Applied Microbial Ecology

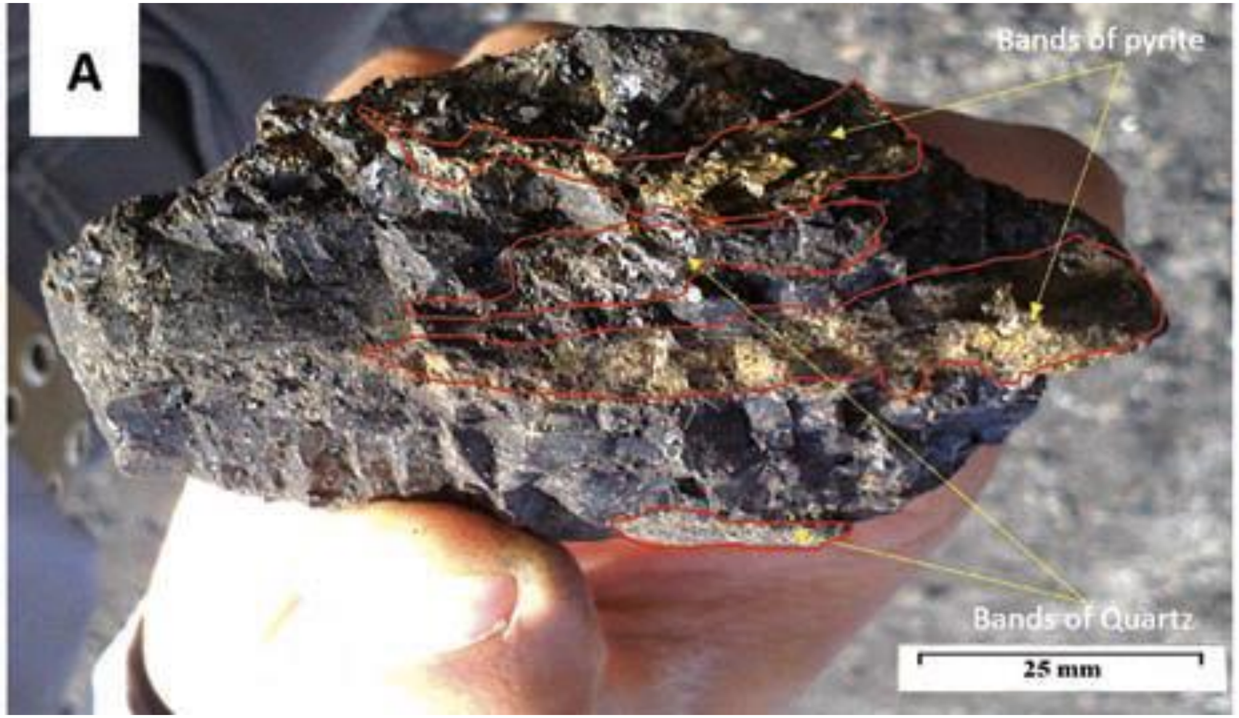
“Microorganisms are Earth’s greatest chemists”

The activities of these tiny biochemical factories have been exploited in many ways.

Mining with Microorganisms

- Pyrite (FeS_2)
  - one of the most common forms of iron in nature
  - found in coals and in metal ores

Pyrite and quartz bands of medium thickness in the coal.



Pyrite nodules and thin bands in the coal lump.

Mining with Microorganisms

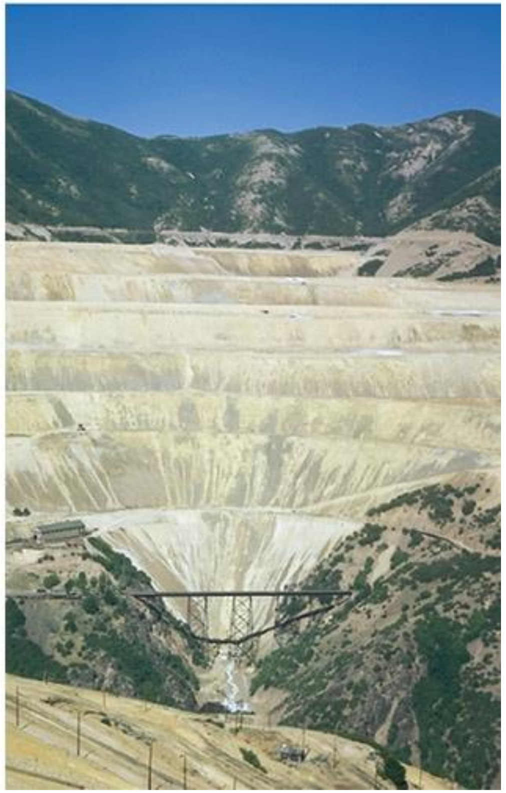
- Pyrite (FeS_2)
  - one of the most common forms of iron in nature
  - found in coals and in metal ores
- Sulfides (HS^-) also form insoluble minerals with metals
- Economically feasible to mine low-grade ores only if the metal can be concentrated

Mining with Microorganisms

- Microbial leaching
  - the removal of valuable metals, such as copper, from sulfide ores by microbial activities
  - particularly useful for copper ores
    - copper sulfate ($CuSO_4$), formed during the oxidation of copper sulfide ores, is very water-soluble
    - approximately a quarter of all copper mined worldwide is obtained by microbial leaching

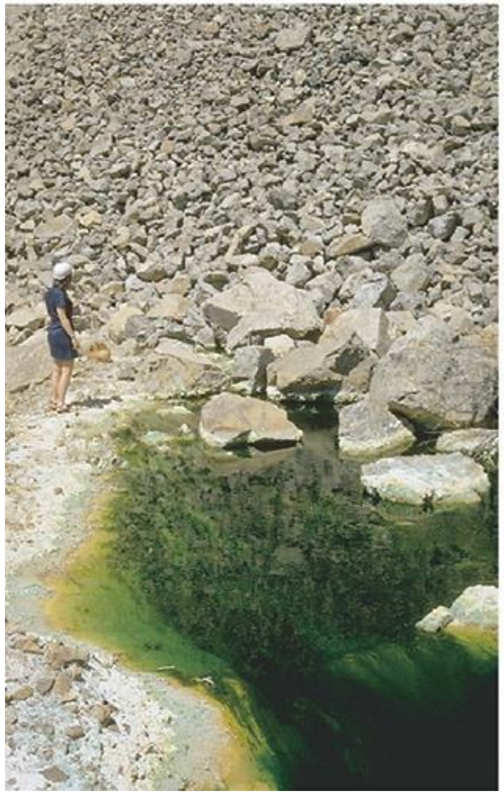
The Leaching of Low-Grade Copper Ores Using Iron-Oxidizing Bacteria

A typical leaching dump



- low-grade ore is crushed and dumped with high surface area exposed
- pipes distribute the acidic leach water over the surface of the pile
- acidic water slowly percolates through the pile and exits at the bottom

Effluent

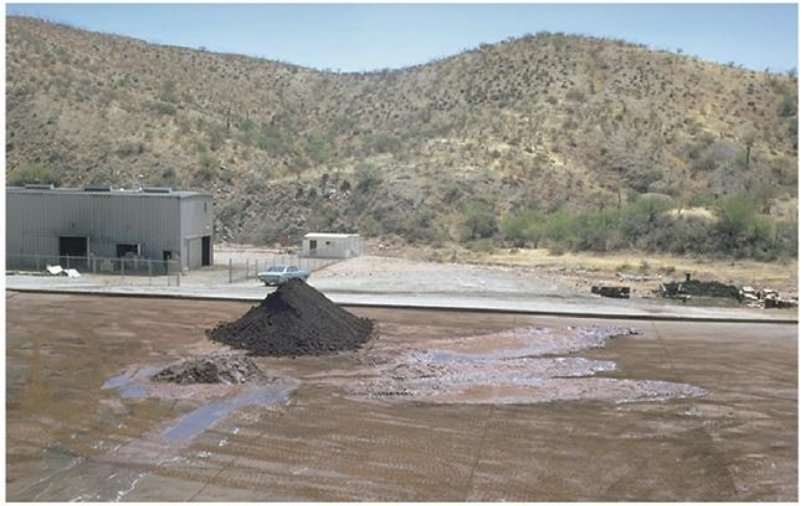


- acidic water is very rich in Cu^2

The Leaching of Low-Grade Copper Ores Using Iron-Oxidizing Bacteria


(c)

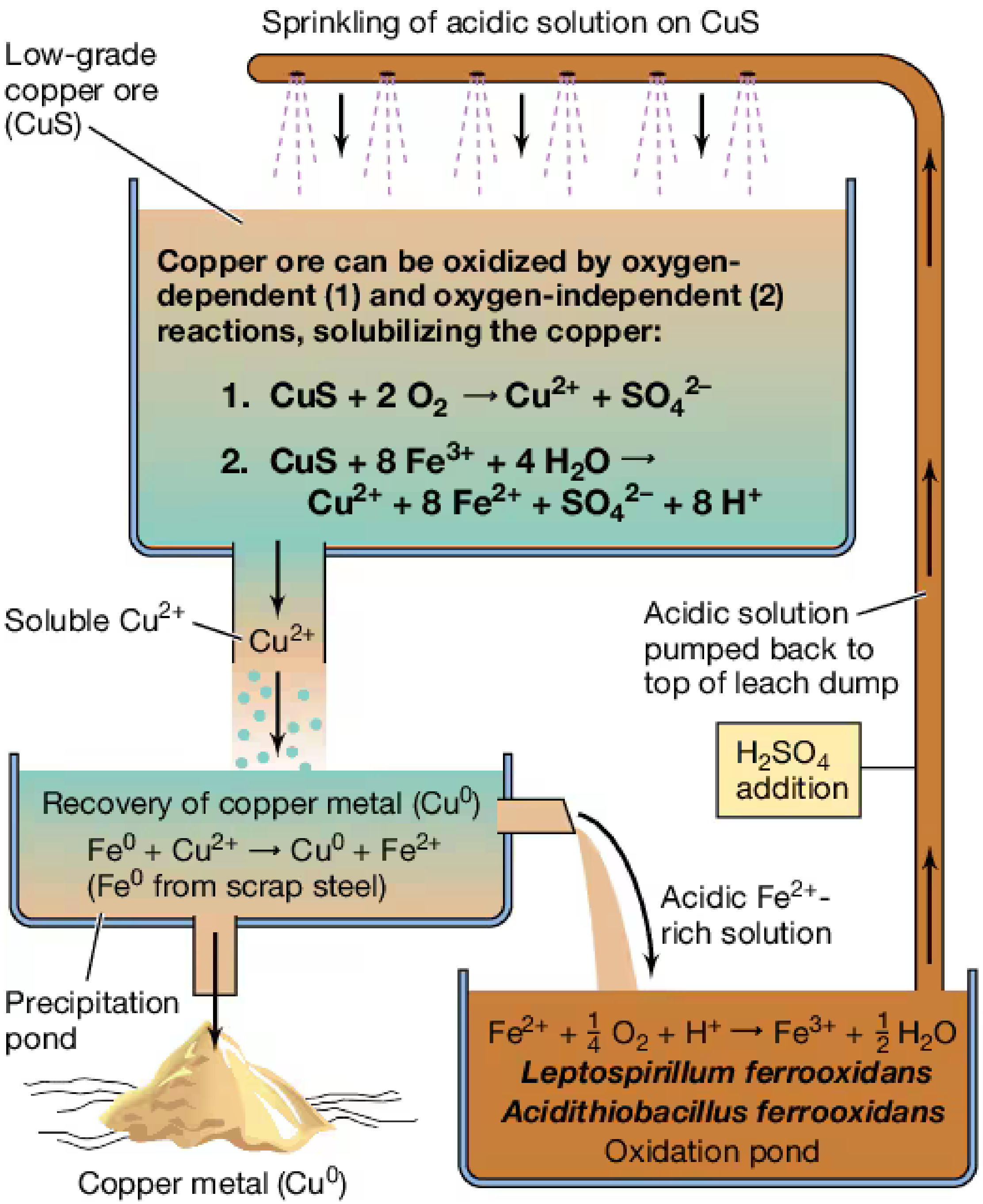
Recovery of copper as metallic copper (Cu^0) by passage of the Cu^{2+}-rich water over metallic iron (Fe0) in a long flume


(d)

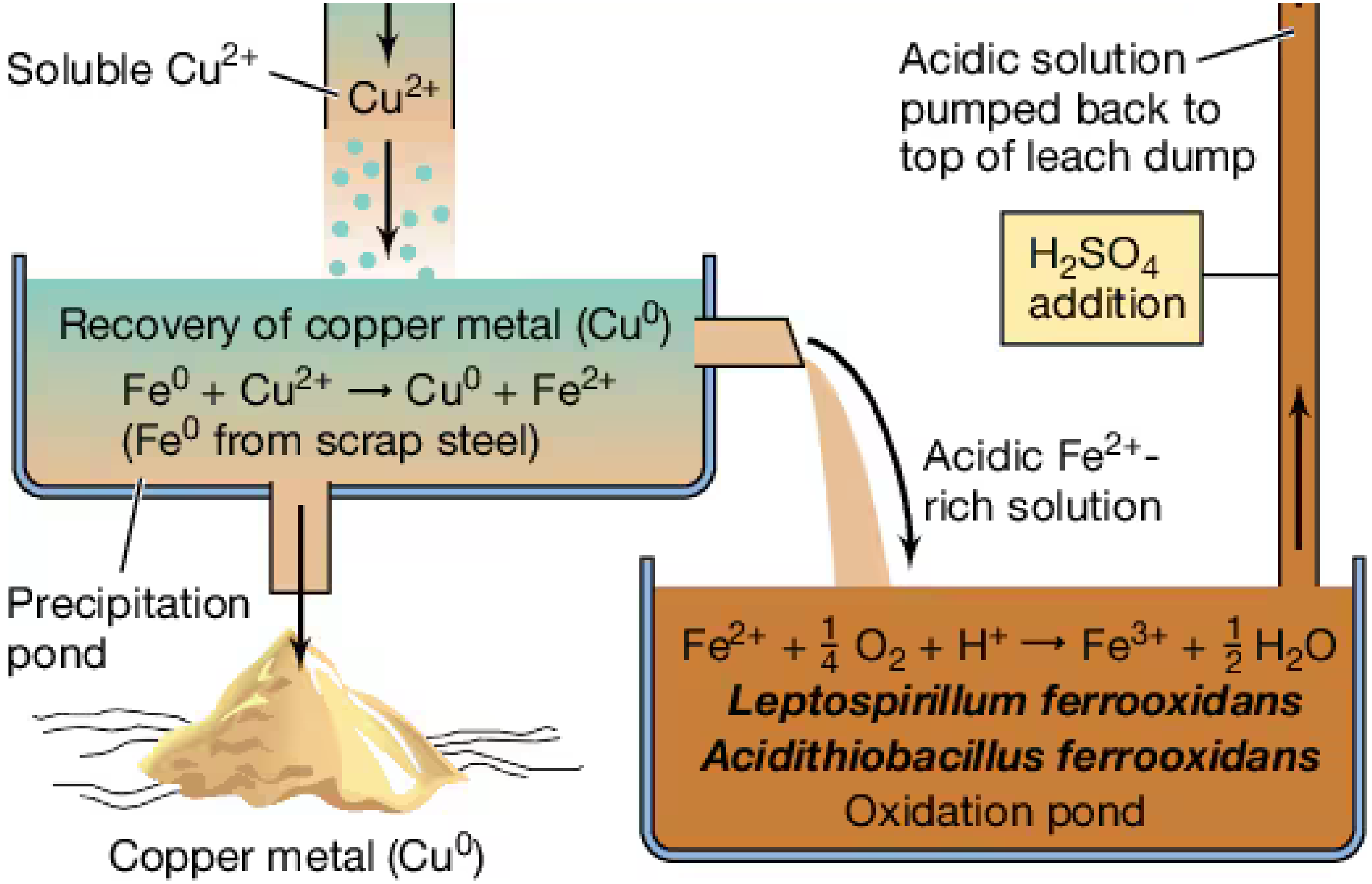
A small pile of metallic copper removed from the flume, ready for further purification

The Leaching Process

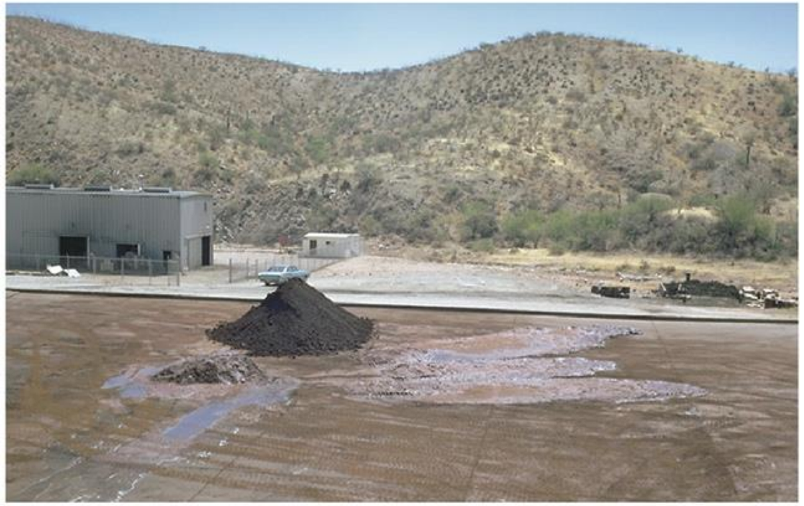
- In microbial leaching, low-grade ore is dumped in a large pile (the **leach dump**) and dilute sulfuric acid (**pH 2**) is added
- The liquid emerging from the bottom of the pile is enriched in dissolved metals and transported to a precipitation plant
- Bacterial oxidation of Fe^{2+} is critical in microbial leaching, as Fe^{3+} itself can oxidize metals in the ores



Metal Recovery



(c)



(d)

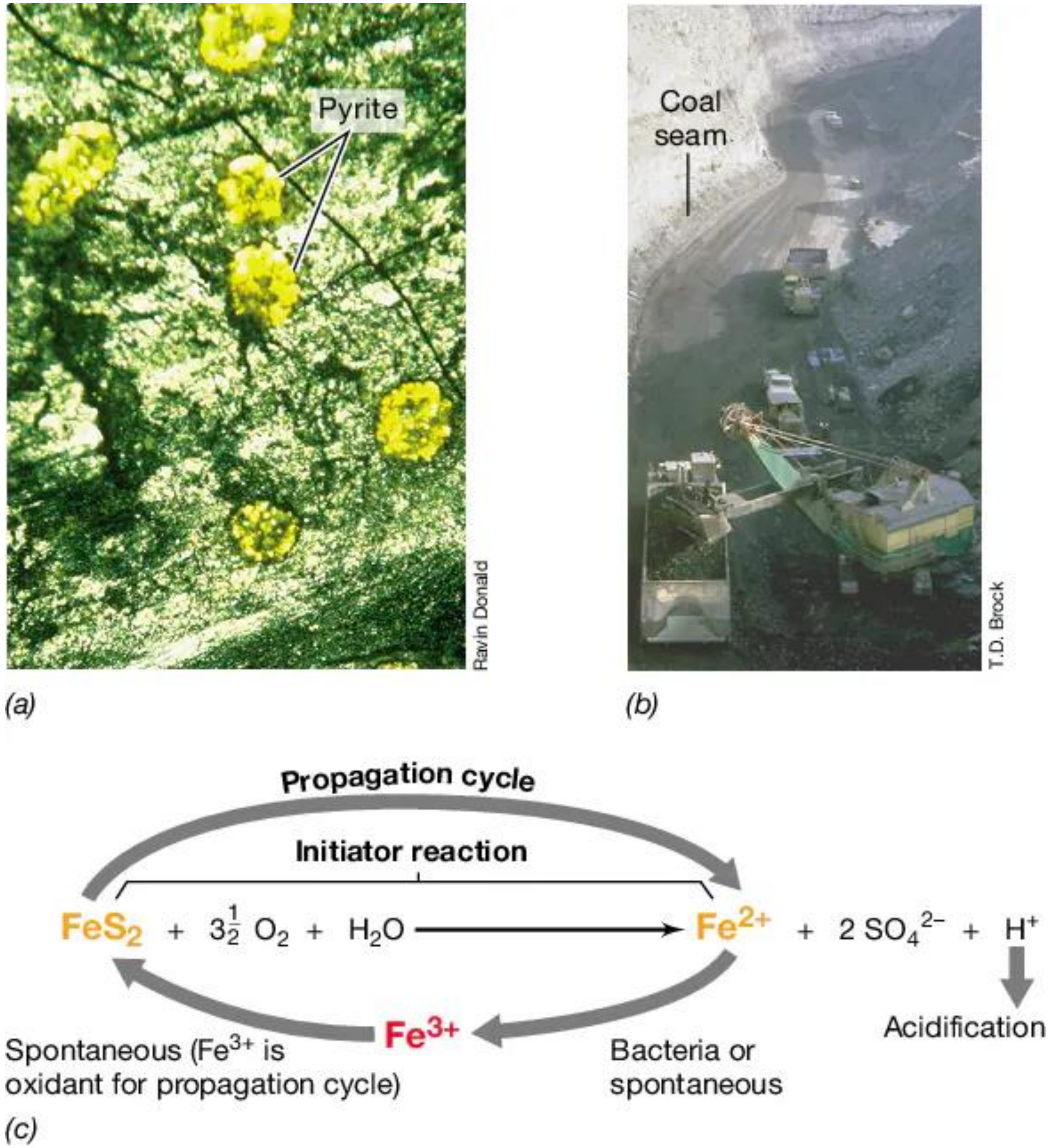
The entire CuS leaching operation is driven by the oxidation of Fe^{+2} to Fe^{+3} by iron-oxidizing chemotrophic bacteria.

Leaching Dump Microbiome

- Temperatures rise in a leaching dump
- Shifts in the iron-oxidizing microbial community
  - *A. ferrooxidans*is a mesophile
  - Heat generated by microbial activities raises temperatures
  - *A. ferrooxidans*is is outcompeted by mildly thermophilic, iron-oxidizing chemolithotrophic *Bacteria*
    - *Leptospirillum ferrooxidans* and *Sulfobacillus*.

Acid Mine Drainage

- Microbial leaching is also responsible for environmental damage
- Improperly handling or disposal of pyrite-containing coal and mineral deposits
    - Rich in sulfides
    - Oxidation of metal sulfides by bacteria can result in acidic conditions



Acid Mine Drainage


T.D. Brock

The yellowish-red colour is due to the precipitated iron oxides in the drainage.

Bioremediation

- Bioremediation is the microbial cleanup of oil, toxic chemicals, or other environmental pollutants by microbes.
- Stimulating the degradative activities of indigenous microbes.
- Addition of microbes having the needed degradative capacity.
- Pollutants can include both natural materials, such as petroleum products, and synthetic chemicals new to nature.

Bioremediation of Uranium-Contaminated Environments

- Uranium contamination of groundwater has occurred where uranium has been processed or stored improperly

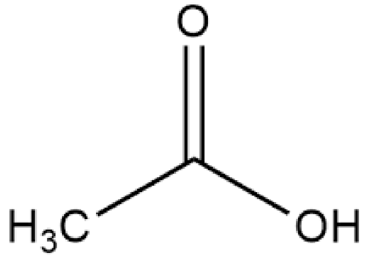
- Because the contamination is often widespread, making mechanical methods of recovery very expensive, microbiologists have joined forces with engineers to develop biological treatments.

Bioremediation of Uranium-Contaminated Environments

- Groundwater can become contaminated with uranium U^{6+} as a consequence of nuclear energy and weapons production

- Biological treatments exploit the ability of some bacteria to reduce U^{6+} to U^{4+}

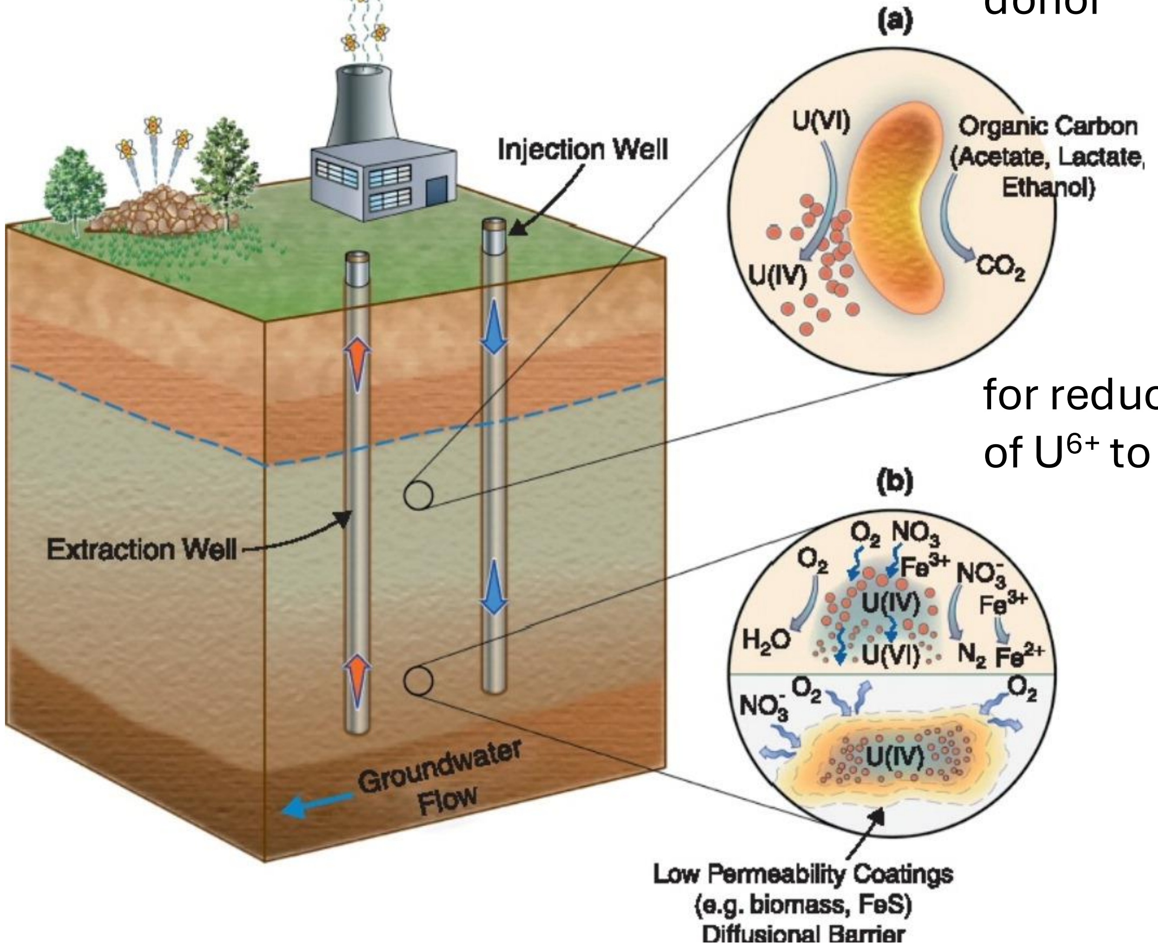
  - U^{6+} is water soluble
  - U^{4+} is NOT water soluble
    - forms an immobile uranium mineral called uraninite



Acetate

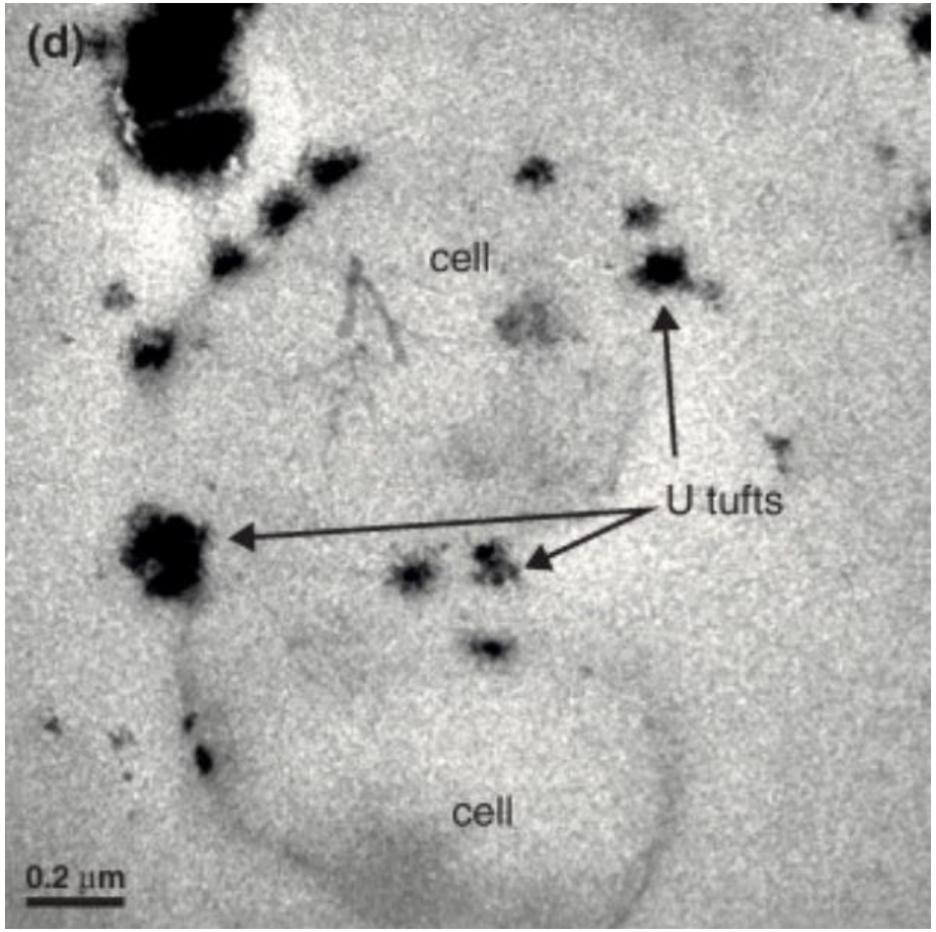
An experimental plot at a uranium-contaminated site

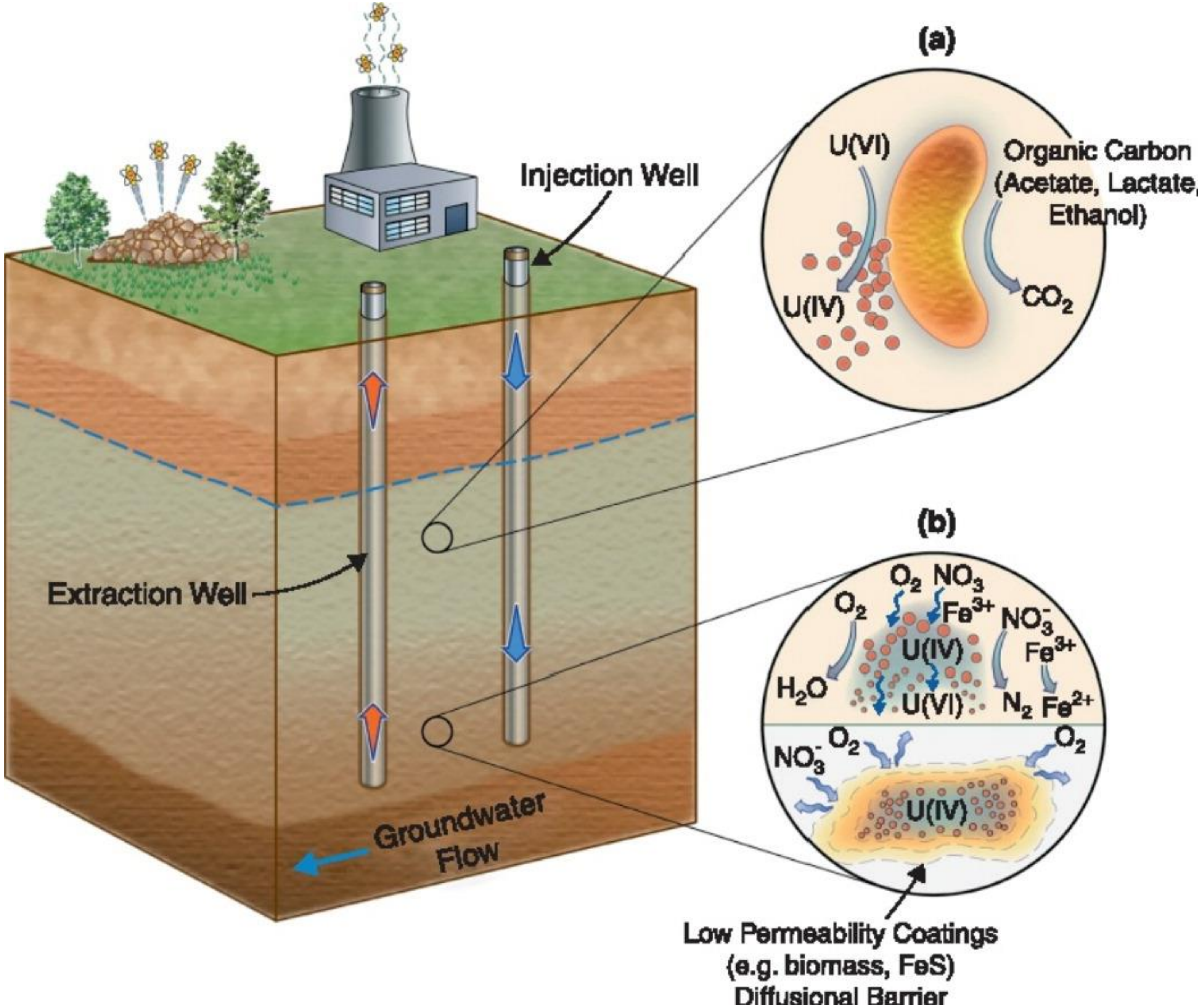
Electron donor



for reduction of U^{6+} to U^{4+}

- Uranium is contained, not removed
  - limiting movement of U into groundwater
  - Reducing contact with humans and other animals



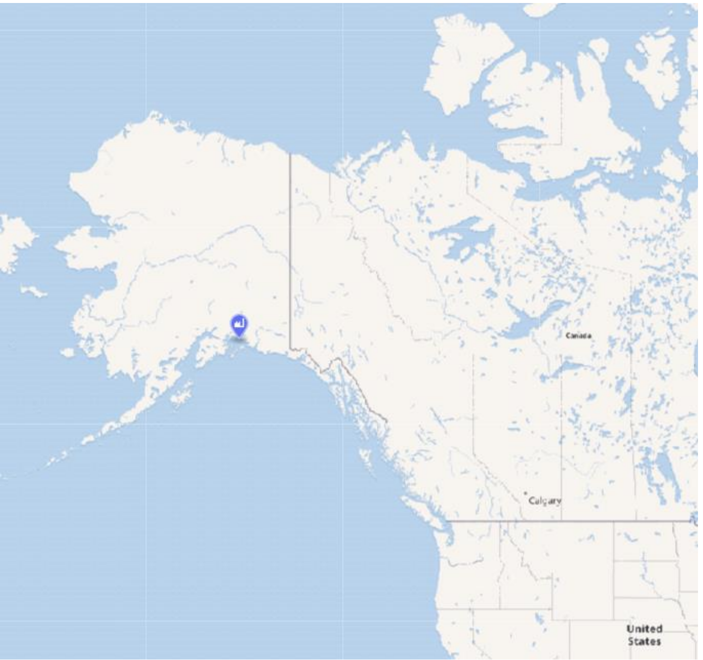


(a)
U(VI)
U(IV)
Organic Carbon
(Acetate, Lactate,
Ethanol)
CO_2
Injection Well
Extraction Well
Groundwater
Flow
(b)
O_2 NO_3
O_2
Fe^{3+}
NO_3^-
Fe^{3+}
U(IV)
H_2O
U(VI)
N_2 Fe^{2+}
NO_3^- O_2
O_2
U(IV)
Low Permeability Coatings
(e.g. biomass, FeS)
Diffusional Barrier

Bioremediation of Organic Pollutants: Hydrocarbons

- Organic pollutants can eventually be completely degraded to CO_2 by microbes
- Prokaryotes have been used in bioremediation of several major crude oil spills

Exxon Valdez Oil Spill



Environmental Consequences of Large Oil Spills and the Effect of Bioremediation

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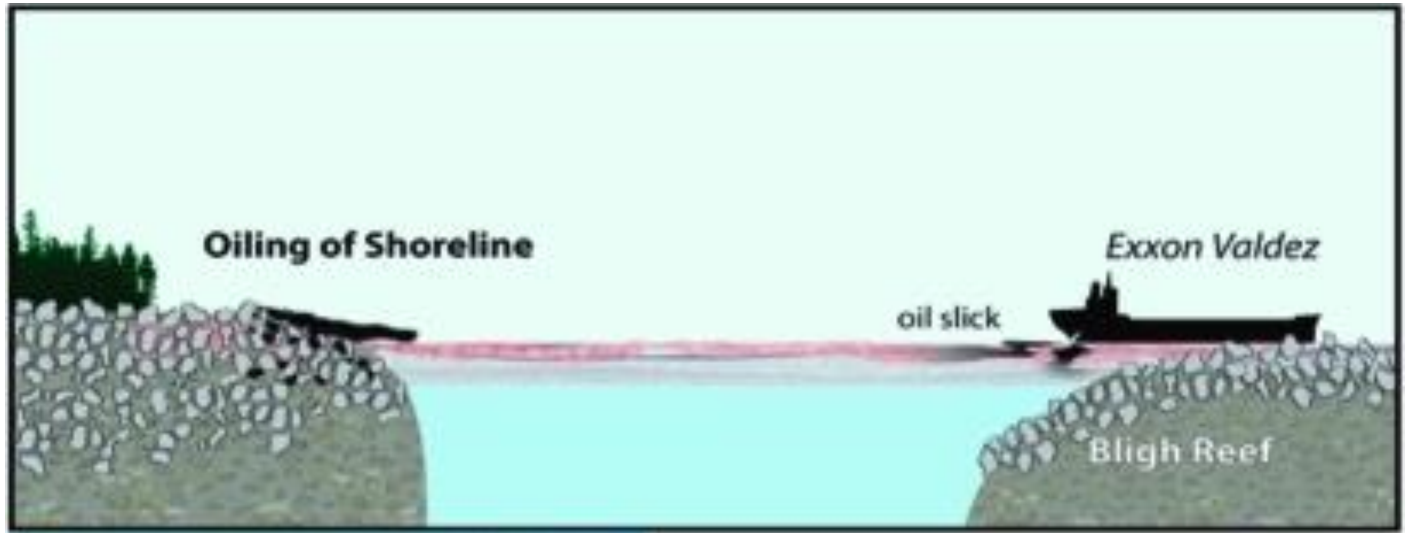


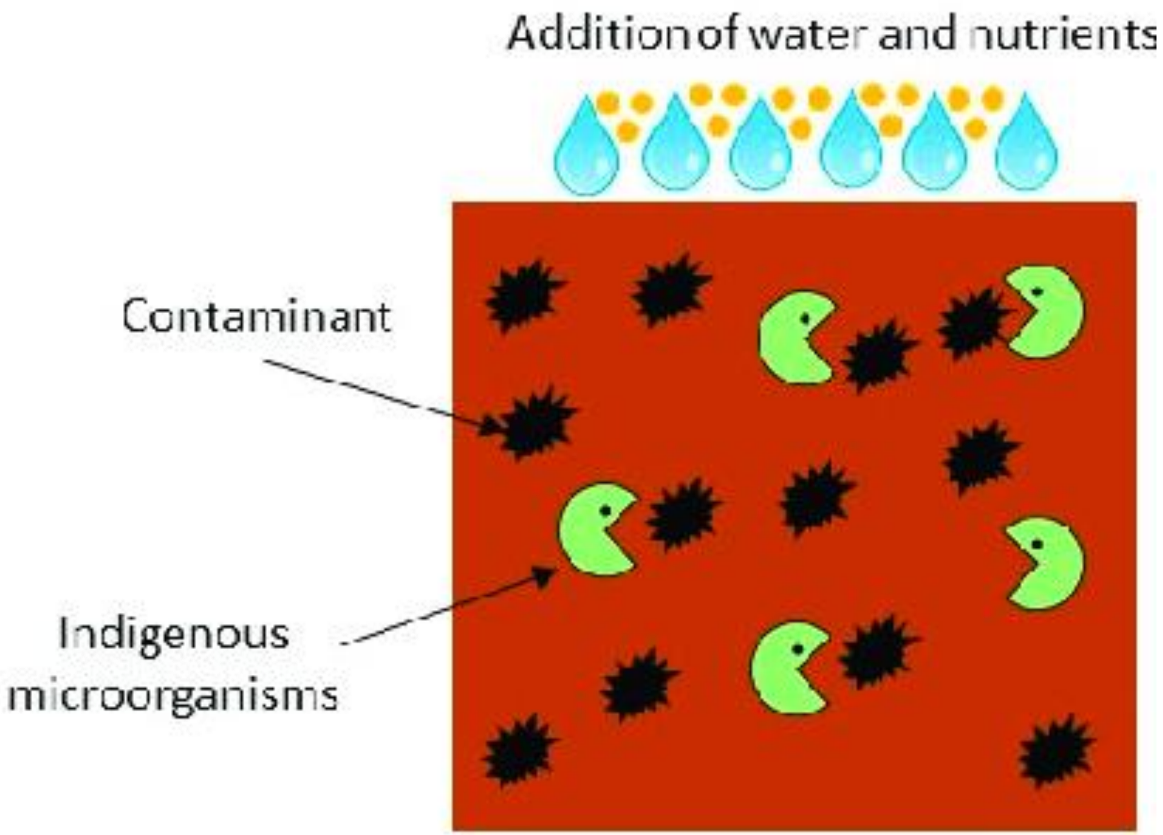
Physical washing of shorelines with high pressure water

Application of fertilizer for bioremediation

Biostimulation

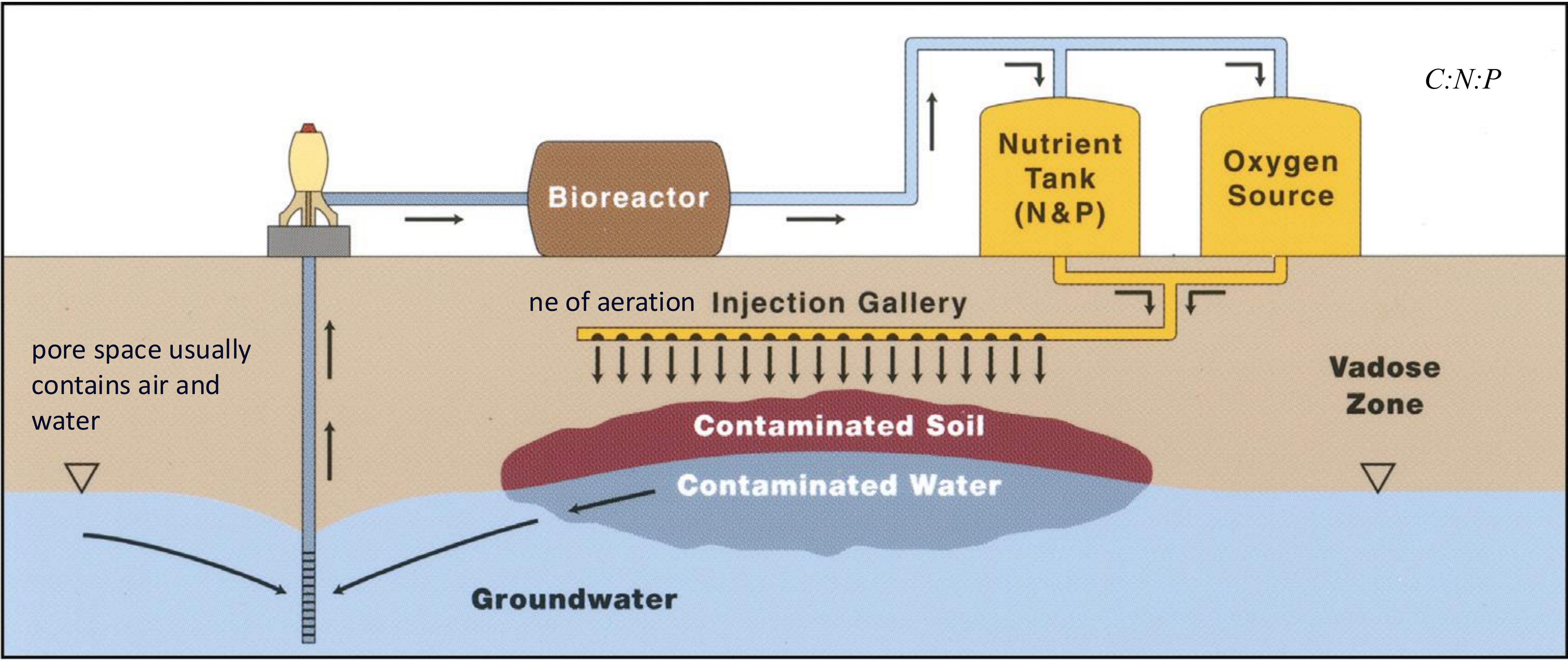
- The modification of environmental conditions to enhance the biodegradation activity of indigenous microorganisms.
  - e.g., addition of oxygen, N, P

- Used to increase the speed and effectiveness of bioremediation



Biostimulation

In-situ and *ex-situ* bioremediation and biostimulation

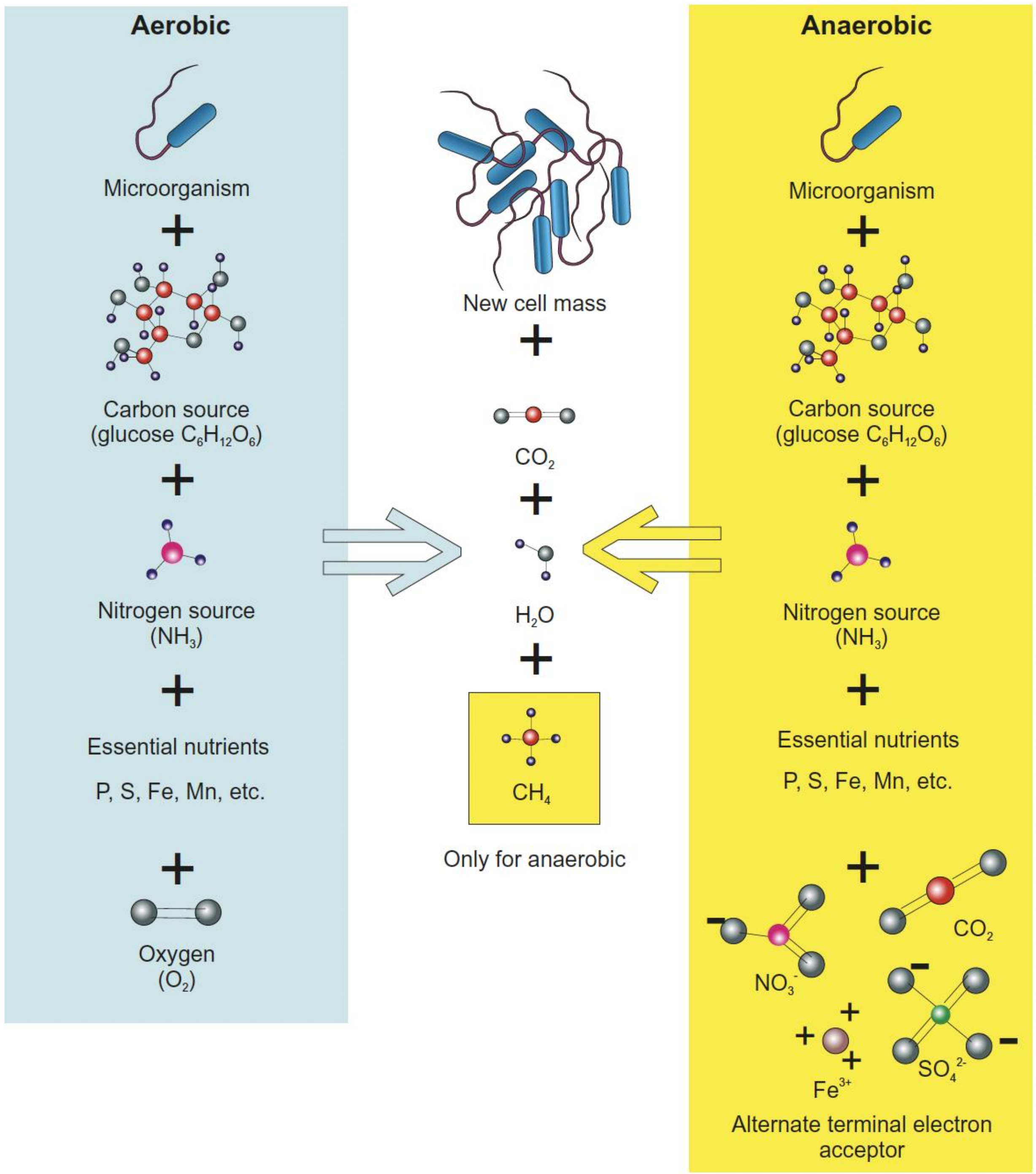


C:N:P

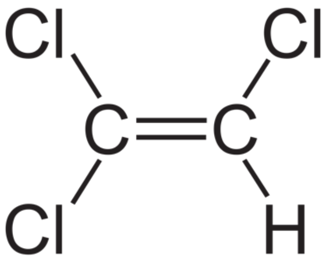
ne of aeration

pore space usually contains air and water

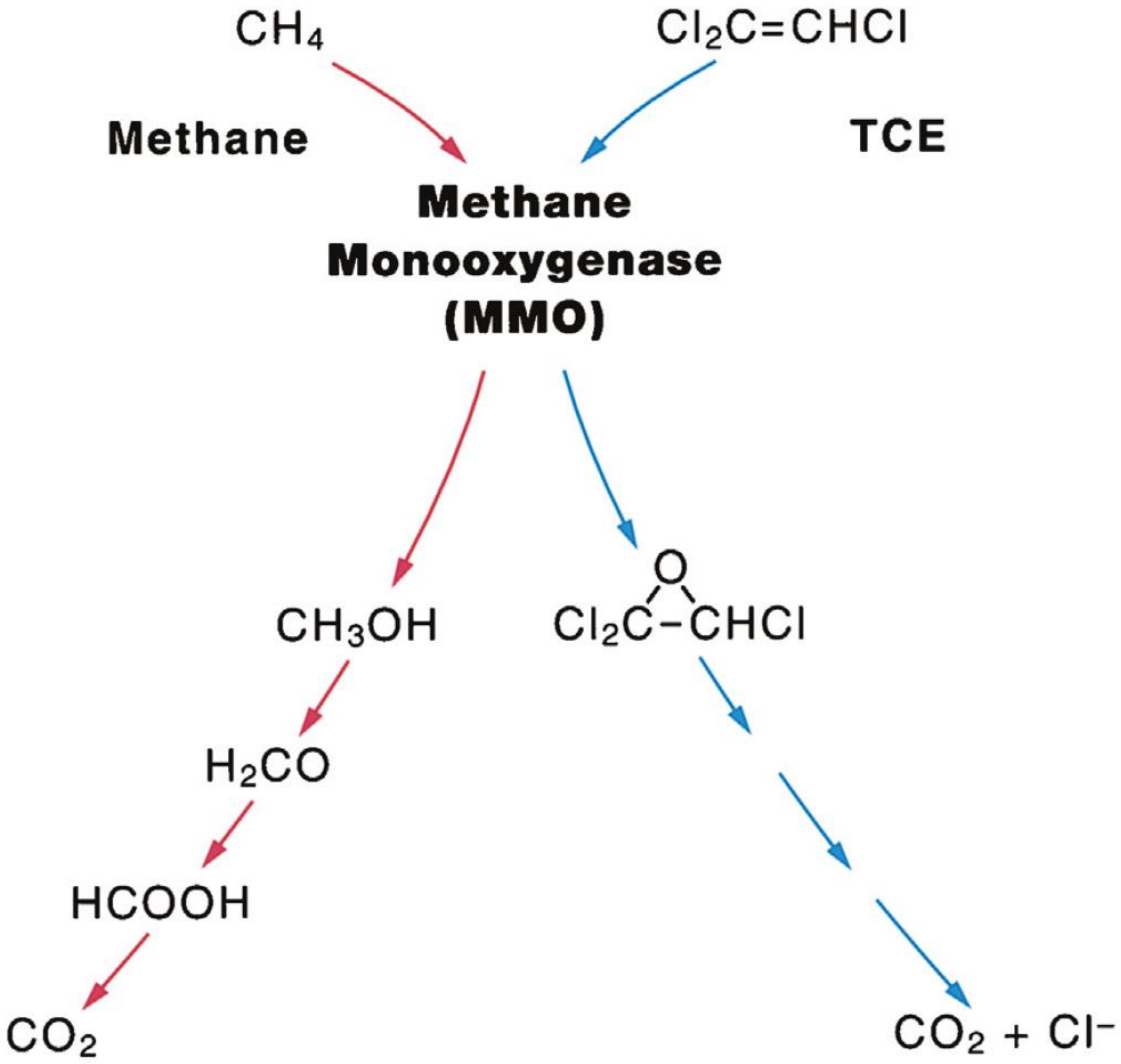
aerobic biodegradation



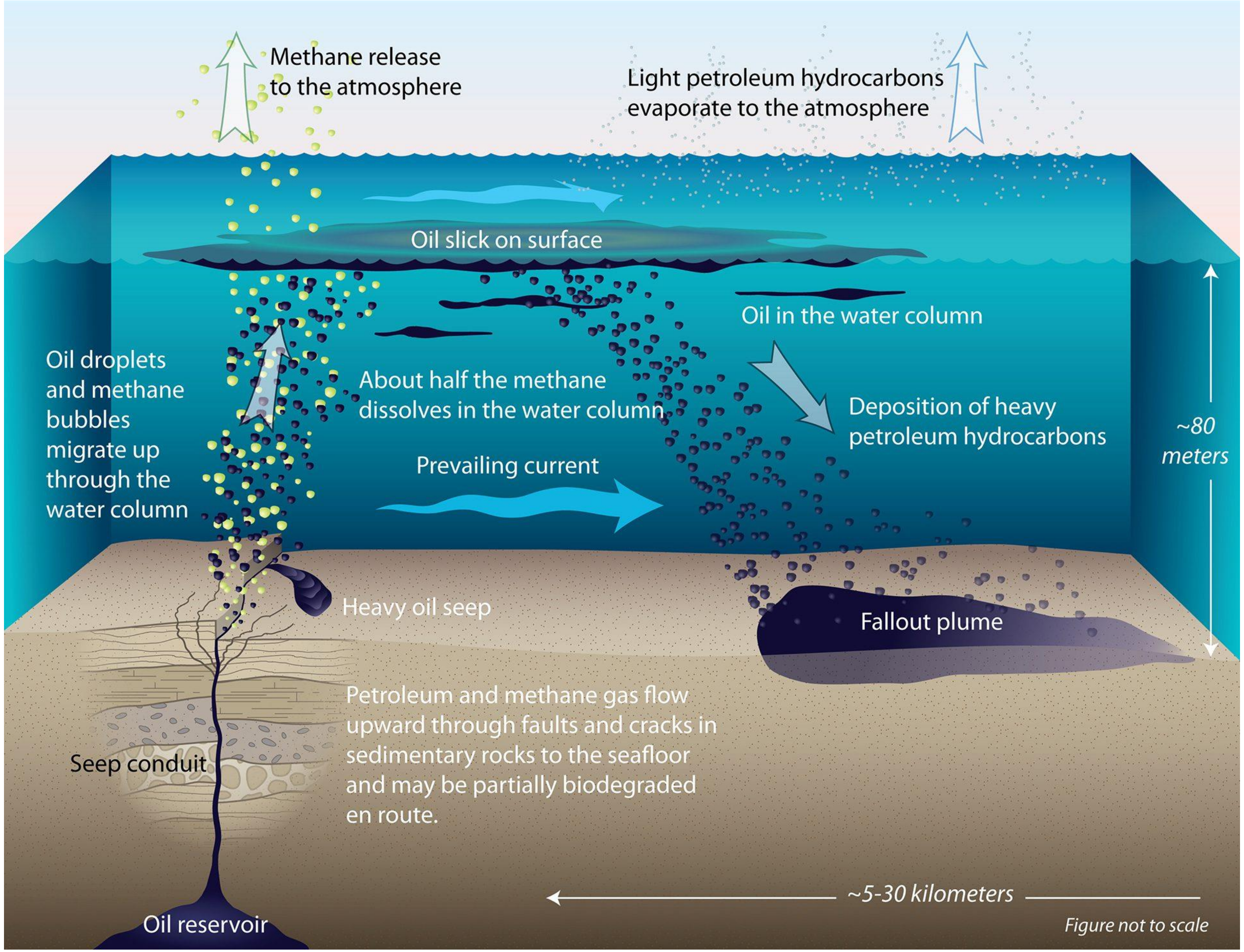
mineralization of an organic compound

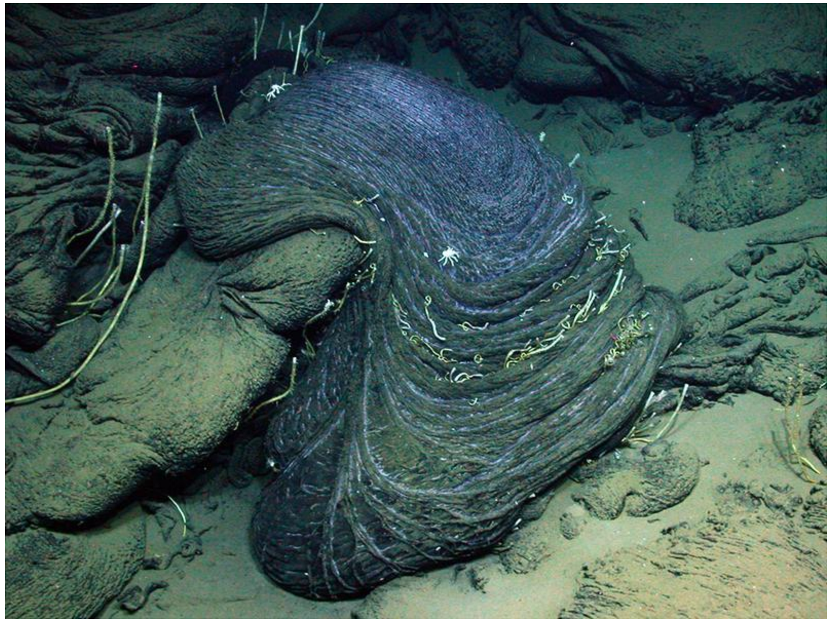


TCE: trichloroethylene



Natural Oil Seeps





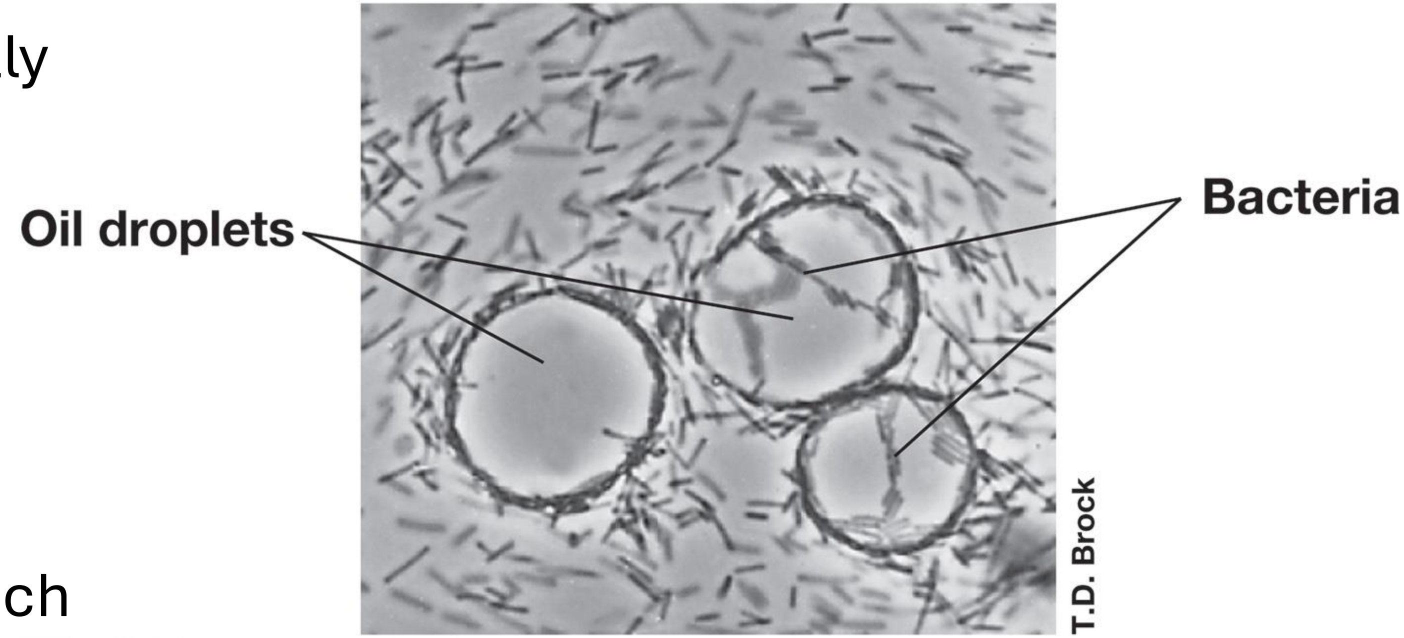
- petroleum hydrocarbons occur naturally in all marine environments
- occur in clusters around the world
- oil flows slowly up through networks of cracks

Bioremediation of Organic Pollutants: Hydrocarbons

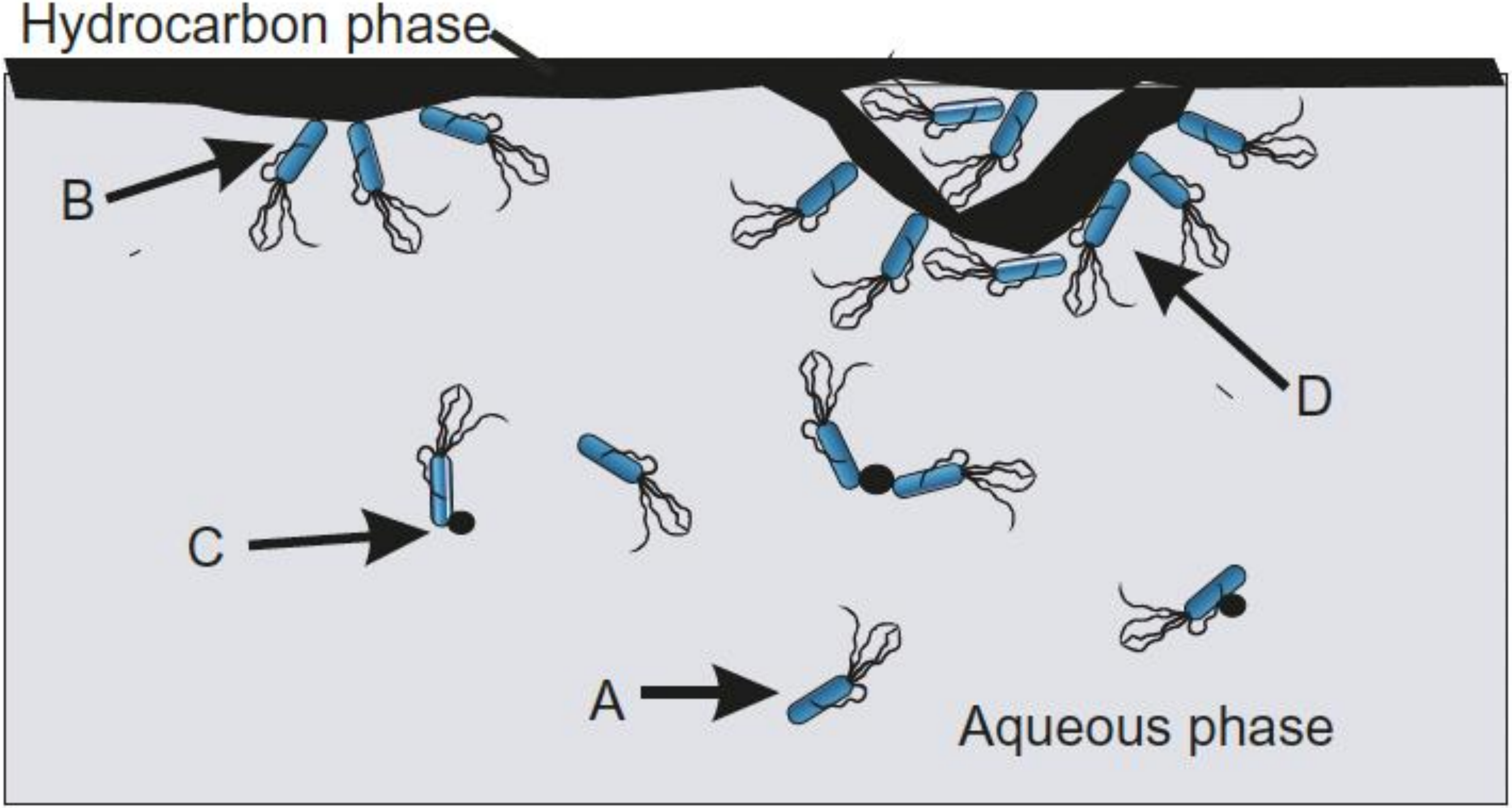
- Diverse bacteria, fungi, and some cyanobacteria and green algae can oxidize petroleum products aerobically

- Oil-oxidizing activity is best if temperature and inorganic nutrient concentrations are optimal, so these nutrients are often added

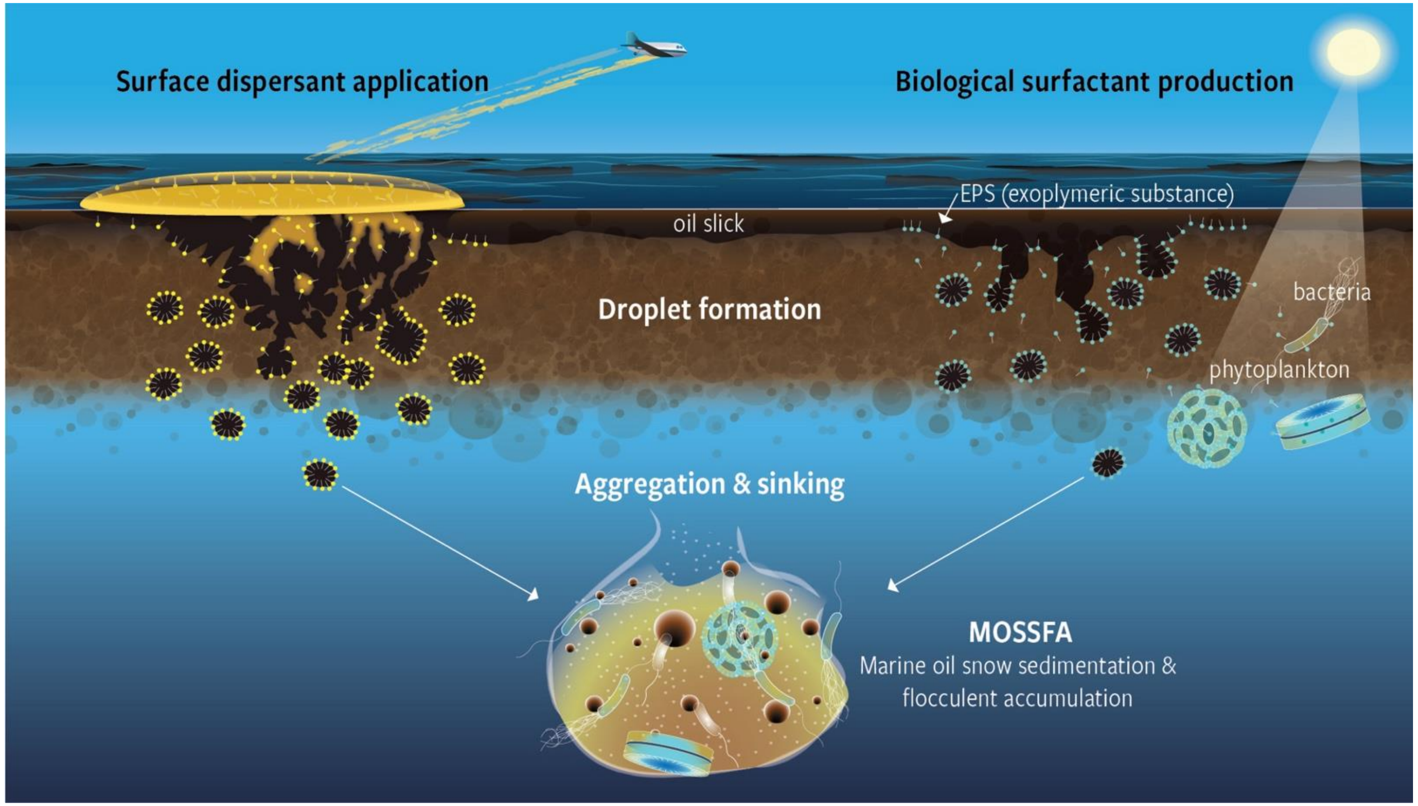
- Hydrocarbon-degrading bacteria attach to oil droplets, decompose the oil, and disperse the slick

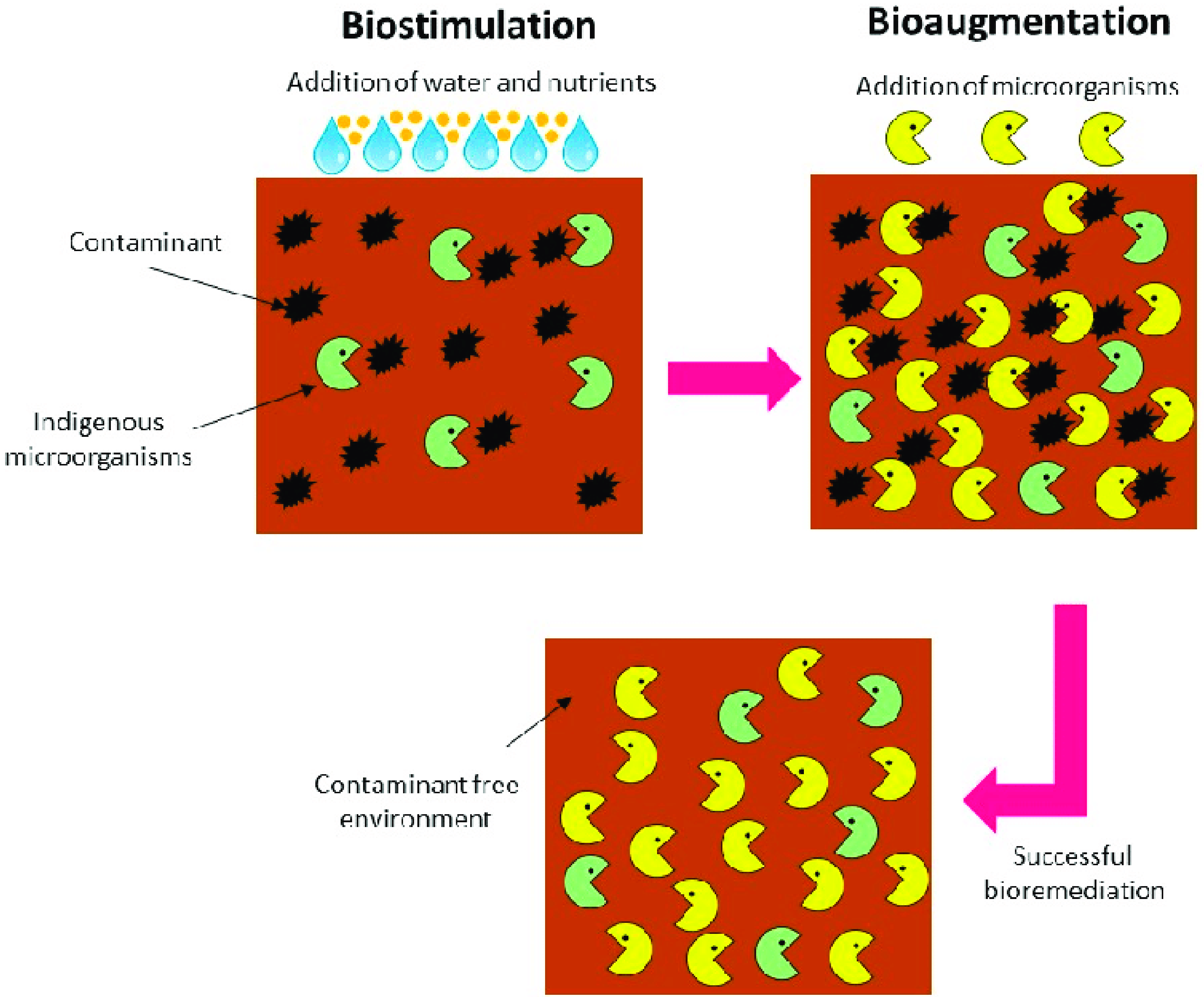


water environment with a petroleum oil phase floating on the surface



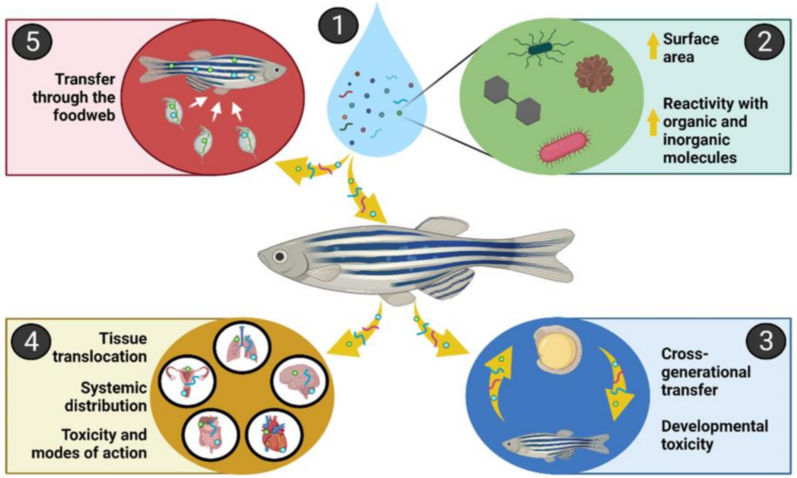
Dispersants




Biostimulation
Addition of water and nutrients
Bioaugmentation
Addition of microorganisms
Contaminant
Indigenous microorganisms
Contaminant free environment
Successful bioremediation

Bioplastics

- Plastics industry worldwide produces over 300 million tons of plastic per year
- Most plastics are produced from fossil-fuels derived from petroleum or natural gas
  - Non-renewable fossilized biomass
  - Low biodegradation ability
  - Production of nanoplastics



Bioplastics

- Production of bacterial plastics
  - polyhydroxyalkanoates (PHA)
  - polylactic acid (PLA)
  - poly(butylene succinate) (PBS)

- monomers synthesized via bacterial transformation

- well known for their biodegradability

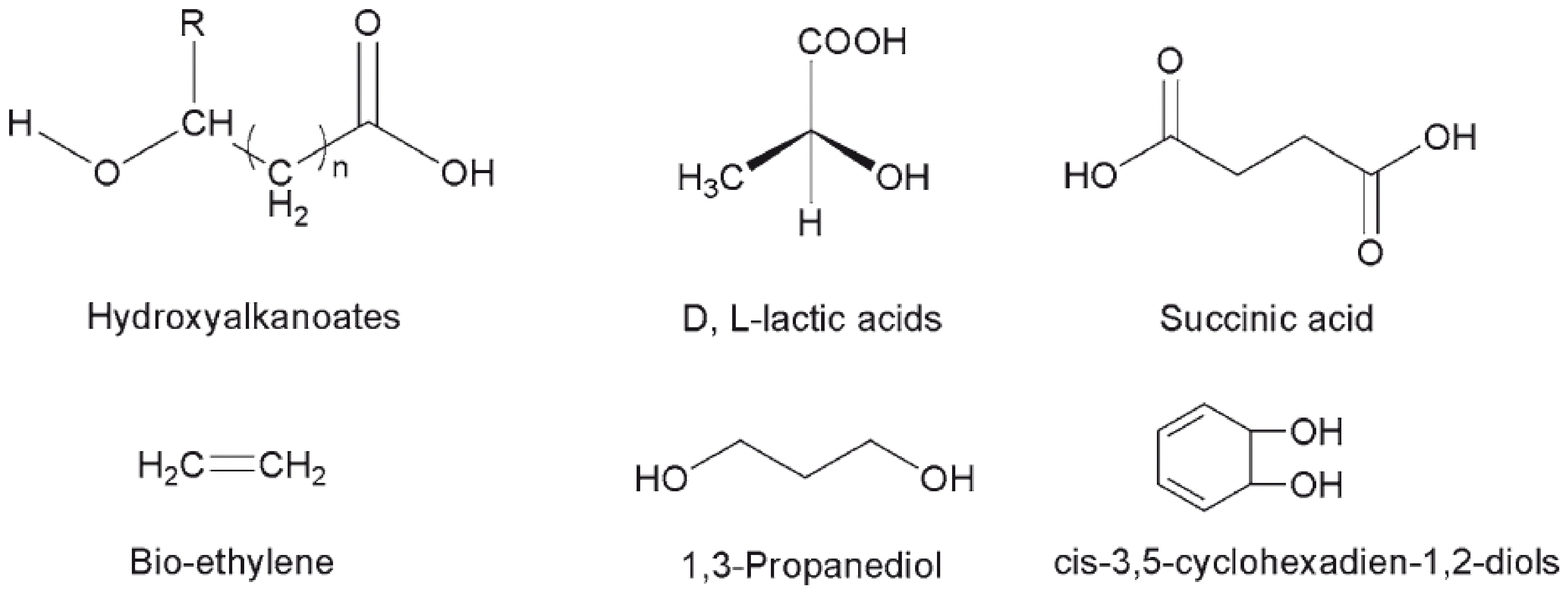


Fig. 1 Most common bio-based polymer building blocks for bacterial plastics

PHA is the only bioplastic completely synthesized by biological means.

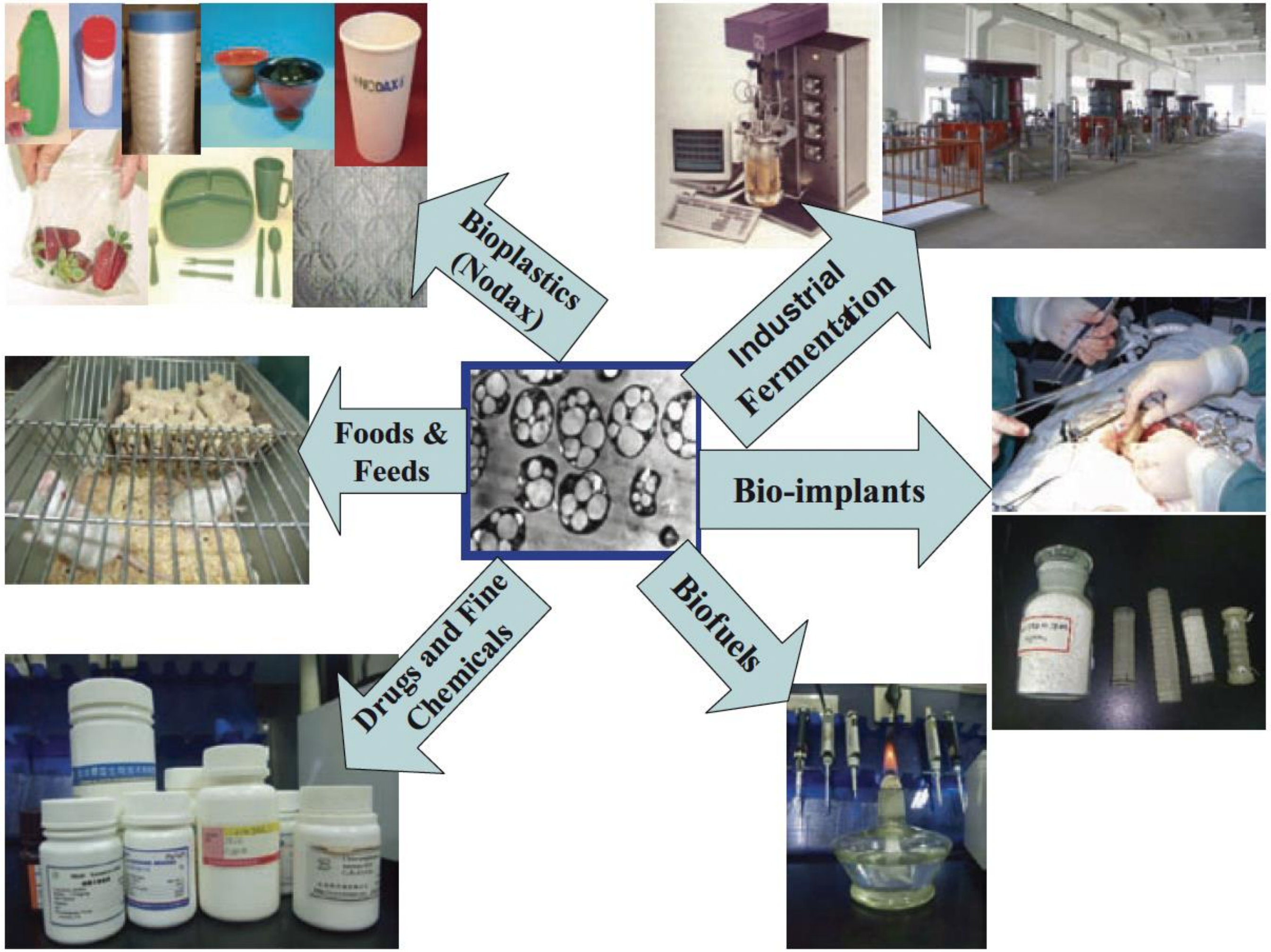
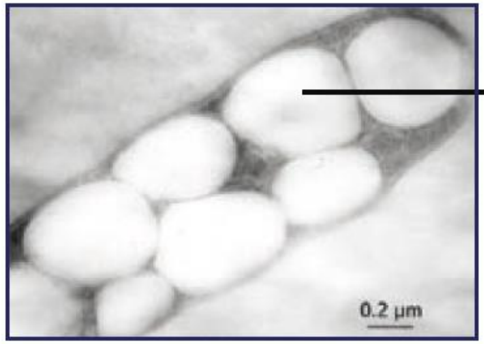


Fig. 1 Applications of polyhydroxyalkanoates (PHA) in various fields (Chen 2009a)

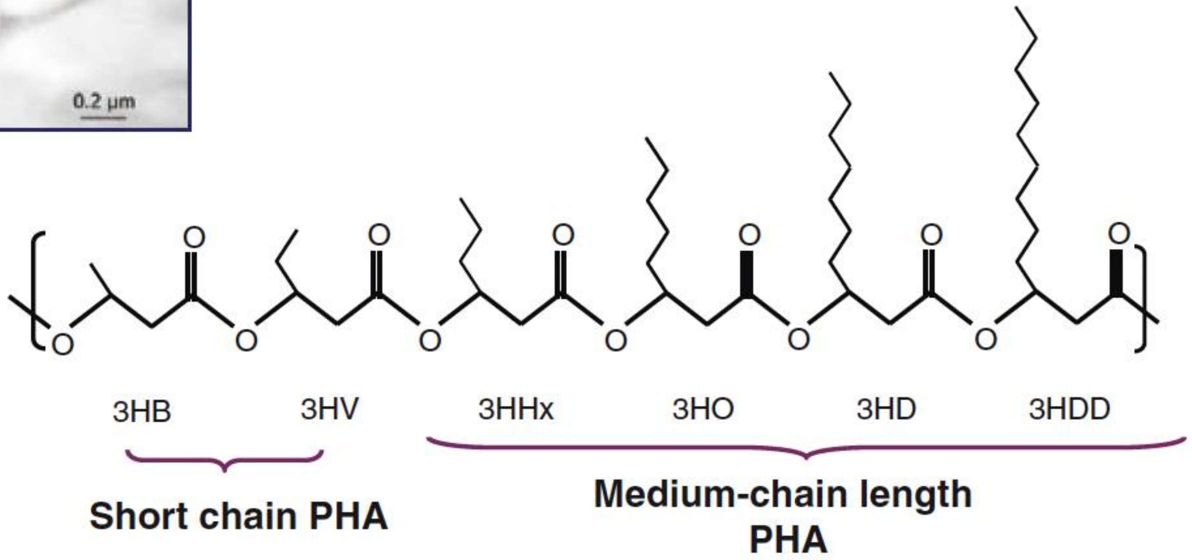
PHA is the only bioplastic completely synthesized by biological means.

- Synthesized by soil-inhabiting bacteria
- Plastic properties can be controlled by growth conditions



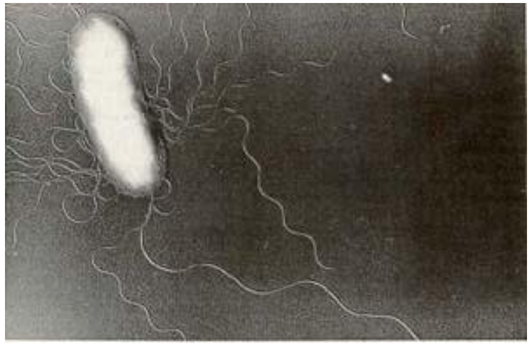
PHA Granules

PHA has 150 monomers reported

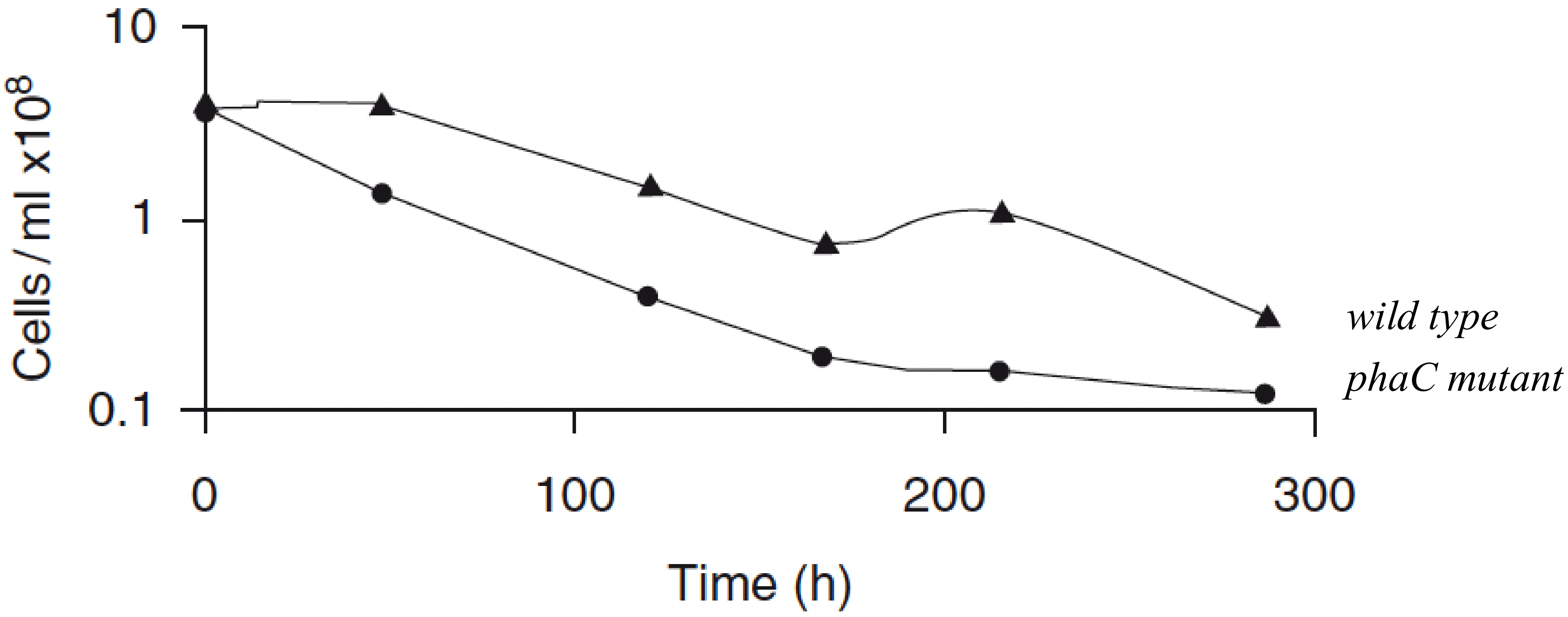


Why microorganism produce PAHs

- Intracellular carbon storage compounds
  - during carbon limitation

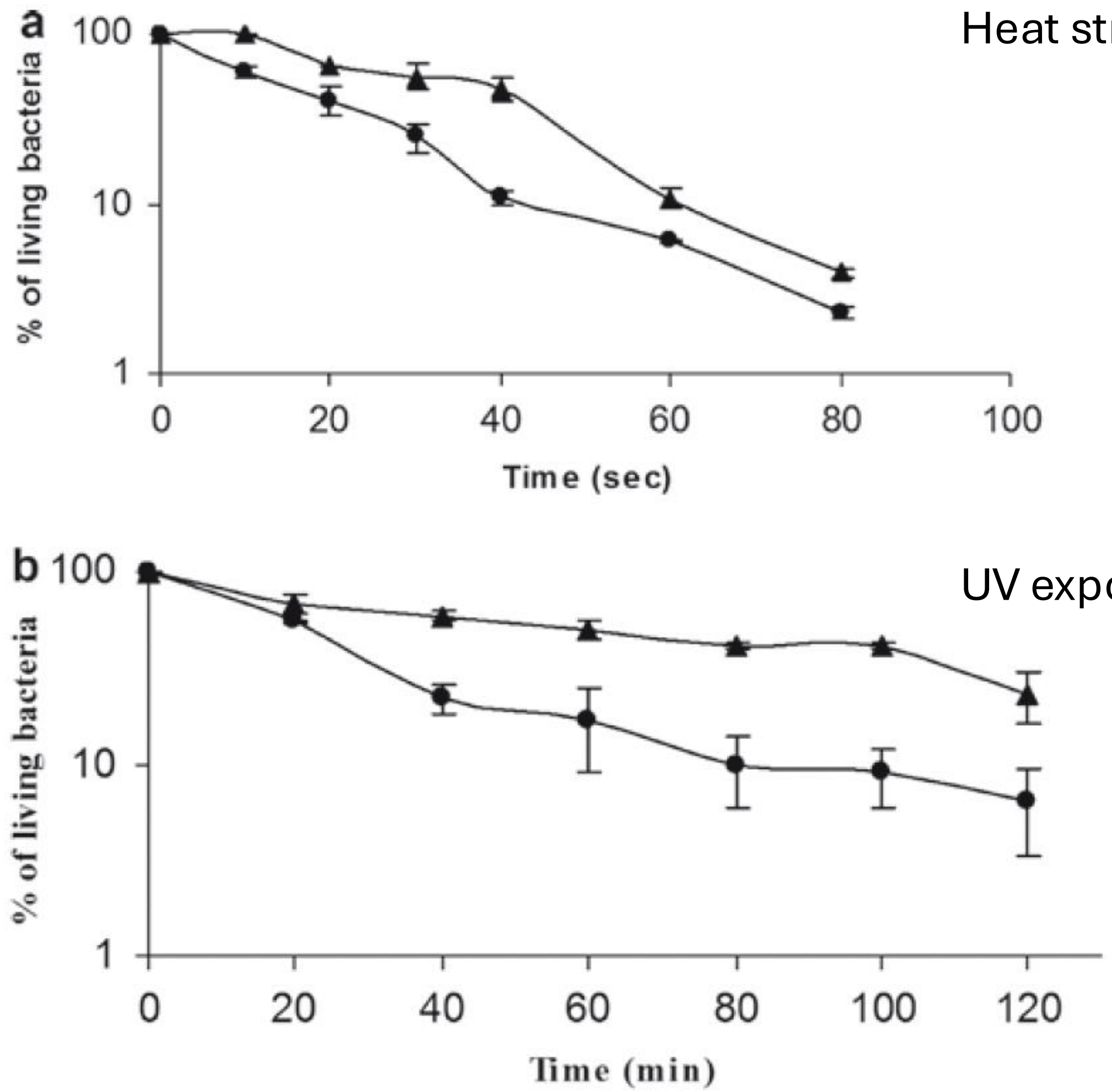


Azospirillum brasilense



Why microorganism produce PAHs

- Enhances the survival of several bacterial species under environmental stress conditions imposed in water and soil,
  - such as UV-irradiation
  - salinity
  - thermal and oxidative stress
  - desiccation



Heat stress

UV exposure

Extra

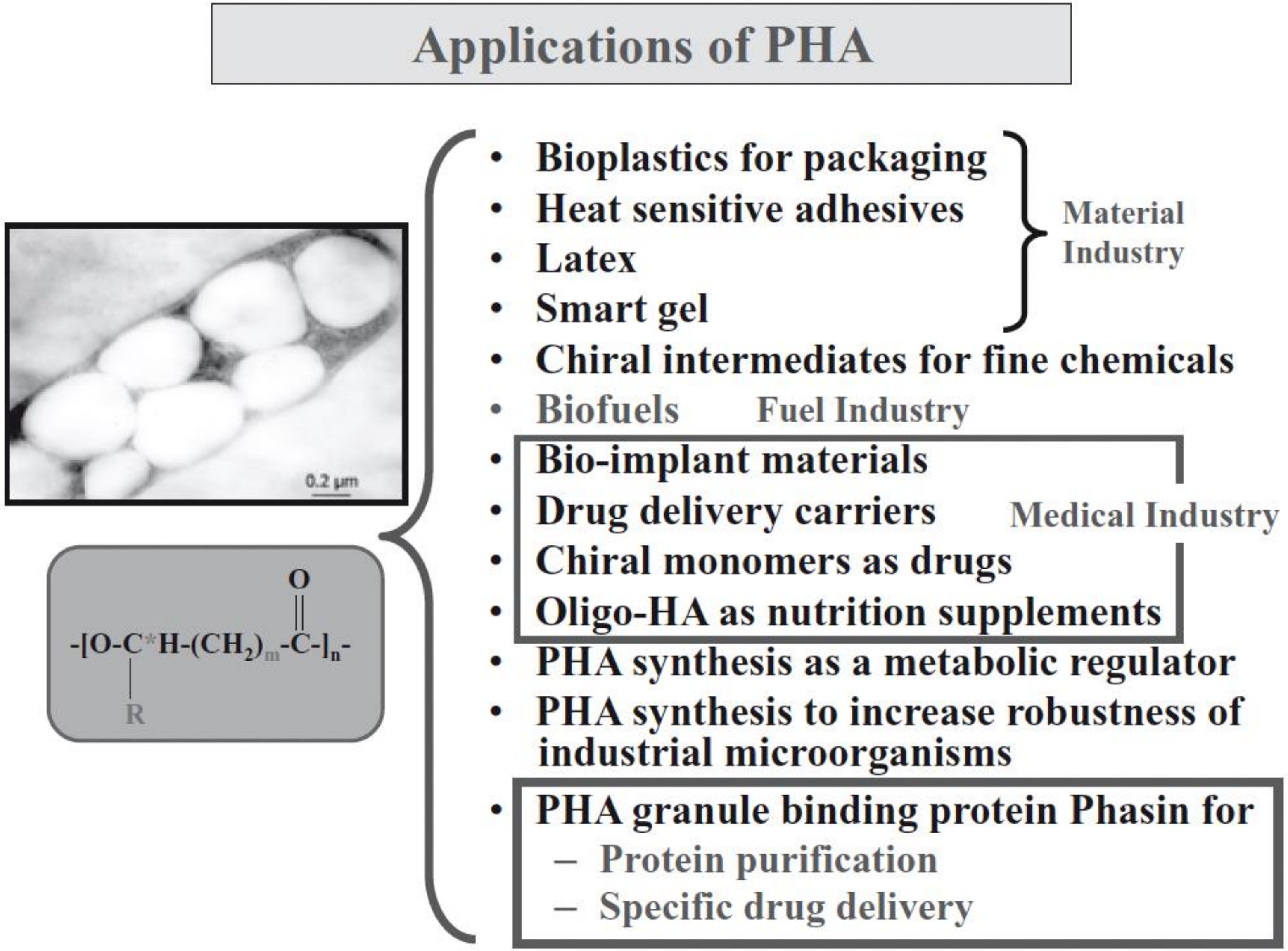


Fig. 7 PHA has been developed into an industrial value chain