Carbon and Nitrogen Cycles

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What process?

What does it need?

Biogeochemical Cycles

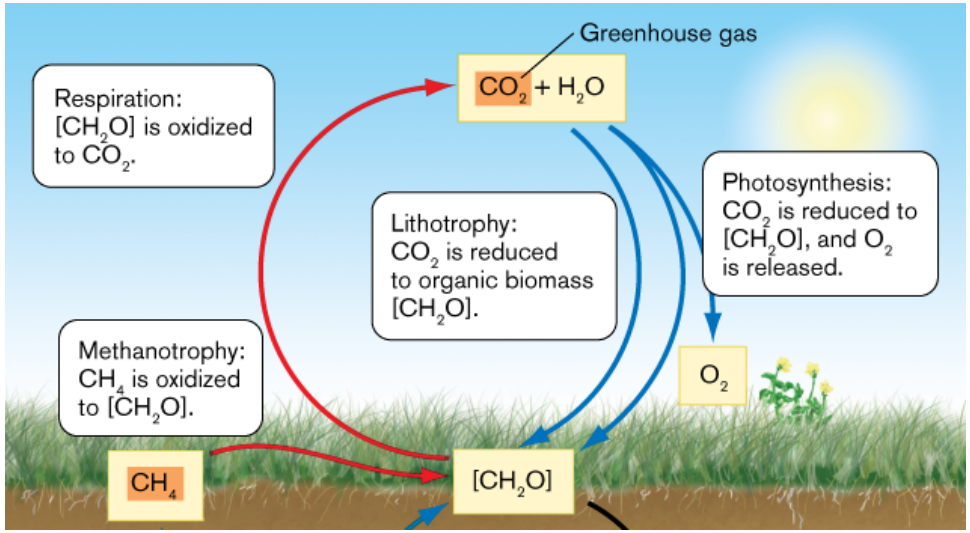
- All living organism elements flow in cycles
  - Rate of cycling varies
    - Biomass vs. organic
    - Environment: atmospheric, land, or ocean
- Lack of necessary elements limits growth
  - Iron
  - Phosphorus
  - Fixed nitrogen
  - Micronutrients

Biogeochemical Cycles

- Elements move from large sources to sinks
  - Reservoirs provide both
    - Ocean important for carbon, nitrogen
    - Land important for sulfur
- Oxidation state governs element reactivity
  - Nitrogen gas plentiful, fixed nitrogen rare
- Measure elements in atmosphere via
  - Chemical reactions
  - Radioactivity measurements

Carbon Cycle

- Major reservoir is ocean
  - Atmospheric reservoir is much smaller
- Aerobic carbon cycling
  - Photosynthesis fixes CO_2 into biomass
    - Produces organic carbon compounds
  - Lithotrophs also reduce CO_2 to biomass
  - Respiration returns CO_2 to atmosphere
    - Net gain of O_2, loss of CO_2 in photic zone



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What process?

What does it need?

RUBISCO & Calvin Cycle

- CO_2 + ribulose 1,5-bisphosphate (5C) → 2 (3C) phosphoglyceric acid

- 6 **CO_2** (from RUBISCO rxn) + 12 **NADPH** + 18 **ATP** → $C_6H_{12}O_6(PO_3H_2)$ + 12 $NADP^+$ + 18 ADP + 17 P_i

- Where does all the NADPH and ATP come from?

Photosynthesis

- *Photo*: Light energy used to make ATP and reducing power (NADPH)

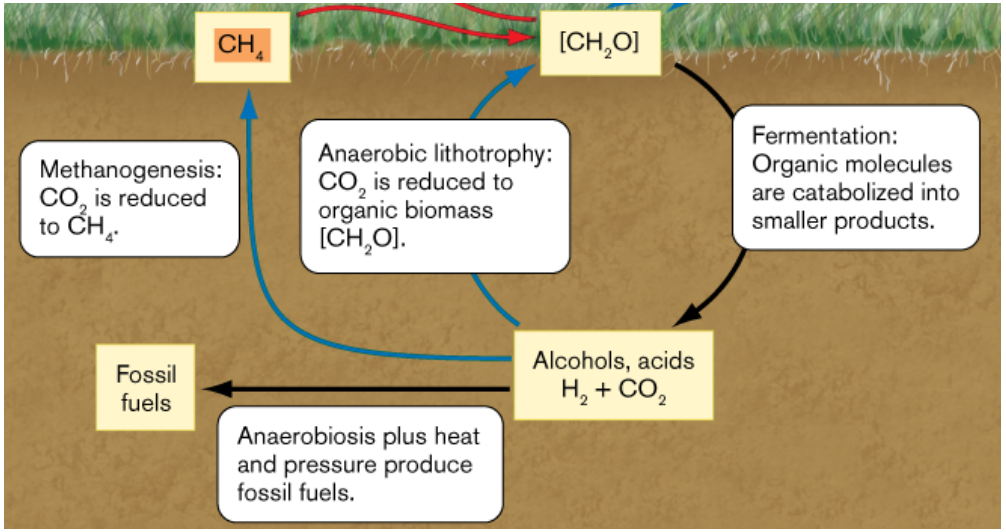
- *Synthesis:* Use ATP and NADPH to reduce CO_2 to Sugar
  - *RUBISCO*
  - *Calvin Cycle*

Photosynthesis

- *Oxigenic:*

- *Anoxigenic: (not the same as anaerobic)*

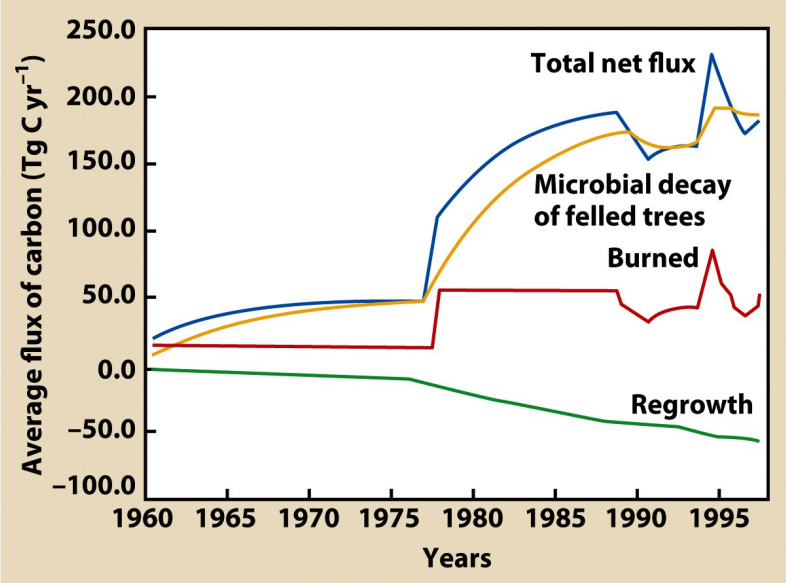
Carbon Cycle



- Anaerobic carbon cycling
  - Lower cycling rate than aerobic cycles
    - Less iron, and less redox potential than oxygen
  - Subsurface environment
    - Soil, benthos, rock
  - Fermentation, lithotrophic respiration
    - Incomplete breakdown of biomass carbon
    - Formation of peat, oil, gas

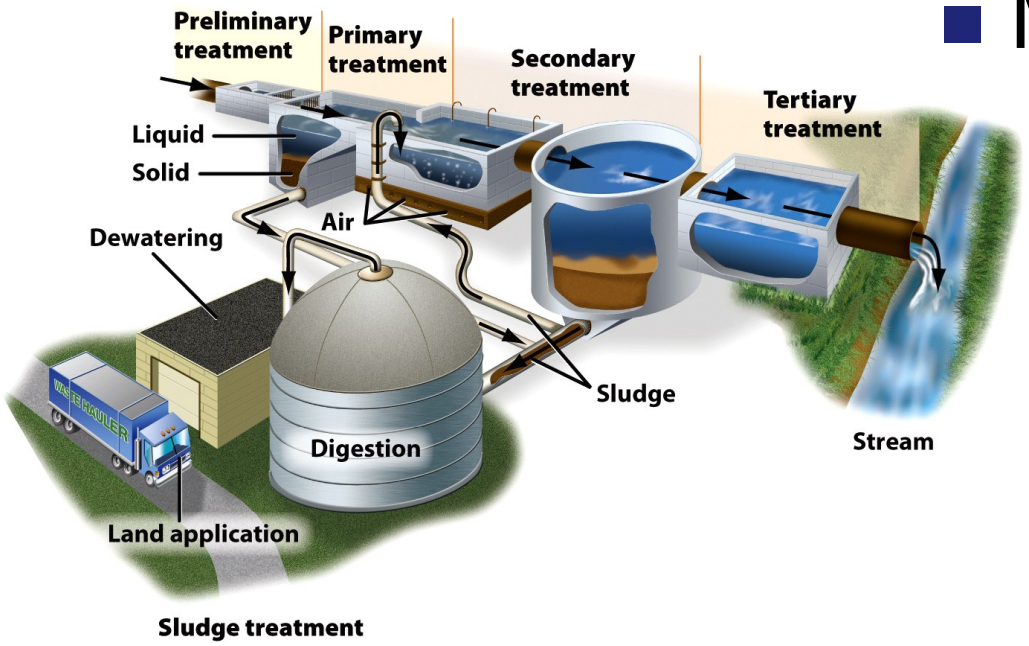
Carbon Cycle

- Human activity accelerates CO_2 release
  - Ocean absorbs most CO_2
  - Increased photosynthesis absorbs CO_2
    - Forests, ocean environments
- Atmospheric CO_2 levels rising
  - Role of newly discovered microbes unclear



Wastewater Treatment

- Natural treatment
  - Wetlands filter water
    - Slow water passage
    - Bacteria in wetland denitrify water



- Municipal treatment
  - Reduce nutrients to reduce BOD
    - Allow microbes to grow, digest nutrients
    - Aerate to restore oxygen levels

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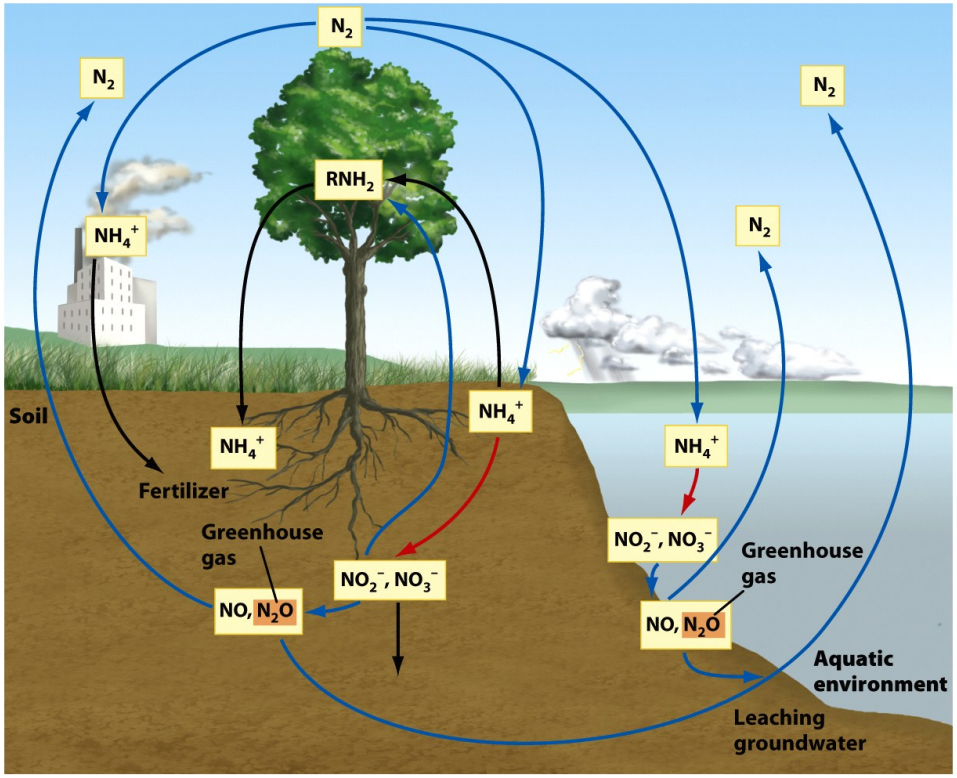
What process?

What does it need?

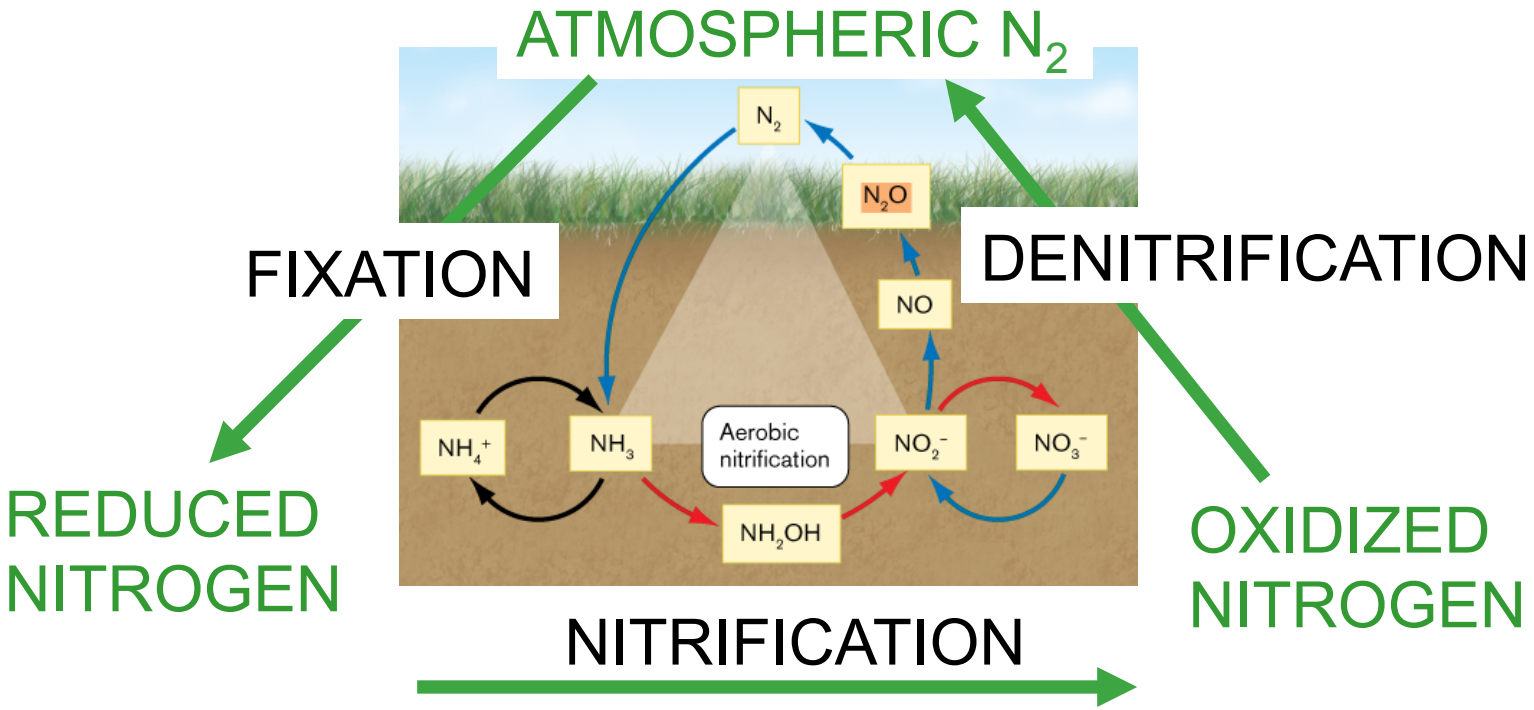
Nitrogen Cycle

- Multiple oxidation states of Nitrogen
  - More than for any other biological molecule



- Prokaryotes crucial for nitrogen conversion
  - Only natural nitrogen fixers
    - Haber process doubled biological fixation

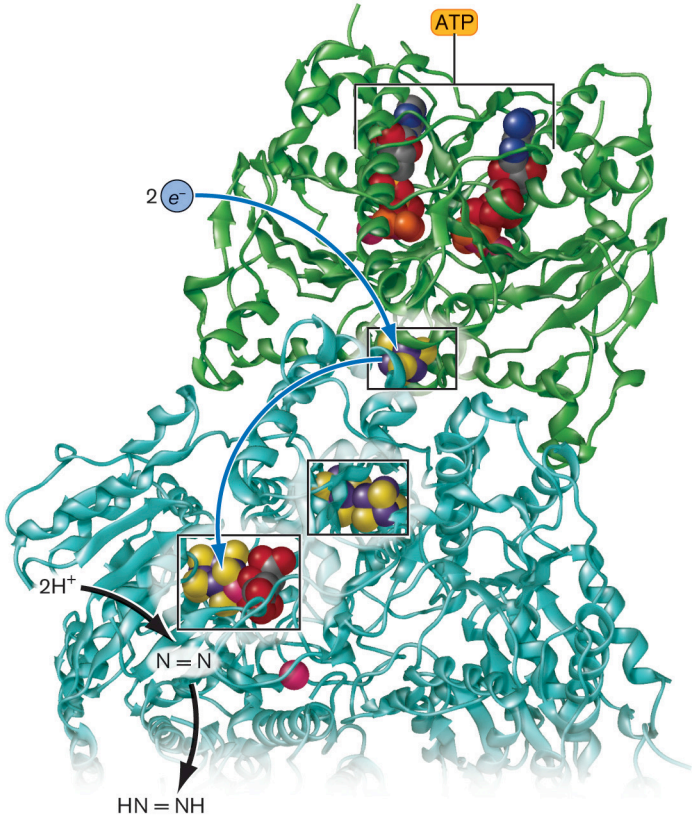
The "Nitrogen Triangle"



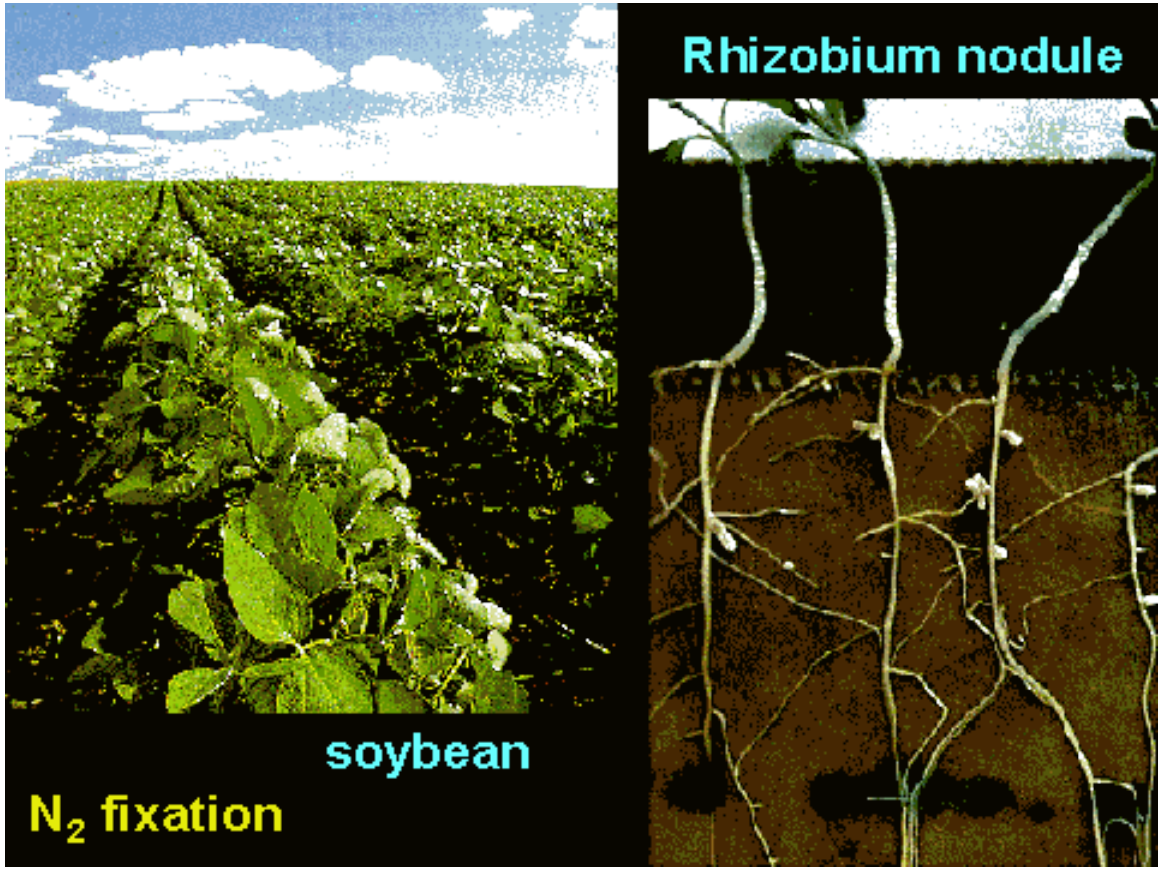
- Both reduced and oxidized N used for biomass

Nitrogen Cycle—N_2 Fixation

- $N_2 \rightarrow NH_3 \rightarrow NH_4^+$
  - NH_4^+ is rapidly assimilated into amino acids
- Catalyzed by nitrogenase
  - Only works anaerobically
  - Occurs in all ecosystems
    - *Klebsiella*, *Clostridium*, *Pseudomonas* in soil
    - *Rhizobium* within legumes
    - Cyanobacteria in oceans, freshwater



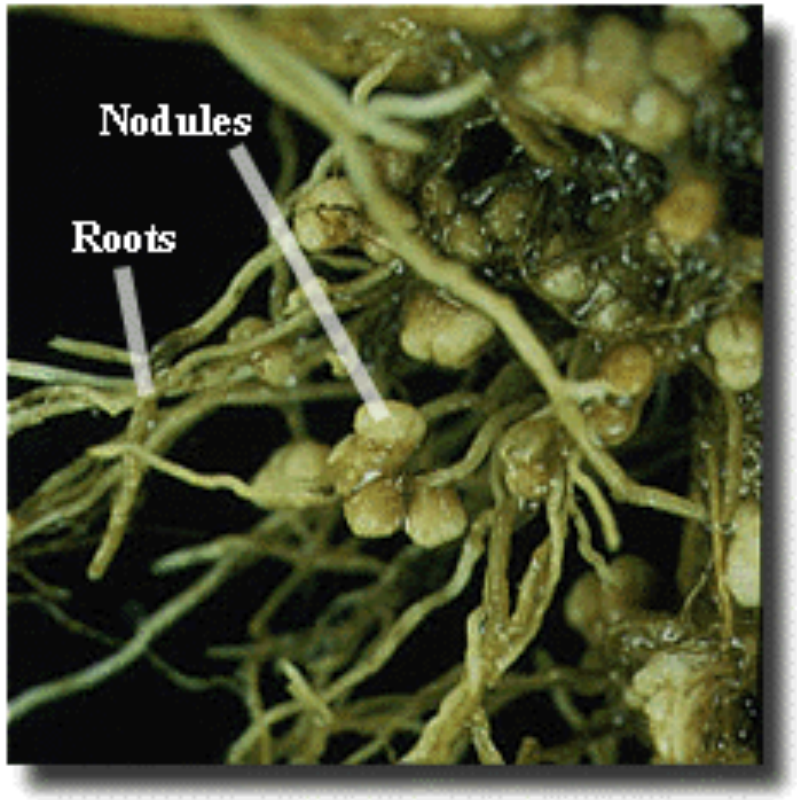
- A mutualistic interaction involving nitrogen fixing bacteria invading the roots of suitable host plant resulting in formation of tumor-like growth called a nodule

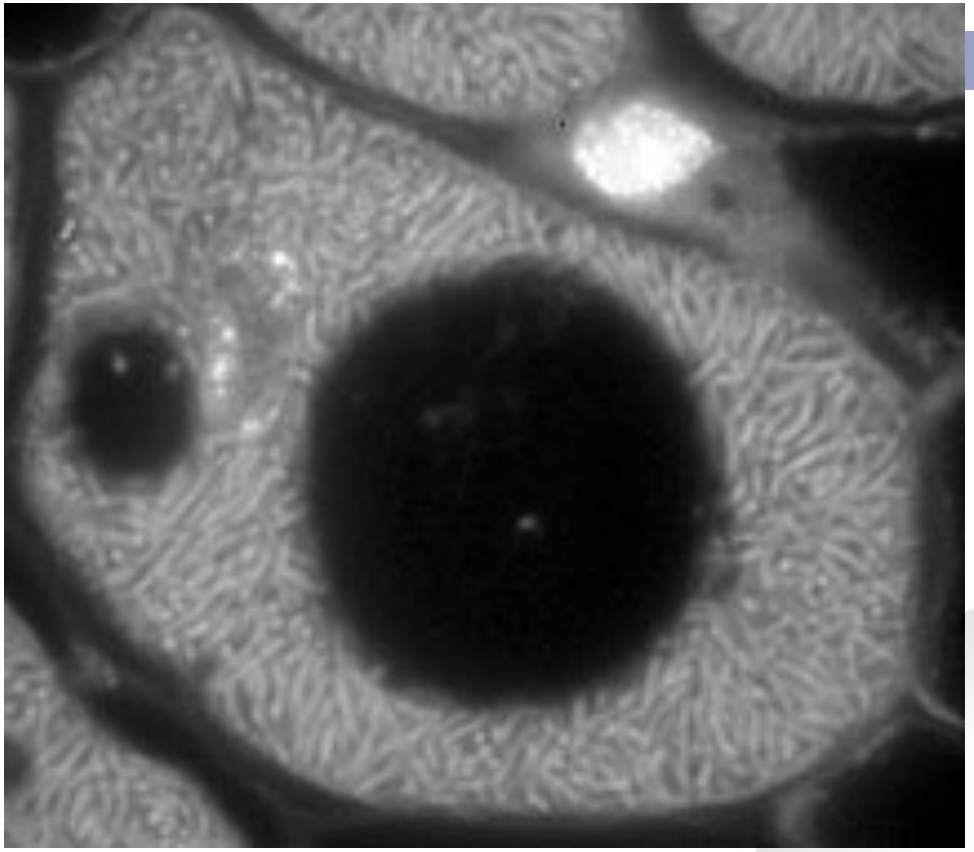


Interaction with plant roots

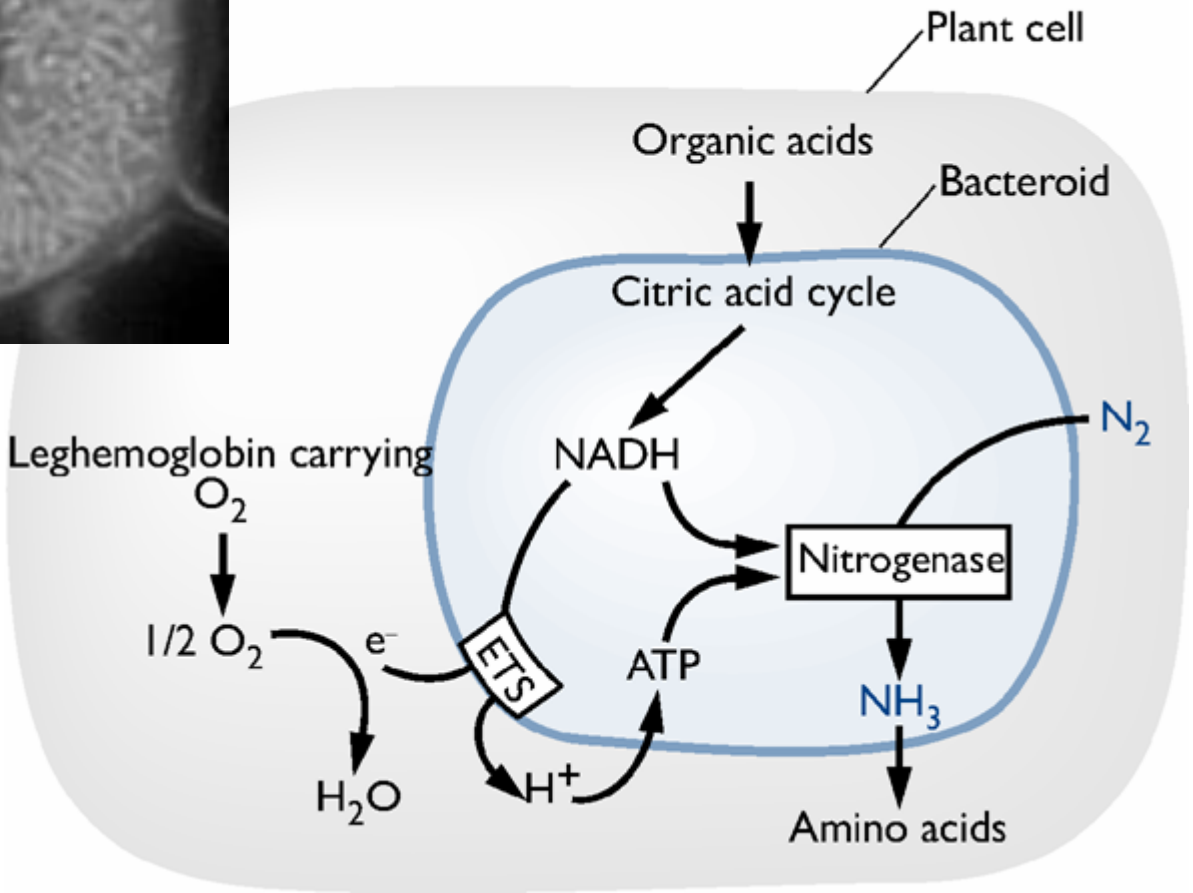
Nitrogen Fixation in Nodules

- Within the nodules N_2 is reduced to NH_3
- Which supplies the bacteria and plant with nitrogen for growth



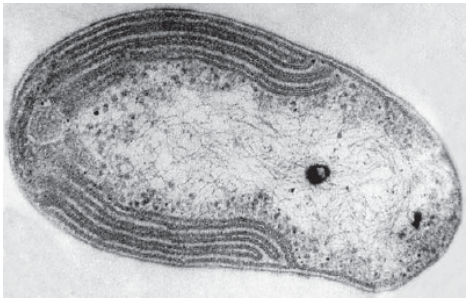


Nitrogen Fixation Association with Legumes



Nitrogen Cycle—Nitrification

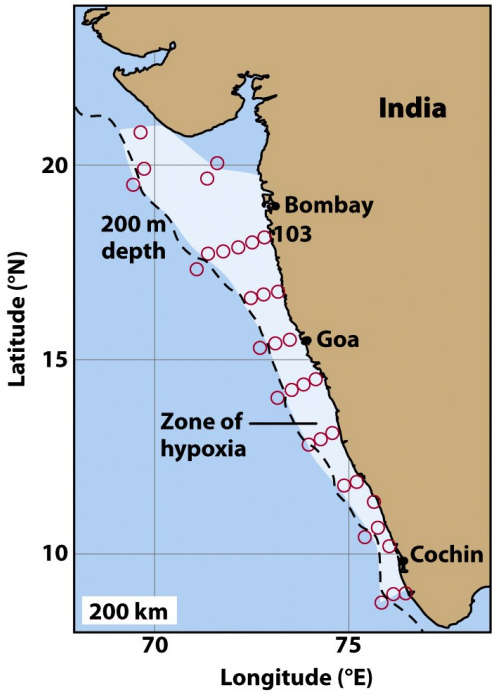
- $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$
  - Oxidation of NH_4^+ provides electrons, energy
  - In soil, one species oxidizes NH_4^+ to NO_2^-
    - *Nitrosomas*
  - 2nd species oxidizes NO_2^- to NO_3^-
    - *Nitrobacter*



- Excessive fertilizer use causes nitrate runoff
  - Eutrophication of streams
  - Danger to water supplies

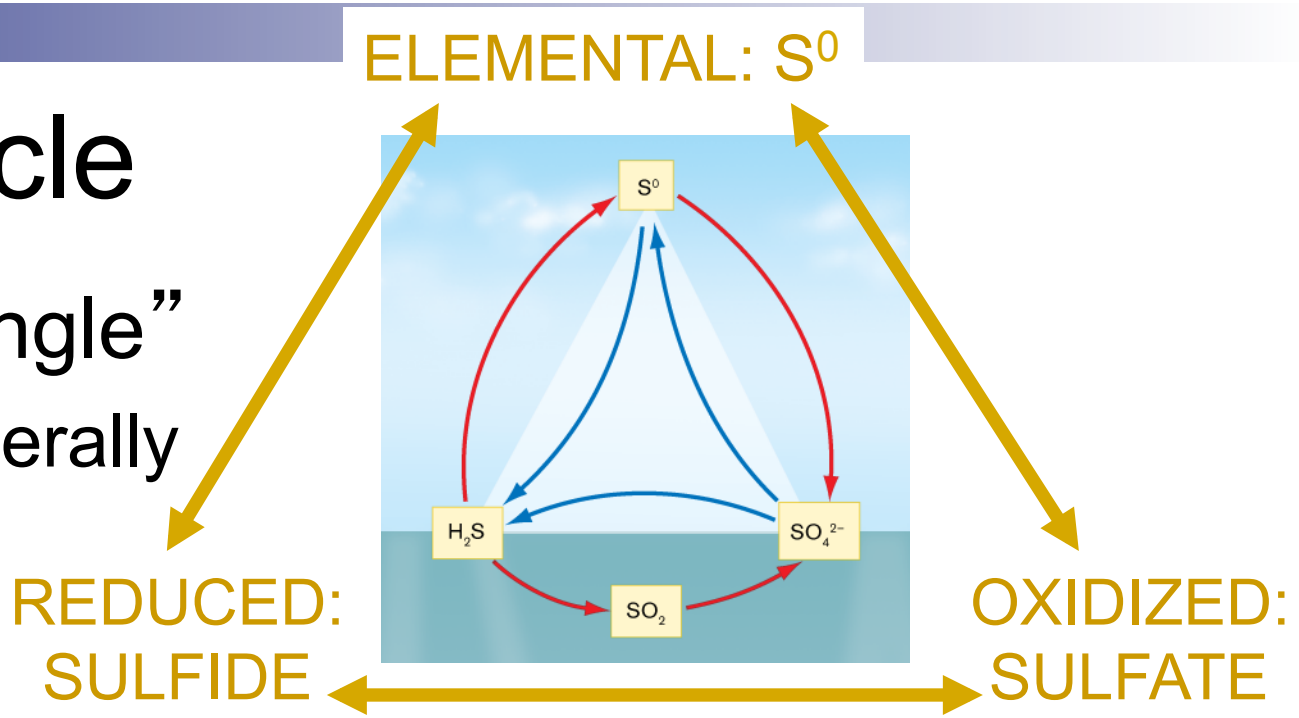
Nitrogen Cycle—Denitrification

- $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$
  - Dissimilatory nitrate reduction
    - Nitrate is anaerobic electron acceptor
  - N_2O (nitrous oxide) buildup if much
    - Prevalent in hypoxic ocean waters
    - Greenhouse gas
  - In some environments, $NO_3^- \rightarrow NH_4^+$
    - Anaerobic sludge, cow rumen
    - H_2 gas available as electron donor



Sulfur Cycle

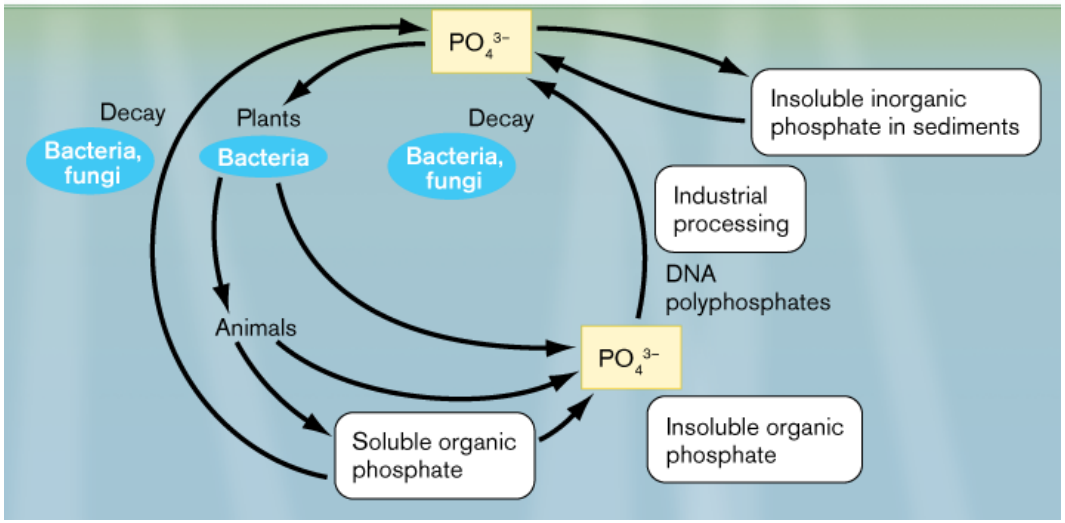
- "Sulfur triangle"
  - Sulfur generally plentiful



- H_2S oxidized by anaerobic respirers
  - Removes toxic gas
- Other respiration reduces $S^0 \rightarrow H_2S$
- Algae excrete dimethyl sulfide → atmospheric S^0

Phosphate Cycle

- PO_4^{3-} plentiful but often insoluble
  - Precipitates with Mg^{2+}, Ca^{2+}
  - Available phosphate limiting in environment
  - Moves from organic to inorganic forms
  - Not often present in reduced form

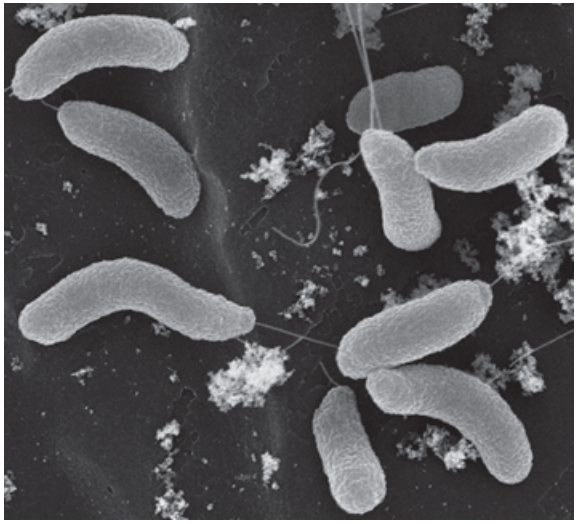


Iron Cycle

- Fe^{3+} (rust) almost insoluble
  - Limiting for growth, especially in ocean
  - Reduced by bacterial assimilation to Fe^{2+}
    - Accumulated via bacterial siderophores
    - Anaerobic respiration to Fe^{2+}
  - Fe^{2+} used by almost all creatures
  - Lithotrophic oxidation: $Fe^{2+} \rightarrow Fe^{3+}$

Other Metals

- Many metals used by bacteria
  - Mn, Hg, As, Cr, V, Se, U
- Bacteria detoxify some elements
  - Cr(VI) → Cr(III)
  - Soluble U(VI) → U(IV)
  - Precipitates from solution
    - *Desulfovibrio desulfuricans*



- Bacteria make some elements more toxic
  - $Hg^0 \rightarrow (CH_3)Hg^+$

Astrobiology

- Life on other planets?
  - What evidence for life?
  - Biosignatures
    - Microfossils
    - Isotope ratios
      - $^{12}C/^{13}C$ affected by life
    - Mineral deposits
      - Some deposits caused by living organisms
    - Metabolic activity
      - Carbon cycling? Isotope tracers

Astrobiology

- Mars?
  - Water present?
    - Essential for all life
    - Likely present in the past
  - Life in the past?
  - Life in the present?
    - Underground?
- Europa
  - Liquid ocean present?