20.106J – Systems Microbiology
Lecture 5
Prof. DeLong

- Reading: p533-555, Bioenergetics and Metabolic Diversity
- Today:
  - Basic modes of energy generation
  - Thermodynamics of growth (continued)
  - Applications of microbial chemolithotrophy and anaerobic respiration

- Review: Most of the energy in the atmosphere today comes from photons from the sun – it's like a big solar cell
  - Cyclic photophosphorylation – extracting energy via excited electrons and the electron transport chain
    - The fundamentals of how you get to ATP is the same for phototrophs and autotrophs
    - There is a lot of diversity in anoxygenic phototrophs
  - Using photon energy to strip electrons off of water
    - You're not going to use up your source of energy
    - Waste product is oxygen – allows other, heterotrophic life
  - Rhodopsins – Haloarchaea – live in hypersaline habitats
    - They can live in salt crystals if there's water available
    - They get energy from light via a simple protein – rhodopsin
      - Organic molecule absorbs a photon, changes shape, and then the whole protein changes, allowing the cell to transport an electron from inside the cell to outside → concentration gradient
      - There are two types of microbial rhodopsins: light-driven ion pumps and sensory rhodopsins
      - We have sensory rhodopsins in our eyes
      - There are different sorts of rhodopsins that exist in bacteria that live almost anywhere in the ocean
      - With retinal in bacteria you can produce proton pumping
      - Rhodopsin is a new kind of light-driven energy generation
      - There's even evidence that it's being laterally transferred
      - Rhodopsin-using hybrids could be likened to hybrid automobiles.
        - Rhodopsin allows them to charge a battery

- Where do organisms get their energy?
  - Chemolithotrophs: Oxidize inorganic compounds
    Chemoorganotrophs: Oxidize organic compounds
    - Neither of these types needs to use oxygen to dump their electrons onto. Oxygen isn't always available in many environments
    - NADH from glycolysis can be used in energy pathways – donate electrons, forming chemi-osmotic gradient

        - Organisms that don't use oxygen have similar electron transport chains, they just don't use oxygen as the final electron acceptor. Often, they use iron, sulfate, or nitrate.
        - Chemolithotrophs are the same story
        - These kinds off microbes are important, for example, in aquariums. You use them to keep the fish from dying of ammonium poisoning from their own waste.

- Applications
    - The nitrogen from fertilizers gets into ground waters → Anammox: "Anaerobic Ammonium Oxidation."
        - This is a pretty new method.
        - Broda predicted (solely based on the thermodynamics) that microbes that do this must exist: $NH_2 + NO_2^- \longrightarrow N_2 + 2H_2O$
        - If a favorable niche exists, then something will evolve to fill it
        - The microbes were discovered ten years ago
        - These microbes produce hydrazine, which is *very* reactive (rocket fuel)
            - The organisms contain this reactive hydrazine within special pockets
        - These organisms are not easy to grow, but with the right conditions you can do it
        - These organisms also do carbon dioxide removal as well as nitrogen removal
        - People have built big plants that do this very efficiently now, particularly in the Netherlands
        - Denitrifiers are another way you can remove nitrogen
    - Picture: Geobacter growing on iron hydroxides. They grow on a solid, not in a solution
    - Microbial redox interactions with uranium: an environmental perspective
    - If you look at a sediment, you can predict where the different types of reduction are going to occur on each level.
        - This has to do with energetics – it explains the order (ΔG_o)
    - Microbial bioremediation of uranium
        - Uranium (VI) is water soluble, radioactive, and toxic, and it can end up in ground water (produced by energy production and nuclear bombs)
        - These microbes convert uranium (VI) to uranium (IV), which is insoluble, so it won't end up in the ground water.
        - All you need to do is add acetates and the microbes (which are already everywhere) will convert the uranium (VI), which then precipitates and falls out of the moving water.
    - Geobacter can use electrodes as an electron acceptor
        - Thus allowing us to harvest power from aquatic sediments and other sources of waste organics
        - Microbial fuel cell, powered by residual organics

        - These aren't very powerful, but they can run small systems
        - How do these organisms dump electrons onto a solid?
            - It's not terribly well understood
            - It involves the pili – they transmit electrons
    - Deep-sea methane hydrates are buried in sediments off of continental margins worldwide
        - They hold huge amounts of carbon in them – there's more carbon in these deposits than there is in petroleum desposits
        - Methane can burn without oxygen: $CH_4 + 2H_2O \rightleftharpoons CO_2 + 4H_2$
            - However, methanogens drive the reaction in reverse. It doesn't really go forward.
        - Instead, we can use this reaction:
          $CH_4 + SO_4^{2-} \longrightarrow HCO_3^- + HS^- + H_2O$
        - There's no individual microbe known that can do this, but they *can* do it in teams. Microbiologically:
          $CH_4 + SO_4^{2-} \longrightarrow HCO_3^- + HS^- + H_2O : \ \Delta G_o' = -25 \, {}^{kJ}\!/\!{}_{mol}$
            - This is a very small amount of energy per mole. Difficult, but it does work. (It's believed that -20kJ/mol would be at the limit of feasibility.)
            - Two different types of microbes work together symbiotically so that this total reaction runs.
        - This can control methane on a global scale
    - All of these applications can be figured out largely from basic principles, so they're very powerful.