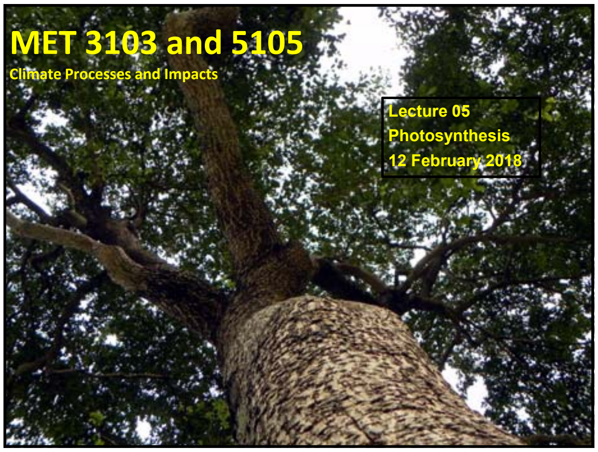
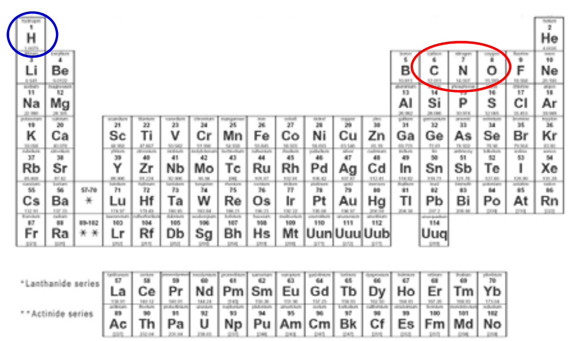


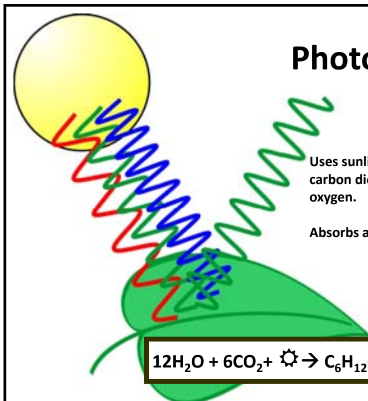
I saw in Louisiana a live-oak growing,
All alone stood it, and the moss hung down from the branches;
Without any companion it grew there, uttering joyous leaves of dark green,

Walt Whitman, *Leaves of Grass*

We live on the upper right side of the Periodic Table



Photosynthesis

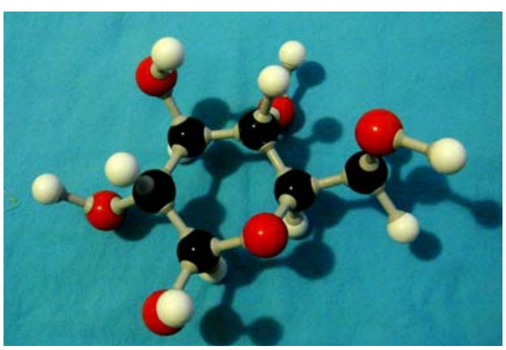


Uses sunlight to combine water and carbon dioxide to make glucose and oxygen.

Absorbs at 0.662 and 0.430 µm.

$12H_2O + 6CO_2 +$ ☼ $\rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$

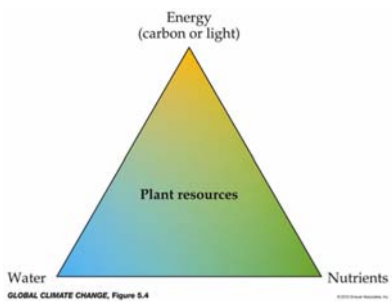
GLUCOSE



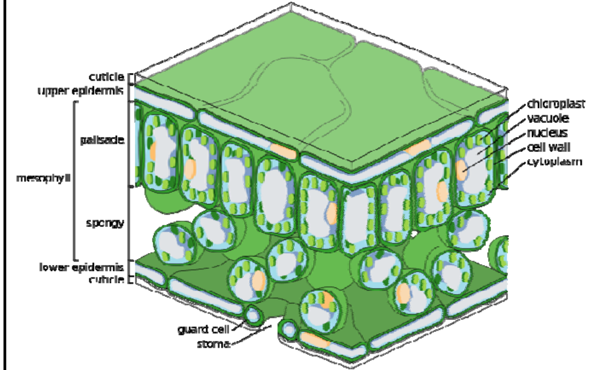
What Does this Mean for the Planet?

- Only a small fraction (0.001%)of the Earth's crust's total carbon in in the atmosphere
- The rest is in:
  - Limestone (99.924%)
  - Dissolved in the sea (0.063%)
  - Fossil fuels (0.007%)
  - Biomass (0.003%)
- The reason CO_2 is building up in the atmosphere is that we are digging up carbon and burning it faster than photosynthesis (or chemical weathering of rocks and dissolving in the sea) can suck it out of the air

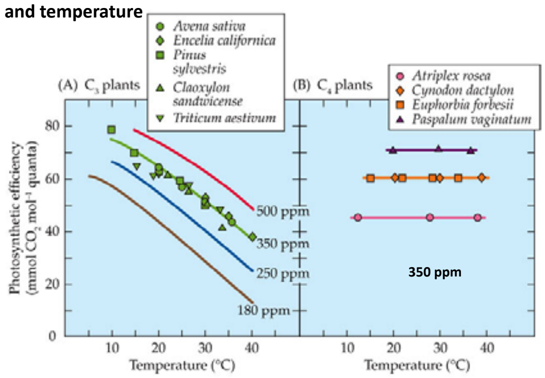
Plant Resources Triangle



Structure of a Leaf



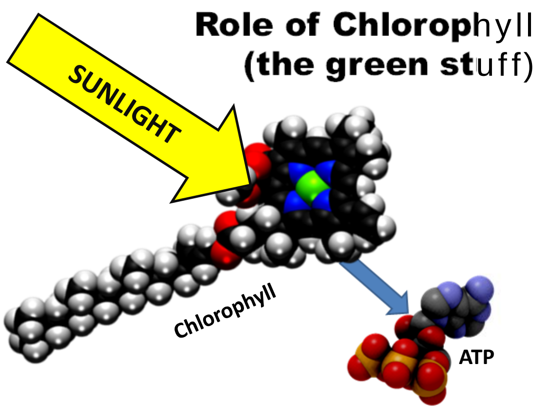
Photosynthetic Efficiency as Functions of CO_2 concentration and temperature



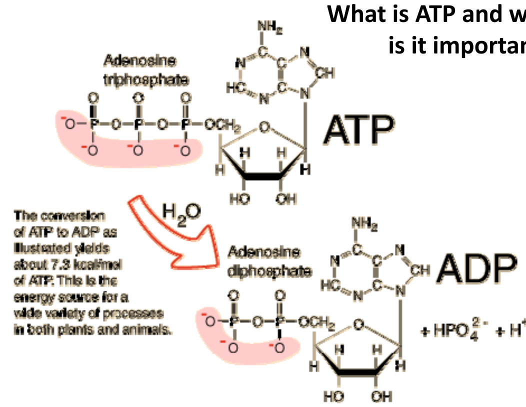
Basics of Photosynthesis

- Simplified reaction $CO_2 + H_2O \longrightarrow H_2CO + O_2$
- Happens in specialized ***Chloroplasts*** (organelles in leaves)
- C3 Photosynthesis
  - Plant takes CO_2 directly from air during the day
  - Works best when its cool with plenty of H_2O, sunlight, and CO_2
  - Evaporate 500-1000 H_2O molecules for every CO_2 assimilated
  - Rice, wheat, barley
- C4 Photosynthesis
  - Plant stores CO_2 in Mesophyll cells
  - Pumps CO_2 to bundle-sheath cells for C3 fixation
  - Works best when its warm, with lower CO_2, and needs less water
  - Evaporate 300-400 H_2O molecules for every CO_2 assimilated
  - Corn, sorghum, sugarcane, millett, amaranth
- CAM (Crassulacean Acid Metabolism) Photosynthesis
  - Stomata open at night to let in CO_2
  - Close during the day to trap water while photosynthesis rolls
  - Mostly in Cacti
- Photorespiration in leaves competes with photosynthesis

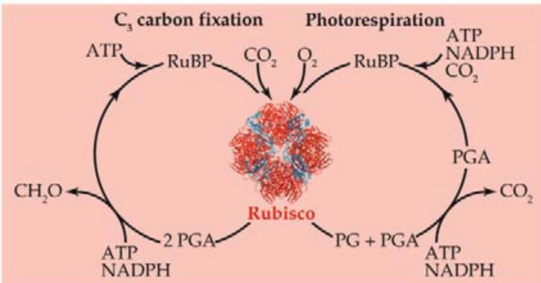
Role of Chlorophyll (the green stuff)



What is ATP and why is it important?

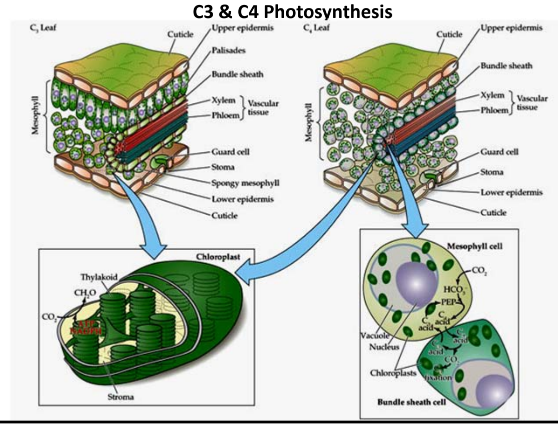


Photosynthesis and Photorespiration

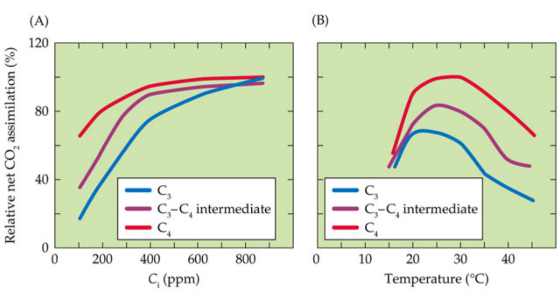


Calvin-Benson Cycle

C3 & C4 Photosynthesis

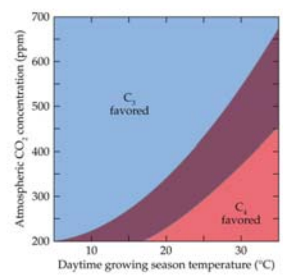


CO_2 Assimilation as Functions of Concentration and Temperature

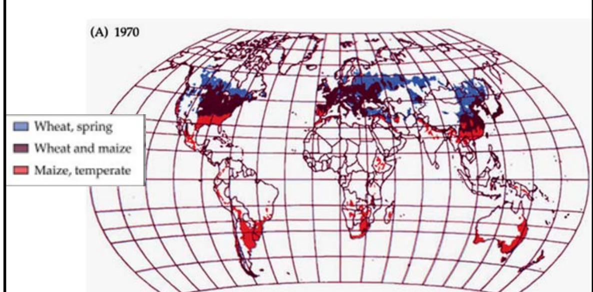


Comparing C3 and C4 Fixation

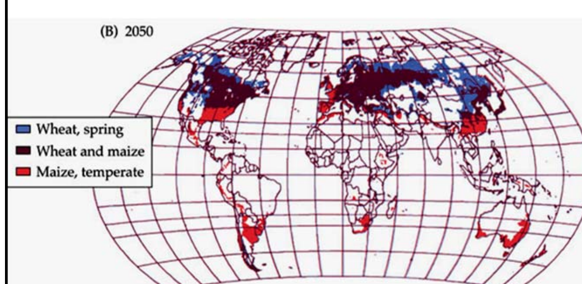
- C3 Advantages
  - Do better in high CO_2 concentrations
  - Physiologically simpler
  - More efficient at lower temperatures
- C4 Advantages
  - Do better in low CO_2 concentrations and bright sunlight
  - Conserve water better
  - More efficient at higher temperatures

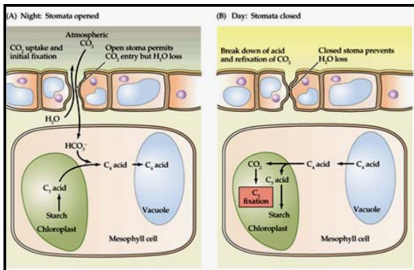


Maize & Wheat in 1970



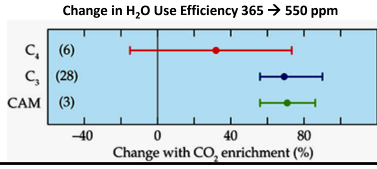
Maize & Wheat in 2050

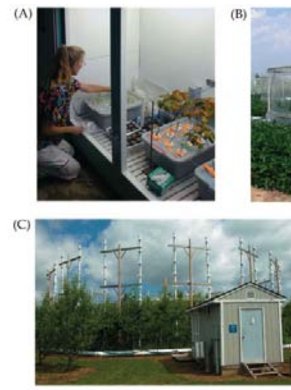




Crassulacean Acid Metabolism (CAM)

Change in H_2O Use Efficiency 365 → 550 ppm



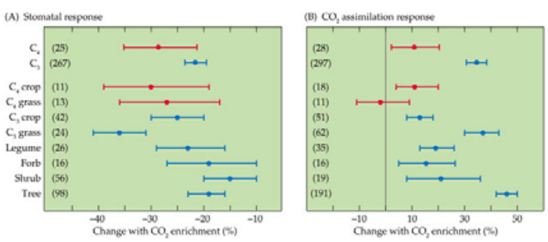


(A) Environmental Chamber
(B) Open-top field chamber
(C) Free-air CO_2 enrichment

GLOBAL CLIMATE CHANGE, Figure 5.14

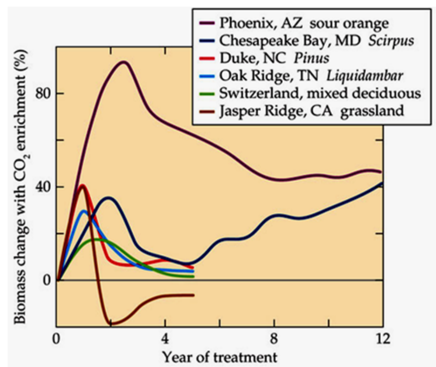
Plant Response to More CO_2

366 ppm → 585 ppm

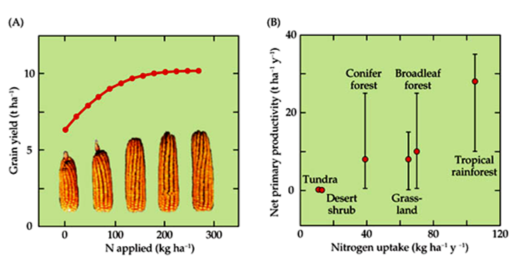


C3 Plants keep stomata open more and fix more carbon
C4 Plants have less dramatic response

Plants Acclimate to More CO_2



Fixed Nitrogen Availability Affects Plant Growth Crop Yields and Protein Content



GLOBAL CLIMATE CHANGE, Figure 5.20

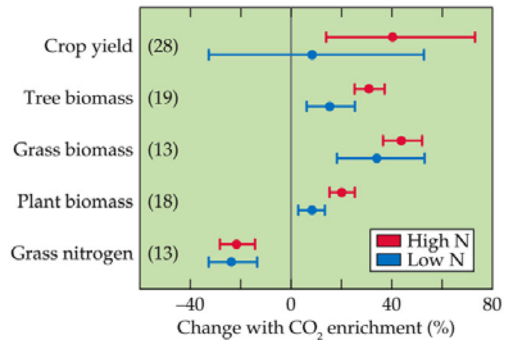
Nitrogen Chemistry

- Haber-Bosch process $N_2 + 3H_2 \text{-->} 2NH_3$
  - Makes ammonia for fertilizer & explosives
- Biological equivalent in some bacteria and cyanobacteria
  - $N_2 + 8e^- + 8H^+ + 16ATP \text{-->} 2NH_3 + H_2 + 16ADP + 16Pi$
- Dissolves in H_2O to make ammonium ion
  - $NH_3 + H_2O \text{-->} NH_4^+ + OH^-$
  - Enters biochemical processes to make Amino Acids (Protein) and Nitrate (NO_3^-)
  - Plants use NH_4^+ and NO_3^- differently in elevated CO_2

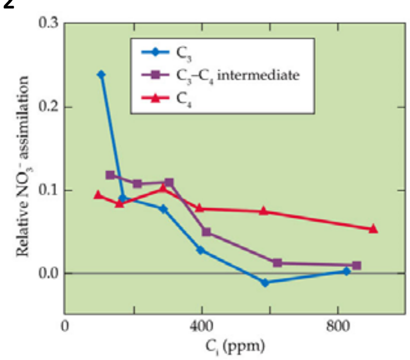
Making Protein From NH_4^+ and NO_3^-

- How to make amino acids for protein:
  - NH_4^++ organic acid + 2ATP + e^- --> amino acid + 2ADP + $2P_i$ +H_2O
  - Requires ammonium and uses only 2 ATP --> ADP
- How to make ammonium from nitrate:
  - NO_3^- +10ATP + 10H$^+$ + 8e– --> NH_4^+ + 10ADP + 10P_i + 3H_2O
  - Making amino acid from nitrate eats a total of 12 ATPs; whereas making it from ammonium takes only 2ATPs.
- On the other hand plants can store NO_3^- more readily
- If both NH_4^+ and NO_3^- are available, most plants will prefer NH_4^+, but if fixed nitrogen is scarce, they will use whatever they can get.

How Does More CO_2 Affect Crops?



CO_2 Affect on Nitrate Assimilation

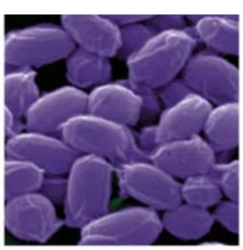


Bloom's Hypothesis

- Photorespiration is not an evolutionary relic that wastes energy
- It generates the NADPH needed to convert nitrate to ammonium
- In C3 Photosynthesis elevated CO_2 (or low O_2) that inhibits photorespiration also inhibits nitrate availability to make protein
- This effect makes C3 plants more energy efficient
- But also makes C3 crops poorer in protein on a high CO2 world
- C4 plants are much less sensitive to high CO_2
- Decreased protein content in C3 forage and food crops (wheat, rice) could be a big deal for our future

Plants and Animals also Use CO2 for Environmental Signaling

Anthrax



Aedes aegypti (Dengue fever and Zica)

SUMMARY

- **Photosynthesis makes sugars CO_2 + H_2O --> H_2CO + O_2 in chloroplasts of plants**
- **Role of ATP**
  - Made (regenerated ADP --> ATP) when sun shines on Chlorophyll in green plats
  - Used in Calvin-Benson cycle to make sugar
  - Sugar used in mitochondria (of plants & animals) to make ATP (ADP --> ATP)
  - ATP supplies energy for everybody's metabolism (ATP --> ADP)
- **C3 Photosynthesis (rice wheat)**
  - CO_2 absorbed directly from air
  - Photosynthesis in palisade cells
  - Energy efficient, water inefficient
  - Better in wetter, cooler, high CO2 environments
  - Elevated CO_2 increase yields, but decreases protein production
- **C4 Photosynthesis (maize, corn)**
  - CO_2 stored in spongy mesophyll cells as bicarbonate (HCO_3^-) during the night
  - Released as CO_2 in bundle sheath cells
  - Photosynthesis in chloroplasts
  - Less energy efficient, more water efficient
  - Better in dryer, warmer, low CO_2 environments
  - Not so responsive to elevated CO_2
- **CAM Crassuleacean acid metabolism(Cacti)**
  - Absorb CO_2 during the night, phorosynthesize during the day
- **Bottom line: Higher CO_2 levels and warmer temperatures may extend areas where crops grow.**
- **But protein content of C3 crops (rice, wheat) may decrease (Bloom's hypothesis)**