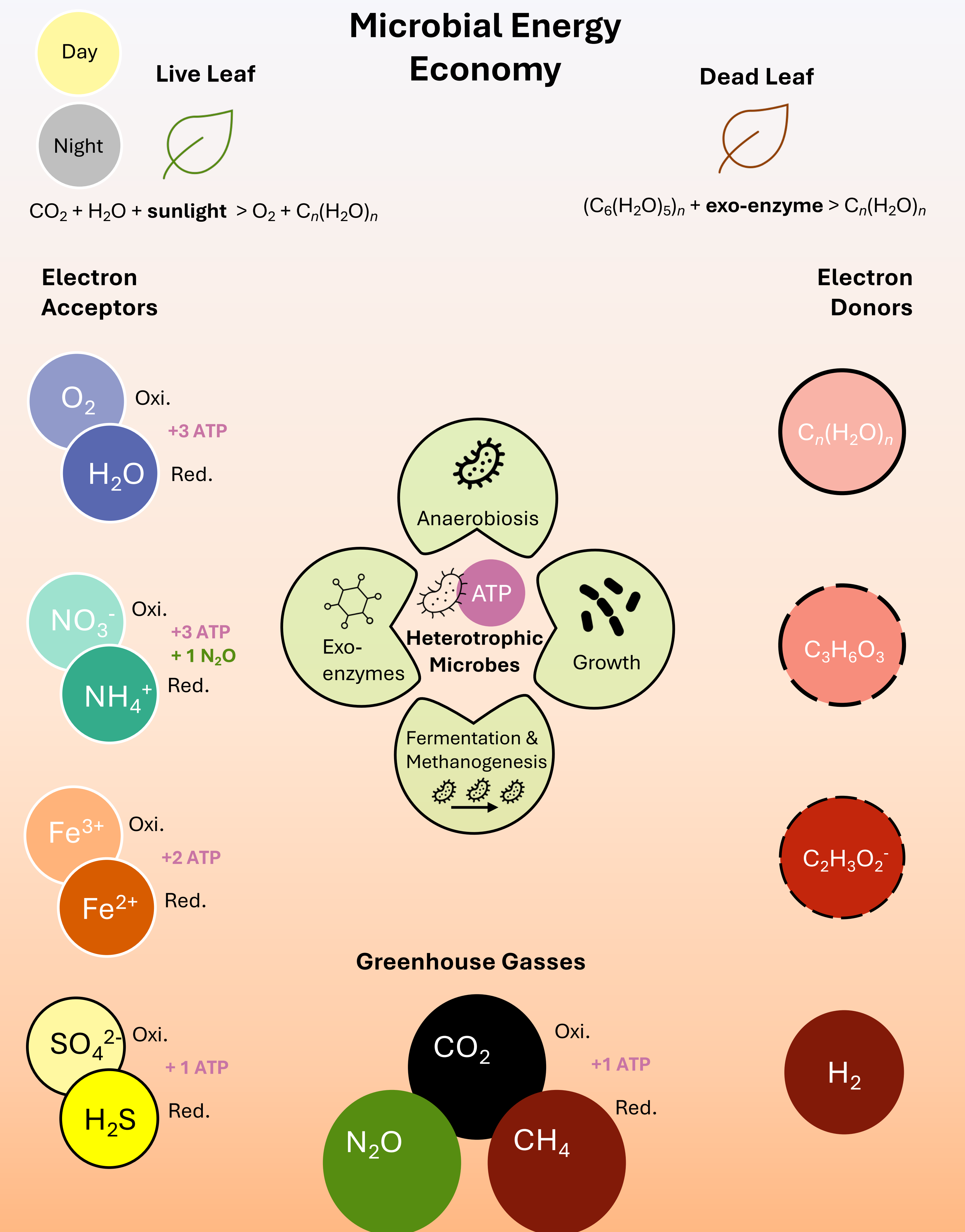

EAES 579 – Fall 2024 - McNicol

Microbial Energy Economy
Materials and Rules

Materials

- **Dark green pieces:** generic marker indicating space is occupied
- **Tiny silver magnets:** electron(s)
- **Tiny colorful magnets:** ATP

Rules

1. Microbes always catalyze highest-energy redox reaction they are capable of.
2. Only one redox reaction per microbe per turn.
3. In Scenario 4: day-night cycle is 4 turns – 4 turns.

Electron Transfers and ATP Generation:

Electron Acceptors

- **Oxygen**: Generates **3 ATP** per electron transfer, reduces to **H_2O**.
- **Nitrate**: Generates **3 ATP** and **1 N_2O** per electron transfer, reduces to **NH_4^+.**
- **Iron:** Generates **2 ATP** per electron transfer, reduces to **Fe^{2+}**.
- **Sulfur**: Generates **1 ATP** per electron transfer, reduces to **H_2S**. Kills one microbe if > 3.
- **CO_2**: Generates **1 ATP** per electron transfer, reduces to **one CH_4.**

Electron Donors

- **Carbohydrate**: Generates **6 CO_2** per electron transfer, or ferments to **2 lactic acids.**
- **Lactic Acid:** Generates **3 CO_2** per electron transfer, or ferments to **3 acetates.**
- **Acetate:** Generates **2 CO_2** per electron transfer, or ferments to **2 CO2** and **3 H2**, or disproportionated to **1 CO_2** and **1 CH_4** under methanogenesis.
- **Hydrogen:** Generates **1 CH4** per **two** electron transfer.

Allochthonous Inputs

- **Photosynthesizing live leaf:** Generates **1 O2** per 1 CO_2 and NO_3^- reduced.
- **Decomposing dead leaf:** Generates **1 glucose** per 1 exo-enzyme consumed.

Microbial Growth and Evolution:

- **Cell death: a** microbe dies if it has no ATP after a turn.
- **Growth**: **3 ATP** to "grow" and double electron transfer capacity per turn.
- **Exo-enzymes**: Spend **3 ATP** to evolve exo-enzymes breakdown of cellulose > monomeric carbohydrate.

Microbial Energy Economy
Scenarios

Scenario 1: Oxidizing Heterotroph (Oxygen Not Limiting)

Goal: Use oxygen (the most favorable acceptor) to oxidize glucose, generating 3 ATP per transfer. Use ATP to grow and evolve, breaking down cellulose for more glucose.

Key Mechanic: Oxygen drives rapid ATP generation, leading to exponential microbial growth and complete oxidation of all carbon sources.

Scenario 2: Reducing Heterotroph (Oxygen Limiting)

Goal: Start with limited oxygen, deplete it quickly, and switch to nitrate (2 ATP), then iron and sulfur (1 ATP each), adapting metabolism as needed. When glucose runs out, ferment glucose to acetate using ATP.

Key Mechanic: With lower ATP yields from alternative electron acceptors, microbial growth is slower, and energy is conserved for necessary adaptations like fermentation.

Scenario 3: Scavenging Pulse of Oxygen

Goal: After exhausting sulfur, introduce a pulse of oxygen, creating a rush of ATP production (3 ATP per oxygen transfer). Use the resulting ATP surge to grow and continue metabolism.

Key Mechanic: Pulses of oxygen provide a burst of energy, enabling rapid microbial growth and adaptation before the environment shifts back to anaerobic conditions.

Scenario 4: Introduction of a Photoautotroph

Goal: Simulate the interaction between heterotrophs and the photoautotroph, emphasizing symbiotic energy flow where the photoautotroph supports heterotrophic metabolism by replenishing oxygen and providing glucose, while consuming nitrate and CO_2.