Bioremediation

THE BASIC PROBLEM:
RELEASE OF HAZARDOUS MATERIALS

- Enormous quantities of organic & inorganic compounds are released into the environment each year as a result of human activities.

- The release may be:
  - Deliberate and well regulated (industrial emissions)
  - Accidental and largely unavoidable (chemical/oil spills)
  - US EPA estimated that in 1980 at least 57 millions metric tons of the total waste can be categorized into three general groups:

- Heavy metal, Pb, Hg, Cd, Ni and Be can accumulate in various organs, interfere with normal enzymatic reactions and cause disease including cancer

- Chlorinated hydrocarbons, also known as organochlorides including pesticides and other organic compounds such as PCB (polychlorinated biphenyls)
  - Research proven a positive correlation between cancer in lab animals and organochlorides.

- Nuclear waste including radioactive material such as plutonium which are dangerous for thousands of years

What are environmental contaminants?

- Pollutants
  - naturally-occurring compounds in the environment that are present in unnaturally high concentrations.
  - Examples:
    - crude oil
    - refined oil
    - phosphates
    - heavy metals
- Xenobiotics
  - chemically synthesized compounds that have never occurred in nature.
  - Examples:
    - pesticides
    - herbicides
    - plastics

Bioremediation

- is defined as the process whereby **organic wastes** are **biologically degraded** under controlled conditions to an innocuous state, or to levels below concentration limits established by regulatory authorities.

Simply:

- The **use of bacteria and fungi and plants** to break down or degrade toxic chemical compounds that have accumulated in the environment

Biodegradation & Bioremediation?

- **Biodegradation** - the use of living organisms such as bacteria, fungi, and plants to degrade chemical compounds
- **Bioremediation** – process of cleaning up environmental sites contaminated with chemical pollutants by using living organisms to degrade hazardous materials into less toxic substances

Early examples of bioremediation

- Outhouse
- Microorganisms oxidize organic waste molecules to carbon dioxide and water
- Sewage treatment plants

- By 1970s it became apparent that we were polluting the environment faster than the natural microbial processes could degrade the pollutants
- 1980 Superfund Program established by U.S. Congress
  - To counteract careless and even **negligent practices of chemical dumping and storage**, as well as concern over how these pollutants might affect human health and the environment
  - Purpose is to **locate and clean up hazardous waste** sites

Most recent

- National Institute of Environmental Health Sciences established the **Environmental Genome Project**
  - Study impact of environmental chemicals on human disease
    - Identify genes and their products that are sensitive to toxic chemicals in the environment
    - Identify genes that encode for products that detoxify the chemicals

What Makes Bioremediation a Promising Approach?

- permanence
  - contaminant is degraded
- potentially low cost
  - 60-90% less than other technologies
- Most approaches **convert harmful pollutants** into relatively **harmless materials** such as carbon dioxide, chloride, water, and simple organic molecules
- Processes are generally cleaner

What Is Bioremediation?

- Biotechnological approaches are essential for
  - Detecting pollutants
  - Restoring ecosystems
  - Learning about conditions that can result in human diseases
  - Converting waste products into valuable energy

Bioremediation Basics

- What needs to be cleaned up?
  - Soil, water, air, and sediment
- Pollutants enter environment in many different ways
  - Tanker spill, truck accident, ruptured chemical tank at industrial site, release of pollutants into air
- Location of accident, the amount of chemicals released, and the duration of the spill impacts the parts of the environment affected

- Pollutants released in air are trapped in clouds and contaminate surface and ground water when it rains. Eg acid rain
- Industrial manufacturing, landfills, illelegal dumps,
- Pesticides
- Mining process

Treatment Environments and Contamination Zones

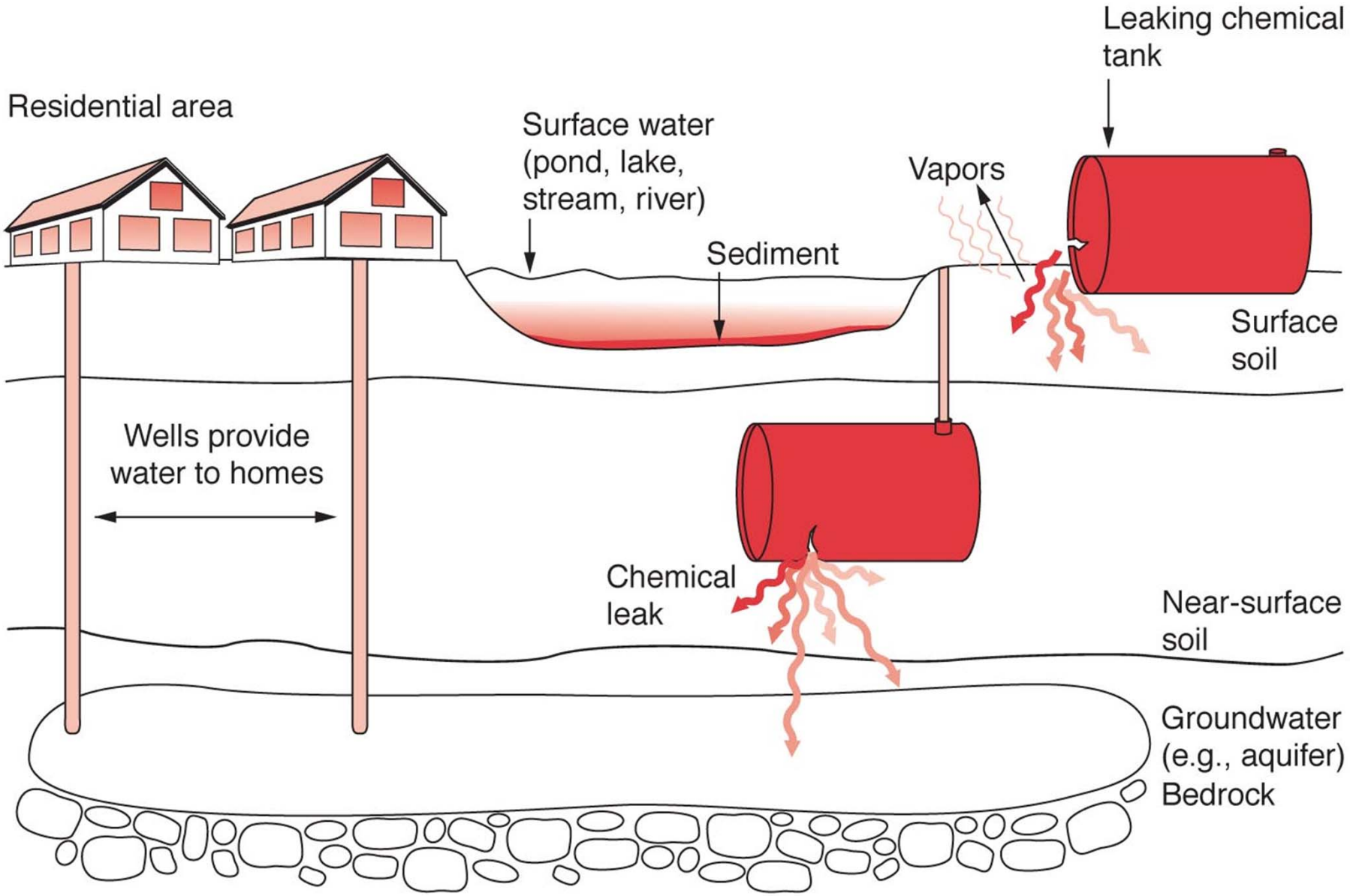


Table 9.1 TWENTY OF THE MOST COMMON CHEMICAL POLLUTANTS IN THE ENVIRONMENT

Chemical Pollutant	Source
Benzene	Petroleum products used to make plastics, nylon, resins, rubber, detergents, and many other materials
Chromium	Electroplating, leather tanning, corrosion protection
Creosote	Wood preservative to prevent rotting
Cyanide	Mining processes and manufacturing of plastics and metals
Dioxin	Pulp and paper bleaching, waste incineration, and chemical manufacturing processes
Methyl t-butyl ether (MTBE)	Fuel additive, automobile exhaust, boat engines, leaking gasoline tanks
Naphthalene	Product of crude oil and petroleum
Nitriles	Rubber compounds, plastics, and oils
Perchloroethylene/ tetrachloroethylene (PCE), trichloroethene (TCE), and trichloroethane (TCA)	Dry cleaning chemicals and degreasing agents
Pesticides (atrazine, carbamates, chlordane, DDT) and herbicides	Chemicals used to kill insects (pesticides) and weeds (herbicides)
Phenol and related compounds (chlorophenols)	Wood preservatives, paints, glues, textiles
Polychlorinated biphenyls (PCBs)	Electrical transistors, cooling and insulating systems
Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated hydrocarbons	Incineration of wastes, automobile exhaust, oil refineries, and leaking oil from cars
Polyvinylchloride	Plastic manufacturing
Radioactive compounds	Research and medical institutions and nuclear power plants
Surfactants (detergents)	Manufacturing of paints, textiles, concrete, paper
Synthetic estrogens (ethinyl estradiol)	Female hormone (estrogen)-related compounds created by a variety of industrial manufacturing processes
Toluene	Petroleum component present in adhesive, inks, paints, cleaners, and glues
Trace metals (arsenic, cadmium, chromium, copper, lead, mercury, silver)	Car batteries and metal manufacturing processes
Trinitrotoluene (TNT)	Explosive used in building and construction industries

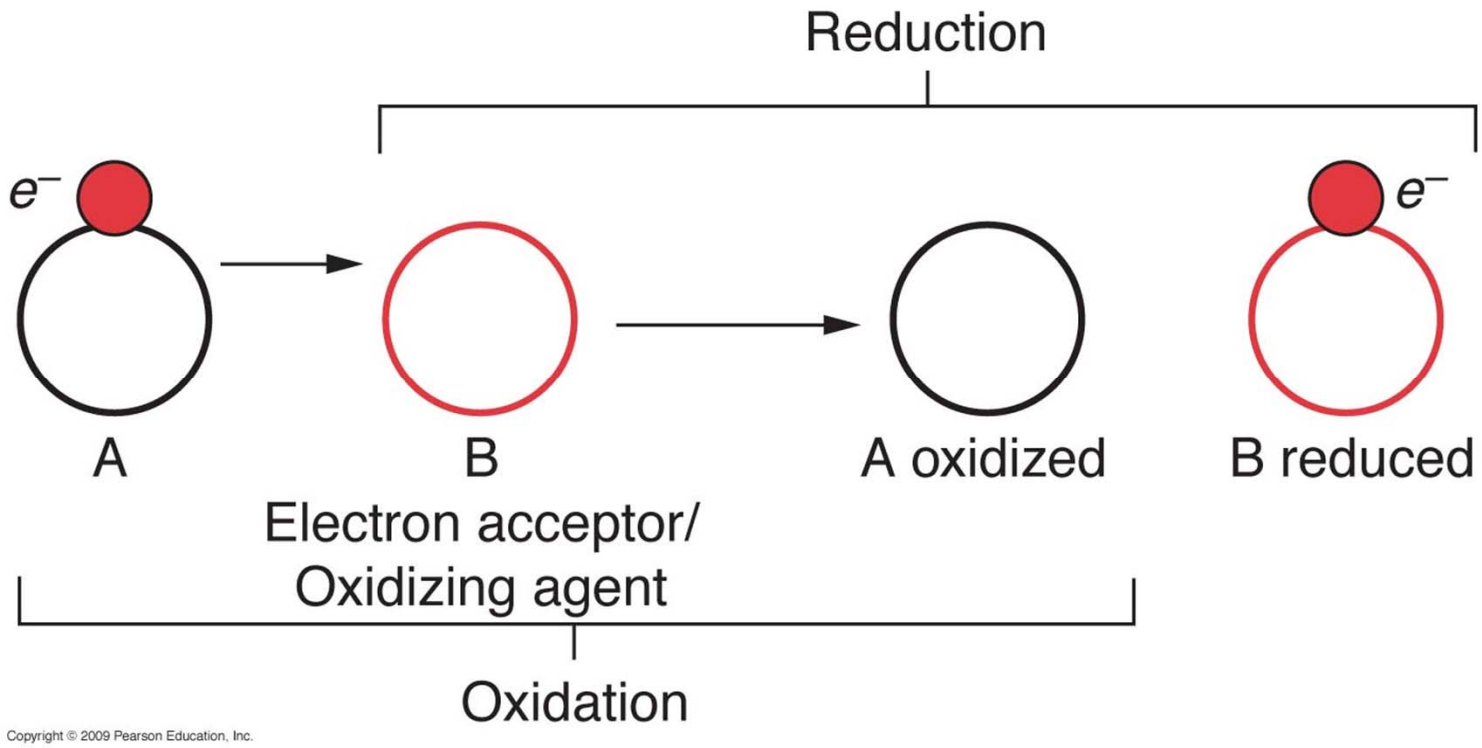
- Effects of Chemicals in the Environment
  - Carcinogens
  - Mutagens
  - Cause skin rashes, birth defects
  - Poison plant and animal life

Fundamentals of cleanup reactions

Microbes convert chemicals into harmless substances by either

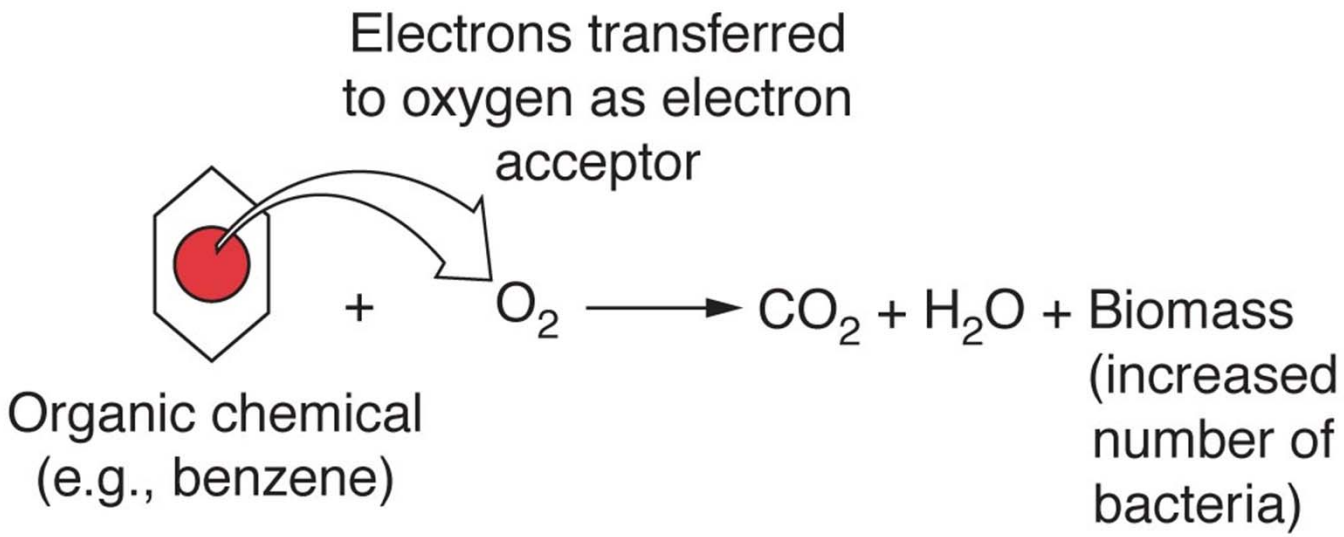
- Aerobic metabolism
  - Microbes use O_2 in their metabolism to degrade contaminants
- Anaerobic metabolism
  - Microbes substitute another chemical for O_2 to degrade contaminants
    - Nitrate, iron, sulfate, carbon dioxide, uranium, technicium, perchlorate

Oxidation and Reduction (Redox) Reactions



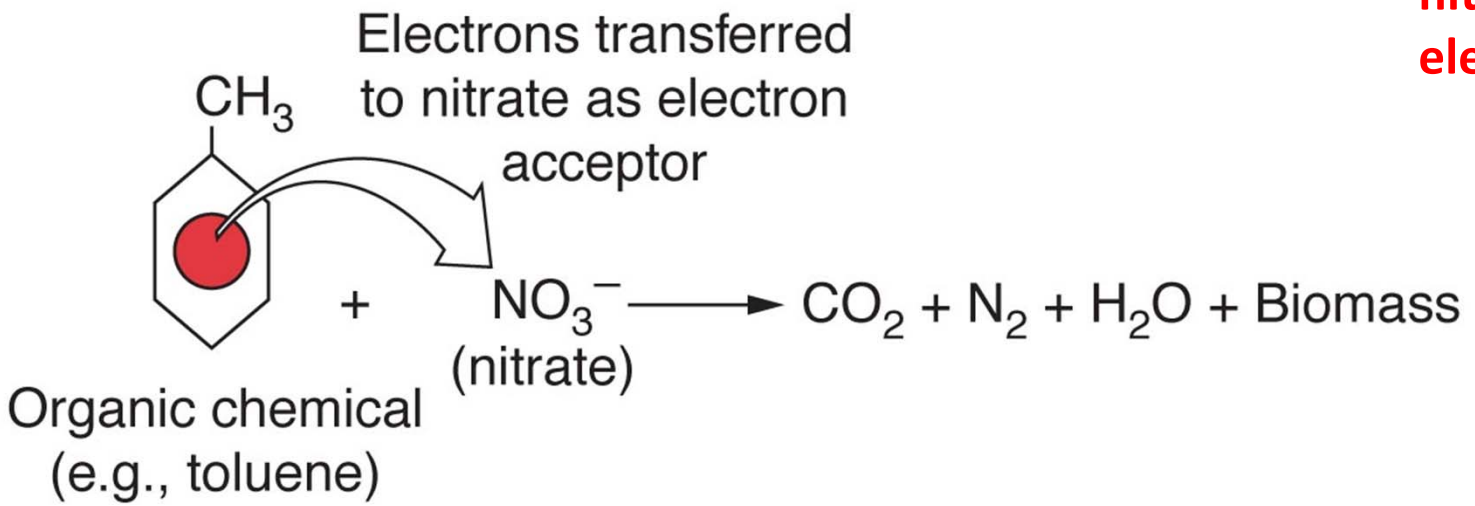
- Aerobic and Anaerobic Biodegradation

Aerobic biodegradation



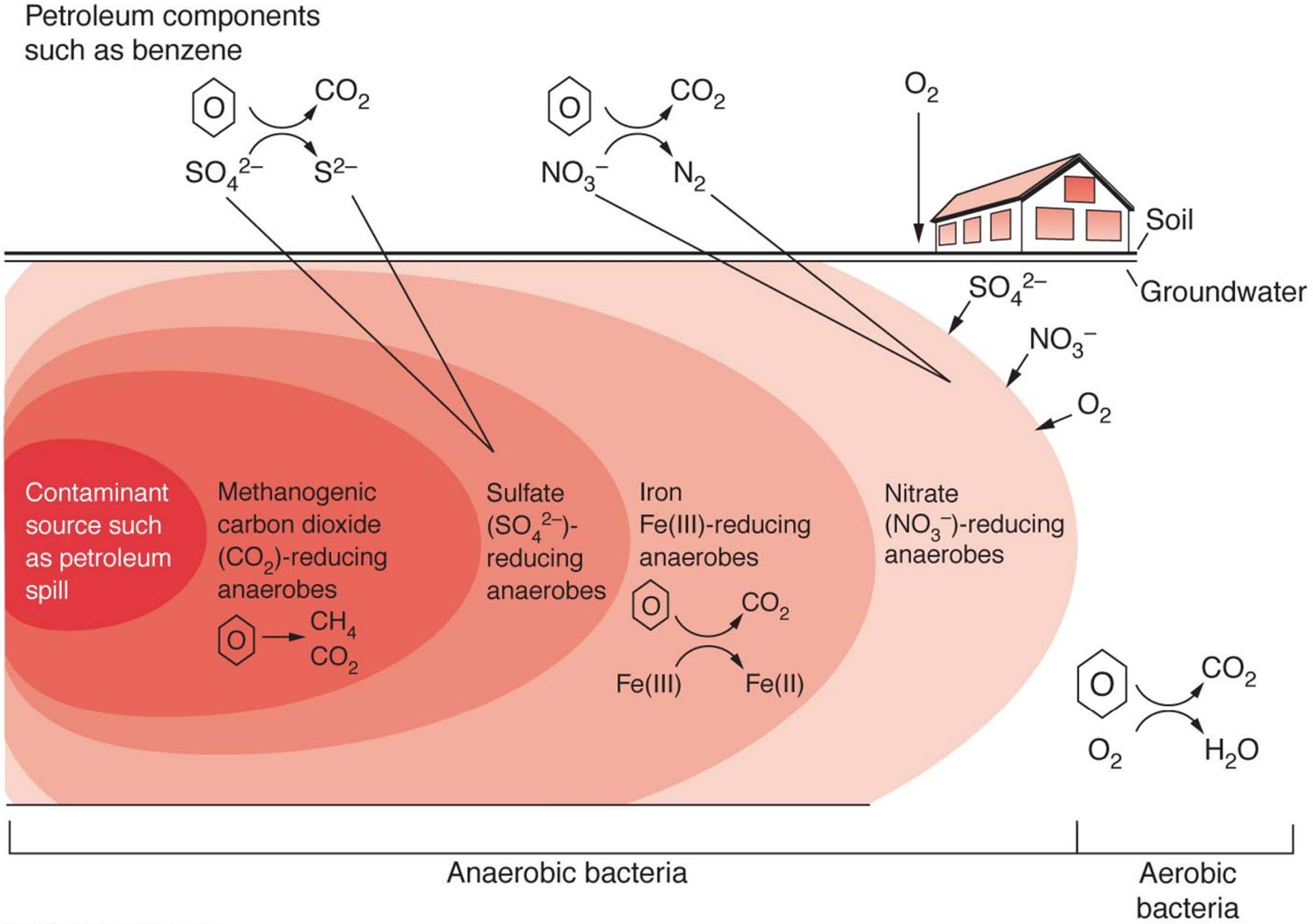
Energy released by biodegradation is utilized for the growth of microbes (biomass)

Anaerobic biodegradation



Iron, Sulphate, and nitrate are common electron acceptors.

Distribution of microbes at source of contamination



The Players: Metabolizing Microbes

- Indigenous microbes – those found naturally at a polluted site
- Bacteria
  - *Pseudomonas*
  - *E.coli*
- Algae and fungi
  - *Phanerochaete chrysosporium & Phanerochaete sordida*
    - Degrade toxic chemicals such as creosote, pentachlorophenol which are not degraded by microbes
  - *Fusarium oxysporum & Mortierella hyaline*
    - Asbestos and heavy metals

Bioremediation Genomics Programs

Table 9.2 EXAMPLES OF BIOREMEDIATION GENOME PROJECTS UNDERWAY OR RECENTLY COMPLETED

Microorganism	Number of Genes (Year Genome Completed)	Bioremediation Applications
Accumulibacter phosphatis	2006 (not completed)	Major wastewater treatment plant microbe used for removing high phosphates loads from wastewaters and sludge
Alcanivorax borkumensis	2,755 (2006)	Hydrocarbon-degrading marine bacterium that is very effective at degrading many components of crude and refined oil
Dehalobacter restrictus	2006 (not completed)	Dechlorinate perchloroethylene (PCE)
Dehalococcoides ethenogenes	1,591 (2005)	Degrades hydrogen and chlorine. Only known organism to fully dechlorinate perchloroethylene (PCE) and trichloroethene (TCE). PCE and TCE cleanup in wastewaters; polychlorinated dioxin degradation.
Geobacter metallireducens	3,676 (2006)	Subsurface metal reduction, carbon cycling, generate electricity (see Figure 9.13)
Populus trichocarpa (poplar tree)	45,555 (2006)	First tree genome sequenced. Thought to have the largest number of genes for any organism sequenced to date. Potential use for reducing atmospheric carbon dioxide.

Stimulating Bioremediation

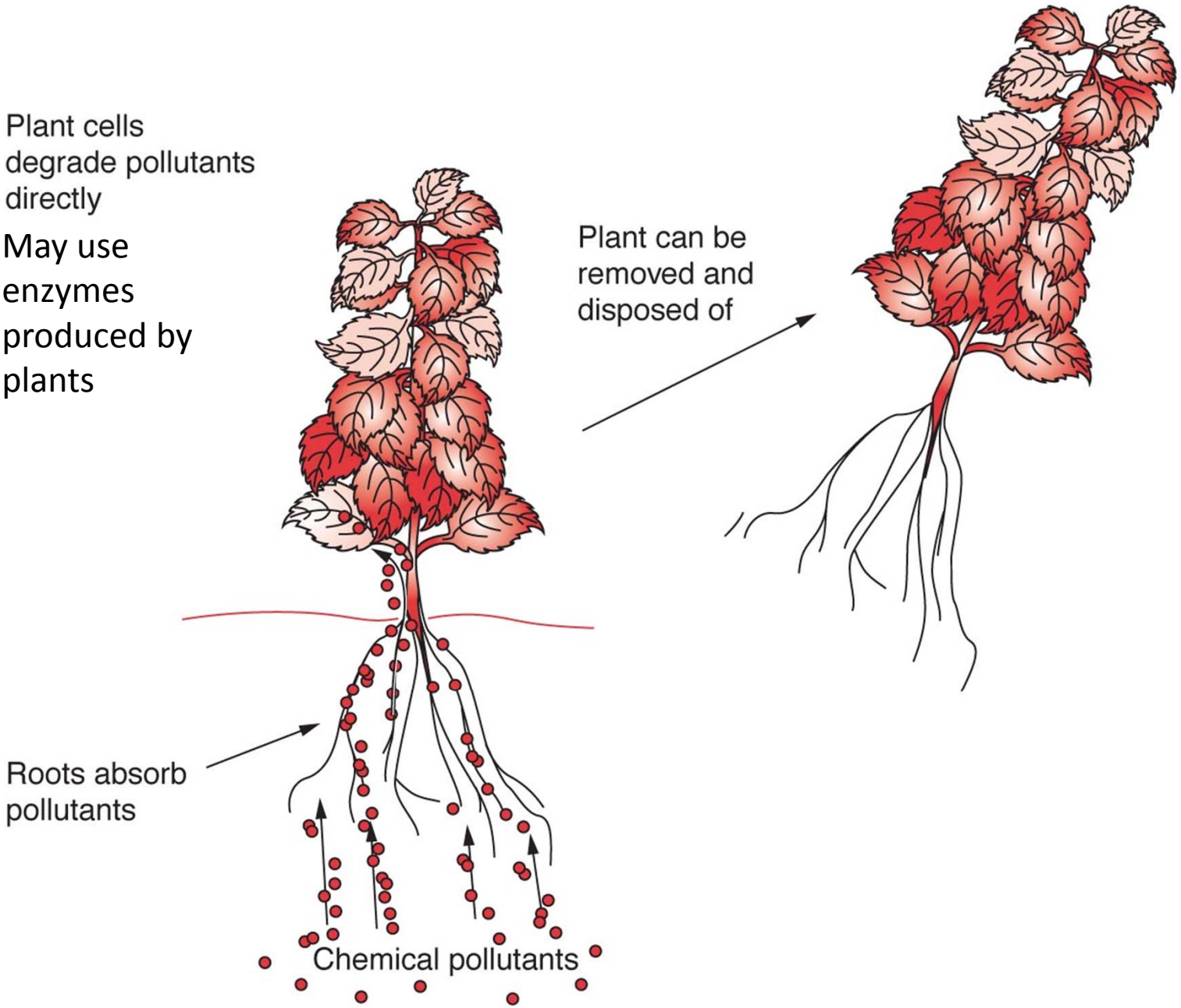
- *Nutrient enrichment* (fertilization) – **fertilizers** are added to a contaminated environment to stimulate the growth of indigenous microorganisms that can degrade pollutants
- *Bioaugmentation* (seeding) –**bacteria** are added to the contaminated environment to assist indigenous microbes with biodegradative processes

Phytoremediation

- Use of plants to remediate polluted soil, water, and air.
- ≈350 plant species naturally take up toxic materials
  - Poplar and juniper trees, certain grasses and alfalfa
  - Sunflowers used to remove radioactive cesium and strontium from Chrenobyl site
  - Water hyacinths used to remove arsenic from water supplies in Bangladesh, India

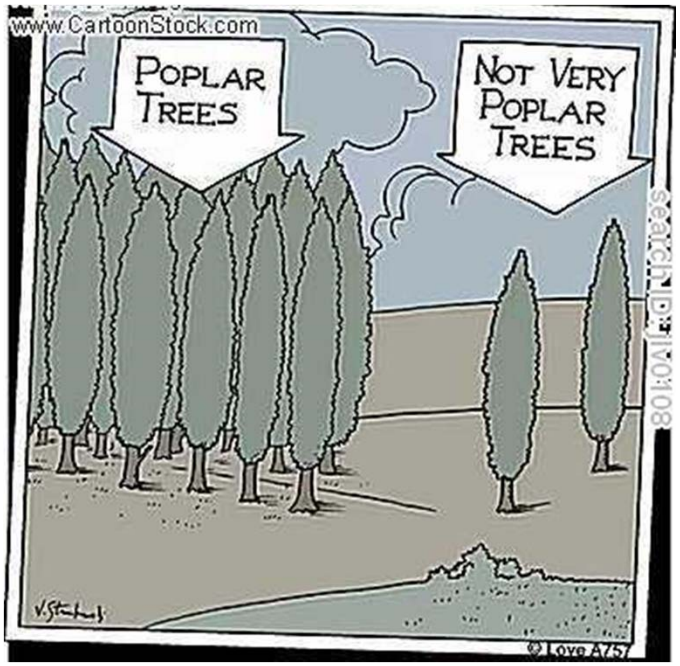
Plant cells degrade pollutants directly

May use enzymes produced by plants



Phytoremediation to clean up air

- Removal of access CO_2
- Genetically engineered poplar tree



Drawbacks

- Only surface soil (root zone) can be treated
- Cleanup takes several years