



# Inovo Global Safety

Training & Advisory Services



*Official Partners: OSH Tree Training & Consultancy Qatar*

CSP EXAMINATION PREPARATION

## DOMAIN 5

### Environmental Management

Supplementary Learning Notes

**Exam Weight: 6% of Total Score**

Covering 5 Core Knowledge Areas

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## DOMAIN 5 — ENVIRONMENTAL MANAGEMENT

CSP V11.0 Examination Preparation • Exam Weight: 6% • Blueprint Objectives 1–5

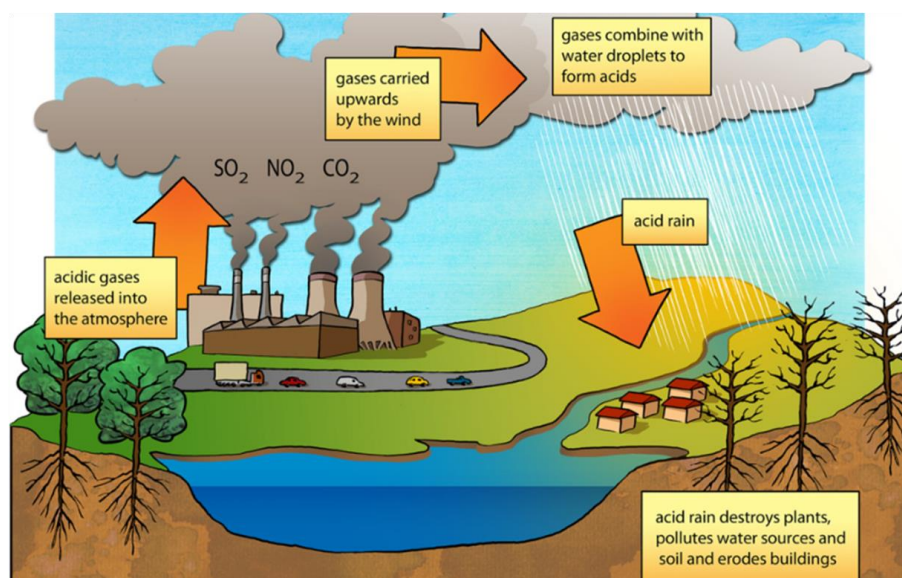
### 1. ENVIRONMENTAL PROTECTION & POLLUTION PREVENTION

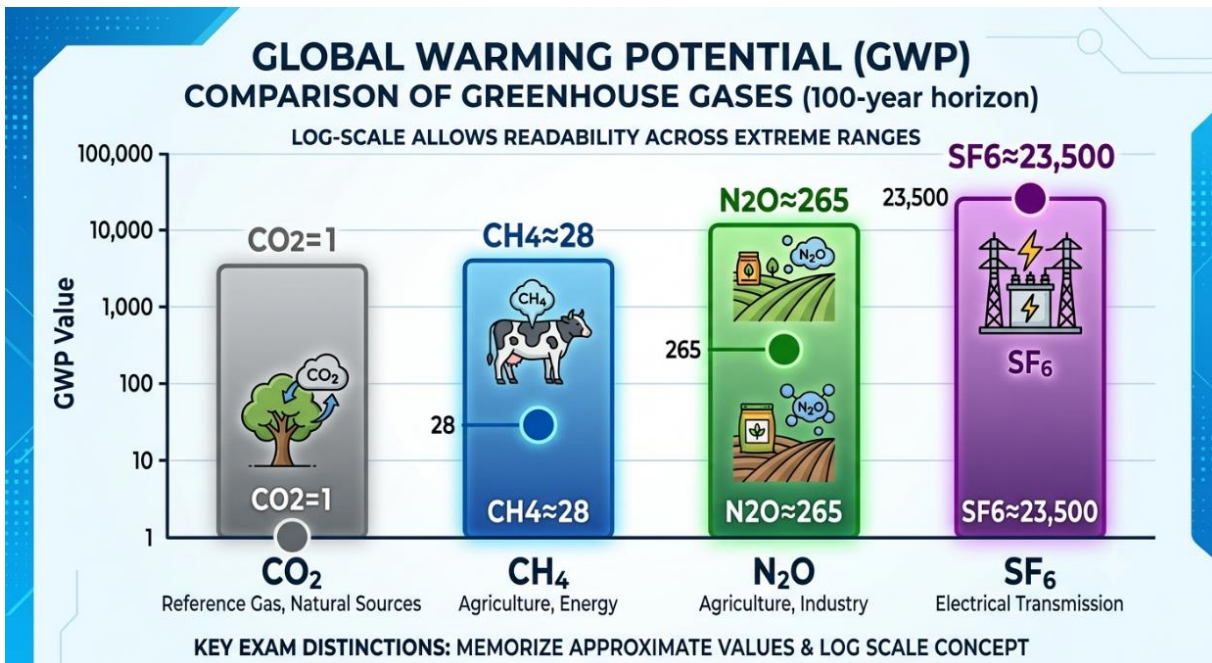
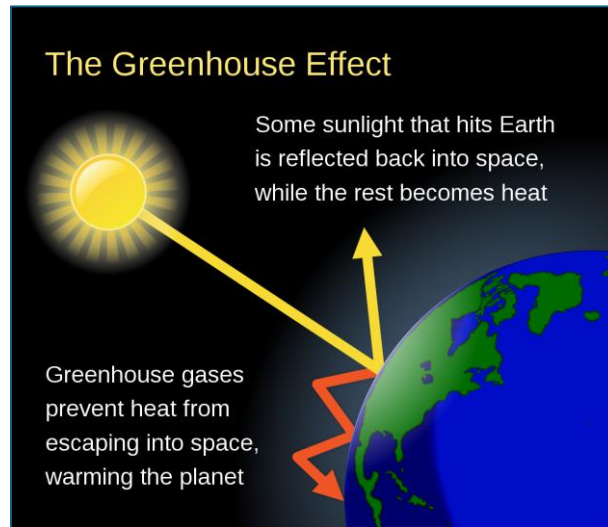
#### 1.1. Air Pollution

##### Key Air Pollution Issues

Air pollution is the introduction of contaminants into the atmosphere that cause harm to human health, the natural environment, or built infrastructure. The CSP must understand both the sources and control technologies for each major pollutant category.

- Global Warming / Greenhouse Effect:  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ , and water vapor trap outgoing infrared radiation. Primary driver is fossil fuel combustion.  $\text{CO}_2$  is the reference greenhouse gas (GWP = 1);  $\text{CH}_4$  has GWP ~28;  $\text{N}_2\text{O}$  ~265;  $\text{SF}_6$  ~23,500.
- Acid Deposition (Acid Rain):  $\text{SO}_2 + \text{NO}_x + \text{atmospheric moisture} \rightarrow \text{H}_2\text{SO}_4$  and  $\text{HNO}_3$ . Damages forests, lakes, aquatic life, and limestone/marble structures.
- Photochemical Smog (Low-Level Ozone):  $\text{NO}_x + \text{VOCs} + \text{sunlight} \rightarrow \text{ground-level O}_3 + \text{peroxyacetyl nitrate (PAN)}$ . Occurs in sunny, warm weather. Causes respiratory irritation.
- Stratospheric Ozone Depletion: CFCs, HCFCs, halons, methyl bromide release Cl/Br radicals that destroy ozone ( $\text{O}_3 \rightarrow \text{O}_2$ ). Protected by Montreal Protocol (1987).

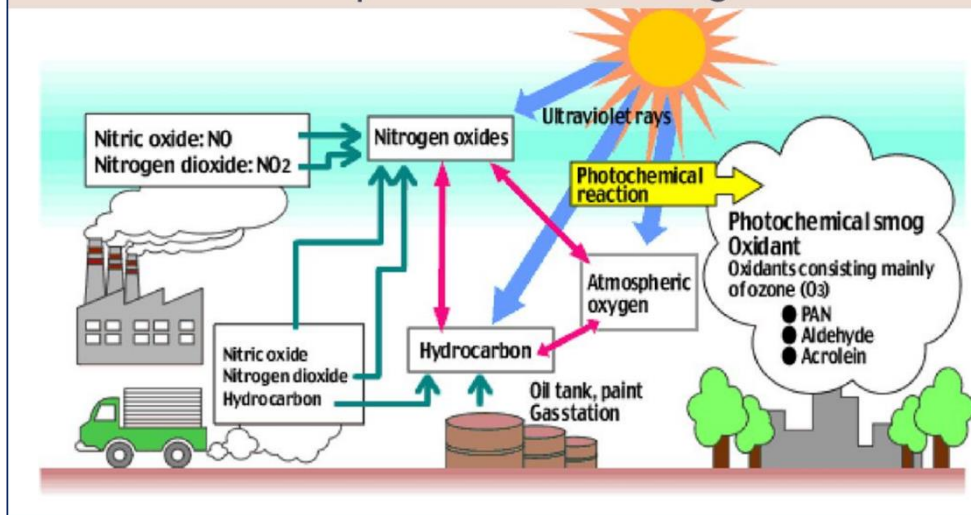




### Industrial vs. Photochemical Smog Comparison

| Characteristic            | Industrial Smog (London-type)                  | Photochemical Smog (LA-type)                                      |
|---------------------------|------------------------------------------------|-------------------------------------------------------------------|
| Weather                   | Cool, damp                                     | Sunny, warm                                                       |
| Primary Pollutants        | Particulates, sulfur oxides (SO <sub>2</sub> ) | NO <sub>x</sub> , hydrocarbons, VOCs, ground-level O <sub>3</sub> |
| Chief Source              | Coal combustion (power, industry)              | Gasoline combustion (vehicles)                                    |
| Control Technology        | Scrubbers, electrostatic precipitators         | Catalytic converters, vapor recovery systems                      |
| Associated Health Effects | Chronic bronchitis, SO <sub>2</sub> irritation | Asthma exacerbation, eye irritation, respiratory inflammation     |

### Low-level ozone - photochemical smog.



### INDUSTRIAL vs PHOTOCHEMICAL SMOG: Side-by-Side Comparison

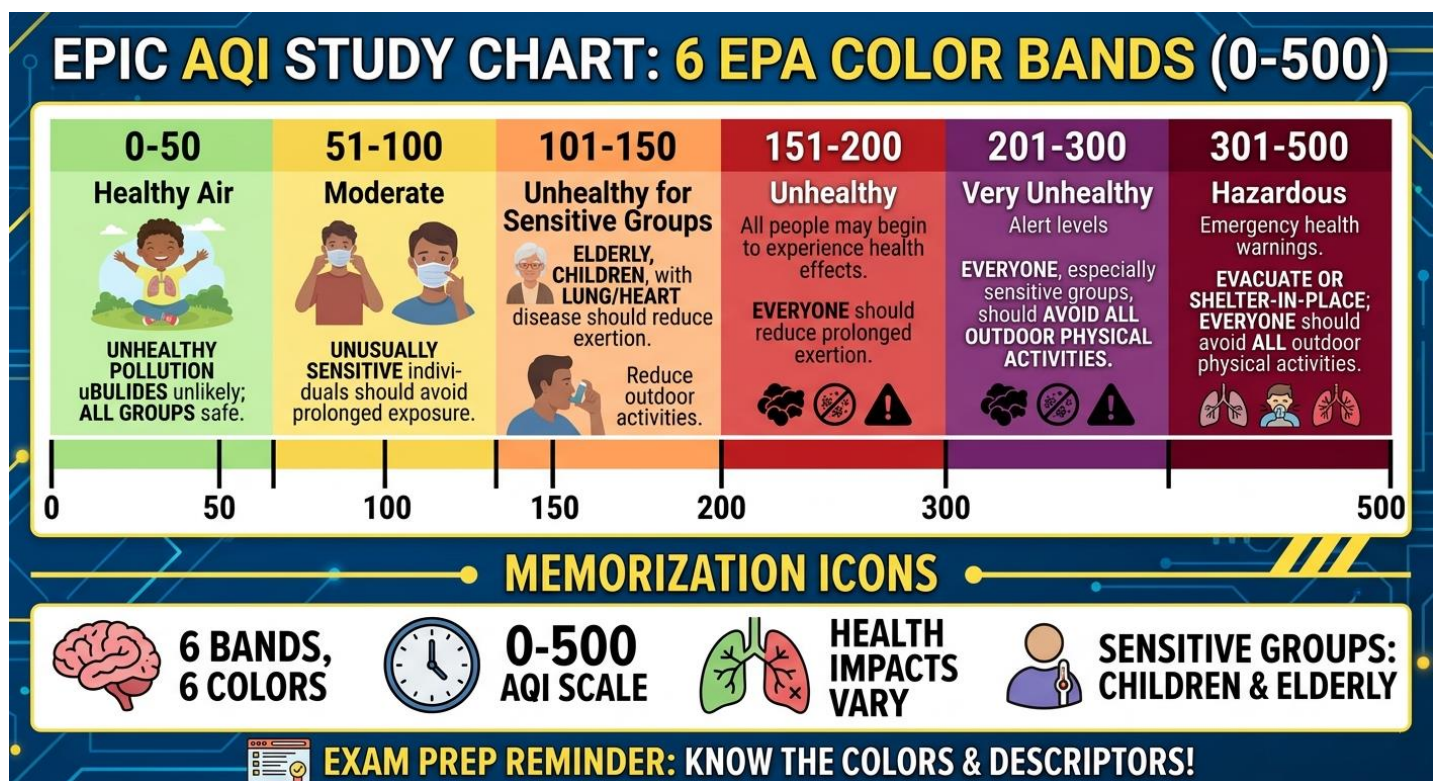
|                                     | Industrial Smog (Classical / London)                                                             | Photochemical Smog (LA-Type)                                                                        |
|-------------------------------------|--------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| <b>WEATHER CONDITIONS</b>           | Cold, Humid, Foggy, Winter<br>                                                                   | Hot, Sunny, Dry, Stagnant Air (Inversion Layer)<br>                                                 |
| <b>PRIMARY POLLUTANTS</b>           | SO <sub>2</sub> (Sulfur Dioxide), Particulate Matter (Soot, Ash), Carbon Monoxide (CO)<br>       | NO <sub>x</sub> (Nitrogen Oxides), VOCs (Volatile Organic Compounds), Hydrocarbons<br>              |
| <b>MAJOR SOURCES</b>                | Coal Burning (Power Plants, Residential Heating), Industrial processes, Heavy Oil<br>            | Motor Vehicle Emissions (Transportation), Oil Refineries, Industrial Solvents, Gas Stations<br>     |
| <b>KEY CONTROLS &amp; SOLUTIONS</b> | Fuel Switching (Less Coal/Oil), Scrubbers in Power Plants, Industrial Regulation<br>             | Catalytic Converters in vehicles, Alternative Fuels (Electric, Hybrid), Smog Checks, Carpooling<br> |
| <b>PRIMARY HEALTH EFFECTS</b>       | Respiratory problems (Chronic Bronchitis), Coughing, Difficulty Breathing, Throat Irritation<br> | Eye and Throat Irritation, Exacerbation of Asthma, Reduced Lung Function, Damaged Plant Life<br>    |

EXAM DISTINCTIONS AT A GLANCE - For Students

## Air Quality Index (AQI)

The EPA Air Quality Index reports daily air quality on a scale of 0–500, based on the worst of six criteria pollutants:  $PM_{2.5}$ ,  $PM_{10}$ ,  $O_3$ , CO,  $SO_2$ ,  $NO_2$ . Higher numbers = greater health risk.

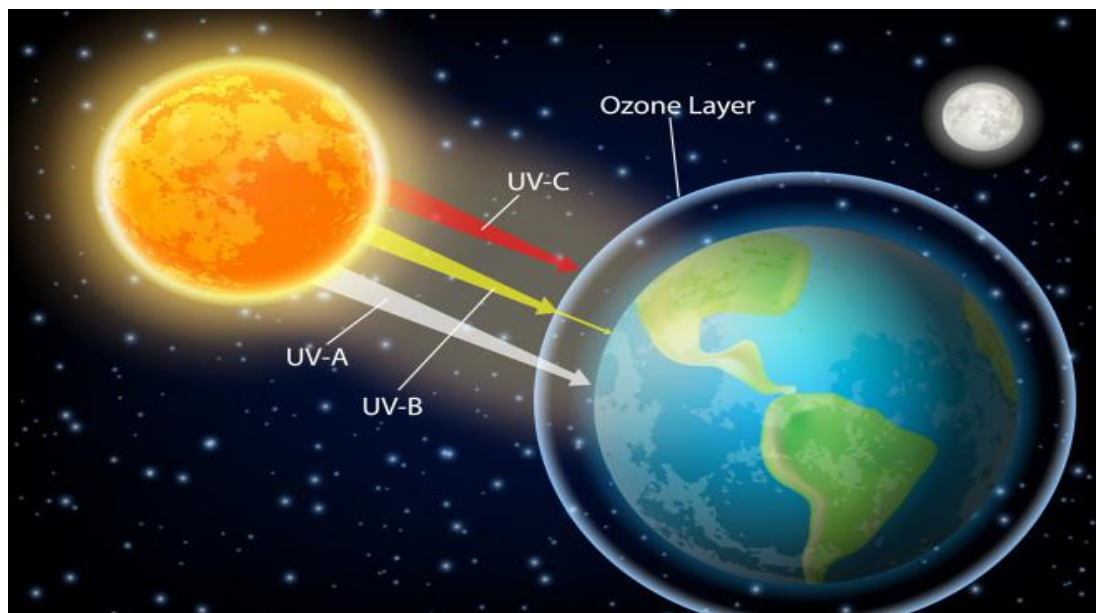
| AQI Range | Level of Concern               | Color  | Action                                              |
|-----------|--------------------------------|--------|-----------------------------------------------------|
| 0–50      | Good                           | Green  | No action needed                                    |
| 51–100    | Moderate                       | Yellow | Sensitive individuals should limit outdoor exertion |
| 101–150   | Unhealthy for Sensitive Groups | Orange | At-risk groups restrict prolonged outdoor activity  |
| 151–200   | Unhealthy                      | Red    | Everyone may experience health effects              |
| 201–300   | Very Unhealthy                 | Purple | Health alert; avoid outdoor activity                |
| 301–500   | Hazardous                      | Maroon | Emergency conditions; everyone affected             |



## Ozone-Depleting Substances (ODS) & Montreal Protocol

| Substance                     | ODP (Relative)          | Primary Use                                | Status                                             |
|-------------------------------|-------------------------|--------------------------------------------|----------------------------------------------------|
| CFCs<br>(chlorofluorocarbons) | 0.6–1.0 (highest)       | Refrigeration, aerosols, foams             | Phased out — developed nations by 1996             |
| Halons                        | 1.2–10 (second highest) | Fire extinguishers (Halon 1211, 1301)      | Phased out — developed nations by 1994             |
| HCFCs                         | 0.01–0.12               | Transitional CFC replacements (HVAC)       | Phase-out ongoing — global completion by 2030–2040 |
| Methyl Bromide                | 0.60                    | Agricultural fumigant, quarantine          | Phase-out with critical-use exemptions             |
| HFCs                          | 0 (ODP)                 | CFC/HCFC replacements (HVAC, refrigerants) | High GWP; regulated under Kigali Amendment (2016)  |

Montreal Protocol (1987): Most successful environmental treaty — ratified by all 197 UN member states. Requires industrialized nations to phase out ODS production and consumption. Subsequent amendments (London, Copenhagen, Montreal, Beijing, Kigali) accelerated schedules and added HFCs.



UV-C is the harmful one.

## Air Pollution Control Technologies

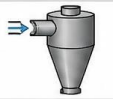
| Technology                        | Target Pollutant                        | Mechanism                                                  | Typical Application                      |
|-----------------------------------|-----------------------------------------|------------------------------------------------------------|------------------------------------------|
| Settling Chambers                 | Coarse particles ( $>75\ \mu\text{m}$ ) | Gravity sedimentation                                      | Pre-cleaner for industrial ducts         |
| Cyclone Separators                | Particulates $>10\ \mu\text{m}$         | Centrifugal force — particles hit wall and drop            | Wood chips, grain dust, industrial dusts |
| Fabric Filters (Baghouses)        | Fine particulates ( $\text{PM}_{2.5}$ ) | Mechanical filtration through fabric media                 | Cement, steel, power plants              |
| Electrostatic Precipitators (ESP) | Fine particles, smoke                   | Particles charged by corona discharge; collected on plates | Coal-fired power plants, smelters        |
| Wet Scrubbers                     | Gases and particulates                  | Liquid contact absorption                                  | $\text{SO}_2$ removal, acid mists, HCl   |
| Dry Scrubbers                     | Acid gases ( $\text{SO}_2$ , HCl)       | Alkali reagent (lime/limestone) injected into gas stream   | Incinerators, coal plants                |
| Thermal Incinerators              | VOCs, odors                             | Combustion at $700\text{--}1,000^\circ\text{C}$            | Solvent recovery, chemical plants        |
| Catalytic Oxidizers               | VOCs                                    | Oxidized at lower temperature over catalyst                | Painting, printing, coating operations   |

## • AIR POLLUTION CONTROL DEVICES •

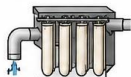
### PARTICULATE MATTER REMOVAL



- Settling chambers.



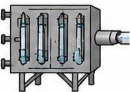
- Cyclones and other inertial separators.



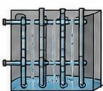
- Fabric filters.



- Wet scrubbers.

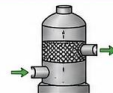


- Electrostatic precipitators.



- Water walls.

### GAS AND VAPOR DEVICES



- Absorption devices.



- Adsorption devices.



- Incinerators.



- Dry scrubbers.



- Coolers and chillers.



- Peat beds.



- Bio scrubbers.

### Particulate Matter Removal

These strategies focus on removing solid or liquid particles (e.g., dust, soot, aerosols) from emissions:

1. **Settling Chambers:**
  - Use gravity to remove large particles from air streams by allowing them to settle at the bottom of a chamber.
2. **Cyclones and Other Inertial Separators:**
  - Use centrifugal force to separate particles from air by spinning the air in a circular motion. Heavier particles are forced to the walls and collected.
3. **Fabric Filters:**
  - Also known as baghouses, these filter particulates through a fabric medium, trapping fine particles while allowing clean air to pass through.
4. **Wet Scrubbers:**
  - Use liquid (often water) to capture particles. Particles are trapped in droplets and removed as wastewater.
5. **Electrostatic Precipitators:**
  - Use electrical charges to attract and collect particles. Charged particles are drawn to plates or wires where they are collected.
6. **Water Walls:**
  - Involves a wall of flowing water to capture particles as air passes through. Particles stick to the water and are carried away.

### Gas and Vapor Control Devices

These strategies are used to control gaseous pollutants and vapors such as volatile organic compounds (VOCs), acidic gases, or hazardous chemicals:

1. **Absorption Devices:**
  - Use a liquid (e.g., water or chemical solution) to dissolve or trap gas pollutants. Often used in chemical processing.
2. **Adsorption Devices:**
  - Use solid materials (e.g., activated carbon) to trap gas molecules on their surface.
3. **Incinerators:**
  - Burn gaseous pollutants and VOCs at high temperatures to convert them into less harmful substances like CO<sub>2</sub> and water.
4. **Dry Scrubbers:**
  - Use dry materials (e.g., lime or activated carbon) to chemically react with and neutralize gases, commonly used for sulfur dioxide (SO<sub>2</sub>).
5. **Coolers and Chillers:**
  - Reduce the temperature of gas streams to condense and capture specific vapors or reduce emissions.
6. **Peat Beds:**
  - Natural biofilters that use peat material to trap and break down pollutants.
7. **Bio Scrubbers:**
  - Use microorganisms to degrade pollutants in a gas stream, often used for odor control or removing organic gases.

### □ KEY REFERENCES

Brauer, R.L. Safety and Health for Engineers, 3rd Ed., Ch. 32: Air pollution control engineering — technology selection based on pollutant particle size, concentration, and regulatory limits. AERMOD dispersion modelling (EPA preferred model) predicts downwind pollutant concentrations from industrial stacks. NAAQS under the Clean Air Act (CAA) set primary (health-based) and secondary (welfare-based) standards for the 6 criteria pollutants: SO<sub>2</sub>, NO<sub>2</sub>, PM, CO, O<sub>3</sub>, Pb.

## 1.2. Water Pollution

Water pollution occurs when contaminants are introduced into water bodies — rivers, lakes, groundwater, oceans — in quantities that adversely affect aquatic ecosystems and human health. The CSP must distinguish pollution types, understand water quality parameters, and know regulatory frameworks.

### Water Pollution Classifications

| Type       | Description                                               | Examples                                                                                 |
|------------|-----------------------------------------------------------|------------------------------------------------------------------------------------------|
| Physical   | Alteration of physical properties without chemical change | Thermal pollution (power plant cooling water), suspended solids, turbidity, litter       |
| Chemical   | Introduction of chemical contaminants                     | Pesticides, heavy metals (Pb, Hg, Cd), nutrients (N, P), acids, alkalis, hydrocarbons    |
| Biological | Introduction of pathogens, viruses, or parasites          | Coliform bacteria, Cryptosporidium, Giardia, viruses causing cholera, typhoid, hepatitis |

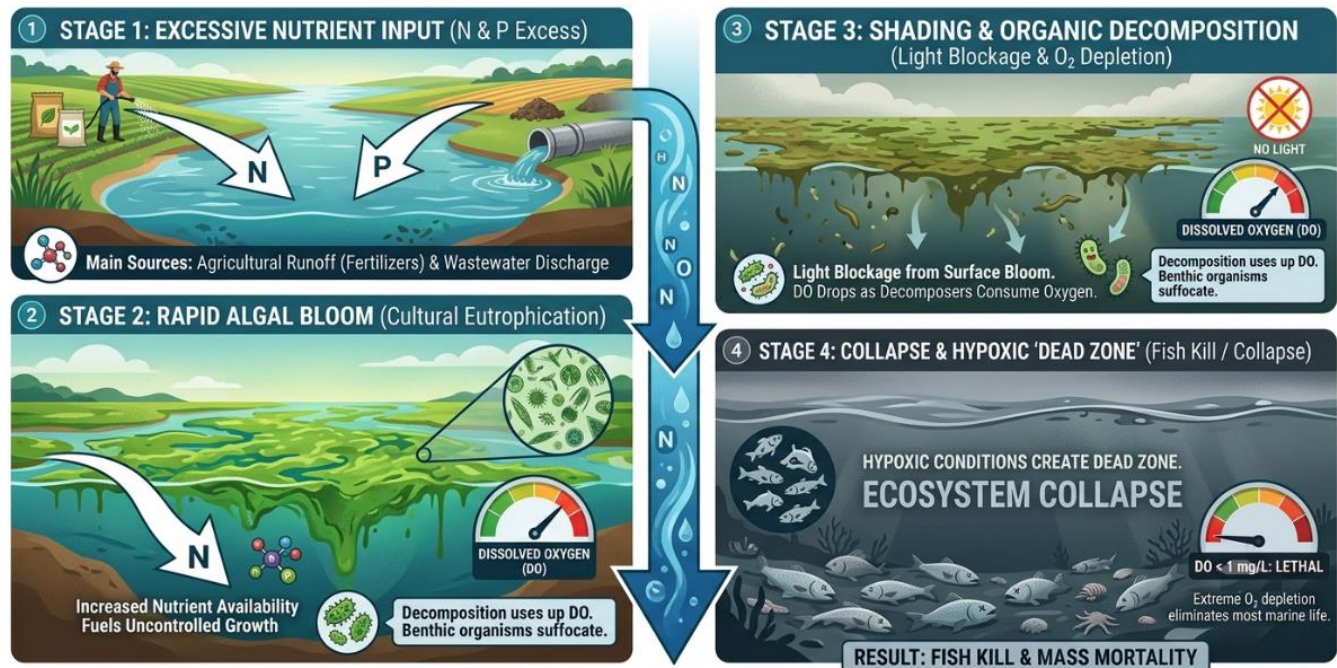
### Eutrophication

Eutrophication is the enrichment of a water body with excess nutrients (primarily nitrogen and phosphorus) from agricultural runoff, sewage effluent, and urban stormwater. The process unfolds in four stages:

- Stage 1 — Algal Bloom: Excess N and P stimulate explosive algal growth on the water surface.
- Stage 2 — Light Blockage: Dense algal mat shades submerged aquatic vegetation, killing it.
- Stage 3 — Oxygen Depletion: Bacteria decompose dead algae, consuming dissolved oxygen (DO) — creating hypoxic zones where DO <2 mg/L.
- Stage 4 — Fish Kill & Dead Zone: Oxygen depletion causes fish kills and collapse of aquatic biodiversity.

Control measures: nutrient limits in NPDES permits; agricultural Best Management Practices (BMPs) — buffer strips, cover crops; phosphorus removal in wastewater treatment (chemical precipitation with lime or ferric chloride).

## 'EUTROPHICATION: THE 4-STAGE CASCADE OF OXYGEN DEPLETION'



## Key Water Quality Parameters

| Parameter                               | Significance                                                                     | Critical Values                                                              |
|-----------------------------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Dissolved Oxygen (DO)                   | Primary indicator of aquatic ecosystem health                                    | <5 mg/L stresses fish; <2 mg/L = hypoxic; 0 = anoxic                         |
| BOD (Biochemical O <sub>2</sub> Demand) | O <sub>2</sub> consumed by microorganisms degrading biodegradable organic matter | Higher BOD = more organic pollution; wastewater typically 200–300 mg/L       |
| COD (Chemical O <sub>2</sub> Demand)    | Total O <sub>2</sub> demand for chemical oxidation of ALL organics; always > BOD | BOD/COD ratio = biodegradability index; ratio <0.5 = non-biodegradable waste |
| Biotic Index                            | Presence/absence of pollution-sensitive macroinvertebrate indicator species      | Stonefly/mayfly = clean water; midge/worm = polluted                         |
| pH                                      | Acid/alkaline balance; affects chemical toxicity and biological life             | Optimal range: 6.5–8.5; outside this range toxic to most aquatic organisms   |
| Total Suspended Solids (TSS)            | Solid particles that reduce light penetration and clog fish gills                | Regulated in NPDES permits; affects primary treatment efficiency             |
| Nitrate (NO <sub>3</sub> <sup>-</sup> ) | Nutrient causing eutrophication; toxic to infants at high concentrations         | SDWA MCL = 10 mg/L as N (causes methemoglobinemia — blue baby syndrome)      |
| Coliform Bacteria                       | Indicator organism for fecal contamination and pathogen risk                     | Zero tolerance in drinking water (MCL = 0 for total coliforms)               |

## Key Terms for Effluent Monitoring

### 1. Biotic Index

- A measure of water quality based on the presence and abundance of living organisms, particularly aquatic macroinvertebrates, which are sensitive to pollution. The biotic index helps assess the health of ecosystems and the impact of effluent discharges.

### 2. Dissolved Oxygen (DO)

- The amount of oxygen dissolved in water, crucial for the survival of aquatic organisms. DO levels indicate the capacity of water to support life and are affected by factors like pollution, temperature, and biological activity.

### 3. Sensors and Colorimetry

- **Sensors:** Devices that measure parameters like DO, pH, turbidity, and temperature in water.
- **Colorimetry:** A method for determining the concentration of substances in water by measuring the intensity of color change in a sample after a chemical reaction.

### 4. Chemical Oxygen Demand (COD)

- The amount of oxygen required to chemically oxidize organic and inorganic substances in water. It is an indicator of the total pollution load in effluent, including substances not biologically degradable.

### 5. Biological Oxygen Demand (BOD)

- The amount of oxygen consumed by microorganisms during the decomposition of organic matter in water over a specified time (usually 5 days). BOD reflects the organic pollution level and its impact on oxygen availability for aquatic life.

### 6. Total Oxygen Demand (TOD)

- The total amount of oxygen required to oxidize all organic and inorganic substances in water, including biological and chemical processes. It combines aspects of both BOD and COD.

### 7. pH Scale

- A scale ranging from 0 to 14 that measures the acidity or alkalinity of water:
  - **pH < 7:** Acidic
  - **pH = 7:** Neutral
  - **pH > 7:** Alkaline Effluent pH monitoring ensures compatibility with aquatic ecosystems and compliance with discharge regulations.

### 8. Total Suspended Solids (TSS)

- The total concentration of solid particles suspended in water, such as silt, plankton, or industrial waste. High TSS can reduce light penetration, harm aquatic organisms, and indicate pollution.

### 9. Total Dissolved Solids (TDS)

- The total concentration of dissolved substances in water, including salts, minerals, and organic compounds. TDS affects water quality and is critical for determining effluent impact on receiving water bodies.

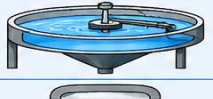
### 10. Turbidity

- A measure of water clarity, indicating the presence of suspended particles like silt, clay, or organic matter. High turbidity can block light penetration, harm aquatic plants, and indicate pollution from effluents.

These terms are essential for understanding and evaluating effluent impacts on water quality and ecosystem health, as well as ensuring compliance with environmental standards.

## Water Treatment

## Water/Waste Treatment – Unit Operations

| Unit Operation                                                                                              | Purpose / Function                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Screening</b>           | To remove sticks, weeds and large particulate matter. <ul style="list-style-type: none"> <li>✓ To eliminate certain odours.</li> <li>✓ To remove objectionable dissolved gases.</li> <li>✓ To retain some metal salts to enable them to be filtered out.</li> </ul>  |
| <b>Aeration</b>            | <ul style="list-style-type: none"> <li>• To remove objectionable dissolved gases.</li> <li>• To retain some metal salts to enable them to be filtered out.</li> </ul>                                                                                                |
| <b>Coagulation</b>         | To make tiny clay/suspended matter to be collected out, in order to scrape bacteria and starch colonies.                                                                                                                                                             |
| <b>Clarification</b>       | To settle out collected tiny/made clay water.                                                                                                                                                                                                                        |
| <b>Filtration</b>          | To remove particles.                                                                                                                                                                                                                                                 |
| <b>pH Adjustment</b>       | To ensure that it is chemically neutral.                                                                                                                                                                                                                             |
| <b>Disinfection</b>       | To remove pathogenic or disease-causing bacteria.                                                                                                                                                                                                                   |
| <b>Hardness Control</b>  | To remove excess quantities of calcium and magnesium salts.                                                                                                                                                                                                        |

This table outlines the key **steps in the water treatment process** and their purposes:

1. **Screening:**

- Removes large physical debris, such as sticks, weeds, and large particulates, to prevent damage or clogging in subsequent treatment stages.

2. **Aeration:**

- **Eliminates certain odors** caused by volatile organic compounds or hydrogen sulfide.
- Removes objectionable dissolved gases, such as carbon dioxide or methane, through exposure to air.
- Oxidizes certain metal salts (e.g., iron or manganese) to form insoluble compounds that can be filtered out.

3. **Coagulation:**

- Adds coagulant chemicals (like aluminum sulfate) to aggregate fine particles into larger clumps (flocs).
- Enables suspended matter to settle out, trapping bacteria and absorbing color impurities.

4. **Clarification:**

- Allows sediment and larger particles to settle out of the water, leaving it clearer and ready for further processing.

5. **Filtration:**

- Removes smaller particles that remain after clarification, typically using sand, gravel, or membrane filters.
- 6. **pH Adjustment:**
  - Ensures the water is chemically neutral (usually between pH 6.5–8.5), preventing corrosion in pipes or harm to ecosystems and consumers.
- 7. **Disinfection:**
  - Destroys pathogenic or disease-causing microorganisms using methods like chlorination, UV light, or ozone treatment, ensuring water is safe for consumption.
- 8. **Softening:**
  - Reduces excess calcium and magnesium salts that cause water hardness, preventing scaling in pipes and improving water usability.

### Water Pollution Prevention

Preventing water pollution is a critical part of environmental management. The objective is to stop contaminants from entering stormwater drains, rivers, lakes, and groundwater by implementing effective engineering and management controls.

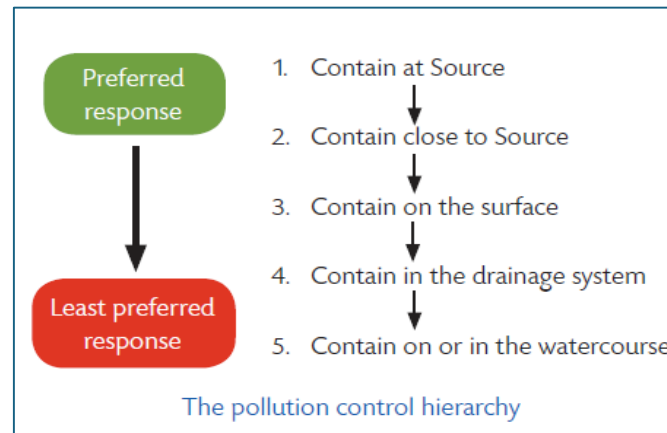
The key prevention measures include:

- **Managerial Means:** Establish environmental policies, conduct risk assessments, implement procedures, provide employee training, and perform regular inspections to minimize pollution risks.
- **Identifying Drains:** Clearly identify whether drains are connected to the stormwater system or the sanitary sewer system to prevent accidental discharge of hazardous substances.
- **Marking Drains:** Label or paint drains (e.g., "Storm Drain – No Dumping") to remind workers that pollutants entering these drains may flow directly into natural water bodies.
- **Maintenance of Drainage Systems:** Regularly inspect and clean drains, channels, and oil-water separators to prevent blockages, flooding, and contamination.
- **Bunding:** Install secondary containment (bunds or spill containment barriers) around tanks, chemical storage areas, and fuel containers to contain leaks or spills before they reach drains.
- **Pipework:** Inspect and maintain pipelines to detect corrosion, leaks, or damage that could release pollutants into the environment.
- **Drum Storage:** Store chemical and waste drums on impermeable surfaces with secondary containment, keep them properly labeled, sealed, and protected from rainwater.
- **Isolated Deliveries:** Conduct fuel and chemical deliveries in designated areas away from storm drains, with spill kits readily available and personnel trained to respond to accidental releases.

## Pollution Control Hierarchy

The preferred approach is to **control pollution as close to the source as possible**:

1. **Contain at the source** (*most effective*)
2. Contain close to the source.
3. Contain on the surface.
4. Contain within the drainage system.
5. **Contain in the receiving watercourse** (*least effective and should only be a last resort*).



## 1.3. Soil Pollution & Contaminant Migration

### Soil Pollution Prevention

- **Barriers and Liners:** For preventing contamination, physical barriers such as clay or synthetic liners are installed under industrial sites or landfills to stop pollutants from seeping into the ground.
- **Remediation Methods:** Techniques like **bioremediation** (using microorganisms to degrade hazardous substances) and **phytoremediation** (using plants to extract or degrade contaminants) are employed to clean up contaminated soils.
- **Regulatory Oversight:** The Resource Conservation and Recovery Act (RCRA) regulates the treatment, storage, and disposal of hazardous waste to prevent soil contamination.

### Soil Vapor Intrusion

- **Prevention Methods:** Installing **vapor barriers** (plastic or other impermeable layers) and **sub-slab depressurization systems** can prevent harmful vapors from volatile organic compounds (VOCs) from migrating into buildings.
- **Assessment:** Vapor intrusion assessments involve testing air quality in and around buildings to identify the presence of hazardous chemicals, typically originating from contaminated soils or groundwater.

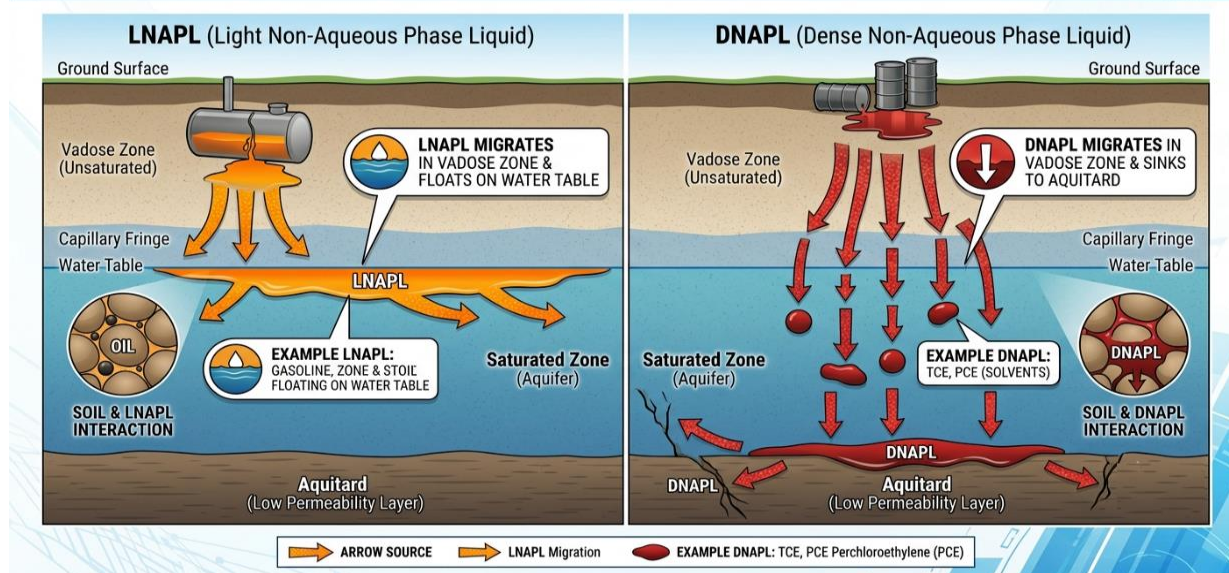
## Non-Aqueous Phase Liquids (NAPLs)

| Type          | Behavior                                                               | Examples                                                         | Remediation Challenge                                                                    |
|---------------|------------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| LNAPL (Light) | Less dense than water — floats on water table as separate phase        | Gasoline, diesel, heating oil, jet fuel                          | Detectable with bailer wells at water table; intercepted by trenches                     |
| DNAPL (Dense) | Denser than water — sinks through aquifer to aquitard, pooling at base | TCE, PCE (dry cleaning solvents), carbon tetrachloride, creosote | Extremely difficult to remediate; bypasses monitoring wells; may reach bedrock fractures |

## Key Environmental Fate Parameters

- Henry's Law Constant (H): Describes equilibrium partitioning of a dissolved contaminant between liquid and vapor phases. High H = contaminant volatilizes readily from soil/groundwater to air. Controls vapor intrusion risk and SVE effectiveness.
- Octanol-Water Partition Coefficient (K<sub>ow</sub>): Ratio of chemical concentration in octanol (lipid surrogate) vs water. High K<sub>ow</sub> = lipophilic — tends to bioaccumulate in fatty tissues (DDT, PCBs, dioxins). Predicts bioaccumulation and biomagnification potential.
- Distribution Coefficient (K<sub>d</sub>): Ratio of contaminant concentration sorbed to soil vs dissolved in water. High K<sub>d</sub> = contaminant is strongly sorbed to soil organic matter and moves slowly in groundwater.
- Retardation Factor (R):  $R = 1 + (\rho_b \times K_d / \text{porosity})$ . Contaminants with high K<sub>d</sub> move slower than groundwater flow (retarded); R=1 = no retardation (conservative tracer).

## LNAPL VS DNAPL SUBSURFACE BEHAVIOR: COMPARATIVE CROSS-SECTION



## Bioaccumulation & Biomagnification

**Bioaccumulation:** The accumulation of a contaminant within a single organism over its lifetime — intake rate exceeds excretion rate. Occurs with persistent, lipophilic compounds (methylmercury, DDT, PCBs) that resist metabolism.

**Biomagnification:** The progressive increase in contaminant concentration at each successive trophic level in the food chain. Example: methylmercury — water (0.0001 ppb) → phytoplankton (0.025 ppb) → zooplankton (0.5 ppb) → small fish (1.2 ppb) → tuna (15 ppb) → humans. Concentration can be 10,000–100,000× higher in apex predators than in ambient water.

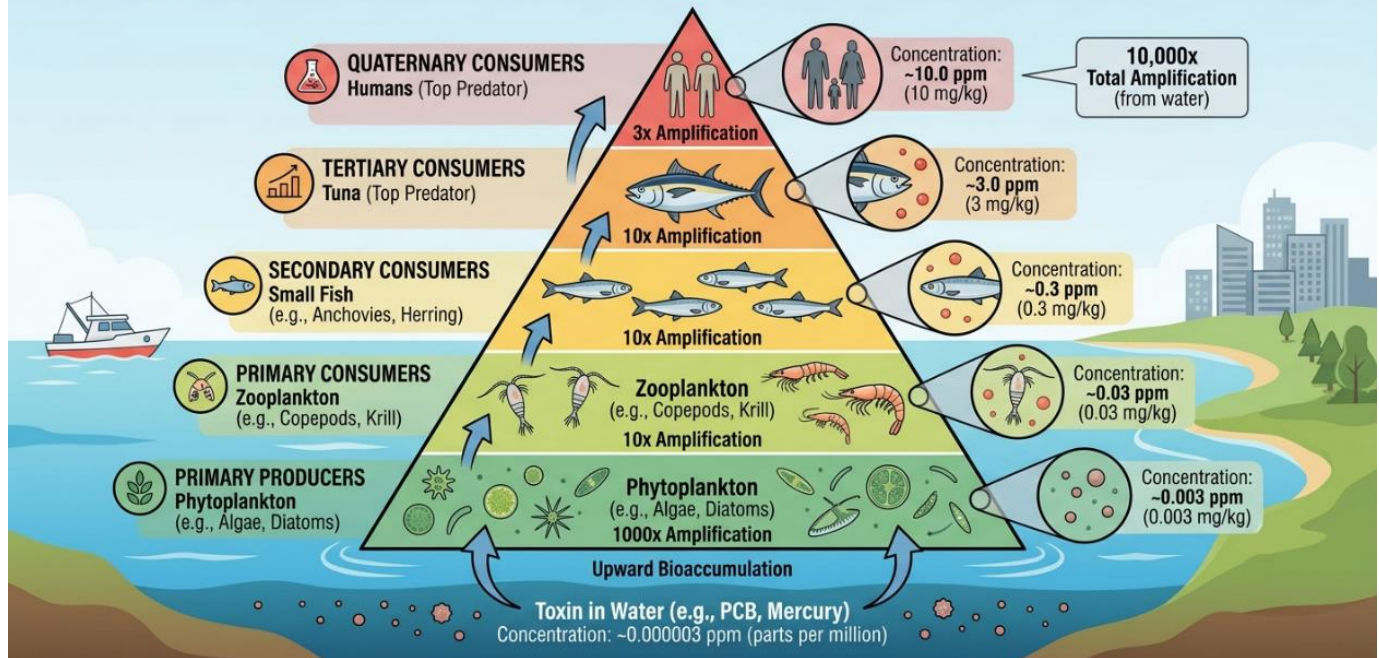
### □ KEY REFERENCES

Yates, D.S. Occupational Safety and Health Management, 2nd Ed., Ch. 16: Soil contamination pathways — leaching, vapor intrusion, dermal contact, and ingestion as primary exposure routes. Risk = Toxicity × Exposure. Reducing either component reduces overall risk. Darcy's Law governs groundwater flow:  $Q = KiA$  ( $K$  = hydraulic conductivity,  $i$  = hydraulic gradient,  $A$  = cross-sectional area).

### ⚡ EXAM TIP

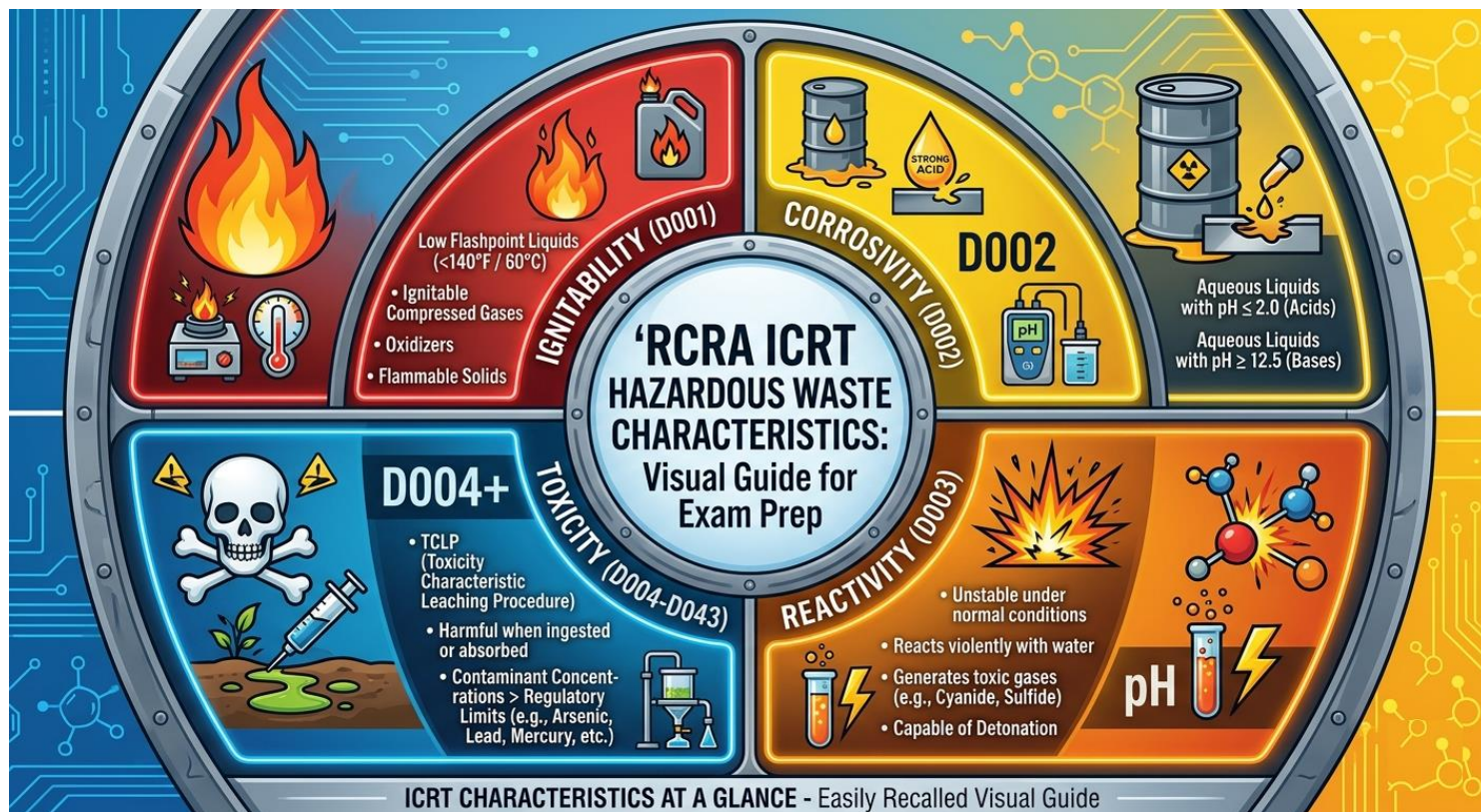
BOD < COD always (COD includes non-biodegradable organics). Eutrophication = N and P excess → algal bloom → oxygen depletion → fish kill. DNAPL sinks to aquitard (TCE, PCE); LNAPL floats on water table (gasoline). AQI 101–150 = Orange = Unhealthy for Sensitive Groups. Nitrate MCL = 10 mg/L as N. High Kow = bioaccumulates. High Henry's Law constant = volatilizes.

## BIOMAGNIFICATION: AMPLIFICATION OF TOXINS THROUGH TROPHIC LEVELS



## 2. HAZARDOUS MATERIALS MANAGEMENT & MIGRATION

### 2.1. RCRA Hazardous Waste Characteristics (ICRT)



The Resource Conservation and Recovery Act (RCRA, 42 USC 6901) governs hazardous waste from 'cradle to grave.' A solid waste is classified as hazardous if it exhibits one or more of four characteristics (ICRT), or if it appears on EPA's F, K, P, or U lists.

| Characteristic | Code | Definition / Test                                                                       | Common Examples                                                     |
|----------------|------|-----------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| Ignitability   | D001 | Liquid: flash point <60°C (140°F); solid: causes fire by friction; oxidizer             | Spent solvents, alcohol wastes, reactive metals                     |
| Corrosivity    | D002 | pH ≤2 or ≥12.5; corrodes SAE 1020 steel >6.35 mm/yr at 55°C                             | Battery acid, caustic cleaning solutions, pickle liquor             |
| Reactivity     | D003 | Unstable; reacts violently with water; generates toxic gases; detonates at standard T/P | Cyanide waste, sulfide-containing wastes, shock-sensitive materials |

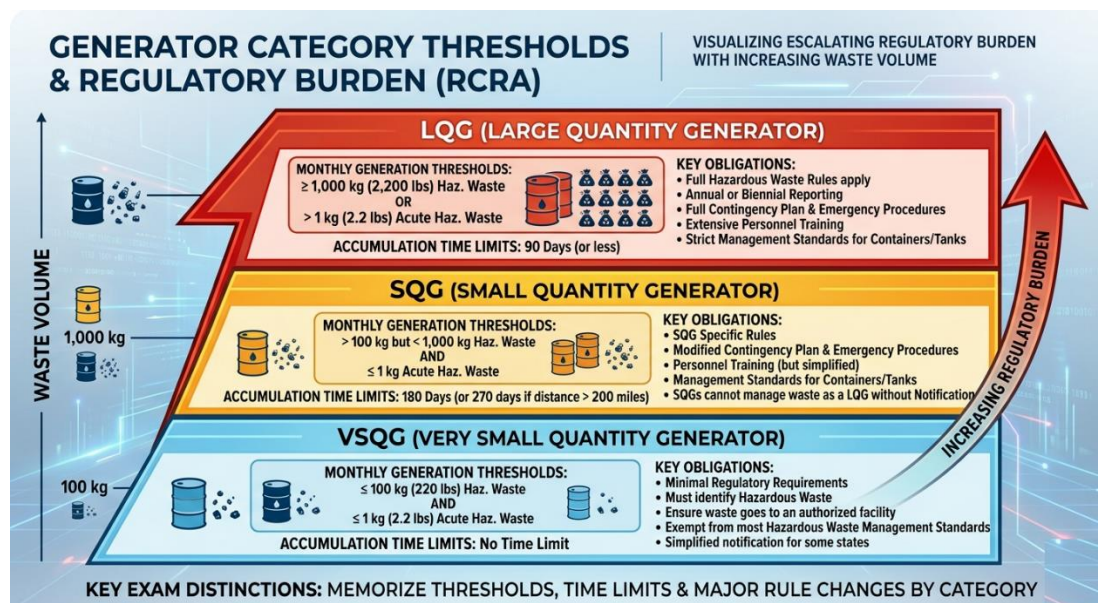
|          |           |                                                                                       |                                                            |
|----------|-----------|---------------------------------------------------------------------------------------|------------------------------------------------------------|
| Toxicity | D004–D043 | Fails TCLP (Toxicity Characteristic Leaching Procedure) for 40 listed metals/organics | Wastes containing Pb, Hg, Cd, As, TCE, benzene, chloroform |
|----------|-----------|---------------------------------------------------------------------------------------|------------------------------------------------------------|

### TCLP (Toxicity Characteristic Leaching Procedure)

The TCLP simulates the leaching environment in a municipal landfill by extracting waste with a weak acidic solution. If the leachate concentration of any of the 40 regulated metals or organics exceeds the regulatory threshold, the waste is classified as hazardous (D004–D043). The TCLP specifically determines the Toxicity characteristic — it does not evaluate ignitability, corrosivity, or reactivity.

## 2.2. RCRA Generator Categories

| Category                             | Monthly Generation Rate              | Max Accumulation Time                     | Key Requirements                                                                     |
|--------------------------------------|--------------------------------------|-------------------------------------------|--------------------------------------------------------------------------------------|
| VSQG (Very Small Quantity Generator) | <100 kg hazardous waste; <1 kg acute | No time limit (quantity limit applies)    | Must identify HW; limited disposal to permitted facility or LQG                      |
| SQG (Small Quantity Generator)       | 100–1,000 kg hazardous waste         | 180 days (270 days if shipped >200 miles) | Emergency coordinator; training; contingency plan; RCRA permit exemption             |
| LQG (Large Quantity Generator)       | >1,000 kg hazardous waste            | 90 days                                   | Written contingency plan; personnel training; biennial report; RCRA permit exemption |



### Satellite Accumulation Areas (SAA)

- Located at or near the point of generation; operated by generator employees knowledgeable in proper HW handling.
- Maximum volume: 55 gallons of hazardous waste OR 1 quart (~1 liter) of acute (P-listed) hazardous waste.
- Once the limit is exceeded, the excess must be moved to the central accumulation area within 3 days.
- Containers must be labeled: 'Hazardous Waste,' waste type, and hazard class.

### 2.3. Universal Waste (40 CFR Part 273)

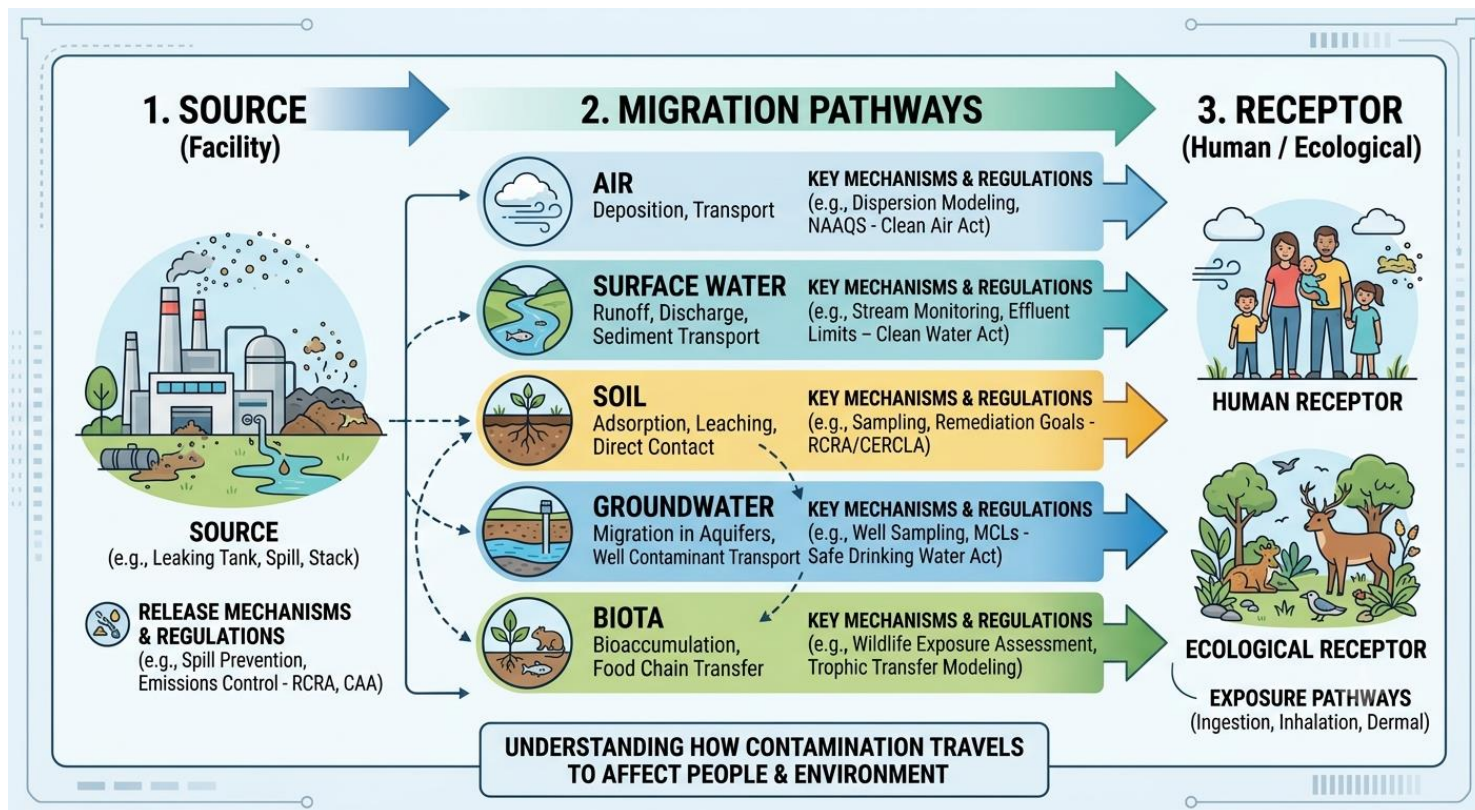
Universal waste provides simplified management standards for commonly generated hazardous wastes to encourage proper recycling and disposal rather than illegal dumping. Covered wastes include:

| Universal Waste Category     | Examples                                                            | NOT Included (Full RCRA Subtitle C)                         |
|------------------------------|---------------------------------------------------------------------|-------------------------------------------------------------|
| Batteries                    | Lithium-ion, nickel-cadmium, lead-acid, nickel metal hydride        | Automotive lead-acid batteries (under separate rule)        |
| Pesticides                   | Recalled, banned, or unused commercial pesticides                   | Residues in empty containers not meeting 'empty' definition |
| Mercury-containing Equipment | Thermostats, fever thermometers, manometers                         | Elemental mercury collected from spills (full HW)           |
| Lamps                        | Fluorescent, neon, high-intensity discharge (HID), LED with mercury | Cathode ray tubes (CRTs)                                    |

### 2.4. Hazardous Material Migration Pathways

| Environmental Medium | Migration Mechanism                                        | Key Concepts & Regulatory Framework                                                |
|----------------------|------------------------------------------------------------|------------------------------------------------------------------------------------|
| Air                  | Volatilization, atmospheric dispersion, dry/wet deposition | AERMOD dispersion model; vapor pressure drives rate; NAAQS and HAP standards (CAA) |
| Surface Water        | Runoff, overland flow, erosion, direct discharge           | NPDES permit (CWA Section 402); stormwater BMPs; Section 404 for wetlands          |
| Soil                 | Leaching, sorption, diffusion, bioturbation                | Kd (distribution coefficient); organic matter content determines sorption capacity |
| Groundwater          | Advection, dispersion, diffusion, retardation              | Darcy's Law ( $Q=KiA$ ); DNAPL sinks; LNAPL floats; CERCLA RI/FS process           |

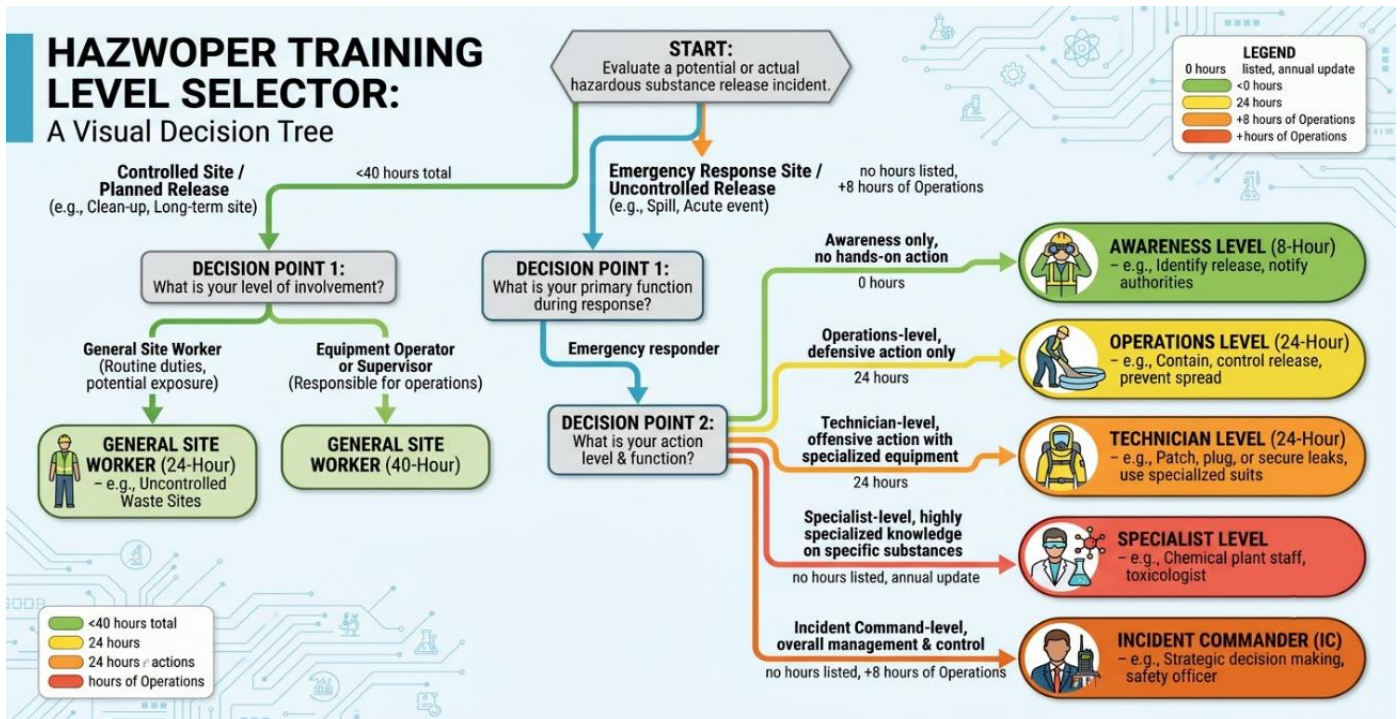
|       |                                                                 |                                                                  |
|-------|-----------------------------------------------------------------|------------------------------------------------------------------|
| Biota | Bioaccumulation in tissues, trophic transfer (biomagnification) | Kow predicts accumulation; food chain pathway to human receptors |
|-------|-----------------------------------------------------------------|------------------------------------------------------------------|



## 2.5. HAZWOPER Training Requirements (29 CFR 1910.120)

| Training Level                       | Minimum Hours                 | Scope                                                                             | Annual Refresher |
|--------------------------------------|-------------------------------|-----------------------------------------------------------------------------------|------------------|
| Level 1 — First Responder Awareness  | No minimum (competency-based) | Recognize hazardous release; alert others; call for help — no offensive action    | 8 hours          |
| Level 2 — First Responder Operations | 8 hours minimum               | Defensive response — contain release without entering hot zone; protect exposures | 8 hours          |
| Level 3 — HazMat Technician          | 24 hours minimum              | Offensive response — enter hot zone; stop/prevent release; offensive control      | 8 hours          |
| Level 4 — HazMat Specialist          | 24+ hours (site-specific)     | Command-level specialist; advanced sampling; site-specific expertise              | 8 hours          |
| Level 5 — Incident Commander         | 24 hours minimum              | Overall scene management; ICS implementation; resource coordination               | 8 hours          |

|                      |         |                                                       |                                                                             |         |
|----------------------|---------|-------------------------------------------------------|-----------------------------------------------------------------------------|---------|
| Uncontrolled Workers | HW Site | 40 hours initial + 3 days supervised field experience | Full Subtitle C site cleanup; hazardous waste characterization and handling | 8 hours |
|----------------------|---------|-------------------------------------------------------|-----------------------------------------------------------------------------|---------|



### KEY REFERENCES

Yates, D.S. Ch. 17: Source-pathway-receptor model for hazardous material risk assessment. Risk = Toxicity × Exposure.

CERCLA (Superfund) Remedial Investigation/Feasibility Study (RI/FS): RI characterizes nature/extent of contamination; FS evaluates cleanup alternatives using nine criteria (CERCLA NCP). Uniform Hazardous Waste Manifest (EPA Form 8700-12) must accompany every hazardous waste shipment — generator initiates, each party signs, TSD returns copy to confirm receipt (cradle-to-grave tracking).

### EXAM TIP

RCRA ICRT: Ignitability D001 (flash pt <60°C), Corrosivity D002 (pH ≤2 or ≥12.5 OR corrodes steel >6.35 mm/yr), Reactivity D003, Toxicity D004+ (TCLP test). SAA limit = 55 gallons OR 1 quart acute. HAZWOPER: 40-hour = uncontrolled hazardous waste sites; 8-hour annual refresher for ALL levels. Universal waste: batteries, pesticides, mercury equipment, lamps.

### 3. WASTE MANAGEMENT PROCEDURES

#### 3.1. Waste Streams

**Classification:** Waste streams can include **solid waste** (municipal waste, industrial refuse), **hazardous waste** (chemicals, toxic substances), and **wastewater** (industrial discharge, sewage).

**Reduction Strategies:** Industries employ strategies like **source reduction**, **reuse**, and **recycling** to minimize waste. Technologies such as **anaerobic digesters** convert organic waste into energy, reducing landfill use.

#### Waste Removal, Treatment, and Disposal

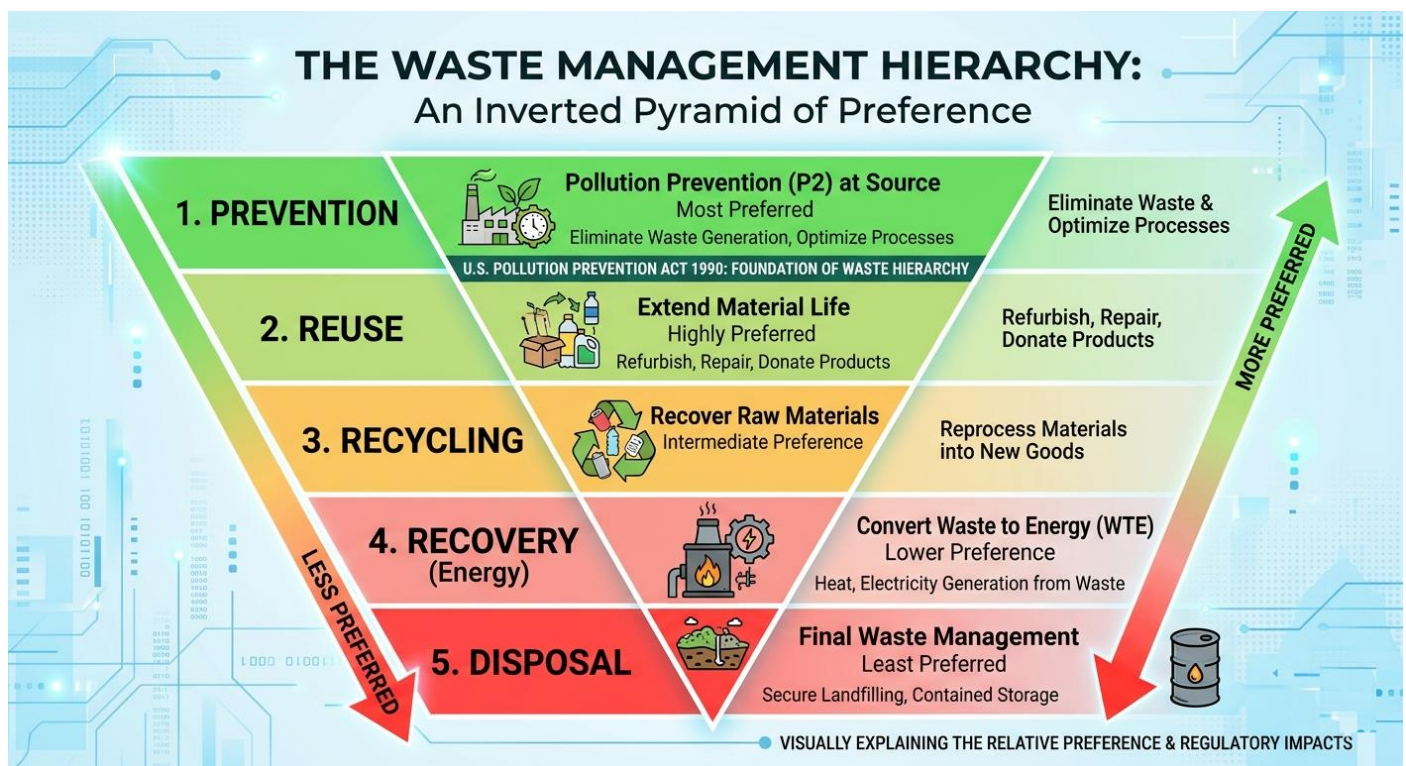
- **Removal:**
  - Includes collection, transport, and storage. Ensuring safe handling of hazardous waste and proper documentation is critical.
  - For example, adhering to DOT guidelines for transporting hazardous materials.
- **Treatment:**
  - **Physical Treatment:** Filtration, centrifugation, and sedimentation to separate or neutralize waste components.
  - **Chemical Treatment:** Neutralization, oxidation, or precipitation of harmful substances.
  - **Biological Treatment:** Use of microorganisms to degrade organic matter (e.g., in composting and anaerobic digestion).
- **Disposal:**
  - Involves landfilling, incineration, and recycling of waste materials.
  - Best practices:
    - Use secure landfills with leachate and gas collection systems.
    - Implement waste-to-energy solutions for incineration byproducts.
    - Monitor disposal sites to ensure compliance and prevent contamination.

#### 3.2. Waste Hierarchy (EU Waste Framework Directive / EPA P2 Act)

The waste hierarchy establishes a priority order for waste management decisions — from most preferred (prevention) to least preferred (disposal). Established in the EU Waste Framework Directive (2008/98/EC) and mirrored in the US Pollution Prevention Act of 1990.

| Priority             | Strategy                      | Description                                                                                           | Examples                                                                                         |
|----------------------|-------------------------------|-------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| 1st (Most Preferred) | Prevention / Source Reduction | Eliminate waste generation at the source — reduce the quantity and hazardous nature of waste produced | Process redesign, material substitution, product reformulation, extended producer responsibility |
| 2nd                  | Reuse                         | Use products again for the same or different purpose without reprocessing                             | Refillable containers, remanufacturing, secondhand equipment                                     |

|                       |           |                                                                           |                                                                                           |
|-----------------------|-----------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| 3rd                   | Recycling | Process waste materials into new products — material recovery             | Aluminum recycling, paper recovery, glass, plastics recycling                             |
| 4th                   | Recovery  | Recover value from waste when recycling is not feasible — energy recovery | Waste-to-energy incineration, anaerobic digestion (biogas), co-processing in cement kilns |
| 5th (Least Preferred) | Disposal  | Land disposal as last resort when no other option is practicable          | Secure hazardous waste landfill (under RCRA Subtitle C); sanitary landfill                |



### 3.3. Hazardous Waste

#### Hazardous Waste Properties

Hazardous waste contains properties that can pose serious risks to people, property, and the environment if not properly managed.

The major hazards include:

- **Ignitability (Flammability):** Waste that can easily catch fire, such as solvents, fuels, and certain chemicals.
- **Reactivity:** Waste that may explode or react violently when exposed to heat, water, air, or incompatible chemicals.
- **Corrosivity:** Acids and alkalis that can corrode metals and cause severe burns to skin and eyes.

- **Toxicity:** Chemicals that can poison humans or wildlife through inhalation, ingestion, or skin contact, or contaminate soil and groundwater.
- **Damage to the Environment:** Improper disposal can pollute air, water, and land, harming ecosystems and creating long-term environmental impacts.

### Aspects of Waste Management

An effective waste management program goes beyond simply disposing of waste. It focuses on reducing waste generation, improving efficiency, and ensuring regulatory compliance.

The main aspects include:

- **Economic Reasons:** Proper waste management reduces disposal costs, prevents fines, and conserves valuable resources.
- **Setting Waste Aims and Objectives:** Organizations should establish measurable targets such as:
  - Reducing waste generation (waste minimisation).
  - Increasing recycling and recovery rates.
  - Diverting waste away from landfills and incineration.
- **Education and Training of Workers:** Employees must understand waste segregation, labeling, storage, handling procedures, and emergency response.
- **Engagement of Authorised Waste Contractors:** Only licensed contractors should transport, recycle, treat, or dispose of hazardous waste to ensure legal compliance.

### Hazardous Waste Management Facilities and Units

Hazardous waste management facilities are specially designed locations where hazardous waste is treated, stored, recycled, or disposed of safely to protect workers, the public, and the environment. These facilities must comply with environmental regulations such as those established by the U.S. EPA.

The different hazardous waste management units include:

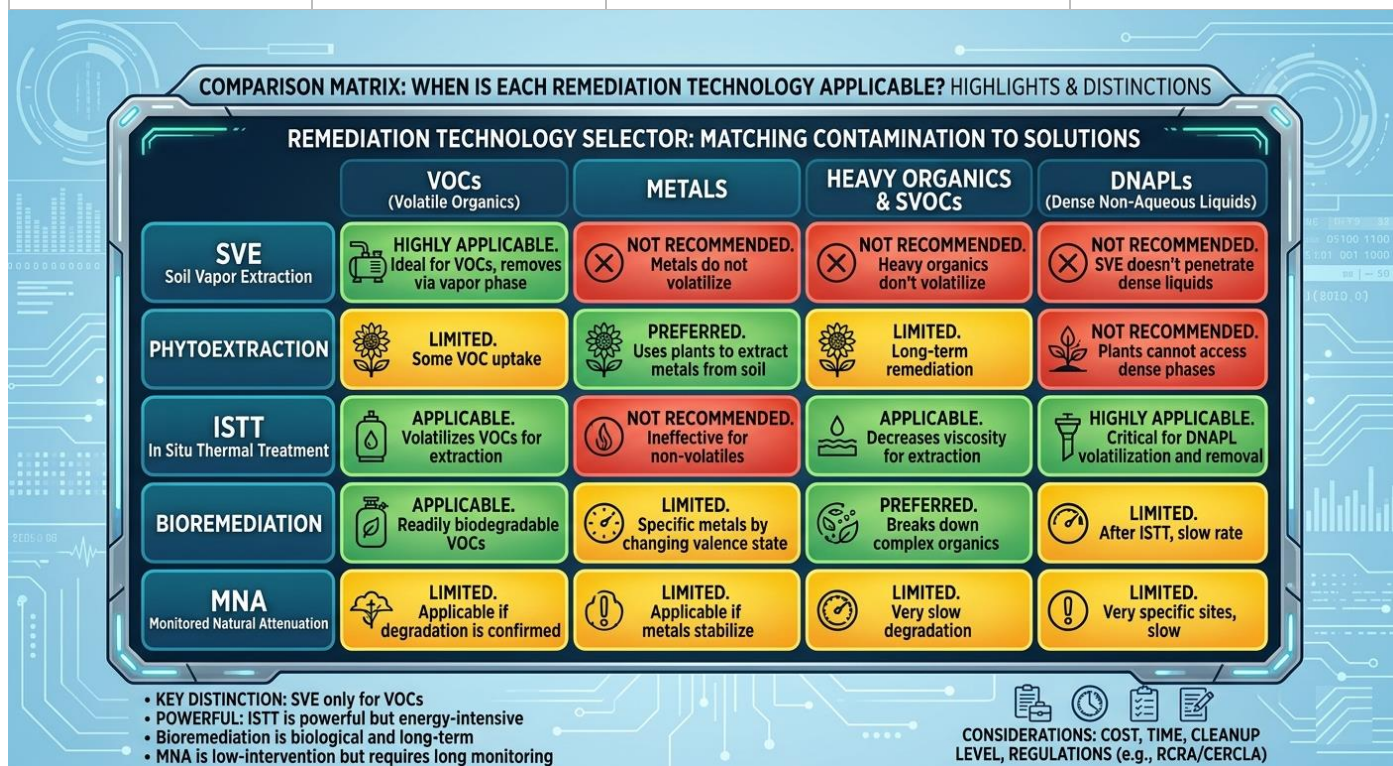
- **Containers:** Drums, barrels, or portable tanks used for temporary storage and transportation.
- **Tanks:** Fixed systems used to store or treat liquid hazardous waste.
- **Drip Pads:** Engineered surfaces that collect hazardous liquids dripping from treated materials, such as preserved wood.
- **Containment Buildings:** Enclosed structures that safely store hazardous waste while preventing releases.
- **Incinerators:** High-temperature combustion units that destroy hazardous organic waste.
- **Boilers and Industrial Furnaces:** Industrial equipment that can recover energy while treating certain hazardous wastes.

- **Landfills:** Engineered disposal sites designed to permanently isolate hazardous waste from the environment.
- **Surface Impoundments:** Ponds or lagoons used to temporarily hold liquid hazardous waste.
- **Waste Piles:** Designated areas for storing solid hazardous waste before treatment or disposal.
- **Land Treatment Units:** Areas where waste is treated biologically or chemically within the soil.
- **Injection Wells:** Deep underground wells used to dispose of specific liquid hazardous wastes safely.
- **Miscellaneous Units:** Specialized treatment or disposal systems that do not fit into the standard categories.

### 3.4. Remediation Technologies

| Technology                            | Target Contamination                       | Mechanism                                                                                                                  | Best For                                                                           |
|---------------------------------------|--------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| Pump-and-Treat                        | Dissolved groundwater contamination        | Extract contaminated GW; treat above ground (air stripping, GAC, bioreactor); reinject or discharge                        | Plume containment; less effective for DNAPL source zones                           |
| Soil Vapor Extraction (SVE)           | VOCs in unsaturated (vadose) zone          | Apply vacuum to wells — airflow volatilizes VOCs extracted to surface for treatment                                        | Benzene, toluene, TCE in permeable soils above water table                         |
| Air Sparging                          | VOCs in saturated zone                     | Inject air into saturated zone — sparging volatilizes dissolved VOCs into vadose zone; combined with SVE                   | Petroleum hydrocarbons, dissolved chlorinated solvents                             |
| In Situ Bioremediation                | Organic contaminants (petroleum, solvents) | Stimulate indigenous microorganisms via nutrient/oxygen injection (biostimulation) or introduce microbes (bioaugmentation) | Diffuse petroleum contamination; chlorinated solvents via reductive dechlorination |
| Phytoremediation — Phytoextraction    | Heavy metals in shallow soil               | Hyperaccumulator plants absorb metals into above-ground biomass; harvest and dispose                                       | Pb, As, Cd, Zn, Ni in surface soils (sunflowers, Indian mustard)                   |
| Phytoremediation — Phytostabilization | Heavy metals in root zone                  | Plants immobilize metals in root zone — reduce leaching and erosion; do not remove contamination                           | When removal not feasible; long-term containment for Pb, As                        |
| Phytoremediation — Rhizodegradation   | Organic contaminants in root zone          | Root exudates stimulate soil microorganism activity to degrade organics                                                    | Petroleum hydrocarbons, PAHs in root zone                                          |
| Thermal Treatment (ISTT)              | Chlorinated solvents, NAPLs                | Steam injection, electrical resistance heating (ERH), or thermal conduction                                                | DNAPLs in low-permeability soils; source zone treatment                            |

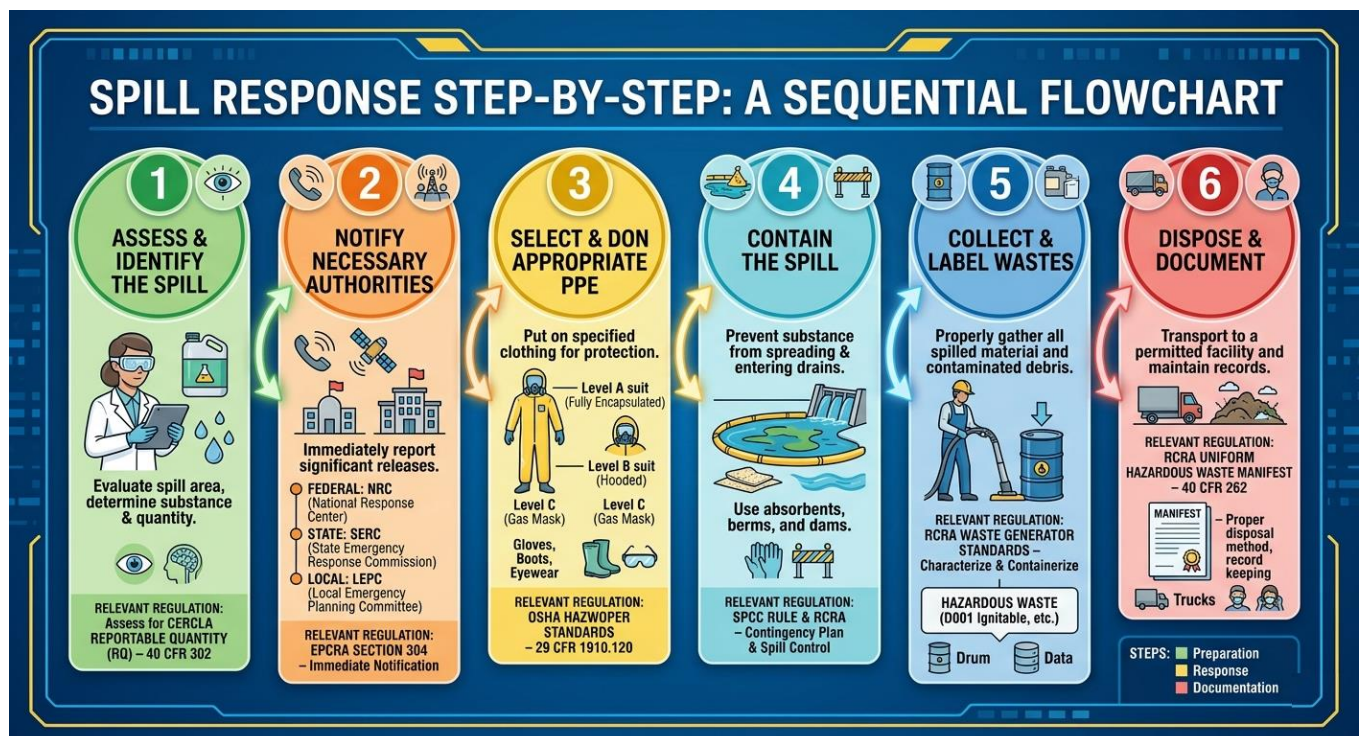
|                                        |                                                         |                                                                                                                                            |                                                                                               |
|----------------------------------------|---------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
|                                        |                                                         | heating raises temperature;<br>volatilizes/destroys contaminants                                                                           |                                                                                               |
| Stabilization/Solidification           | Metals, inorganics,<br>radioactive waste                | Mix waste with cement, lime, or<br>pozzolanic materials — immobilize<br>contaminants in solid matrix; reduce<br>leachability               | Pb, Cr, Hg, radioactive waste;<br>reduces TCLP leachability                                   |
| Monitored Natural<br>Attenuation (MNA) | Petroleum<br>hydrocarbons, some<br>chlorinated solvents | Document that natural processes<br>(biodegradation, dispersion, dilution,<br>adsorption) are reducing contamination<br>at acceptable rates | Where active remediation not cost-<br>effective; long time frames; with<br>monitoring program |



### 3.5. Spill Response Procedures

Spill response follows a structured sequence to protect human health and the environment while preserving site evidence and meeting regulatory notification requirements.

- Step 1 — Assess and Secure: Identify the substance (SDS, placard); estimate volume; assess immediate hazards (fire, toxicity, reactivity); establish safety perimeter; protect drains/waterways.
- Step 2 — Notify: Alert site emergency coordinator; contact regulatory authorities if required. CERCLA Section 103: Notify National Response Center (NRC: 1-800-424-8802) if release exceeds CERCLA Reportable Quantity (RQ). EPCRA Section 304: Notify State Emergency Response Commission (SERC) and Local Emergency Planning Committee (LEPC) for Extremely Hazardous Substances (EHS) above TPQ.
- Step 3 — Don PPE: Select appropriate level (A–D) based on hazard; never enter spill area without adequate respiratory and skin protection.
- Step 4 — Contain: Stop the source (close valve, right container); contain spread with absorbents, booms, berms, or earthen dikes; prevent entry into floor drains and waterways.
- Step 5 — Collect and Label: Package contaminated materials as hazardous waste; label with accumulation start date, waste description, and hazard class; store in compatible container.
- Step 6 — Dispose: Ship to permitted TSDF via uniform hazardous waste manifest; document chain of custody; retain all records per RCRA requirements.



### □ KEY REFERENCES

Yates, D.S. Ch. 18: Waste hierarchy — prevent > reuse > recycle > recover > dispose. Chain of custody documentation critical: Uniform Hazardous Waste Manifest (EPA Form 8700-12) must accompany every hazardous waste shipment. RCRA Land Disposal Restrictions (LDR, 40 CFR Part 268): many hazardous wastes cannot be land-disposed without treatment to reduce toxicity/mobility below EPA treatment standards. CERCLA Section 107: Potentially Responsible Parties (PRPs) are jointly and severally liable for site cleanup — current owner/operator, past owner/operator, arranger, and transporter.

### ⚡ EXAM TIP

Waste hierarchy: Prevention > Reuse > Recycling > Recovery > Disposal (P2 Act 1990). CERCLA RQ release → Notify National Response Center (NRC). SVE targets VOCs in unsaturated (vadose) zone. DNAPL source zone treatment = thermal (ISTT). Phytoextraction removes metals (harvest/dispose); Phytostabilization immobilizes in root zone. MNA = document natural attenuation.

## 4. SUSTAINABILITY PRINCIPLES

### 4.1. Supply Chain Sustainability

#### Definition

Integrating environmental and social responsibility throughout all stages of the supply chain — from raw material sourcing to end-of-life disposal.

#### Reduce

Minimize raw material use, energy consumption, packaging waste, and transport emissions (e.g., lean manufacturing, green procurement)

#### Reuse

Refurbish equipment, reuse containers and pallets, and adopt circular economy principles to extend product life

#### Recycle

Partner with certified recyclers for scrap, electronics, and packaging; track material diversion rates from landfill

#### Supplier Standards

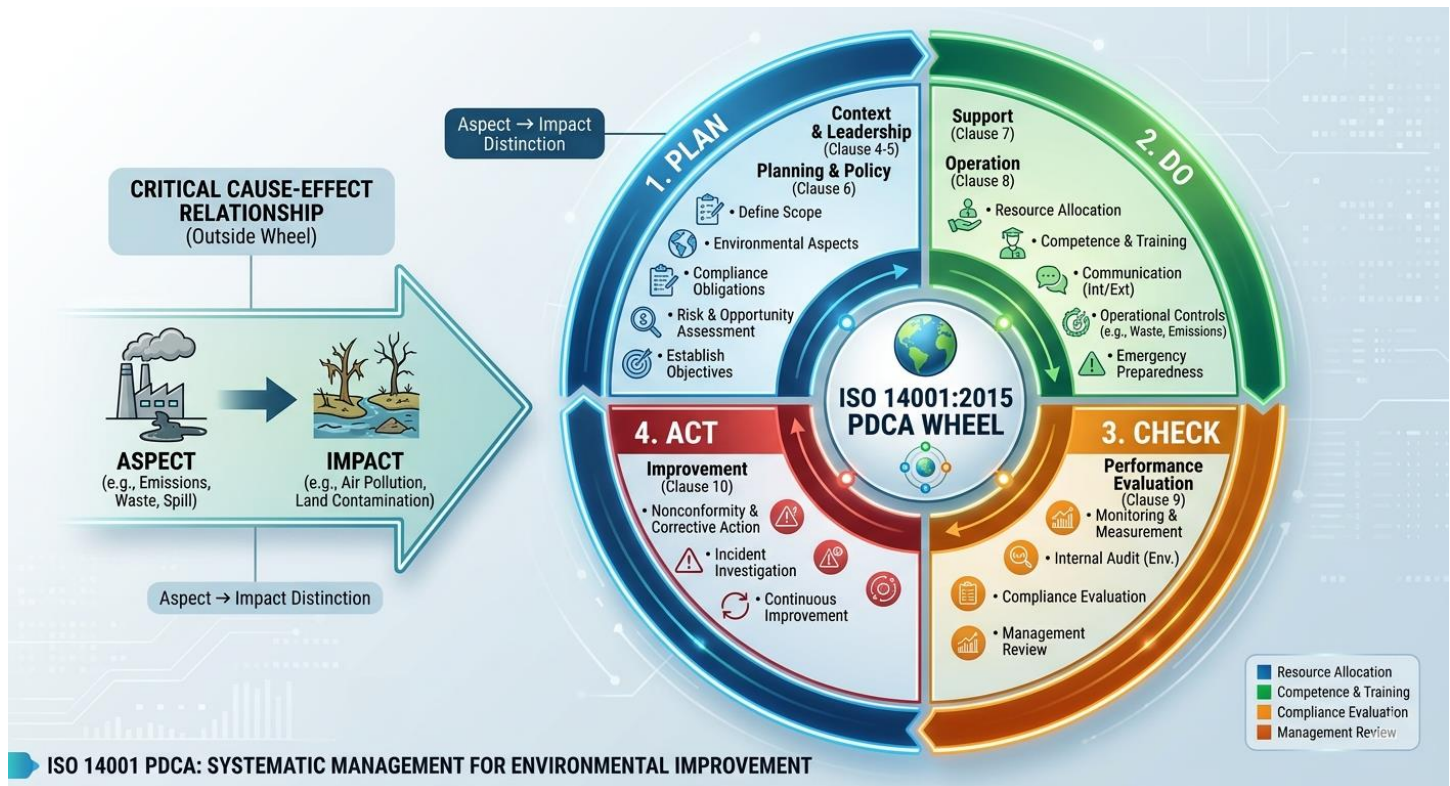
Require ISO 14001 certification, conduct supplier audits, and include environmental clauses in procurement contracts

### 4.2. ISO 14001:2015 — Environmental Management System (EMS)

ISO 14001 is the international standard for Environmental Management Systems (EMS). It provides a framework for any organization — regardless of size, type, or sector — to manage environmental responsibilities systematically. It follows the Plan-Do-Check-Act (PDCA) cycle embedded in the Annex SL high-level structure shared with ISO 45001 and ISO 9001.

#### Key Distinction: Aspects vs. Impacts

- Environmental Aspect (Clause 6.1.2): An element of an organization's activities, products, or services that can interact with the environment. The aspect is the CAUSE. Example: Chemical storage → potential spill.
- Environmental Impact: Any change to the environment — positive or negative — that results from an aspect. The impact is the EFFECT. Example: Spill → soil and groundwater contamination.
- Significant Aspects: Determined by evaluating aspects against criteria: scale, severity, probability, regulatory requirements, stakeholder concerns. Significant aspects drive objectives and controls.



| ISO 14001 Clause | Requirement                 | Key Output / PDCA Phase                                                                             |
|------------------|-----------------------------|-----------------------------------------------------------------------------------------------------|
| Clause 4         | Context of the Organization | Internal/external issues; needs of interested parties; EMS scope definition   PLAN                  |
| Clause 5         | Leadership                  | Environmental policy commitment; roles, responsibilities, authorities   PLAN                        |
| Clause 6         | Planning                    | Aspects & impacts register; legal compliance obligations; objectives & targets; action plans   PLAN |
| Clause 7         | Support                     | Resources (financial, human); competence; awareness; communication; documented information   DO     |
| Clause 8         | Operation                   | Operational controls for significant aspects; emergency preparedness and response   DO              |
| Clause 9         | Performance Evaluation      | Monitoring & measurement; compliance evaluation; internal audit; management review   CHECK          |
| Clause 10        | Improvement                 | Nonconformity & corrective action; continual improvement   ACT                                      |

### 4.3. BPEO and BAT

| Concept | Full Form                             | Definition                                                                                                                                                                                                           | Regulatory Context                                                                                             |
|---------|---------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| BPEO    | Best Practicable Environmental Option | Select the option that provides the most benefit or least damage to the environment as a whole — across air, water, and land — at acceptable cost (short and long term). Prevents cross-media transfer of pollution. | UK Royal Commission on Environmental Pollution; Integrated Pollution Control (IPC); Brauer Ch. 33              |
| BAT     | Best Available Techniques             | The most effective techniques for achieving high general protection of the environment that are technically and economically viable — considering costs and benefits. Not necessarily the most advanced technology.  | EU Industrial Emissions Directive (IED, 2010/75/EU); defined in sector-specific BREF (BAT Reference) documents |
| BAT-AEL | BAT-Associated Emission Level         | Emission level range associated with the application of BAT — used to set permit conditions for industrial installations. Installations must meet BAT-AELs unless granted derogation.                                | EU IPPC/IED; European IPPC Bureau (EIPPCB) BREF documents                                                      |

### 4.4. Hierarchy of Conservation

#### Reduce:

Reduce consumption of natural resources and waste generation.

Examples: Implementing energy-efficient appliances, optimizing manufacturing processes, and eliminating single-use plastics.

#### Reuse:

Extending the lifecycle of products by repurposing.

Examples: Reusing glass containers, refurbishing furniture, and donating old equipment to schools or charities.

#### Recycle:

Converting waste into new materials to prevent resource extraction.

Examples: Paper recycling to save trees, e-waste recycling to recover rare metals, and converting plastics into industrial materials.

#### Energy Hierarchy:

Emphasis on conserving energy, shifting to renewable sources, and improving efficiency.



#### 4.5. Sustainability Concepts

**Triple Bottom Line (TBL):** Sustainability is about balancing economic, environmental, and social goals. Companies must ensure profitability while reducing environmental impacts and promoting social well-being.

**Circular Economy:** This model aims to eliminate waste by reusing, recycling, and remanufacturing products, ensuring materials flow continuously in closed loops. It contrasts with the traditional **linear economy** of "take, make, dispose."

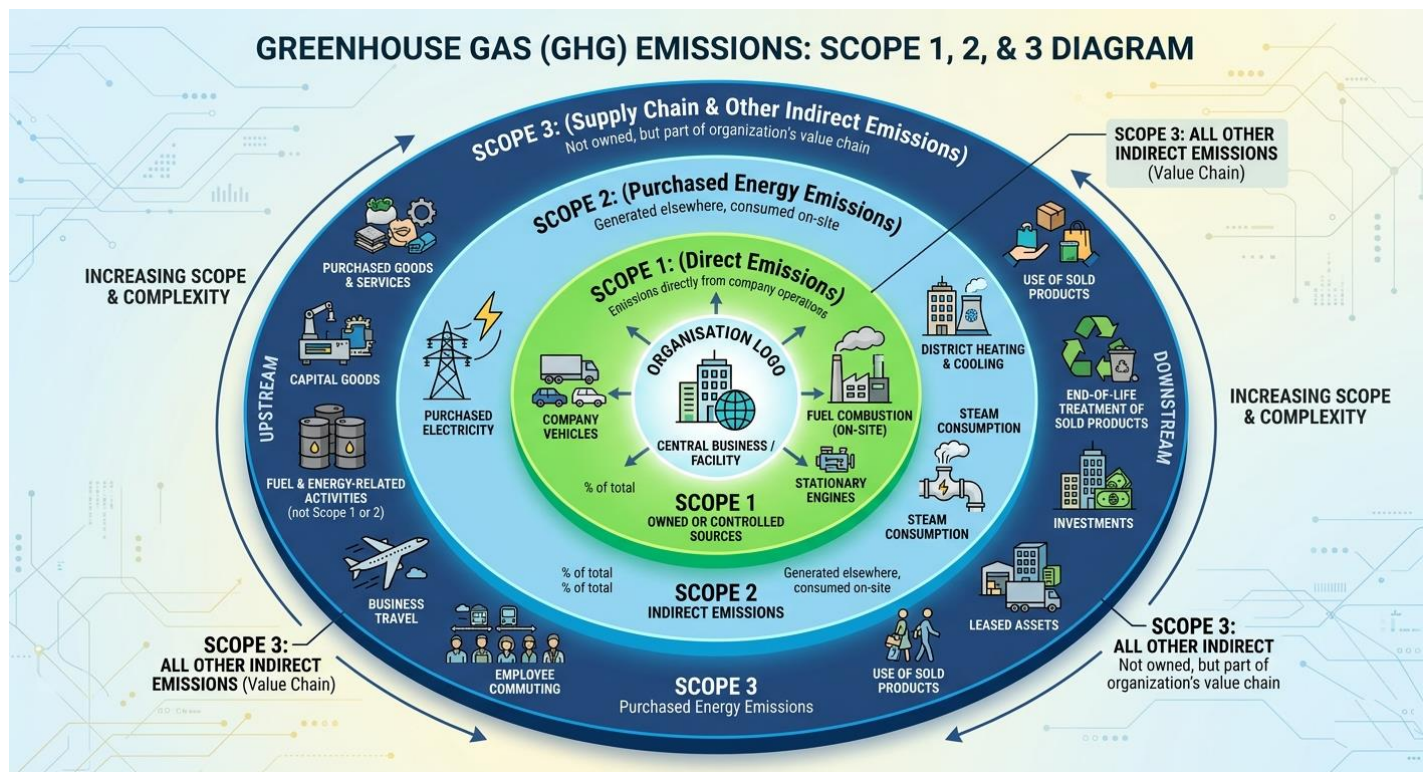
**Carbon Neutrality:** A core sustainability goal is reducing greenhouse gas emissions to achieve **net-zero carbon emissions**. This involves using renewable energy, enhancing energy efficiency, and offsetting remaining emissions through carbon credits or reforestation.

**Sustainable Development Goals (SDGs):**

- Initiated by the United Nations, the **17 SDGs** focus on addressing global challenges such as poverty, inequality, climate change, and environmental degradation through sustainable practices.

## Scope 1, 2, and 3 Greenhouse Gas Emissions

| Scope   | Definition                                                             | Examples                                                                                               | CSP Relevance                                                                                           |
|---------|------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| Scope 1 | Direct emissions from owned or controlled sources                      | Combustion in boilers/furnaces/vehicles; process emissions; fugitive emissions (refrigerants, methane) | Quantify using emission factors; reduce through fuel switching, efficiency improvements, leak detection |
| Scope 2 | Indirect emissions from purchased electricity, steam, heating, cooling | Power plant emissions attributable to facility electricity use                                         | Reduce through renewable energy purchase, energy efficiency, on-site generation                         |
| Scope 3 | All other indirect emissions across the value chain                    | Supply chain manufacturing, employee commuting, business travel, product use, end-of-life disposal     | Largest category for most organizations; requires supply chain engagement and LCA data                  |



### □ KEY REFERENCES

Brauer, R.L. Ch. 33: Pollution Prevention (P2) Act of 1990 establishes source reduction as the national priority over waste treatment and disposal. Industrial ecology principles — material flow analysis, industrial symbiosis (one facility's waste as another's feedstock) — represent advanced sustainability practice. Life Cycle Assessment (LCA, ISO 14040/14044): Cradle-to-grave analysis covering raw material extraction, manufacturing, use, and end-of-life disposal. Functional unit (e.g., '1 tonne of paper delivered') normalizes comparisons between alternative products.

### ⚡ EXAM TIP

ISO 14001 uses PDCA. Aspect = CAUSE (chemical storage). Impact = EFFECT (soil contamination). BPEO = best across ALL environmental media (UK); BAT = best economically viable technique (EU IED). ESG: E = environmental, S = social (safety metrics!), G = governance. Scope 3 = supply chain — largest category. GRI = most widely used ESG framework.

## 5. IMPACT OF ENVIRONMENTAL ISSUES

### 5.1. Aging Infrastructure

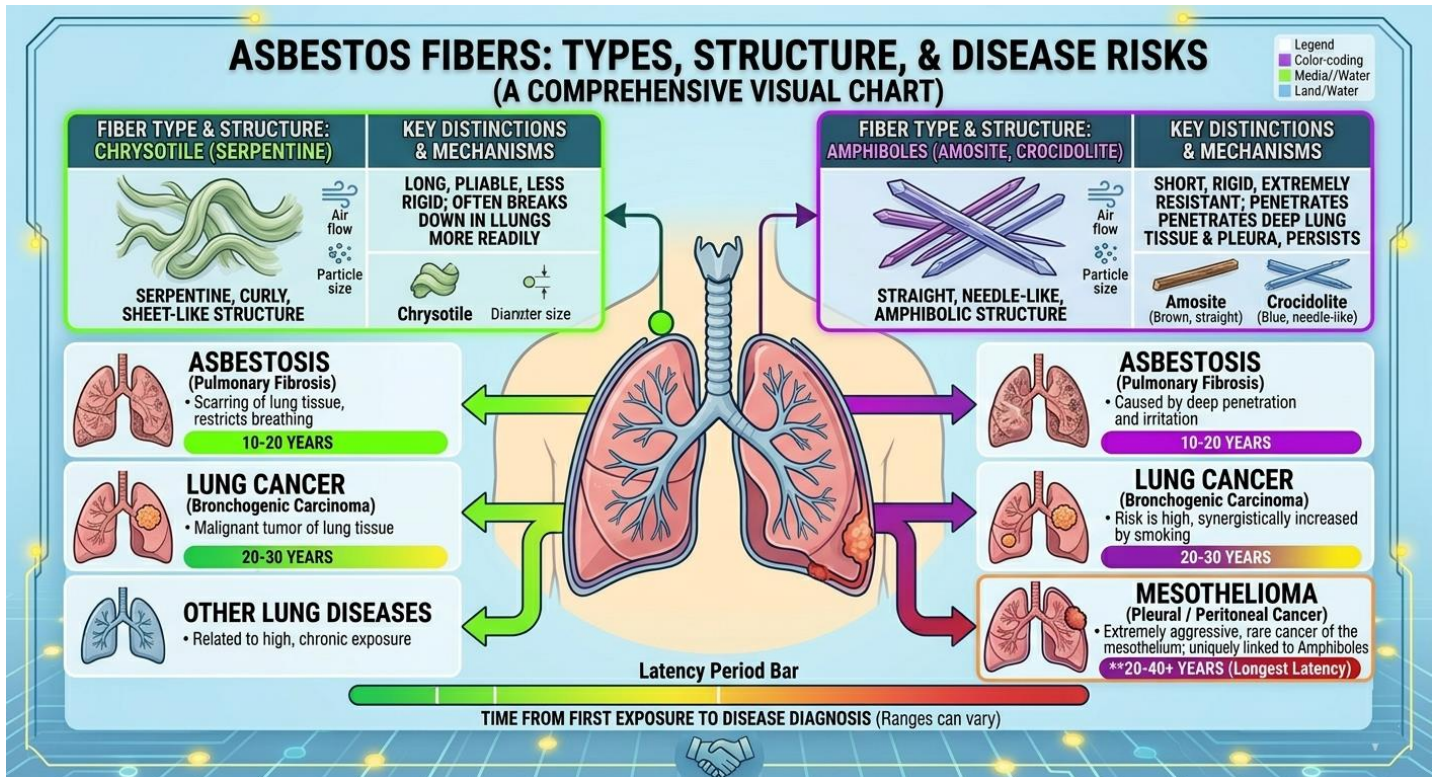
Aging infrastructure presents compounding safety and environmental risks. Deteriorating pipelines, underground storage tanks (USTs), and industrial equipment can release legacy contaminants with serious health and liability implications.

- **Underground Storage Tanks (USTs):** EPA requires leak detection, corrosion protection, spill/overflow containment, and proper closure. Aging USTs release petroleum hydrocarbons (LNAPL) to soil and groundwater.
- **Lead Piping:** Still present in distribution systems installed before 1986. Corrosion releases lead into drinking water. Lead and Copper Rule Action Level: 15 µg/L (micrograms per liter). SDWA MCLG = 0 (no safe exposure level).
- **PCBs in Legacy Equipment:** Transformers and capacitors installed before 1979 may contain PCBs. TSCA (40 CFR Part 761) regulates marking, disposal, storage, and spill cleanup.
- **OSHA PSM (29 CFR 1910.119):** Mechanical integrity requirements for aging process equipment containing highly hazardous chemicals — includes written procedures, inspections, testing, training, and quality assurance.
- **EPA Risk Management Program (RMP, 40 CFR Part 68):** Prevention programs for aging facilities with threshold quantities of regulated substances — requires hazard assessment, prevention program, and emergency response plan.

### 5.2. Asbestos

| Aspect                      | Details                                                                                                                                                                           |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Material Types              | Chrysotile (serpentine, most common — 95%); Amosite, Crocidolite, Anthophyllite, Tremolite, Actinolite (amphiboles — more dangerous, associated with mesothelioma)                |
| Historical Uses             | Insulation, fireproofing, roofing shingles, floor tiles, pipe insulation, friction products (brakes, gaskets), cement products                                                    |
| Health Effects              | Mesothelioma (primary association — pleural, peritoneal); Asbestosis (pulmonary fibrosis from fiber scarring); Lung cancer (IARC Group 1 carcinogen); Latency period: 10–40 years |
| OSHA PEL (General Industry) | 29 CFR 1910.1001: 0.1 fiber/cc as 8-hr TWA; 1.0 fiber/cc STEL (30-min)                                                                                                            |
| OSHA PEL (Construction)     | 29 CFR 1926.1101: 0.1 fiber/cc TWA; 1.0 fiber/cc STEL                                                                                                                             |
| EPA NESHAP                  | 40 CFR Part 61, Subpart M: Regulated during renovation and demolition — threshold 260 linear feet / 160 square feet; wet methods; licensed abatement contractors                  |

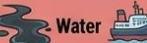
|                   |                                                                                                                               |
|-------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Abatement Options | Encapsulation (penetrating/bridging sealants); Enclosure (barrier materials); Removal (full abatement by licensed contractor) |
| Waste Disposal    | Wet, double-bagged in impermeable containers; labelled; disposed in EPA-approved asbestos landfill                            |



### 5.3. Major Environmental Regulations

| Regulation            | Agency | Primary Coverage                                                                              | Key CSP Exam Points                                                                                                           |
|-----------------------|--------|-----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Clean Air Act (CAA)   | EPA    | NAAQS for 6 criteria pollutants; HAPs (Title III); GHG reporting; operating permits (Title V) | 6 criteria pollutants: SO <sub>2</sub> , NO <sub>2</sub> , PM, CO, O <sub>3</sub> , Pb. Primary = health; Secondary = welfare |
| Clean Water Act (CWA) | EPA    | NPDES permits (Section 402); Dredge & Fill (Section 404); Water Quality Standards             | Section 402 = point-source discharge. Section 404 = wetlands (Army Corps of Engineers)                                        |
| RCRA                  | EPA    | Cradle-to-grave HW management; Subtitle C (hazardous); Subtitle D (solid); Corrective Action  | ICRT characteristics; generator categories; land disposal restrictions (LDR); TSDF permits                                    |
| CERCLA (Superfund)    | EPA    | Cleanup of uncontrolled contaminated sites; PRP                                               | Section 107: Joint and several liability — current owner, past owner, arranger, transporter                                   |

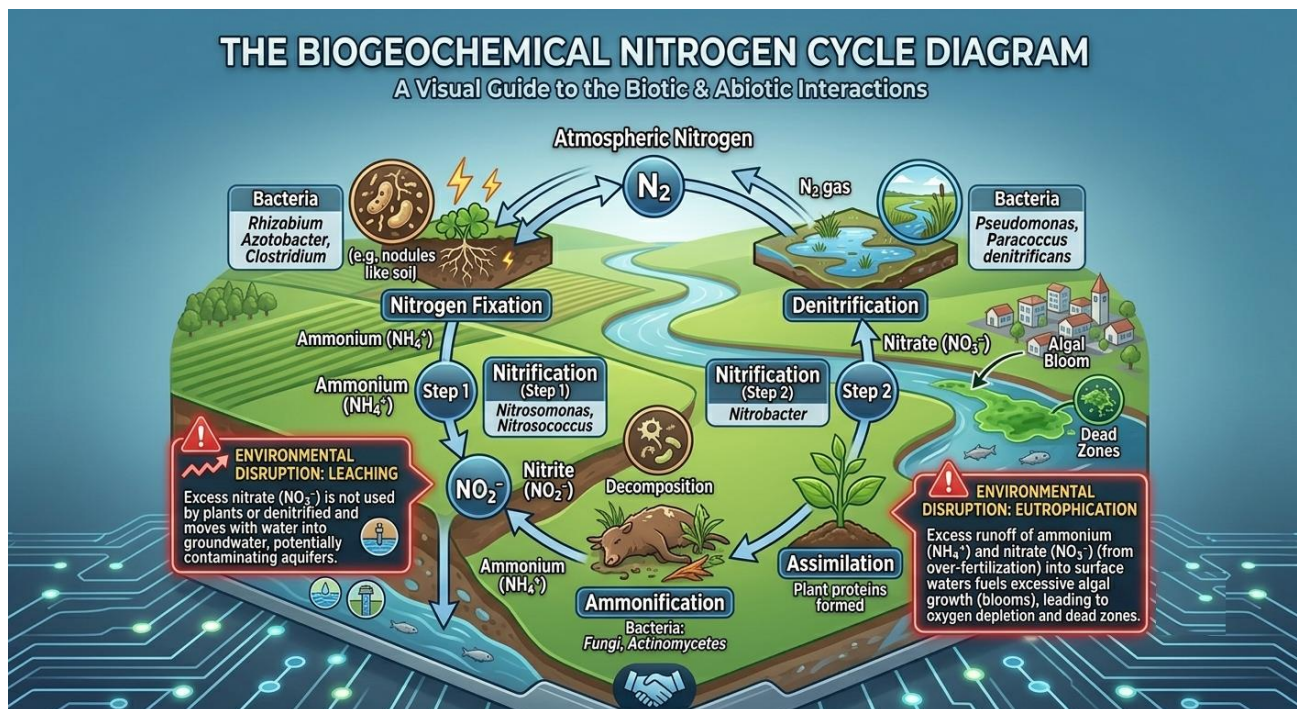
|                         |          |                                                                                                                       |                                                                                             |
|-------------------------|----------|-----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
|                         |          | liability; National Priorities List (NPL)                                                                             |                                                                                             |
| TSCA                    | EPA      | Chemical regulation; risk evaluation and management for existing chemicals; PCBs, asbestos, lead                      | Requires chemical manufacturers to report new substances; Toxic Substances Inventory        |
| SDWA                    | EPA      | Drinking water Maximum Contaminant Levels (MCLs); Lead and Copper Rule; Source Water Protection                       | MCL Nitrate = 10 mg/L as N; Lead Action Level = 15 µg/L; MCLG Lead = 0                      |
| EPCRA (SARA Title III)  | EPA      | Emergency Planning (Section 302); Emergency Notification (304); MSDS/inventory reporting (311/312); TRI (Section 313) | Section 304: Release of EHS above RQ → notify SERC and LEPC. TRI = Toxics Release Inventory |
| OPA (Oil Pollution Act) | EPA/USCG | Oil spill prevention, liability, and response for navigable waters                                                    | Facility Response Plans (FRP); SPCC Plans (Spill Prevention Control and Countermeasure)     |

| KEY US ENVIRONMENTAL LAWS: A ONE-PAGE VISUAL OVERVIEW MATRIX                                       |                                                          |                                                                                                                                      |                                                                                                                                                                                            |                                                                                                            |
|----------------------------------------------------------------------------------------------------|----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| CRITICAL EXAM NUMBERS & DISTINCTIONS                                                               |                                                          |                                                                                                                                      |                                                                                                                                                                                            |                                                                                                            |
| LAW ACRONYM<br>(With Full Name)                                                                    | AGENCY<br>(Leading Authority)                            | MEDIA COVERED<br>(Air/Water/Land)                                                                                                    | PRIMARY MECHANISMS<br>(Brief text and icons)                                                                                                                                               | CRITICAL EXAM NUMBER<br>(Isolated for memorization)                                                        |
| <b>CAA</b><br>Clean Air Act                                                                        | <b>EPA</b>                                               |  Air                                              | <ul style="list-style-type: none"> <li>NAAQS (Primary/Secondary standards)</li> <li>BACT/RACT/LAER</li> </ul>                                                                              | <b>108/109</b><br>(Criteria Pollutants listing)                                                            |
| <b>CWA</b><br>Clean Water Act                                                                      | <b>EPA, USACE</b><br>(Joint 404)                         |  Water                                            | <ul style="list-style-type: none"> <li>NPDES permits</li> <li>Water Quality Standards (WQS)</li> <li>TMDLs</li> </ul>                                                                      | <b>311</b><br>Oil & Hazardous Substance Liability                                                          |
| <b>RCRA</b><br>Resource Conservation and Recovery Act                                              | <b>EPA</b>                                               |  Land                                             | <ul style="list-style-type: none"> <li>Cradle-to-Grave Management</li> <li>Waste Characterization</li> <li>Land Disposal Restrictions (LDR)</li> </ul>                                     | <b>261/262</b><br>Hazardous Waste listing/Generator requirements                                           |
| <b>CERCLA</b><br>Superfund - Comprehensive Environmental Response, Compensation, and Liability Act | <b>EPA</b>                                               |  Land/Water                                       | <ul style="list-style-type: none"> <li>PRP Identification</li> <li>National Priorities List (NPL)</li> <li>Retroactive &amp; Strict Liability</li> </ul>                                   | <b>107</b><br>PRP Liability - Four categories                                                              |
| <b>TSCA</b><br>Toxic Substances Control Act                                                        | <b>EPA</b>                                               |  Other                                            | <ul style="list-style-type: none"> <li>Chemical substance reporting (e.g., TSCA Inventory)</li> <li>PMN (Pre-manufacture notice)</li> <li>Prioritization for existing chemicals</li> </ul> | <b>4/5/6/8</b><br>(Specific sections for testing, new chemicals, existing chemicals, reporting, reporting) |
| <b>SDWA</b><br>Safe Drinking Water Act                                                             | <b>EPA</b>                                               |  Water                                            | <ul style="list-style-type: none"> <li>Maximum Contaminant Levels (MCLs)</li> <li>Public Water System (PWS) supervision</li> <li>Wellhead Protection</li> </ul>                            | <b>MCLs</b><br>(Specific examples for Nitrate for common contaminants)                                     |
| <b>EPCRA</b><br>Emergency Planning and Community Right-to-Know Act                                 | <b>EPA</b><br><b>State (SERC)</b><br><b>Local (LEPC)</b> |  Land/Air/Water<br>(right-to-know, right-to-know) | <ul style="list-style-type: none"> <li>Community Right-to-Know Reporting</li> <li>Emergency Planning</li> <li>Toxics Release Inventory (TRI)</li> </ul>                                    | <b>304</b><br>Immediate Notification of releases over RQ                                                   |
| <b>OPA</b><br>Oil Pollution Act of 1990                                                            | <b>EPA, USCG</b>                                         |  Water                                            | <ul style="list-style-type: none"> <li>Prevent and Respond to Oil Spills</li> <li>Vessel Response Plans</li> <li>Double-Hull tankers</li> </ul>                                            | <b>1002</b><br>Single-hull phase-out dates                                                                 |

## 5.4. Nitrogen Cycle — Environmental Impact

The nitrogen cycle is a biogeochemical process that converts atmospheric nitrogen ( $N_2$ ) into biologically available forms and returns it to the atmosphere. Disruption by industrial and agricultural activities causes eutrophication, groundwater contamination, and climate impact.

| Process                | Reaction / Mechanism                                  | Key Microorganisms                                         | Environmental Significance                                                            |
|------------------------|-------------------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Nitrogen Fixation      | $N_2$ (gas) $\rightarrow$ $NH_3$ (ammonia)            | Rhizobium (legume root nodules); Azotobacter (free-living) | Makes $N_2$ biologically available; basis of agricultural fertilizers                 |
| Nitrification (Step 1) | $NH_3 \rightarrow NO_2^-$ (nitrite)                   | Nitrosomonas bacteria                                      | Aerobic process; intermediate step                                                    |
| Nitrification (Step 2) | $NO_2^- \rightarrow NO_3^-$ (nitrate)                 | Nitrobacter bacteria                                       | Nitrate is the most mobile form in soil — leaches to groundwater                      |
| Assimilation           | $NO_3^- / NH_4^+ \rightarrow$ Plant/microbial biomass | Plants, fungi, bacteria                                    | Nitrogen incorporated into living organisms                                           |
| Ammonification         | Organic N (proteins) $\rightarrow$ $NH_4^+ / NH_3$    | Decomposer bacteria and fungi                              | Releases N from dead organic matter back into soil                                    |
| Denitrification        | $NO_3^- \rightarrow N_2O \rightarrow N_2$ (gas)       | Pseudomonas, Thiobacillus (anaerobic)                      | Returns $N_2$ to atmosphere; critical for wastewater treatment (biological N removal) |



## 5.5. ESG — Environmental, Social, and Governance

ESG is a framework used by investors, regulators, and stakeholders to evaluate organizational sustainability, ethics, and risk management. Safety professionals contribute directly to both E and S pillars.

### Environmental (E)

How organizations manage their impact on the natural environment: carbon emissions, climate risk, water use, waste generation, biodiversity

### Social (S)

How organizations manage relationships with employees, suppliers, communities: worker safety, health programs, human rights, diversity

### Governance (G)

Internal systems of controls, policies, and practices: executive accountability, regulatory compliance, transparency, anti-corruption

| ESG Pillar        | Safety & Environmental Metrics Included                                                                              | CSP Contribution                                                                                            |
|-------------------|----------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| Environmental (E) | Carbon emissions (Scope 1/2/3), water use, waste generation/diversion, spill incidents, NOVs, permit violations      | Environmental compliance audits; pollution prevention programs; waste reduction targets; ISO 14001 EMS      |
| Social (S)        | TRIR, DART rate, near-miss frequency, occupational illness rate, fatality rate, worker health programs, human rights | Safety program development; injury/illness recordkeeping (OSHA 300); health surveillance; training programs |
| Governance (G)    | Board accountability, regulatory compliance rate, anti-corruption, executive compensation disclosure                 | EHS compliance management; incident reporting systems; regulatory relationship management                   |

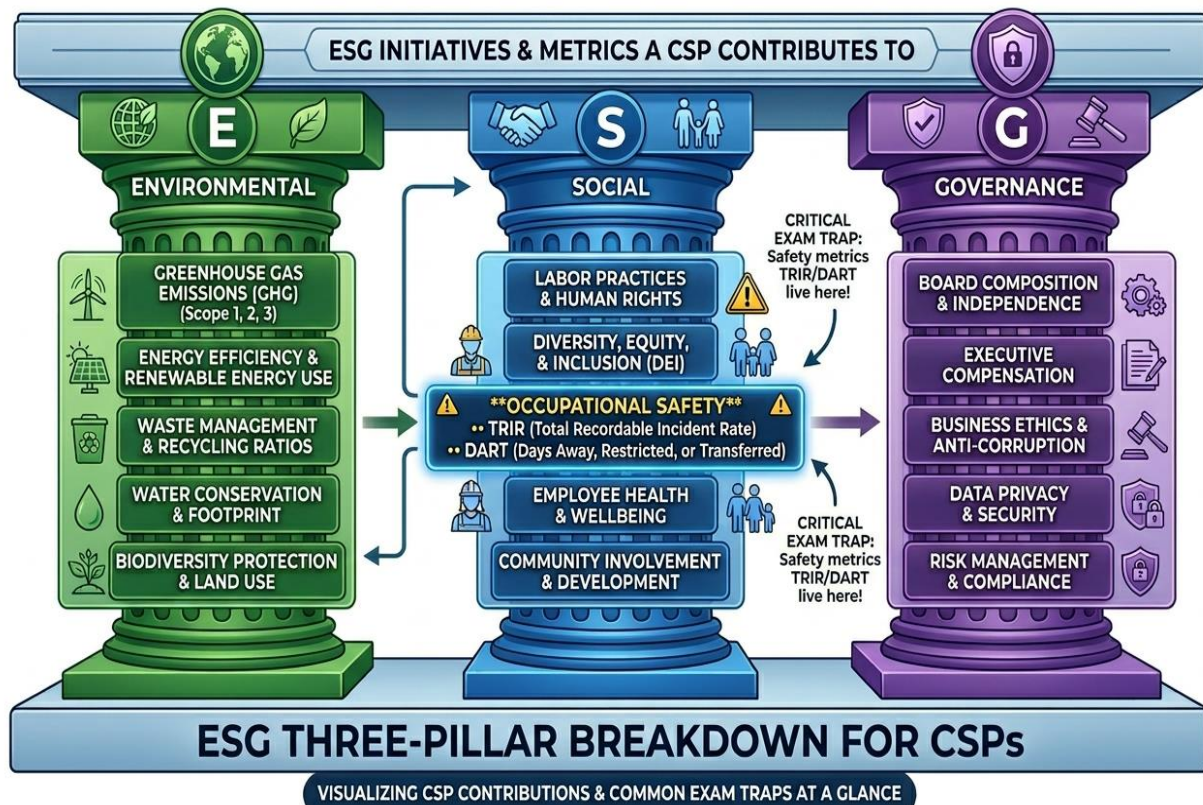
## ESG Reporting Frameworks

| Framework | Full Name                                           | Focus                                                         | Key Feature                                                       |
|-----------|-----------------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------------|
| GRI       | Global Reporting Initiative Standards               | Comprehensive — economic, environmental, social impacts       | Most widely used; stakeholder-inclusive; topic-specific standards |
| SASB      | Sustainability Accounting Standards Board           | Industry-specific financial materiality                       | 77 industry standards; maps to GAAP financial reporting           |
| CDP       | Carbon Disclosure Project                           | Climate, water, forests — supply chain focus                  | Questionnaire-based; rated A–D; used by investors                 |
| TCFD      | Task Force on Climate-related Financial Disclosures | Climate risk governance and financial impact                  | Governance, strategy, risk management, metrics and targets        |
| UN SDGs   | UN Sustainable Development Goals                    | 17 goals for global sustainability (poverty, climate, health) | Voluntary alignment framework; CSPs contribute to SDG 3, 8, 13    |

## ESG and CSP Professional Relevance

The CSP directly contributes to ESG performance by managing the data that feeds into sustainability reporting. Safety professionals must understand that ESG is not merely a public relations exercise — it drives investment decisions, regulatory scrutiny, and organizational reputation.

- **Environmental (E) contributions:** Environmental compliance records; NOV/permit violation tracking; spill incident management; waste minimization programs; ISO 14001 EMS management.
- **Social (S) contributions:** TRIR, DART, and near-miss rates (directly reported in ESG disclosures); occupational health surveillance programs; training completion rates; contractor safety performance.
- **Integrated Management Systems (IMS):** ISO 45001 (OHS) + ISO 14001 (EMS) + ISO 9001 (QMS) can be integrated using the Annex SL high-level structure — shared context, leadership, planning, support, operation, evaluation, and improvement clauses.

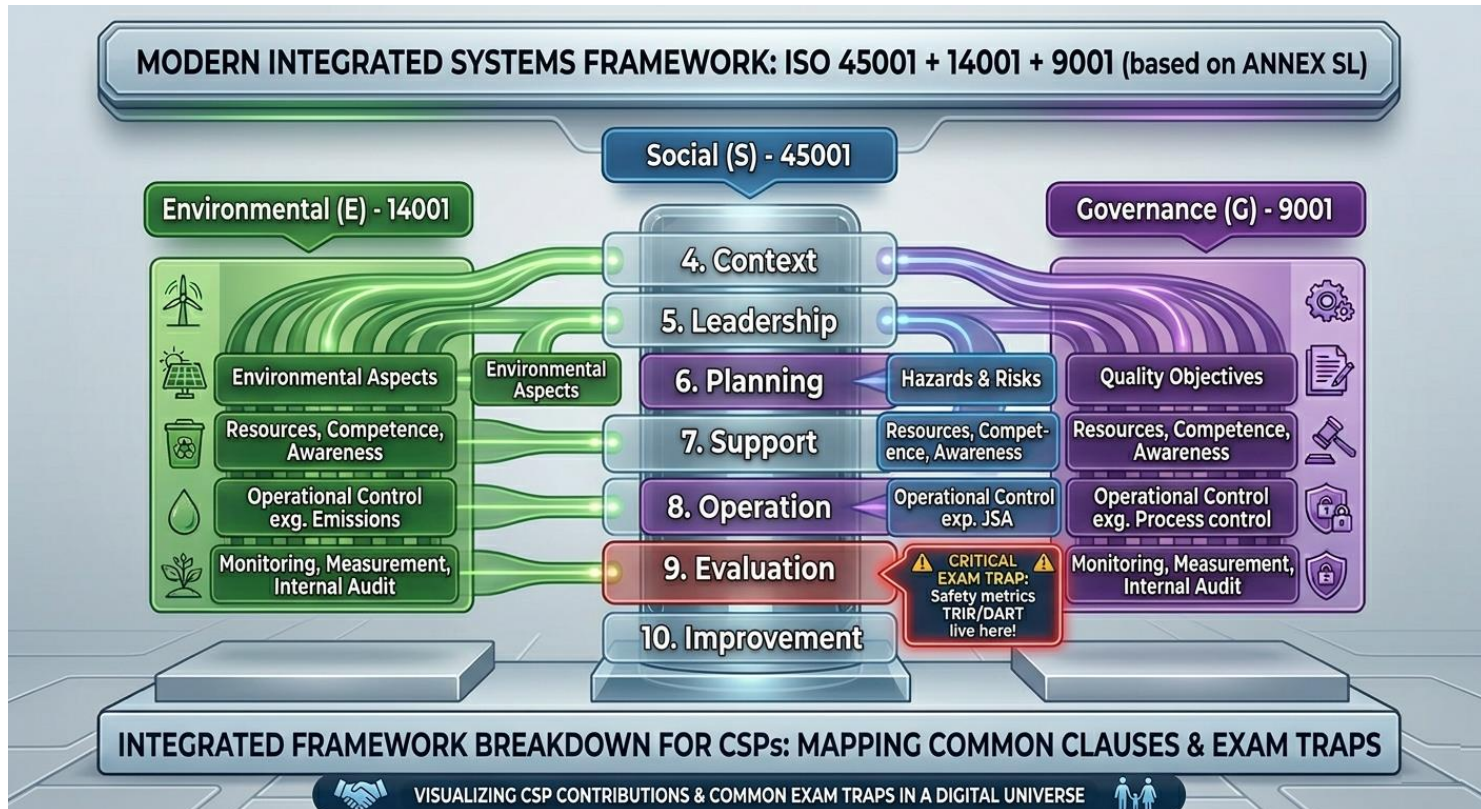


### □ KEY REFERENCES

Yates, D.S. Ch. 18: Integration of safety and environmental programs under a unified HSEQ management system. Regulatory compliance is a floor, not a ceiling — sustainability leadership requires going beyond minimum legal requirements. ISO 14001:2015 is compatible with ISO 45001:2018 through the Annex SL framework, enabling integrated management systems that address OHS and environmental performance under a single system architecture.

### ⚡ EXAM TIP

Asbestos PEL = 0.1 f/cc TWA; Mesothelioma = primary disease; Latency = 10–40 years. NAAQS = 6 criteria pollutants: SO<sub>2</sub>, NO<sub>2</sub>, PM, CO, O<sub>3</sub>, Pb. CWA NPDES = point-source discharge permit. CERCLA = joint and several PRP liability. Nitrate MCL = 10 mg/L as N. Lead action level = 15 µg/L. Denitrification (*Pseudomonas*) returns NO<sub>3</sub><sup>-</sup> → N<sub>2</sub> to atmosphere (anaerobic). ESG Social pillar = safety metrics!



## Skills and Scenarios

Applying the knowledge areas related to environmental protection and pollution prevention methods to the skills in waste management practices and hazardous waste operations can be demonstrated through practical scenarios and examples. Here's how each knowledge area translates into action for the skill areas:

### Skill 1: Use Waste Management Practices

#### 1. Segregation and Separation

##### Scenario:

An industrial manufacturing facility generates multiple types of waste, including plastic, metal shavings, hazardous chemical by-products, and organic waste from cafeteria services. To minimize environmental impact and ensure regulatory compliance, the facility implements a waste segregation system.

##### Application:

- **Air Pollution Prevention:** By segregating waste, the company can recycle materials (like plastics and metals) rather than sending them to landfills, reducing emissions from waste incineration. For instance, properly sorting hazardous chemicals prevents the release of toxic fumes during disposal.
- **Water Pollution Prevention:** Segregating hazardous waste from non-hazardous waste prevents chemical spills from contaminating water systems. For example, in a plant using chemicals for metal finishing, keeping acidic waste separate from solid waste helps avoid leaks into stormwater drains.
- **Soil Protection:** Separating hazardous waste ensures it is disposed of in secure landfills with liners to prevent soil contamination. If chemical waste is improperly mixed with general waste, soil can become contaminated, requiring expensive remediation.

#### 2. Containment

##### Scenario:

A chemical processing plant stores hazardous materials in large tanks. To avoid accidental leaks or spills, the facility installs secondary containment systems around all storage areas.

##### Application:

- **Soil Vapor Intrusion:** Proper containment systems prevent the escape of volatile organic compounds (VOCs) into the atmosphere, where they could migrate into surrounding soil and groundwater. By using double-walled storage tanks and containment dikes, the plant reduces the risk of vapor intrusion and subsequent human exposure.
- **Soil and Water Table Protection:** Secondary containment helps to capture spills before they reach the soil or groundwater. In case of a tank rupture, the liquid remains confined within the containment area, preventing environmental contamination and reducing the need for extensive soil remediation.

### 3. Disposal

#### Scenario:

A hospital generates medical waste, including sharps, pharmaceutical waste, and biohazardous materials. The hospital must dispose of these materials following strict regulations to avoid environmental contamination.

#### Application:

- **Waste Stream Knowledge:** Understanding waste stream classifications (e.g., solid waste, hazardous waste, infectious waste) helps the hospital create a proper disposal system. Sharps and biohazardous materials are incinerated under high temperature to neutralize pathogens, while pharmaceuticals are treated through chemical processes before disposal.
- **Air and Water Pollution Prevention:** Proper disposal of medical waste prevents harmful emissions or toxic substances from contaminating air or water systems. For example, ensuring pharmaceutical waste doesn't enter the sewage system prevents contamination of public water systems.

### 4. Chain of Custody

#### Scenario:

A pharmaceutical company manufactures drugs that include hazardous solvents. The company is legally required to maintain a chain of custody from production to final disposal of these hazardous substances.

#### Application:

- **Regulatory Compliance (REACH/RoHS):** By tracking the movement of hazardous chemicals through a chain of custody system, the company ensures compliance with REACH and RoHS regulations. This prevents restricted chemicals from entering the consumer market or being improperly disposed of, which could harm human health or the environment.
- **Waste Streams:** Proper documentation and control of hazardous waste ensure that the company can account for every stage of waste management, from generation to final disposal, minimizing the chance of illegal dumping or mismanagement.

### 5. Waste Management Policy

#### Scenario:

A university adopts a campus-wide sustainability initiative, incorporating waste management policies to reduce waste, recycle more, and compost organic material.

#### Application:

- **Sustainability Principles:** The university implements policies that align with sustainability goals, such as minimizing waste sent to landfills and increasing recycling rates. By introducing composting programs and purchasing materials with lower environmental impact, the university reduces its carbon footprint.
- **Wastewater Treatment:** A policy to handle laboratory chemicals ensures that wastewater from experiments is properly treated before entering public systems, preventing contamination and reducing the burden on municipal wastewater treatment plants.

## Skill 2: Conduct Hazardous Waste Operations

### 1. Spill Clean-Up

#### Scenario:

A large warehouse storing industrial chemicals experiences a spill of a toxic solvent used in cleaning heavy machinery. The spill threatens to contaminate nearby soil and groundwater if not managed quickly.

#### Application:

- **Air and Soil Contamination:** By using spill kits with absorbent materials and neutralizing agents, the response team prevents the solvent from evaporating into the air or leaching into the soil. Using barriers or booms around the spill area minimizes the risk of further migration of hazardous chemicals.
- **Containment and Migration Prevention:** The team implements secondary containment and covers the spill with impermeable barriers to stop chemicals from penetrating the ground. This immediate action ensures that groundwater remains uncontaminated.

### 2. Remediation

#### Scenario:

An industrial site that previously used heavy metals in its production process is slated for redevelopment. The site's soil is heavily contaminated with lead, cadmium, and mercury, which pose a risk to future users and the surrounding ecosystem.

#### Application:

- **Soil and Water Table Migration:** The site undergoes extensive remediation using methods like **soil excavation** and **soil washing** to remove contaminants. **Phytoremediation** is employed by planting specific vegetation to extract heavy metals from the soil over time.
- **Regulatory Compliance and Pollution Prevention:** By following remediation standards (e.g., EPA's Superfund program), the company ensures the site is decontaminated and safe for future use. Without proper remediation, contaminants could have leached into the groundwater, polluting local water systems and endangering public health.

### 3. Waste Handling During Clean-Up

#### Scenario:

A trucking accident releases a large quantity of a hazardous chemical into a river, creating an immediate risk to aquatic life and downstream water users. Emergency crews are dispatched to contain the spill.

#### Application:

- **Surface Water Protection:** The emergency response team deploys floating booms and absorbent materials to capture the chemical before it spreads downstream. They also use **vacuum trucks** to remove contaminated water for treatment at a designated facility.
- **Chain of Custody in Remediation:** Throughout the clean-up, the team maintains detailed logs of the hazardous waste collected, its transportation, and final disposal at a certified hazardous waste facility. This documentation ensures regulatory compliance and transparency in the remediation process.

#### 4. Regulatory Response

##### Scenario:

A manufacturing plant is required to clean up an old disposal site where they buried chemical waste years ago. The site is now leaching hazardous materials into the surrounding environment.

##### Application:

- **REACH and RoHS Compliance:** The plant is required to report on the hazardous materials released and follow a strict clean-up process under REACH regulations. This includes removing contaminated soil, treating leachate, and preventing further chemical migration.
- **Sustainability and Long-Term Monitoring:** As part of the remediation, the company installs **groundwater monitoring wells** and commits to a long-term plan to track the site's recovery. They also implement a **sustainability plan** to reduce future waste generation and avoid similar incidents.

## DOMAIN 5 — QUICK-REFERENCE SUMMARY TABLE

| Topic                       | Key Facts & Numbers to Memorize                                                                                                                                                                          |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AQI Levels                  | 0–50 Good (Green); 51–100 Moderate (Yellow); 101–150 Unhealthy Sensitive Groups (Orange); 151–200 Unhealthy (Red); 201–300 Very Unhealthy (Purple); 301–500 Hazardous (Maroon)                           |
| Greenhouse Gas GWP          | CO <sub>2</sub> = 1 (reference); CH <sub>4</sub> ≈ 28; N <sub>2</sub> O ≈ 265; SF <sub>6</sub> ≈ 23,500 (highest)                                                                                        |
| Montreal Protocol           | 1987 — phase-out of ODS (CFCs highest ODP; halons 2nd; HCFCs lower ODP). All 197 UN nations ratified.                                                                                                    |
| Eutrophication              | Excess N & P → algal bloom → O <sub>2</sub> depletion → hypoxic dead zones. Nitrate MCL = 10 mg/L as N.                                                                                                  |
| NAPL Behavior               | LNAPL floats on water table (gasoline, diesel); DNAPL sinks to aquitard (TCE, PCE, carbon tet). High K <sub>ow</sub> = bioaccumulates.                                                                   |
| RCRA ICRT                   | Ignitability D001 (FP <60°C); Corrosivity D002 (pH ≤2 or ≥12.5; steel corrosion >6.35 mm/yr); Reactivity D003; Toxicity D004+ (TCLP)                                                                     |
| Generator Categories        | VSQG <100 kg/month; SQG 100–1,000 kg (180 days); LQG >1,000 kg (90 days)                                                                                                                                 |
| SAA Limit                   | 55 gallons hazardous waste OR 1 quart acute (P-listed) hazardous waste                                                                                                                                   |
| HAZWOPER                    | 40-hour initial + 3 days field experience (uncontrolled HW sites). Annual 8-hour refresher ALL levels.                                                                                                   |
| Universal Waste             | Batteries; Pesticides (recalled); Mercury-containing equipment; Lamps (fluorescent, HID)                                                                                                                 |
| Waste Hierarchy             | Prevention > Reuse > Recycling > Recovery > Disposal (P2 Act 1990; EU WFD)                                                                                                                               |
| Remediation Technologies    | SVE = VOCs in vadose zone; Air Sparging = VOCs in saturated zone; ISTT = DNAPLs (source zone); Phytoextraction = metals (harvest); Bioremediation = organics in situ; MNA = document natural attenuation |
| CERCLA Notification         | Release > RQ → Notify National Response Center (NRC: 1-800-424-8802). EPCRA 304 EHS release → SERC + LEPC.                                                                                               |
| ISO 14001                   | EMS standard; PDCA; Clauses 4–10; Aspect (CAUSE) vs Impact (EFFECT)                                                                                                                                      |
| BPEO / BAT                  | BPEO = best across all media at acceptable cost (UK); BAT = best economically viable technique (EU IED)                                                                                                  |
| ESG                         | E=Environmental, S=Social (safety metrics), G=Governance; GRI most widely used framework. Scope 1=direct; 2=purchased energy; 3=supply chain                                                             |
| Asbestos                    | PEL = 0.1 f/cc TWA; STEL = 1.0 f/cc. Mesothelioma = primary disease. Latency 10–40 years. NESHAP threshold = 260 LF / 160 SF.                                                                            |
| 6 NAAQS Criteria Pollutants | SO <sub>2</sub> , NO <sub>2</sub> , PM (PM <sub>2.5</sub> and PM <sub>10</sub> ), CO, O <sub>3</sub> , Pb. Primary = health; Secondary = welfare.                                                        |

|                    |                                                                                                                                                                                                                                  |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Nitrogen Cycle     | Fixation (Rhizobium $\rightarrow$ $\text{NH}_3$ ); Nitrification (Nitrosomonas $\rightarrow$ $\text{NO}_2^-$ ; Nitrobacter $\rightarrow$ $\text{NO}_3^-$ ); Denitrification (Pseudomonas $\rightarrow$ $\text{N}_2$ , anaerobic) |
| Lead & Copper Rule | Action Level = 15 $\mu\text{g/L}$ . MCLG = 0. Triggers corrosion control treatment if >10% samples exceed AL.                                                                                                                    |

### □ KEY REFERENCES

CORE REFERENCES FOR DOMAIN 5: • Roger Brauer, Safety and Health for Engineers, 3rd Ed.: Ch. 32 (Air Pollution Control Engineering), Ch. 33 (Environmental Management & Waste) • D.S. Yates, Occupational Safety and Health Management, 2nd Ed.: Ch. 16 (Soil/Groundwater/Nitrogen Cycle), Ch. 17 (Hazardous Materials Management), Ch. 18 (Waste Management & Sustainability) • RCRA (42 USC 6901) — Resource Conservation and Recovery Act | 40 CFR Parts 261–268 (Hazardous Waste Regulations) • CERCLA (42 USC 9601) — Comprehensive Environmental Response, Compensation & Liability Act • OSHA 29 CFR 1910.120 — HAZWOPER | 29 CFR 1910.1001 — Asbestos (General Industry) • Clean Air Act (42 USC 7401) — NAAQS, HAPs, Title V Permits | Clean Water Act (33 USC 1251) — NPDES, Section 404 • SDWA (42 USC 300f) — Drinking Water Standards | EPCRA (42 USC 11001) — SARA Title III • ISO 14001:2015 — Environmental Management Systems | ISO 14040/14044 — Life Cycle Assessment • Montreal Protocol (1987) — Ozone Depleting Substances | 40 CFR Part 273 — Universal Waste Program • EPA NAAQS Table — <https://www.epa.gov/criteria-air-pollutants> | EU IED (2010/75/EU) — Industrial Emissions Directive

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