UNIT 2.2

Microbial Mat Ecology

Presented by:
Dr. Lee Prufert-Bebout

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Vocabulary:

- Microbe
- Microbial Mat
- Oxic
- Anoxic
- Phototroph
- Heterotroph

Purpose:

Among NASA's primary goals are the imperatives to further our knowledge of how life from Earth can adapt to space conditions. Life on Earth is dominated by microbes, in terms of biomass, overall rates of activity, use of potentially available habitats, and length of time present on the planet. Microbes are intimately associated with humans and necessary for regenerative cycling of energy and elements in enclosed systems (space) just as they are on the Earth. It is essential to NASA's space exploration goals to achieve an advanced capability to understand, manage and manipulate microbial ecosystems, particularly as we attempt to expand beyond the Earth.

Objectives:

A crucial element of this exploration is to recognize that microorganisms rarely exist in isolation, but rather live, interact and evolve in highly interdependent, complex communities such as microbial mats. In this module we will focus on:

a) Understanding several basic microbial groups and their energy metabolisms.

b) Understanding the micro-scale environment which differs vastly from bulk environment.

c) Examining interactions between microbial ecosystems and ambient environment.

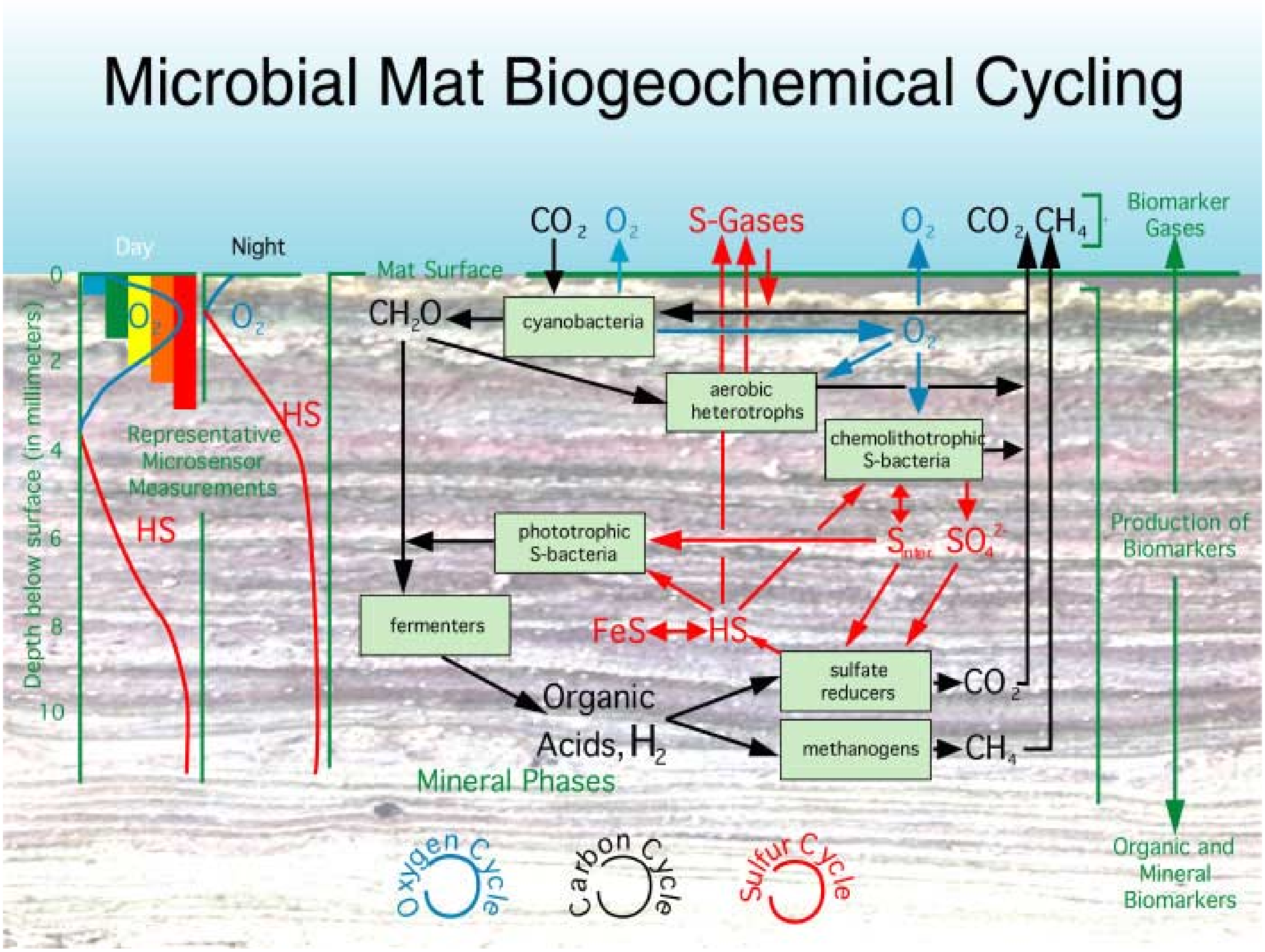
d) Considering design requirements for maintaining microbial ecosystems in the laboratory.

e) Considering design requirements for maintaining microbial ecosystems in space.

Prevalent Functional Groups

Cyanobacteria
Aerobic heterotrophs
Chemolithotrophic S bacteria
Phototrophic S Bacteria

Fermenters
Sulfate Reducing Bacteria
Methanogens



Microbial Mats: Cyanobacteria, Sulfate Reducing Bacteria, Methanogens

Characteristics of Microbial Mats

- **Appearance:** laminated, flat, attached to surface different layers exhibit different pigments
- **Nutritional requirements:** Carbon, nitrogen, phosphorus, Sulfur, Cations (Ca, Mg), Anions, Trace metals
- **Metabolism:** Primary producers (cyanobacteria require CO2, H20 and sunlight) they produce organic material which is then re-mineralized by various groups.
- Extreme Variations in oxic /anoxic conditions
- Rapid Extinction (absorption and scattering) of irradiance
- Tight Coupling of processes
- Surfaces exposed to sunlight and water (transient to persistent)
- Biological Limitations: Unable to survive in temperatures above 90 degrees? Can withstand freezing temperatures for 10 minutes maximum?

Environmental Microbial Metabolism

How do microbes get the materials for life from their environment?

- Gaining the Building Blocks
  - macronutrients: C, H, O, N, P, S, K, Mg, Na, Ca, Fe
  - micronutrients: trace elements (metals), vitamins
  - anabolic processes: biosynthesis
- Gaining the Energy
  - chemical energy gained as electrons are transferred
  - many possibilities, catabolic processes

How do microbes gain energy for life from their environment?

Basic Modes:

1. Photosynthesis
2. Chemolithotrophy
3. Fermentation
4. Respiration
5. Anaerobic Respiration

Energy released by chemical reduction and oxidation reaction pairs (redox reactions) is captured by cells.

Energetics Overview

Metabolic modes classified by electron donor / electron acceptor pair

	Electron Donor	Energy Source/Electron Donor	Electron Acceptor
Photosynthesis	Water	Light	Carbon Dioxide
Chemolithotrophy		Reduced Inorganic Compounds	Oxygen and Inorganic Compounds
Fermentation		Organic Compounds	Organic Compounds
Respiration		Organic Compounds	Oxygen
Anaerobic Respiration		Organic Compounds	Oxidized Inorganic Compound

Energy Storage[1]

Proton Motive Force: An energized state of a membrane created by expulsion of protons usually occurring through action of an electron transport chain.

Chemiosmosis: The use of ion gradients, especially proton gradients, across membranes to generate ATP.

ATP: Adenosine triphosphate, the principal energy carrying molecule of the cell—short term energy "currency"

Photosynthesis: Conversion of light energy into chemical energy

$$CO_2 \xrightarrow{\textit{Light}} (CH_2O)n$$

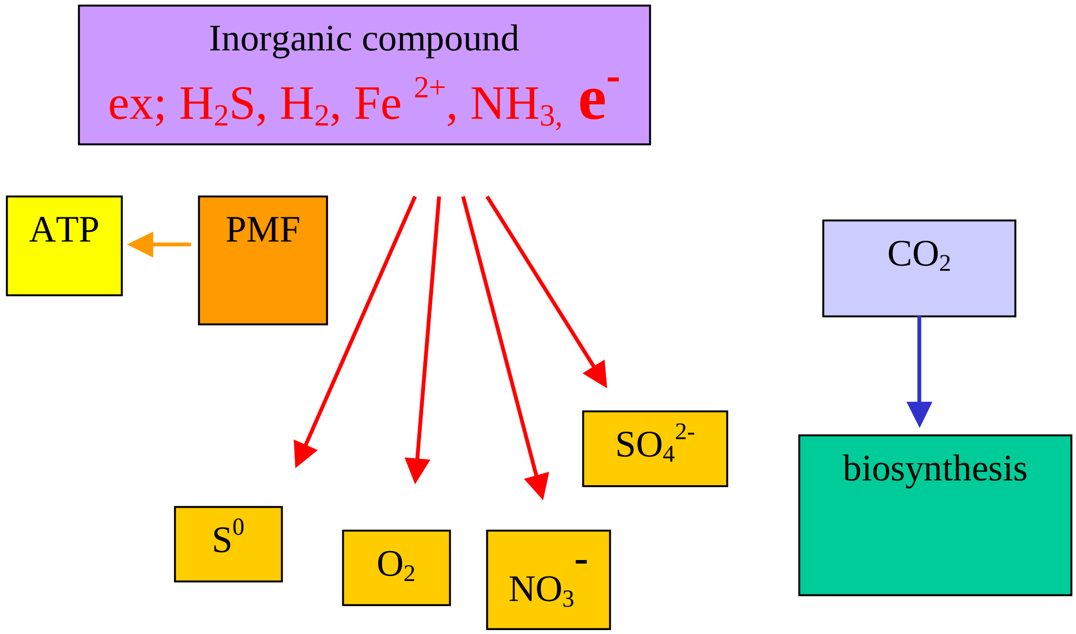
Oxygenic: cyanobacteria (algae, plants, prochlorophytes) two photosystems (means for absorbing light energy) Chl a (blue and red) electron donor: water

Anoxygenic: 4 bacterial groups: Purple, Green Sulfur, Green Filamentous, Heliobacteria one photosystem, variety of bacteriochlorophylls (near IR)
electron donor: variety of inorganic (H202, H2, reduced sulfur species) or organic sources

[1] *Definitions from Brock Biology of Microorganisms, 9th Edition, Madigan, Martinko and Parker Eds, 2000, Prentice-Hall Inc.*

Energetics Overview *(cont.)*

Chemolithotrophy: Production of organic matter from inorganic materials (similar to photosynthesis), but energy from oxidation of reduced inorganic compounds. Carbon for growth from CO_2 (autotrophic)



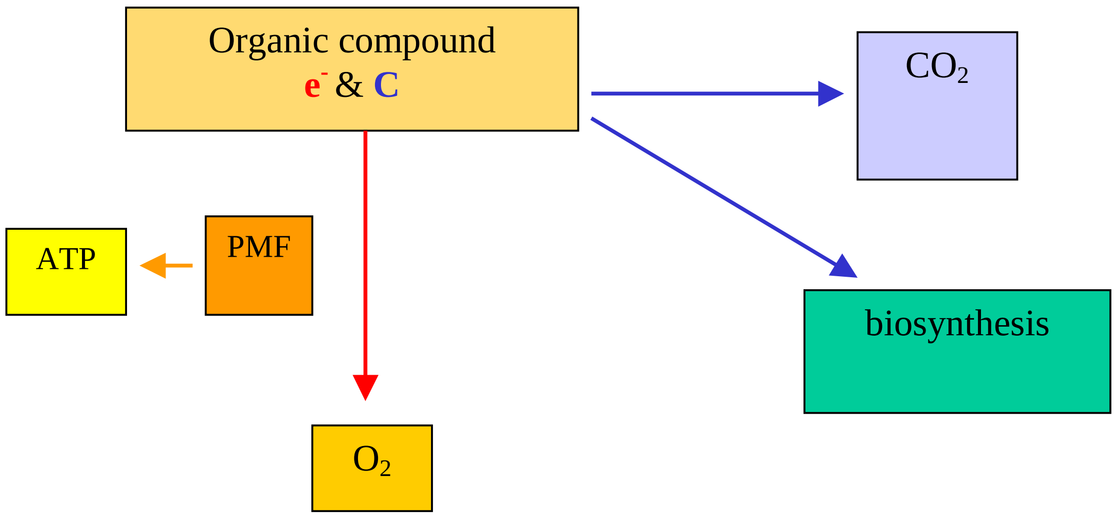
Examples: Sulfide Oxidation, Iron Oxidation, Nitrification

Fermentation: Organic compounds serve as both primary electron donor and ultimate electron acceptor

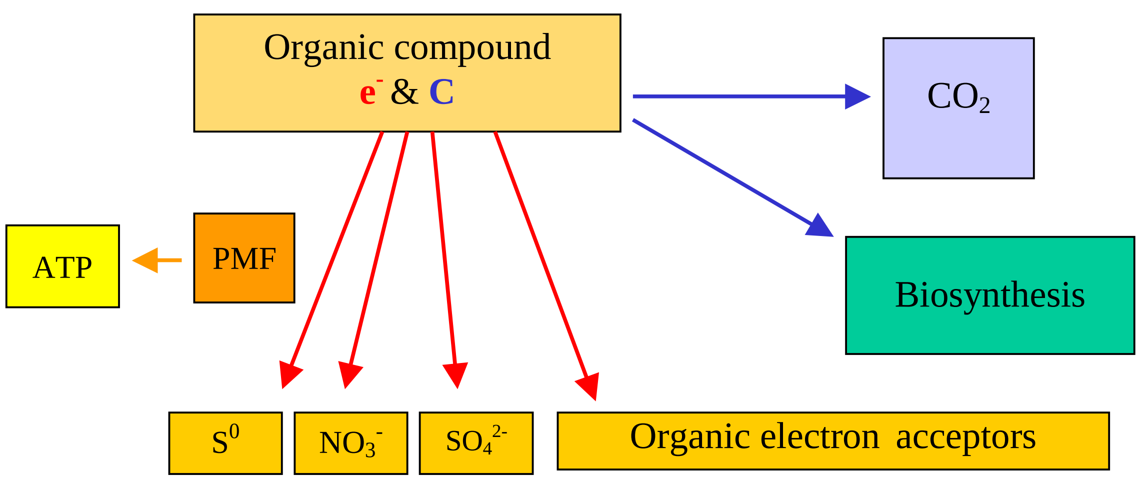
- Relatively small energy gain (small difference in redox potential between donor and terminal acceptor)
- Release organic compounds – excreted from cell (ethanol, lactic acid)

Energetics Overview *(cont.)*

Aerobic Respiration:
Organic compound is energy source, terminal electron acceptor is oxygen, therefore high energy yield is possible, many microbes



Anaerobic Respiration:
Organic compound is energy source. Uses terminal electron acceptor other than oxygen: less energy is released. However, permits microorganisms to respire in environments where oxygen is absent.



Ex: nitrate reduction, sulfate reduction, iron and manganese reduction

Energetics Overview *(cont.)*

<u>Summary</u>:

- Many modes of energy metabolism

- Modes do not necessarily indicate taxonomy

- Most modes make use of energetically favorable reactions of compounds in the environment, but make use of membranes and special chemistry to capture energy (contained in the bonds of chemical compounds) into bond energy of chemical compounds (such as ATP) which are a biologically useful energy form

Photosynthesis is able to accomplish a thermodynamically unfavorable reaction (the splitting of water) only with the additional help of energy provided by sunlight; therefore allowing photosynthetic organisms to transfer light energy into biologically useful chemical bond energy.

MATS as a Model Organism or Ecosystem

Why should we use microbial mats for scientific space research?

- They can presumably withstand the extreme conditions associated with take off and landing and microgravity as they exist in self generated gel matrix where diffusional processes dominate.

- They contain all of the basic biochemical processes found in spatially expansive ecosystems on Earth within a few millimeters

- High data yield from small ecosystem - A "rainforest" in a centimeter depth.

What will we learn from microbial mats in space?

- Is there any difference in these ecosystems function in low gravity (already live at low Reynolds)?

- Can they be engineered to:
  - produce needed materials, methane, hydrogen?
  - facilitate uptake / re-capture of nutrients (activated sludge)?
  - facilitate uptake/ removal of toxins?

- Can they be developed as biosensors?

Notes: