv) or $\mu g/m^3$

PRIMARY AIR POLLUTANTS



PRIMARY AIR POLLUTANTS



SECONDARY AIR POLLUTANTS

- Atmospheric sulfuric acid is one example of a secondary pollutant.
- Air pollution in urban and industrial areas is often called **smog**
- **Photochemical smog**, a noxious mixture of gases and particles, is produced when strong sunlight triggers **photochemical reactions** in the atmosphere
- The major component of photochemical smog is **ozone**
- Although considerable progress has been made in controlling air pollution, the quality of the air we breathe remains a serious public health problem

CRITERIA AIR POLLUTANTS

- Based on health effects with measured air quality levels that violate the National Ambient Air Quality Standards (NAAQs):
  - CO
  - NOx
  - SOx
  - VOCs
  - PM
  - Pb

AIR POLLUTANTS: CONVERSION OF UNITS

Conversion from µg/m³ to ppm for gaseous air pollutants:

- **Can we directly convert µg/m³ to ppm for air as in case of water? Think!**

$$Volume-basis: 1\ ppm = \frac{1\ volume\ of\ \ gaseous\ \ pollu\tan t}{10^6\ volumes\ (air + pollu\tan t)}$$

$$Mass-basis: 1\ \mu g/m^3 = \frac{1\ \mu g\ of\ \ gaseous\ \ pollu\tan t}{cubic\ meter\ (air + pollu\tan t)}$$

Conversion Expression at a combination of Pressure (P) & Temperature (T):

$$\mu g/m^3 = ppm \times \frac{MW\ of\ \ Pollu\tan t\ (g)}{L/mol\ of\ \ Pollu\tan t\ at\ P\ \&\ T} \times 10^3$$

Example - Conversion of ppm to µg/m³:

The exhaust gas from an automobile contains 1.0 percent by volume of CO. What is the concentration of CO in µg/m³ at NTP?

Solution:

1 percent by volume = 10^4 ppm

MW of CO = 28 g

µg/m³ = $(10^4 \times 28 \times 10^3)/24.5 = 17.1 \times 10^6$

Air Pollutants: Particulate Matter (PM)

- Properties: varied

  Mixture of solid phase and absorbed materials (organic, inorganic and biological)

  Carbonaceous core 40-60%

- Sources:
  - Combustion - oil and coal
    - Industry
    - Automobiles
  - Tobacco smoke
  - Biomass burning
  - Metal smelters

AIR POLLUTANTS: PARTICULATE MATTER (PM)

Terminal Settling Velocity:

Assumptions:

- Terminal settling velocity of PM is based on Stokes' Law
- Only considers quiescent settling rather than turbulent nature of atmosphere
- Applicable to only spherical PM of size in the range of 0.1 to 100 µm
- Can only be used when Reynolds Number (Re) is less than 1i.e. under laminar flow condition

$$v_t = \frac{g(\rho_p - \rho_a)d_p^2}{18\mu}$$

$$\text{Re}\,ynolds\ Number\ \text{Re} = \frac{\rho_a v_t d_p}{\mu}$$

where,

$v_t = ter\,\min al\ settling\ velocity, m/s$

$g = gravitational\ cons\tan t, 9.81\ m/s^2$

$\rho_p = density\ of\ \ particle, 1000 - 2000\ kg/m^3$

$\rho_p = density\ of\ \ air, 1.2\ kg/m^3$

$d_p = diameter\ of\ \ particle, m$

$\mu = dynamic\ vis\cos ity\ of\ \ air, 1.85\times10^{-5}\ N.s/m^2\ \ OR\ kg/m.s$

AIR POLLUTANTS: PARTICULATE MATTER (PM)

Aerodynamic diameter:

- Defining particle size for spherical particles is easy; it is simply the diameter of the particle
- For non-spherical particles, the term 'diameter' does not appear to be strictly applicable
- Also, particles of identical shape can be composed of quite different chemical compounds and, therefore, have different densities
- The differences in shape and density could introduce considerable confusion in defining particle size
- In air pollution control, it is necessary to use a particle size definition that directly relates to how the particle behaves in a fluid such as air
- The term 'aerodynamic diameter' has been developed by aerosol physicists in order to provide a simple means of categorizing the sizes of particles having different shapes and densities with a single dimension

AIR POLLUTANTS: PARTICULATE MATTER (PM)

Aerodynamic diameter:

- The aerodynamic diameter is the diameter of a unit density hypothetical spherical particle that has the same inertial properties i.e. terminal settling velocity in the gas/air as the particle of interest
- The aerodynamic diameter for all particles greater than 0.5 micrometer can be approximated using the following equation:

$$d_{pa} = d_{ps}\sqrt{\rho_p}$$

where,

$d_{pa} = aerodynamic\ particle\ diameter, \mu m$

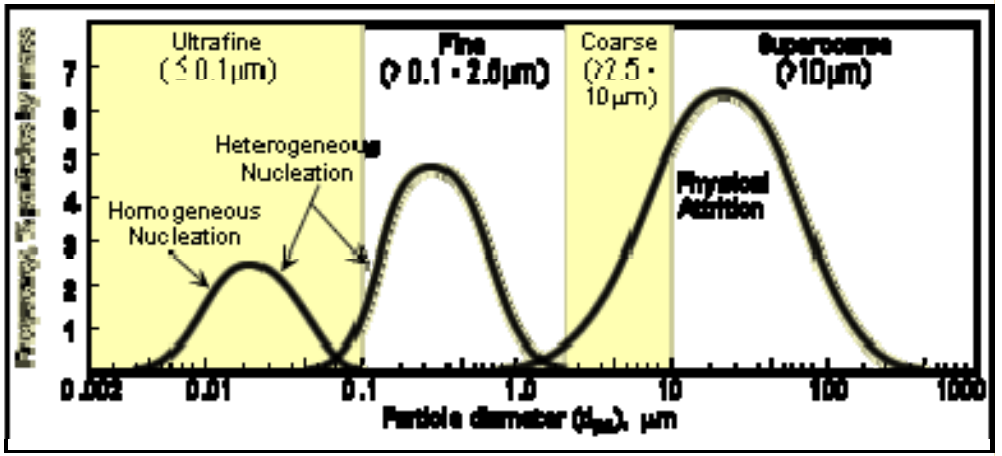
$d_{ps} = Stokes\ particle\ diameter, \mu m$

$\rho_p = density\ of\ particle, g/cm^3$

The Stokes diameter for a particle is the diameter of the sphere that has the same density and settling velocity as the particle

AIR POLLUTANTS: PARTICULATE MATTER (PM)

- Physical size:
  - Large
  - Small ~10um
  - Fine ~2.5um



Tri-modal distribution of PM in atmosphere

- Based on <u>Aerodynamic diameter</u>
  - Large - local irritation (>100um)
  - Inhalable (<100um)
  - Thoracic fraction (<20um)
    - Coarse PM_{10} (<10um)
    - Fine $PM_{2.5}$ (<2.5um)
    - Ultrafine (<0.1um)

respirable

- Chemical reactivity – very high
- Water content

Air Pollutants: Particulate Matter (PM) & Related Secondary Pollutants - Definitions

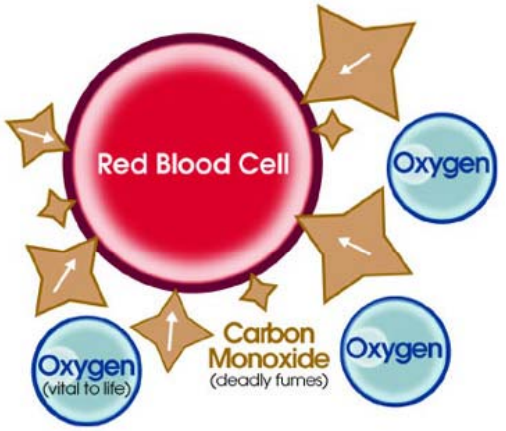
Terms	Definition
PM	Any material, except uncombined water, that exist in the solid or liquid state in the atmosphere or gas stream at standard condition
Aerosol	A dispersion of microscopic solid or liquid particles in gaseous media
Dust	Solids particles larger than colloidal size i.e. > 0.1 μm capable of temporary suspension in air
Fog	Visible (0.4 – 0.7 μm) aerosol
Fume	Particles formed by condensation, sublimation, or chemical reaction, predominantly smaller than 1 μm (tobacco smoke)
Smoke	Small gasborne particles resulting from combustion
Mist	Dispersion of small liquid droplets of sufficient size to fall from the air
Particle	Discrete mass of solid or liquid matter
Soot	An agglomeration of carbon particles

AIR POLLUTANTS: CARBON MONOXIDE (CO)

- Colorless, odorless, tasteless gas - stronger binder to haemoglobin (Hb) than O_2

  $\rightarrow$ 'Silent Killer'
- Review:
  - Cause: incomplete combustion of organic material (coal, gas, wood, etc.)
  - Sources: transportation sector, energy production, residential heating units, some industrial processes
  - Automobiles biggest source (80%)
  - Traffic (inside the car, parking garages, tunnels)
  - Inside cars = 3times the urban streets, and = 5times the residential streets

- ***Reacts with haemoglobin in blood***
  - ***Forms carboxy-haemoglobin (COHb) rather than oxy-haemoglobin (HbO_2)***
  - ***Prevents oxygen transfer***



AIR POLLUTANTS: SULFUR DIOXIDE (SO_X)

- Sulfur dioxide, referred to as SO_x in air pollution terminology, is a major primary pollutant in the atmosphere
- Sulfur dioxide is usually oxidized by ozone and hydrogen peroxide to form sulfur trioxide, a secondary pollutant that is extremely soluble in water
- Reacts with H_2O and forms sulfurous acid (H_2SO_3), which oxidizes to sulfuric acid (H_2SO_4)
- Sulfur oxides present in the atmosphere when condensation occurs results in droplets of sulfuric acid called 'acid rain'
- Can be present in both gaseous and particulate phases
- Cause: Burning fuel that contains sulfur
- Sources: Biomass and fossil fuel combustion, open burning of garbage and municipal incinerator, diesel-driven automobiles, Electric power generation i.e. thermal power plants, other industrial processes/units like refineries and smelting
- Thermal power plants emit SO_x in quantities as high as $1/10^{th}$ of coal burnt by the plants

Air Pollutants: Nitrogen Oxide (NO_X)

- NO (nitric oxide) is the principal emitted NOx gas from high temperature combustion

  - Acts a catalyst in the reactions that cause the formation of ozone

  - Reacts with tropospheric radicals to help form NO_2, ozone, and other secondary pollutants such as peroxyacetyl nitrate (PAN)

- NO_2 is the lesser of the two emitted NOx gases from high temperature combustion

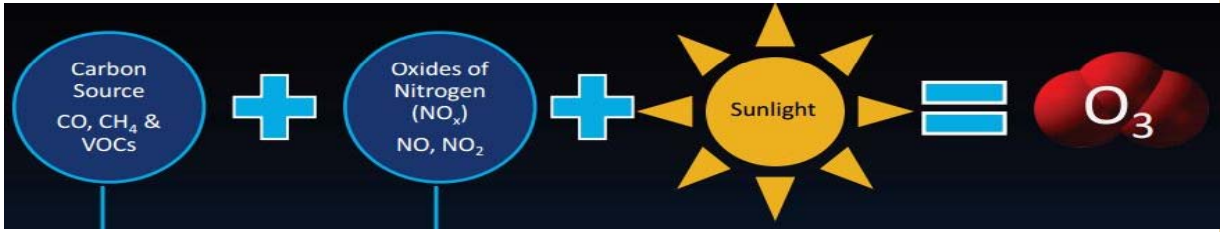
  - It is an important species in the atmosphere as it absorbs in the visible wavelength region

  - Manifests as the 'Brown Cloud' seen over large polluted cities

  - NO_2 is a precursor to photochemical smog; can be photolyzed to yield oxygen atoms that can react with molecular oxygen to create ozone

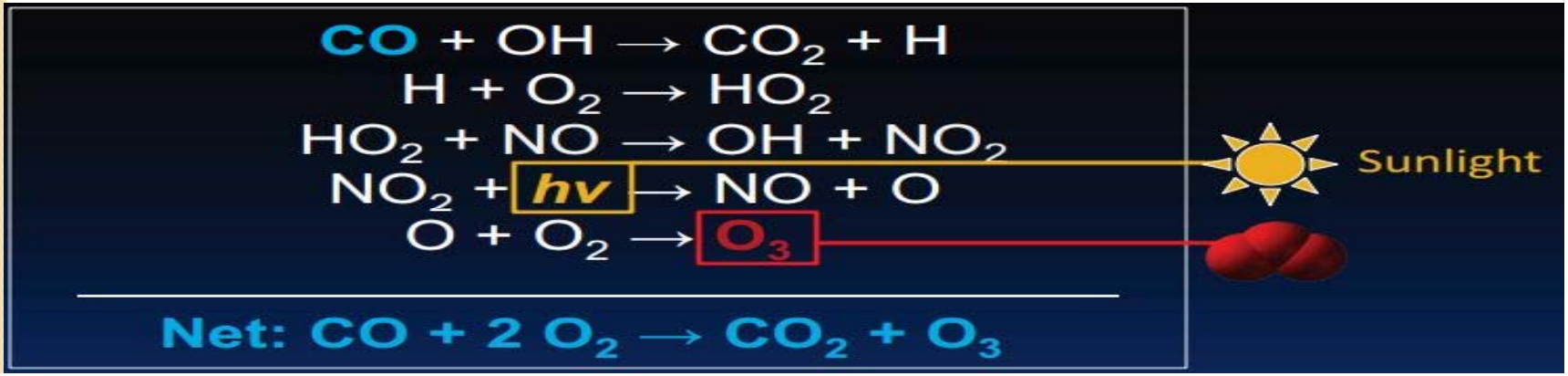
UV sunlight + Hydrocarbons + NOx → Ozone

AIR POLLUTANTS: OZONE (O_3)



- Short-lived, highly reactive, water soluble
- Source: Photochemical reactions
- O_3 absorbs UV radiation and creates a warm layer of air responsible for the thermal structure of the stratosphere
- O_3 present in the troposphere is mainly due to man-made pollution; higher concentrations are found in urban areas
- O_3 is formed when NOx combines with volatile organics compounds (VOC i.e. chemical vapors) in the presence of sunlight

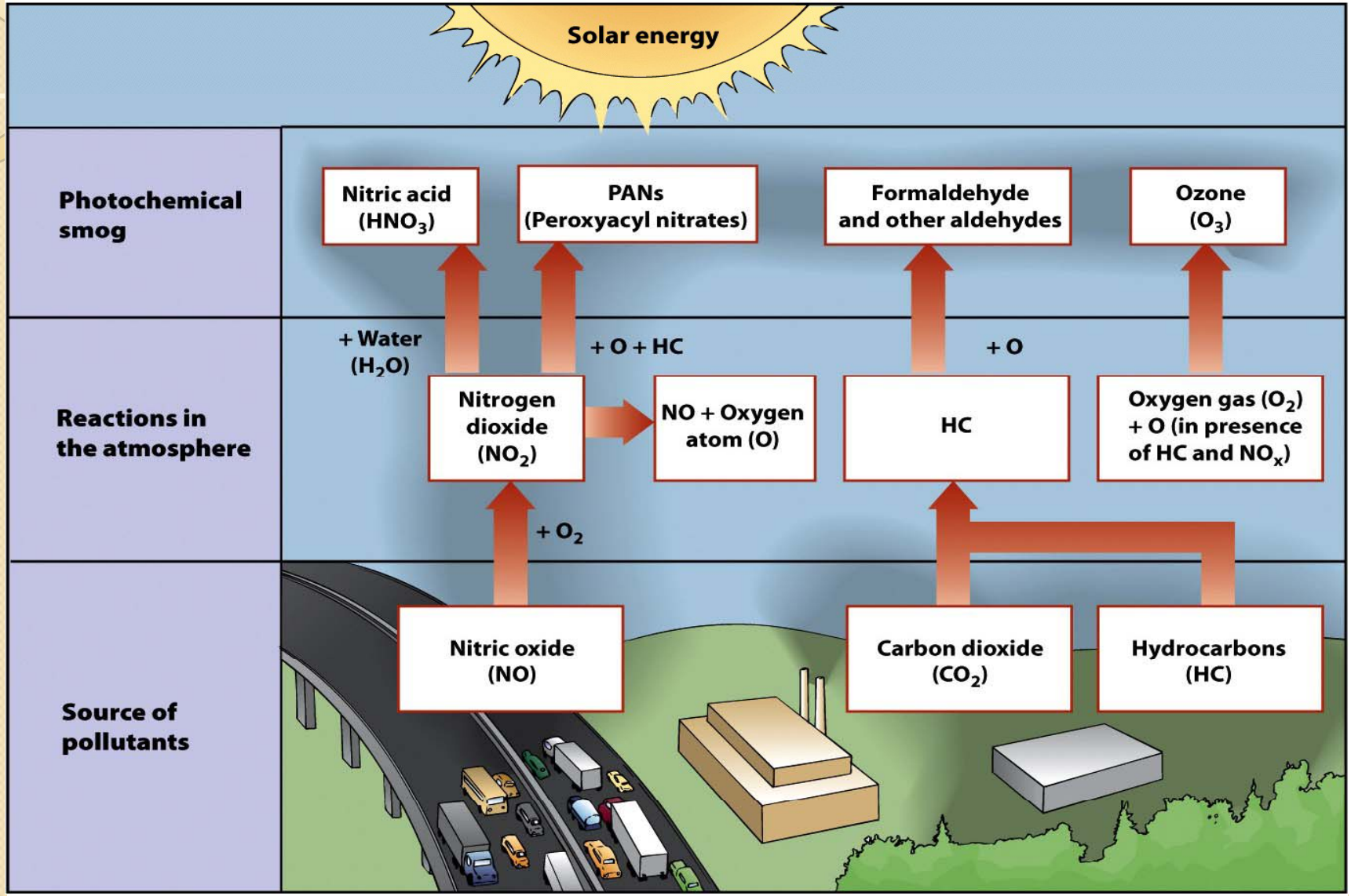
VOC + NOx + Sunlight → Ozone



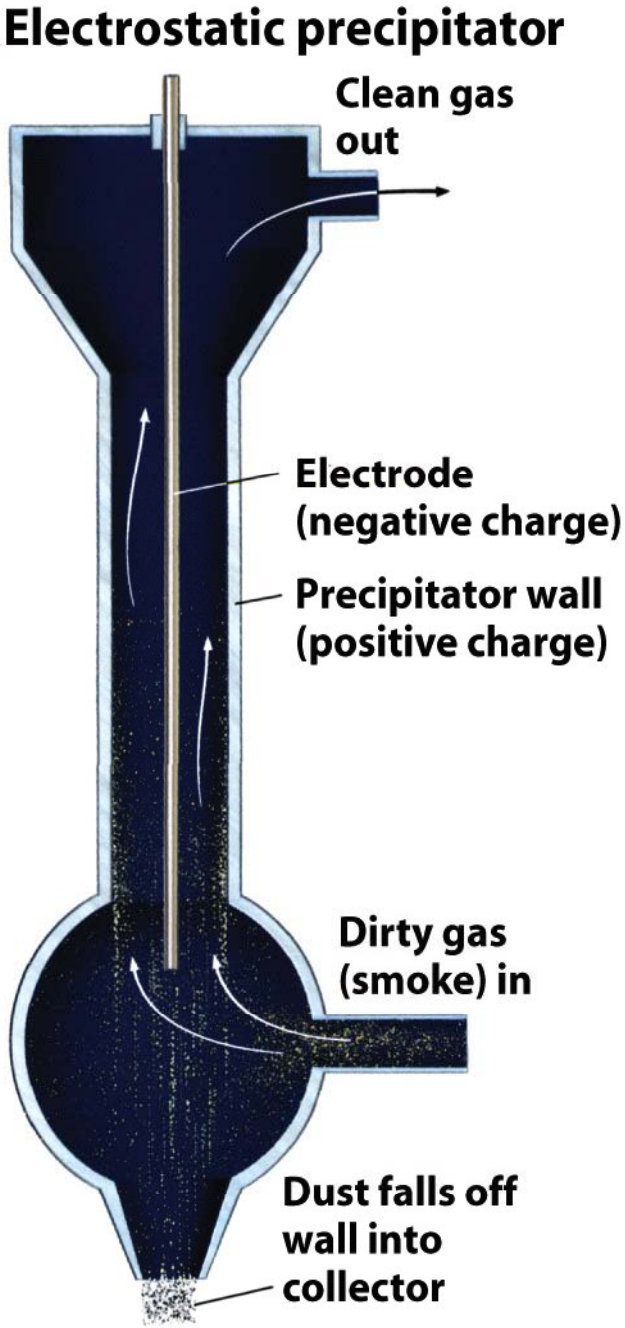
Air Pollutants: Lead

- Source: burning fuels that contain lead (phased out), metal processing, waste incinerators
- Absorbed into blood
- Accumulates in blood, bones, muscles, fat
  - Damages organs – kidneys, liver, brain, reproductive system, bones (osteoporosis)
  - Brain and nervous system – seizures, mental retardation, behavioral disorders, memory problems, mood changes,
    - Young children - lower IQ, learning disabilities
  - Heart and blood – high blood pressure and increased heart disease
  - Chronic poisoning possible

Formation of Photochemical Smog

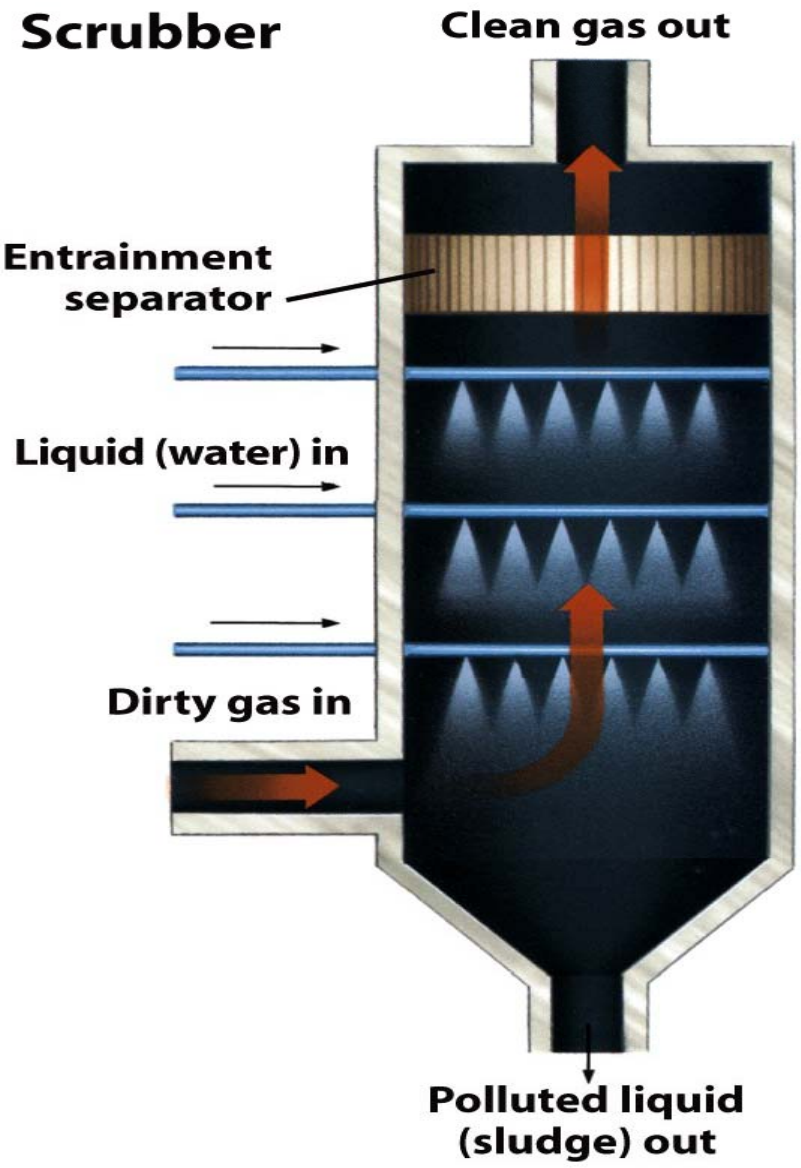


Controlling Air Pollution



Controlling Air Pollution

- Smokestacks with scrubbers (right)
- Particulate material can also be controlled



Waste Management

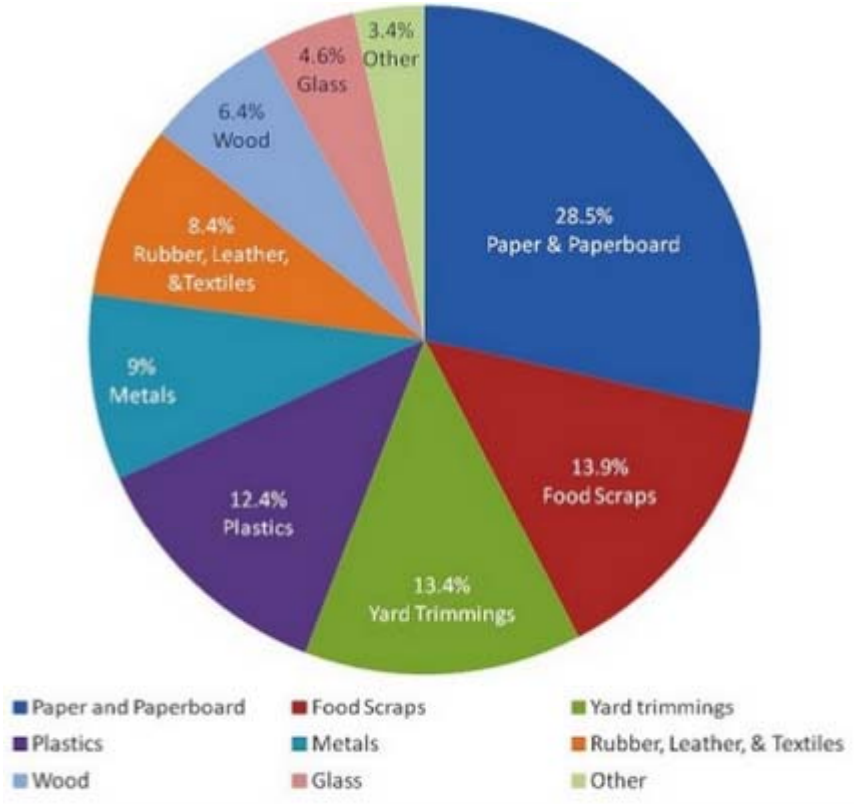
Municipal Solid Waste (MSW)

- The MSW refers to all solid wastes collected by local authority or municipality and is the most diverse category of waste

- Per capita MSW generation increasing by 1.3% per annum

- With urban population increasing between 3 – 3.5% per annum, the yearly increase in MSW generation is around 5% annually

- Per capita generation of MSW varies from 0.2 kg to 0.6 kg per capita per day



Characteristic of Hazardous Wastes

- ***Ignitability (flammability):*** ***If any waste can create fire or spontaneously combust at temperatures less than 60°C or 140°F***
- ***Examples: ethyl ether, xylene, oxidizers***

- ***Reactivity:*** ***If any waste tends to be unstable at normal temperatures and pressures. It may react violently with water, air, and other materials***
- ***Examples: explosives, peroxides***

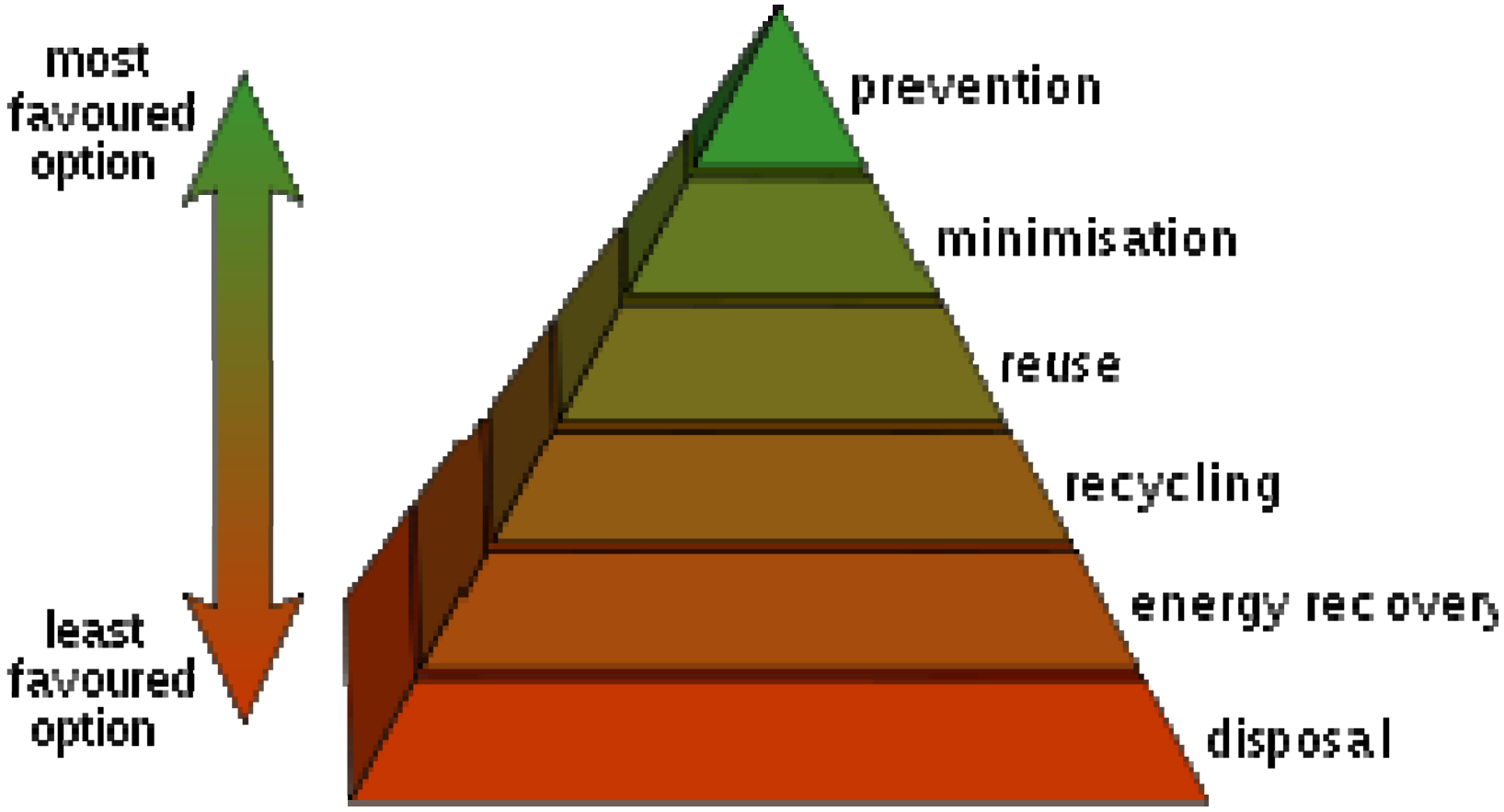
Characteristic of Hazardous Wastes

- ***Corrosive:*** ***If any waste has pH less than or equal to 2 or pH greater than or equal to 12.5***
- ***Examples: hydrochloric acid, glacial acetic acid***

- ***Toxicity:*** ***If any waste is harmful or fatal if you are exposed and can pollute groundwater if released on land***
- ***Examples: lead-based paints, cadmium, arsenic***

Waste Management Hierarchy

Waste hierarchy refers to 3 Rs: Reduce, Reuse, Recycle

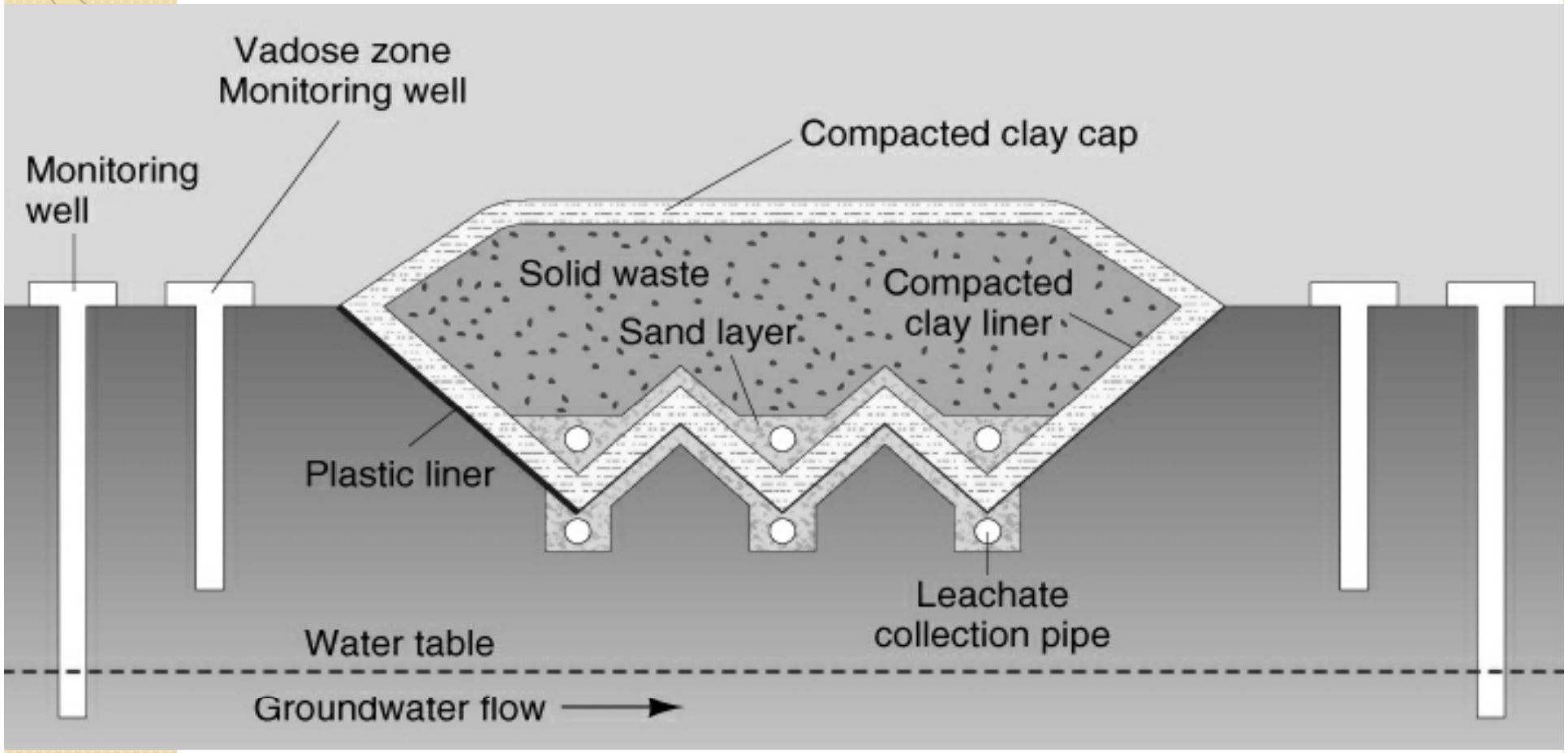


MSW Processing Options

- Biological Treatment
  - ✓Composting / Vermicomposting
  - ✓Anaerobic digestion/Biogasification
- Thermal Treatment
  - ✓Incineration
  - ✓Refuse Derived Fuel Burning
- Physical Treatment
  - ✓Making building blocks/bricks from inert waste
- Chemical Treatment
  - ✓To recover compounds such as glucose, synthetic oil and cellulose acetate, etc.

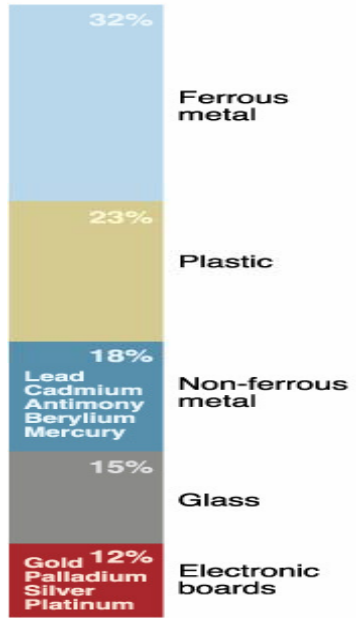
MSW Processing Options

- Sanitary Landfilling



Electronic Waste (E-waste)

- Electrical and electronic equipment (EEE) are one of the fastest growing sectors of economy.
- Every year about 20-30 million tons of E-waste is generated worldwide.
- Among E-waste, Printed Circuit Boards (PCBs) are core component of EEE constituting about 3-6% of their total weight.
- PCBs are typically consist of around 28% metallic and 72% non-metallic (plastic, ceramic, etc.) constituents.
- Metals present in PCBs include heavy metals, precious metals as well as toxic metals which turns them hazardous and at the same time secondary metal reservoirs.
- The toxicity of e-waste is however mainly linked to the presence of heavy metals, viz. As, Hg, Cd, Cr, Pb, etc.
- Thus, recycling of e-waste is an important aspect not only from the point of waste treatment for environmental protection but also from the recovery of metals for economic development.



Elements present in PCB of Computer

Strategies of E-waste Management