Microbial metabolism

BIO3124 General microbiology

Chap 13 and 14 Norton textbook

Chap.8 in OpenStax Microbiology

Source: Pellissippi State News

Chapter 13 Overview

- Energy and entropy for life
- Energy carriers and electron transfer
- Catabolism: the microbial buffet
- Glucose fermentation and respiration
- ~~The gut microbiome: friends with benefits~~
- ~~Aromatic catabolism and syntropy~~

Chapter 14 Overview

- Electron transport systems and the proton motive force
- The respiratory ETS and ATP synthase
- Anaerobic respiration
- ~~Nanowires, electron shuttles, and fuel cells~~
- ~~Lithotrophy and methanogenesis~~
- ~~Phototrophy~~

Introduction

- All living cells need energy to move and grow.
- The energy to build cells comes from chemical reactions.
  - **Catabolism:** breakdown of complex molecules into smaller ones
  - **Anabolism:** reactions that build molecules
- Catabolism provides energy for anabolism.
  - However, some of the energy is released as heat.

Life requires energy

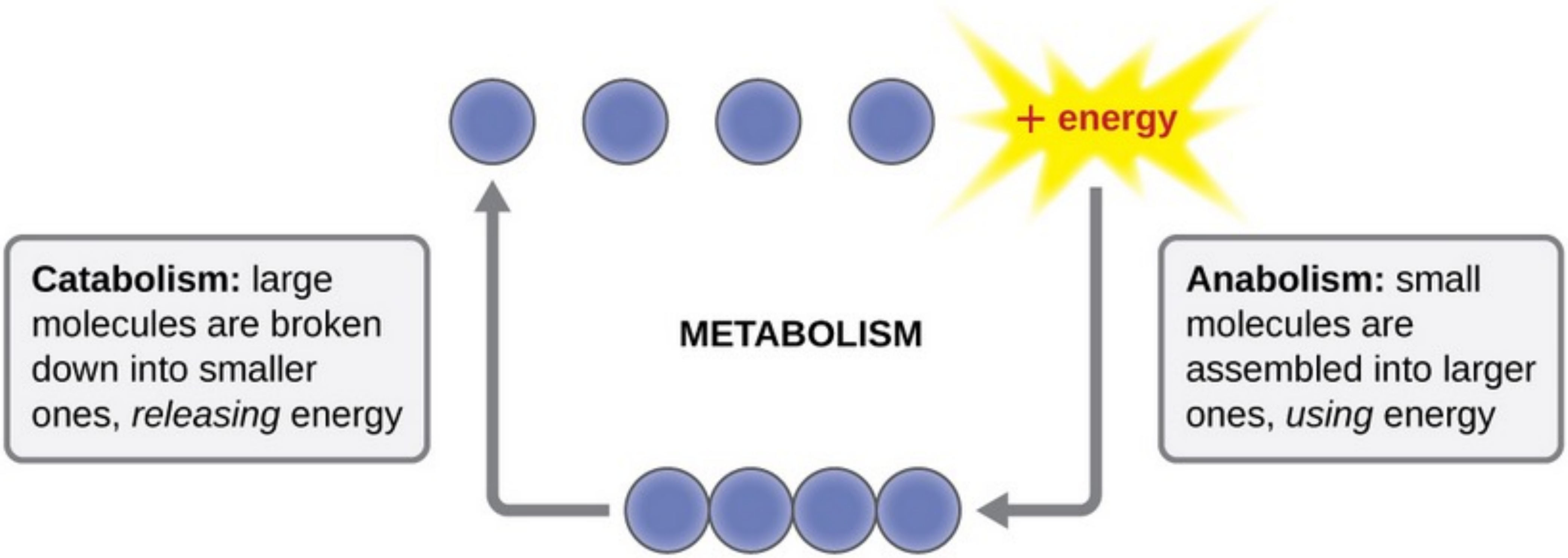


Figure 1. Metabolism includes catabolism and anabolism. Anabolic pathways require energy to synthesize larger molecules. Catabolic pathways generate energy by breaking down larger molecules. Both types of pathways are required for maintaining the cell's energy balance.

Microbiology v2 OpenStax Chap. 8.1

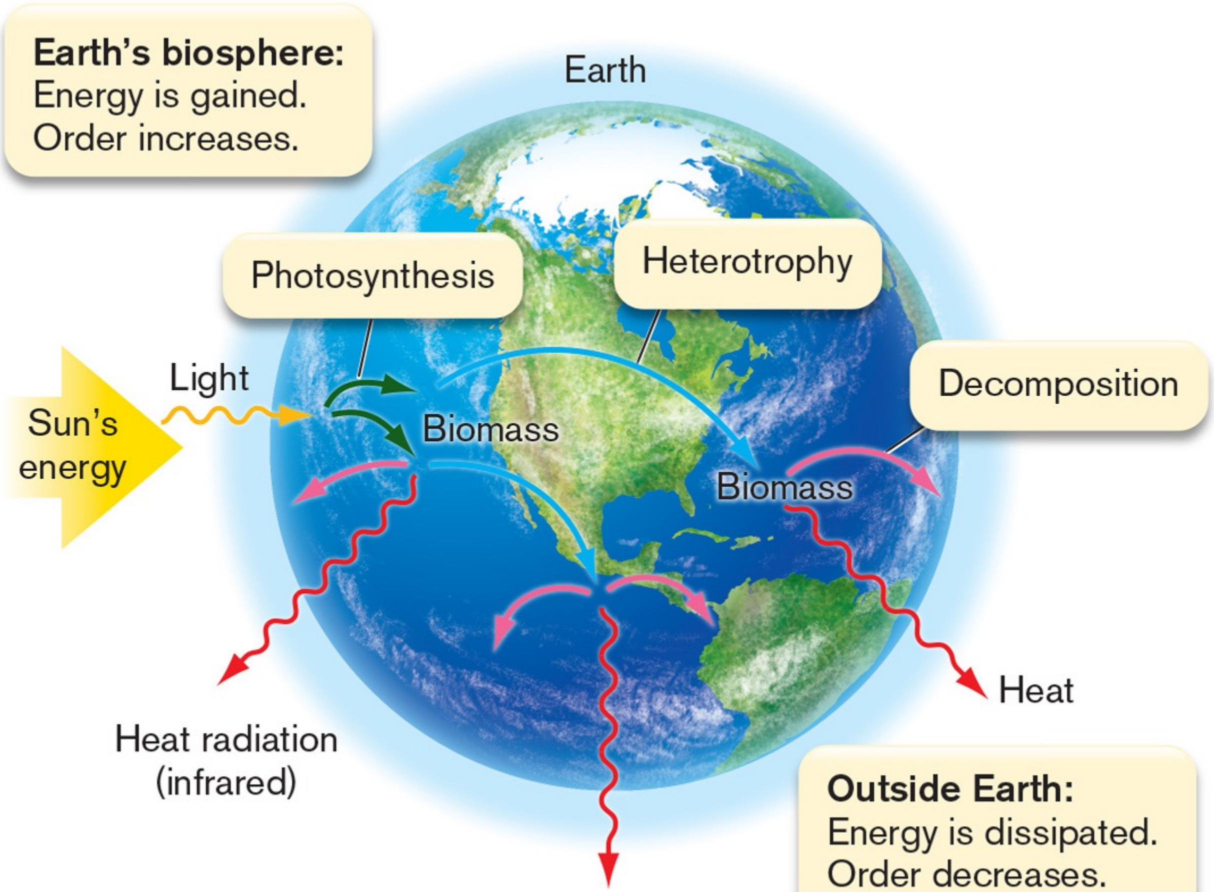
13.1 Energy for Life

- Every form of life, from a composting microbe to a human body, uses energy.
- **Energy** is the ability to do work.
- **Entropy** is a measure of the disorder or randomness of a system.
- Cells use energy to assemble simple, disordered molecules into complex, ordered forms.

Microbes Use Energy to Build Order

- The local, temporary gain of energy enables the cell to grow.
  - Continued growth requires a continual gain of energy and continual radiation of heat.
- What is true of the cell holds as well for the entire biosphere.
  - On Earth, the total metabolism of all life-forms must ultimately dissipate most energy as heat.
    - So overall, Earth's biosphere behaves as a **giant thermal reactor**.

Solar Energy



Where do trees get their mass from?

a) Water

b) Soil

c) Air

d) Sun

Before we check the answer, let's watch the following video:


WHERE DO TREES GET THEIR MASS?

Important Prefixes

- Prefixes are used to distinguish the types of metabolism used by cells.
  - **Carbon source for biomass**
    - **Auto** (**make your own**): CO_2 is fixed and assembled into organic molecules.
    - **Hetero** (**outsourced**): Preformed organic molecules are acquired and assembled into new organic molecules.
  - **Energy source**
    - **Photo-**: **Light** absorption captures energy.
    - **Chemo-**: **Chemical** reactions yield energy without absorbing light.
  - **Electron source**
    - **Litho-**: **Inorganic** molecules donate electrons.
    - **Organo-**: **Organic** molecules donate electrons.

Many Sources of Energy

- Collectively, microbes use more diverse energy sources than do multicellular organisms.
- **Chemotrophy** yields energy from electron transfer between chemicals.
  - Chemoorganotrophy = electrons from organic compounds
  - Chemolithotrophy = electrons from inorganic compounds
- **Phototrophy** yields energy from light absorption.
  - Photoautotrophy = light absorption with CO_2 fixation
  - Photoheterotrophy = light absorption without CO_2 fixation

Energy Acquisition in Bacteria and Archaea

Energy source	Source of e⁻	Carbon source
Photo	litho	heterotroph
Chemo	organo	autotroph

TABLE 13.1 Energy Acquisition in Bacteria and Archaea

Energy source	Class of metabolism	Examples of energy-yielding reactions	Electron acceptor	Systems for energy acquisition
CHEMICAL				
Chemoorganotrophy Organic compounds (at least one C–C bond) donate electrons	**Fermentation** Catabolism	$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$ (or other small molecules)	Organic	Glycolysis and other catabolism
	Organic respiration Catabolism with inorganic electron acceptor, or with small organic electron acceptor	$C_6H_{12}O_6 + 6H_2O + 6O_2 \rightarrow 6CO_2 + 12H_2O$ $C_6H_{12}O_6 + 6H_2O + 12NO_3^- \rightarrow 6CO_2 + 12H_2O + 12NO_2^-$	O_2 NO_3^-, SO_4^{2-}, Fe^{3+}, or other	Glycolysis and other catabolism, TCA cycle, and electron transport systems
Chemolithotrophy Inorganic compounds donate electrons	**Lithotrophy or chemolithoautotrophy** CO_2 fixation	Electron donor for respiration is H_2, Fe^{2+}, H_2S, NH_4^+	O_2, NO_3^-, or other	Electron transport system
	Methanogenesis	Electron donor is H_2: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$	CO_2	Methanogenesis
LIGHT				
Phototrophy Light absorption provides electrons	**Photoautotrophy** Light absorption drives CO_2 fixation	Photolysis of H_2O: $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$	CO_2	Photosystems I and II
		Photolysis of H_2S, HS^-, or Fe^{2+}: $6CO_2 + 12H_2S \rightarrow C_6H_{12}O_6 + 6H_2O + 12S$	CO_2	Photosystem I or II
	Photoheterotrophy Light absorption without CO_2 fixation	Photolysis of H_2S, HS^-, or light-driven H^+ pump. Usually supplements organotrophy.	Organic	Photosystem I or II; bacteriorhodopsin or proteorhodopsin

Which of these is TRUE for a chemolithoautotroph?

a) inorganic molecules as energy sources and inorganic carbon as a carbon source.

b) organic molecules as electron sources and inorganic carbon as a carbon source.

c) organic molecules as energy sources and organic carbon as a carbon source.

d) inorganic molecules as electron sources and organic carbon as a carbon source.

e) inorganic molecules as energy sources and organic carbon as a carbon source.

Cyanobacteria carry out oxygenic photosynthesis, producing oxygen as a by-product from the oxidation of water, which serves as the electron donor for the light-dependent reactions. How would cyanobacteria be classified?

a) chemoorganoautotroph

b) chemoorganoheterotroph

c) photolithoheterotroph

d) photoorganoautotroph

e) photolithoautotroph

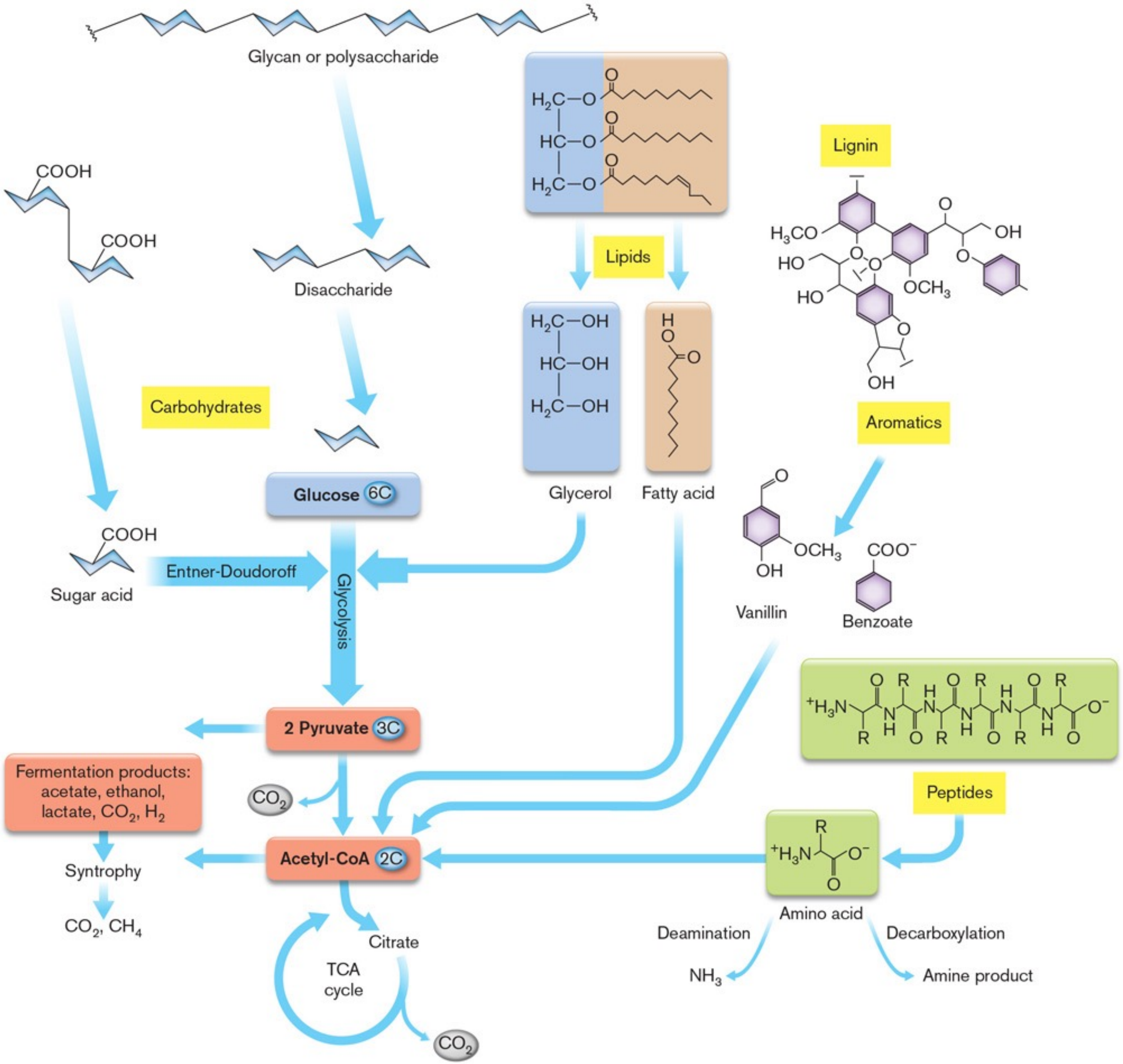
13.2 Energy Carriers and Electron Transfer

- Many of the cell's energy transfer reactions involve **energy carriers**.
  - Molecules that gain or release small amounts of energy in reversible reactions
  - Examples: NADH, ATP or PEP
- Some energy carriers also transfer electrons.
  - **Electron donor**: a reducing agent
  - **Electron acceptor**: an oxidizing agent

13.3 Catabolism: The Microbial Buffet

- Microbes catalyze many kinds of substrates.
  - **Polysaccharides** are broken down to disaccharides, and then to monosaccharides; sugar and sugar derivatives, such as amines and acids, are catabolized to pyruvate.
  - **Pyruvate and other intermediary products** of sugar catabolism are fermented or further catabolized to CO_2 and H_2O via the TCA cycle.
  - **Lipids and amino acids** are catabolized to glycerol and acetate, as well as other metabolic intermediates.
  - **Aromatic compounds**, such as lignin and benzoate derivatives, are catabolized to acetate through different pathways such as the catechol pathway.

Many Carbon Sources Enter Central Pathways of Catabolism



Products of Catabolism

- There are three main catabolic pathways:

1. **Fermentation**: partial breakdown of organic food without net electron transfer to an inorganic terminal electron acceptor

2. **Respiration**: complete breakdown of organic molecules with electron transfer to a terminal electron acceptor such as O_2

3. **Photoheterotrophy**: catabolism is conducted with a “boost” from light (ex. bacteriorhodopsin).

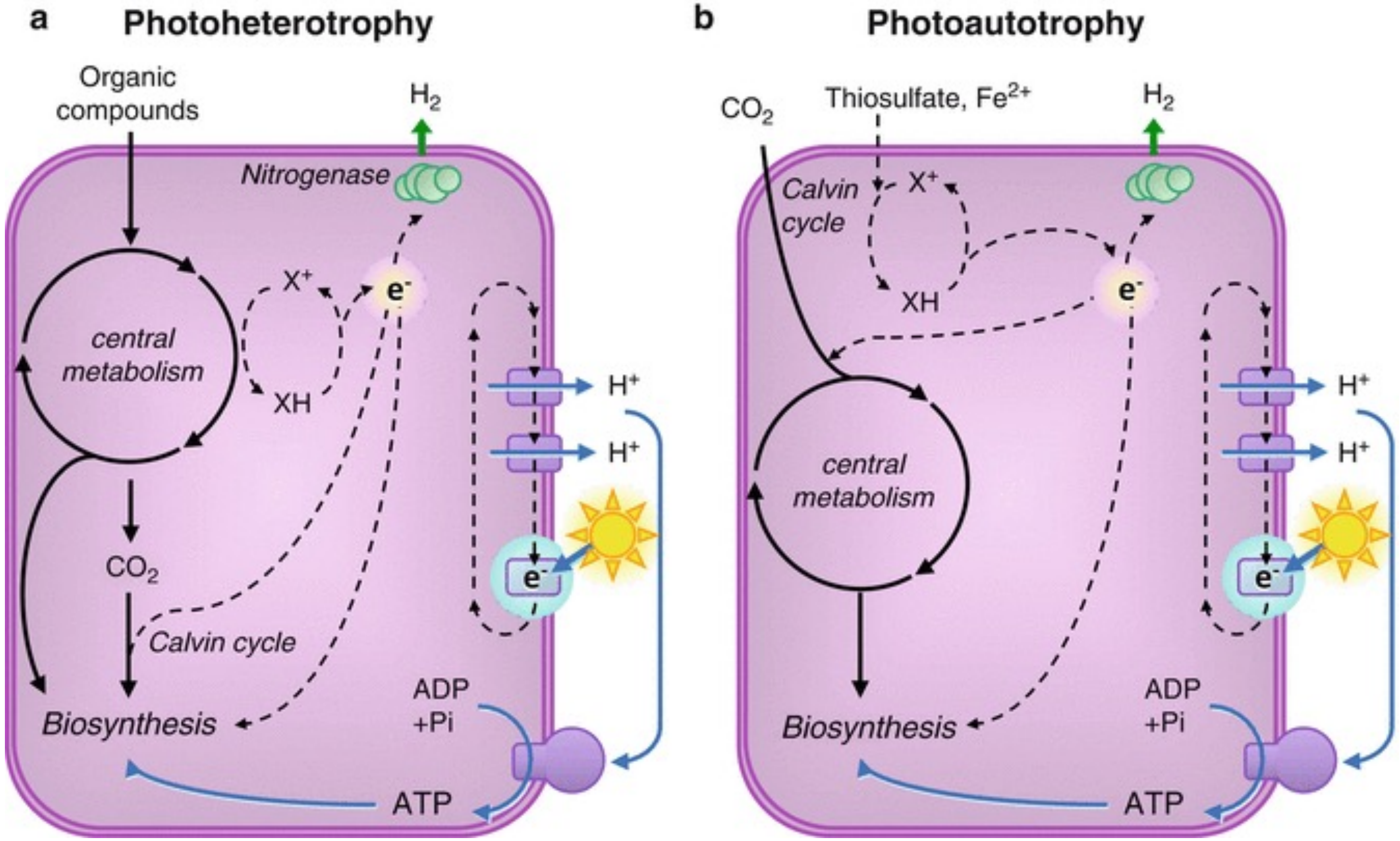
Photoheterotrophy vs Photoautotrophy

Source of carbon:
Organic compounds

Source of energy:
sun

Source of electrons:
Organic compounds

Electron acceptor: H_2



Source of carbon:
Fixing CO_2

Source of energy:
sun

Source of electrons:
Thiosulfate, Fe^{2+}

Electron acceptor: H_2

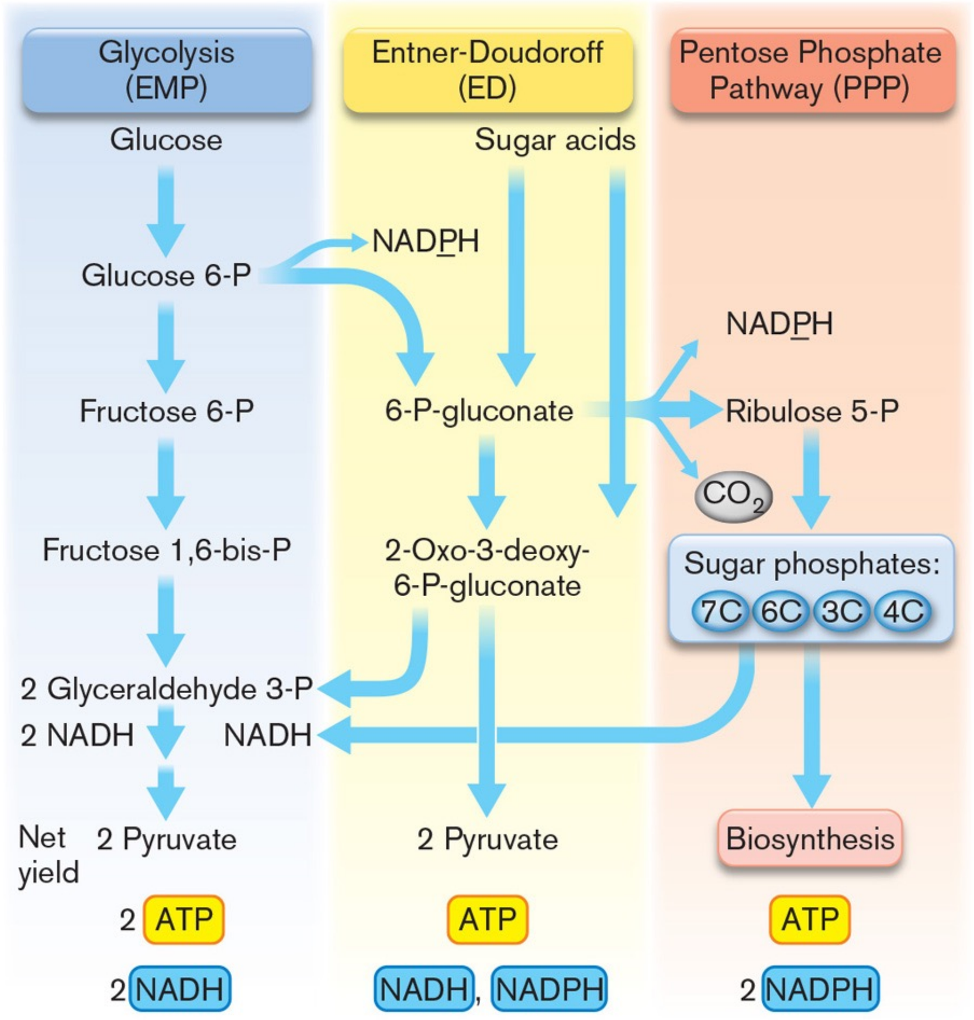
Solid black lines, carbon metabolism; solid blue lines, energy metabolism; dotted lines, electron metabolism.

Source: https://overallscience.com/purple-phototrophic-bacteria/ and https://www.pnas.org/doi/pdf/10.1073/pnas.1006175107

13.4 Glucose Fermentation and Respiration (chemoorganotrophy)

- Bacteria and archaea use three main routes to catabolize glucose:

  1. **Glycolysis,** or the Embden-Meyerhof-Parnas (EMP) pathway
  2. **Entner-Doudoroff (ED) pathway**
  3. **Pentose phosphate pathway (PPP),** also known as the pentose phosphate shunt



Metabolism in eukaryotes (overview and review)

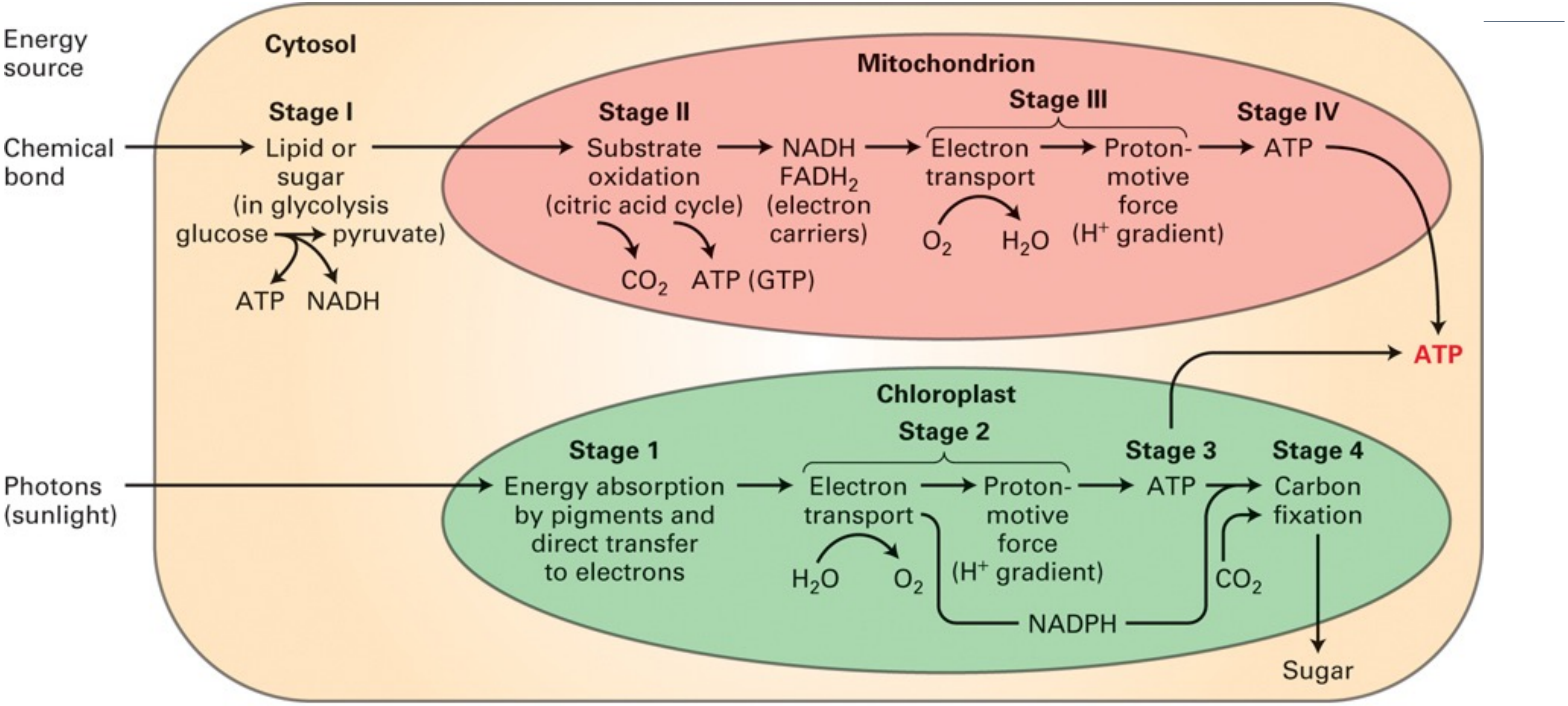


Figure 12.1
Molecular Cell Biology, Seventh Edition

Metabolism in bacteria overview

(not including fermentation)

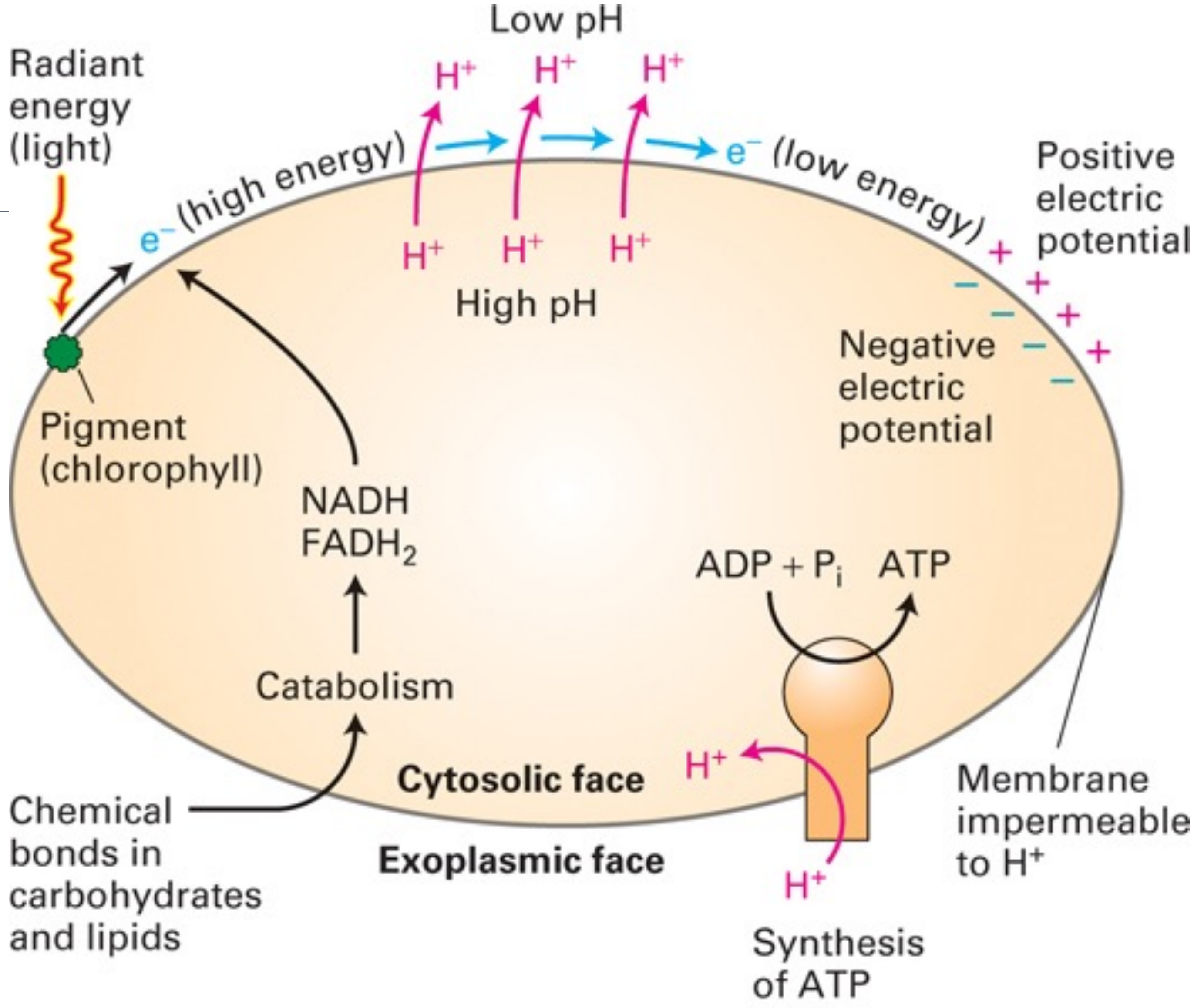
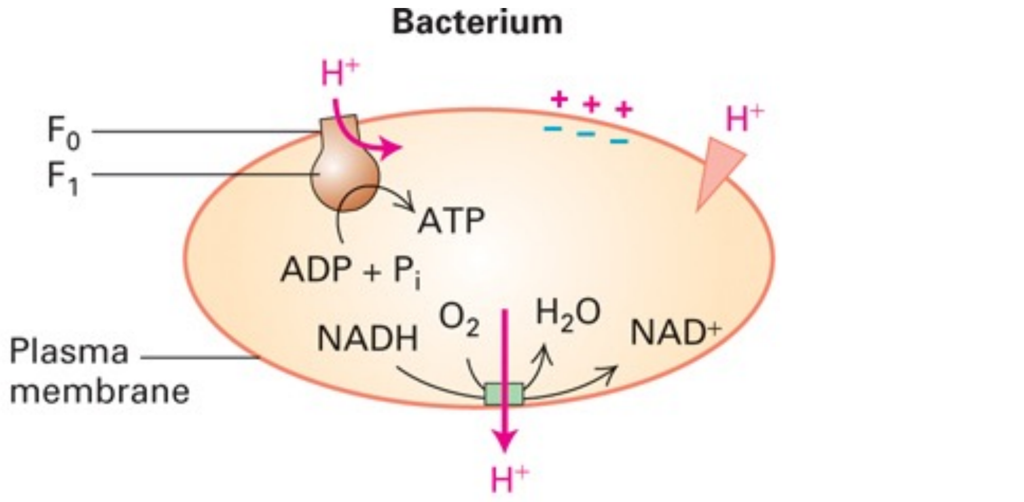
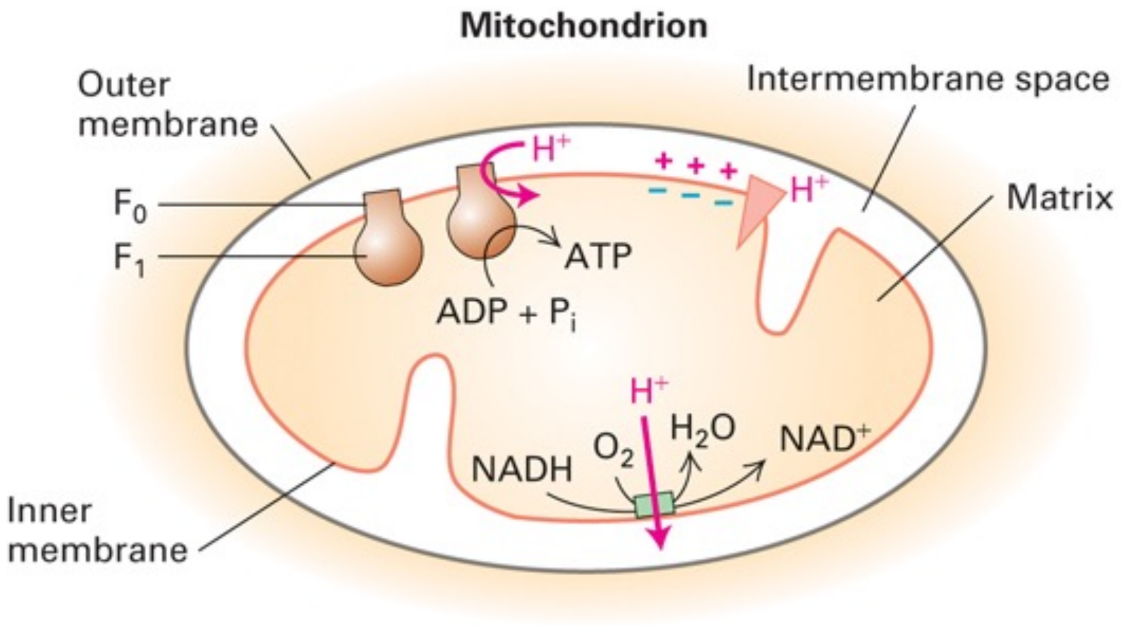


Figure 12.2
Molecular Cell Biology, Seventh Edition

Cell respiration across organisms

(but remember many organisms can use light energy (bacteriorhodopsin) or ferment without using respiration)





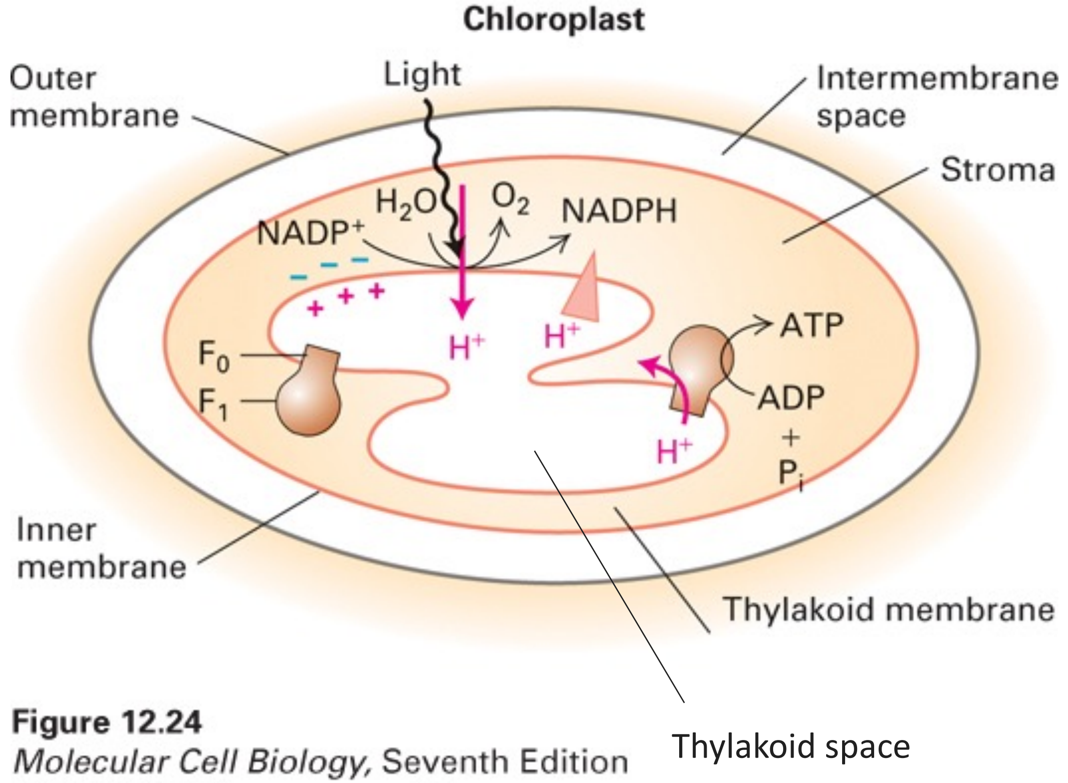


Figure 12.24
Molecular Cell Biology, Seventh Edition

What can the proton motive force generated by the electron transport system be used for?

a) NADH oxidation, ATP synthesis, and flagella rotation

b) NADH oxidation, ATP synthesis, and nutrient transport

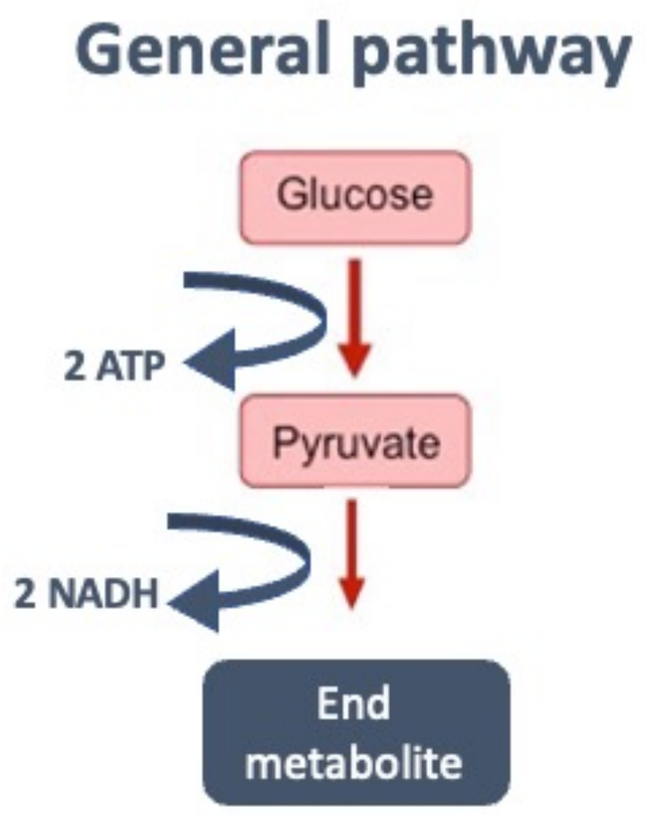
c) ATP synthesis, flagella rotation, and nutrient transport

d) NADH oxidation, flagella rotation, and nutrient transport

e) oxygen reduction and ATP synthesis

Fermentation Completes Catabolism

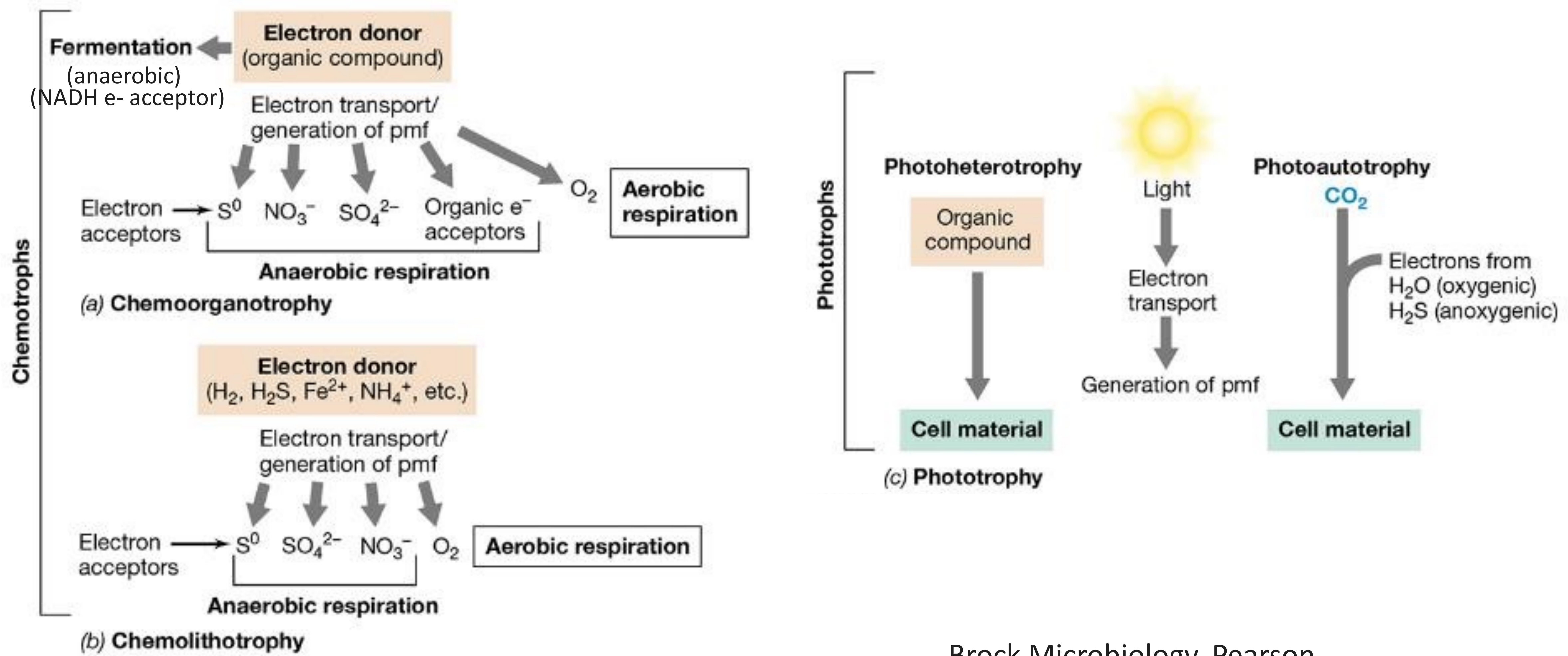
- **Fermentation** is the completion of catabolism without the electron transport system and an exogenous terminal electron acceptor.
  - The hydrogens from NADH + H^+ are transferred back onto the products of pyruvate, forming partly oxidized fermentation products.
- Most fermentations do not generate ATP beyond that produced by **substrate-level phosphorylation**.
  - Microbes compensate for the low efficiency of fermentation by consuming large quantities of substrate and excreting large quantities of products.



Fermentation Completes Catabolism

- **Homolactic fermentation**
  - Produces two molecules of lactic acid
- **Ethanolic fermentation**
  - Produces two molecules of ethanol and two CO_2
- **Heterolactic fermentation**
  - Produces one molecule of lactic acid, one ethanol, and one CO_2
- **Mixed-acid fermentation**
  - Produces acetate, formate, lactate, and succinate, as well as ethanol, H_2, and CO_2

Microorganisms are metabolically diverse



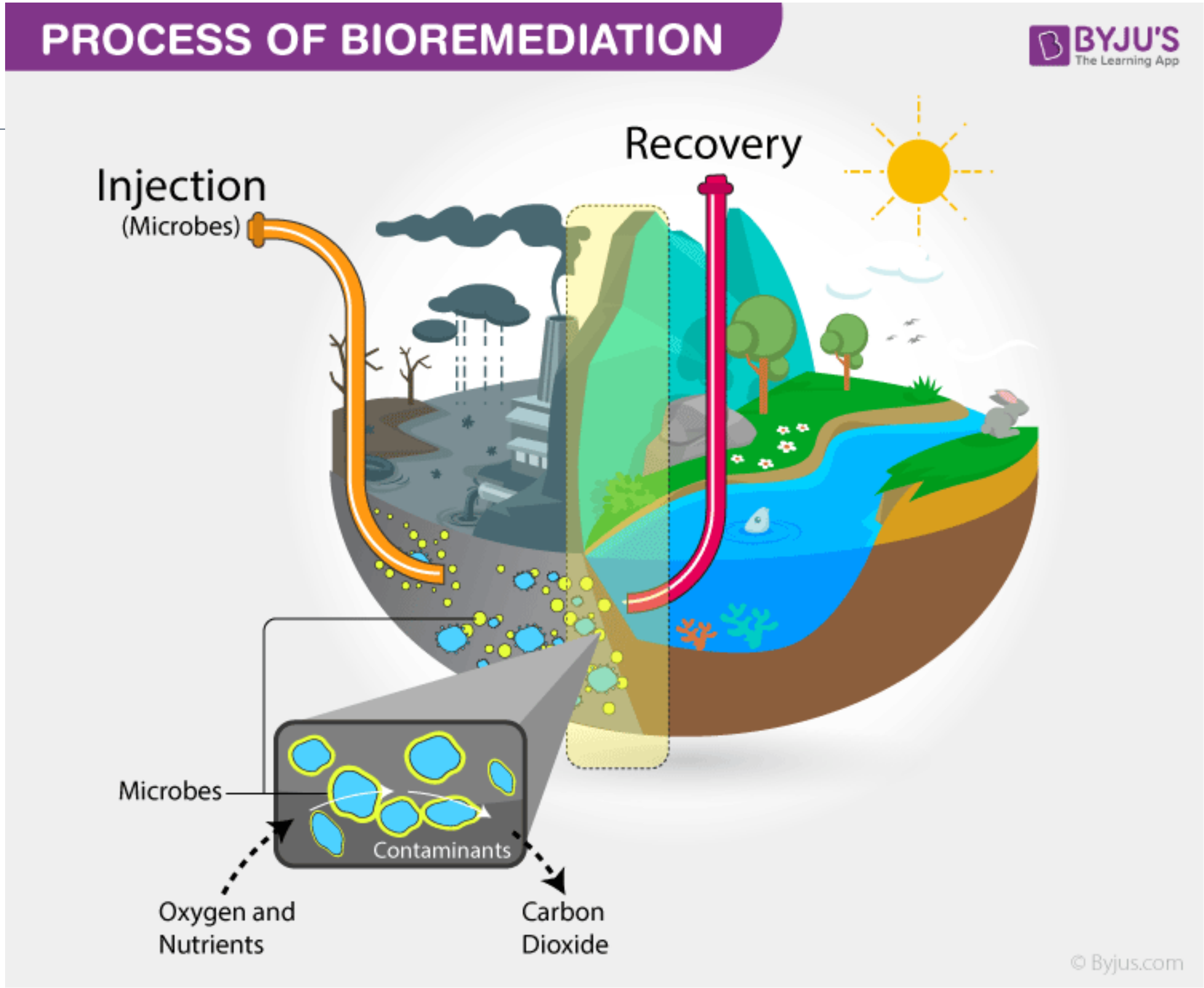
Brock Microbiology, Pearson

Bioremediation

The use of microbes to remove pollutants or xenobiotics, such as the **aromatic** compounds in oil spills.

Bioremediation may also make use of microbes that have been **selected for growth** on a certain pollutant or of **genetically modified bacteria** that are specially adapted to metabolize petroleum products or other pollutants.

The addition of such specialized microbes is called **bioaugmentation**



In situ bioremediation of an oil spill

- Bioremediation occurs naturally as microbes attack the petroleum if conditions are aerobic.
- However, microbes usually obtain their nutrients in aqueous solution, and oil-based products are relatively non-soluble.
- Also, petroleum hydrocarbons are deficient in essential elements, such as nitrogen and phosphorus.
- Bioremediation of oil spills is greatly enhanced if the resident bacteria are provided with **"fertilizer"** containing nitrogen and phosphorus (**Biostimulation**)

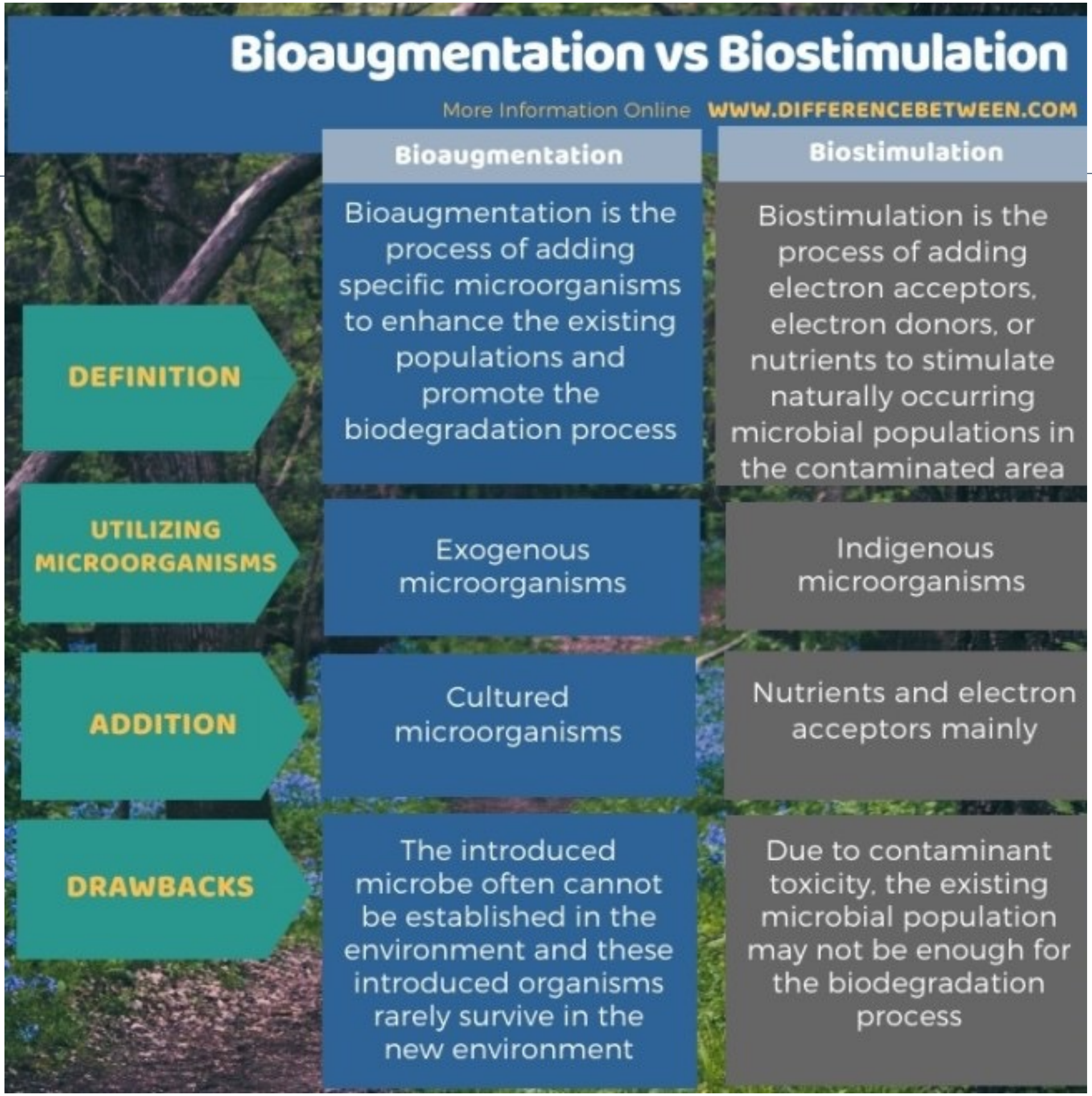
(a) Oily rocks after the Exxon Valdez oil spill

(b) One month after addition of nitrogen-phosphorous fertilizer

Microbiology: an introduction, Tortora, Pearson publishing, Chap 27

Different types of bioremediation

Bioaugmentation vs Biostimulation



Bioaugmentation vs Biostimulation

More Information Online WWW.DIFFERENCEBETWEEN.COM

	Bioaugmentation	Biostimulation
DEFINITION	Bioaugmentation is the process of adding specific microorganisms to enhance the existing populations and promote the biodegradation process	Biostimulation is the process of adding electron acceptors, electron donors, or nutrients to stimulate naturally occurring microbial populations in the contaminated area
UTILIZING MICROORGANISMS	Exogenous microorganisms	Indigenous microorganisms
ADDITION	Cultured microorganisms	Nutrients and electron acceptors mainly
DRAWBACKS	The introduced microbe often cannot be established in the environment and these introduced organisms rarely survive in the new environment	Due to contaminant toxicity, the existing microbial population may not be enough for the biodegradation process

https://www.differencebetween.com/difference-between-bioaugmentation-and-biostimulation/

Next class…

Bacterial growth