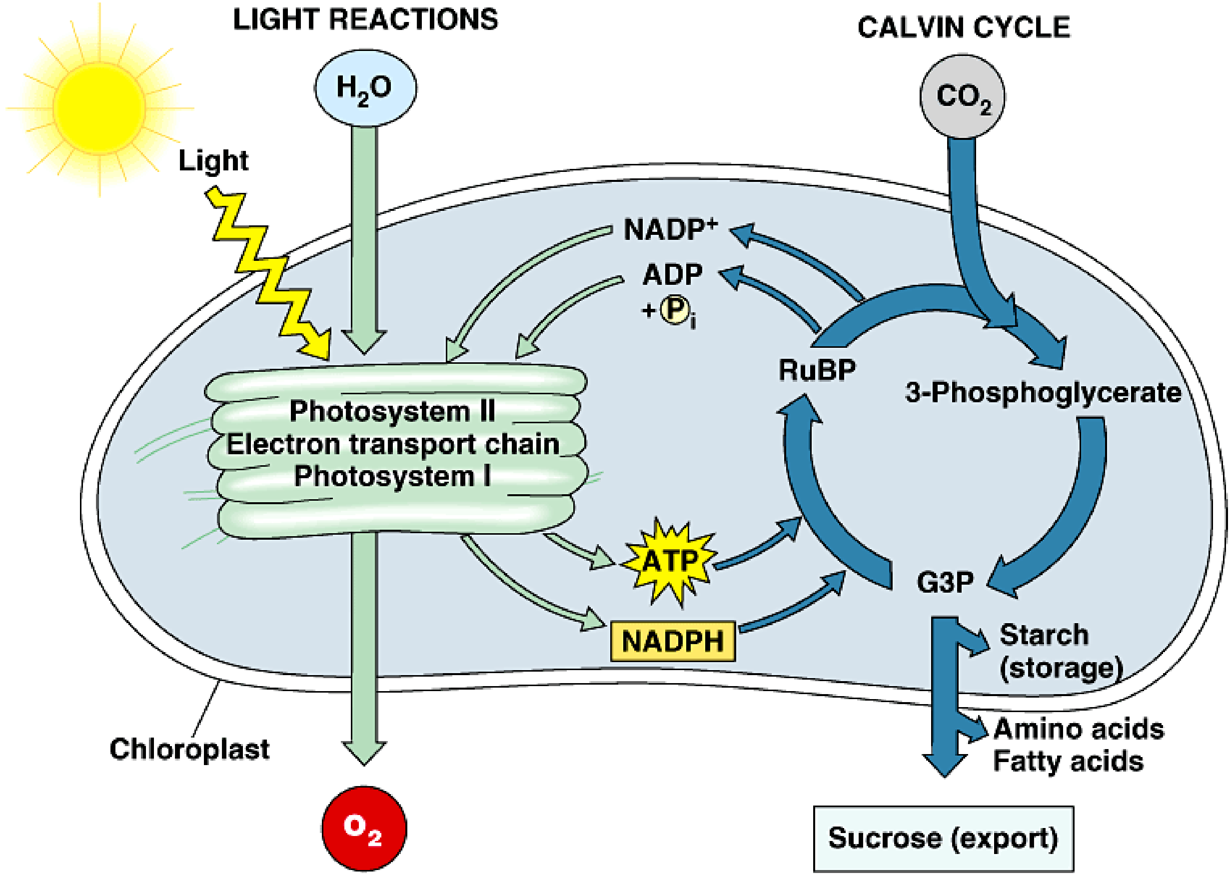

Light reactions:

- done by molecules in thylakoid membranes
- convert light to chemical energy (ATP & NADPH)
- split water and release oxygen & H^+

Calvin cycle reactions:

- in the stroma
- use ATP and NADPH to make sugar
- return ADP, P & NADP to light reactions

Reviews

The most abundant protein in the world

R. John Ellis

The most abundant protein in nature is probably the chloroplast enzyme ribulose bisphosphate carboxylase/oxygenase (Fraction I protein). It is arguably the most important enzyme because it catalyses the carbon dioxide-fixing step in photosynthesis. The synthesis of this protein depends upon the interaction of nuclear genes with the genetic system located in the chloroplast, and involves the transfer of polypeptides across the chloroplast envelope by a post-translational mechanism.

New Phytologist

Commentary

Rubisco: still the most abundant protein of Earth?

Ribulose bisphosphate carboxylase-oxygenase (Rubisco) is the core autotrophic carboxylase in all oxygenic photosynthetic organisms, and > 99.5% of the inorganic carbon (C) assimilated in primary producers (chemolithotrophs as well as photolithotrophs) involves Rubisco (Raven, 2009). The global gross primary productivity of at

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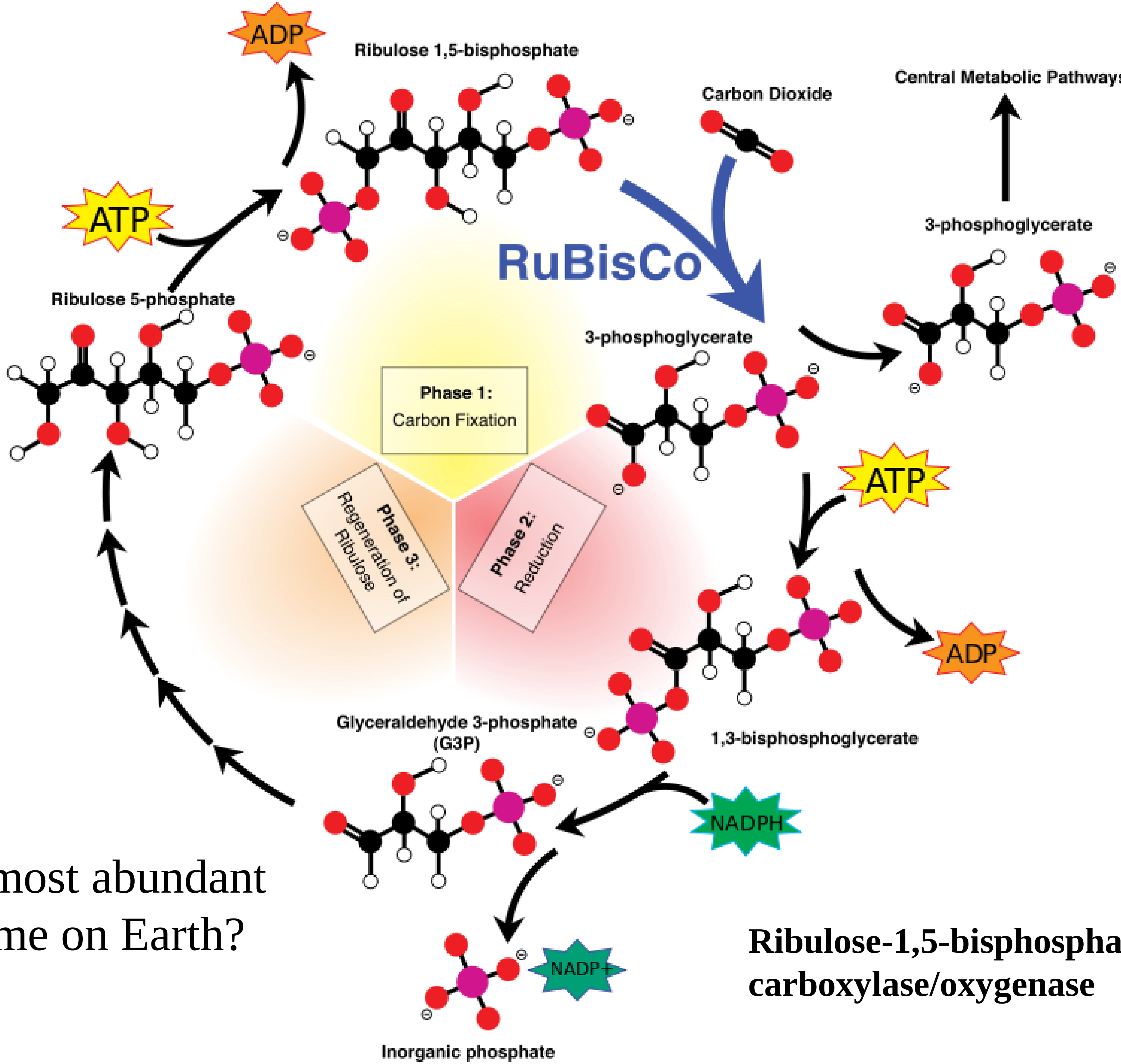
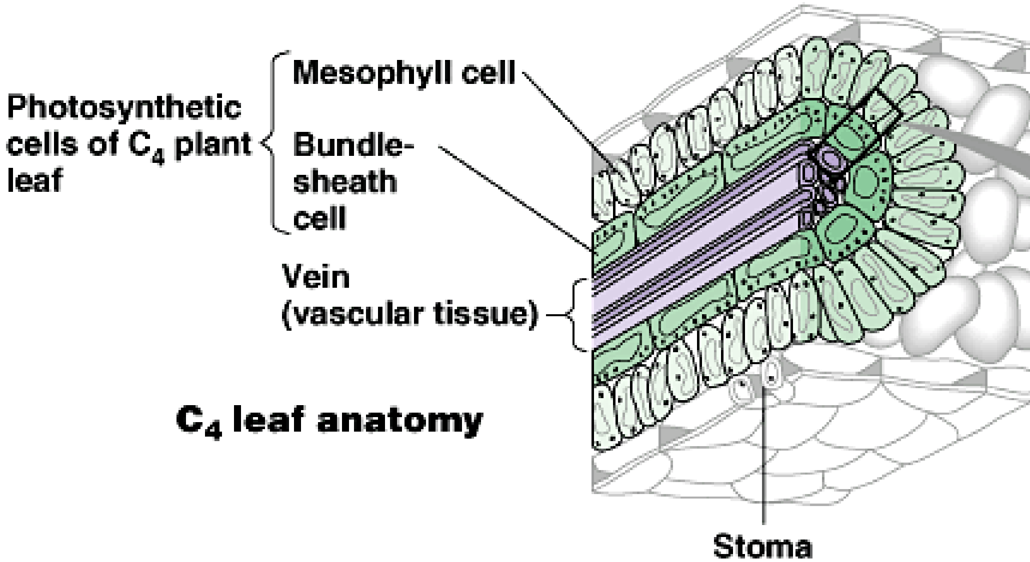


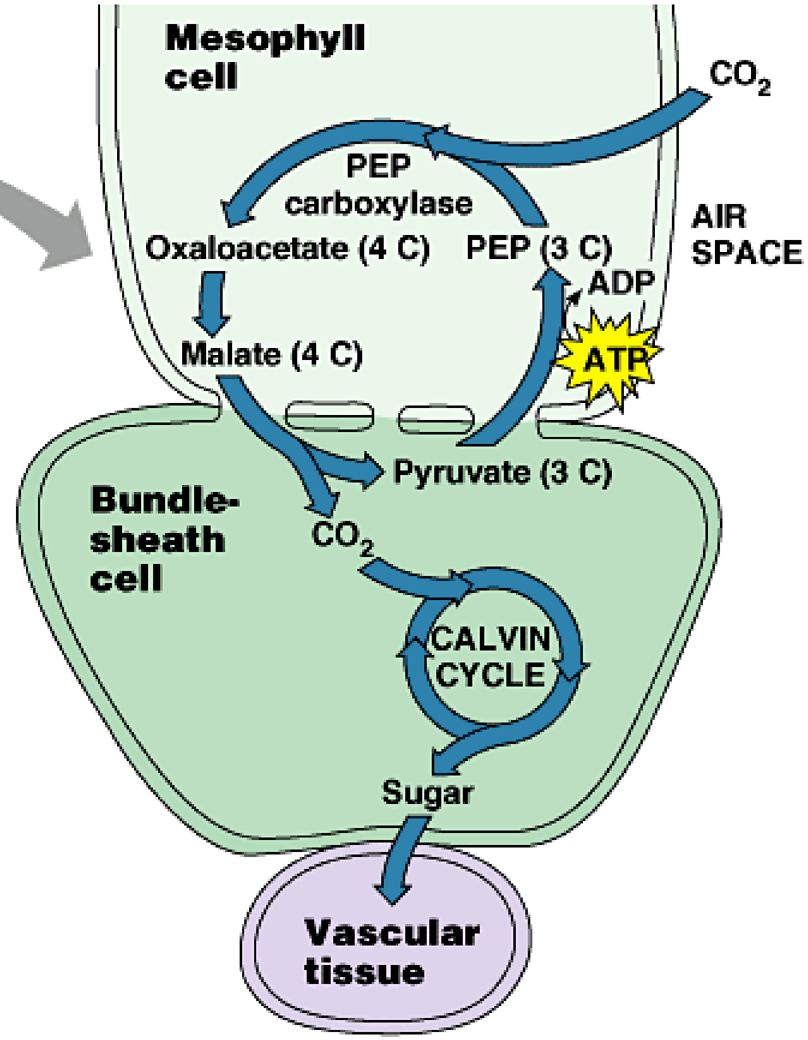
The most abundant enzyme on Earth?

Ribulose-1,5-bisphosphate carboxylase/oxygenase

C_4 photosynthesis: what is it?



C_4 leaf anatomy



The C_4 pathway

Phosphoenolpyruvate carboxylase – *note it's not an oxygenase…*

What does C_4 photosynthesis accomplish in hot dry climates?

The problem is dehydration. Why is it such a big problem?

Source of water for light reactions? Soil via roots and stems; via veins made of xylem

How is water lost from leaves? Via interstitial spaces surrounding mesophyll cells in leaves, and open stomata

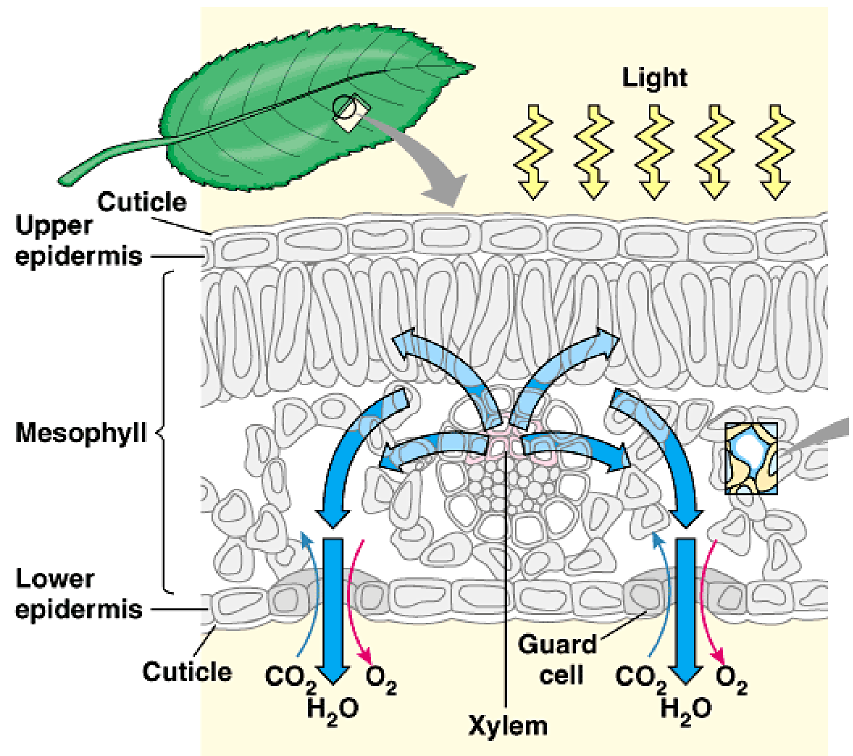
Why are stomata open? CO_2 needed for photosynthesis

On hot, dry days, C_3 plants do close stomata to prevent water loss; tradeoff = ?

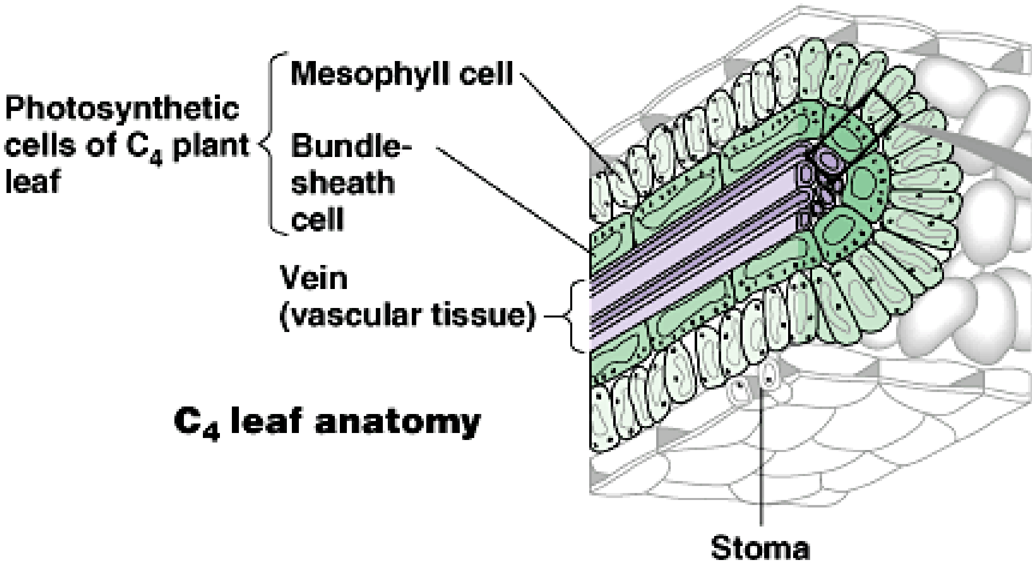
Less photosynthetic output to avoid water loss due to transpiration

Another problem: **photorespiration**

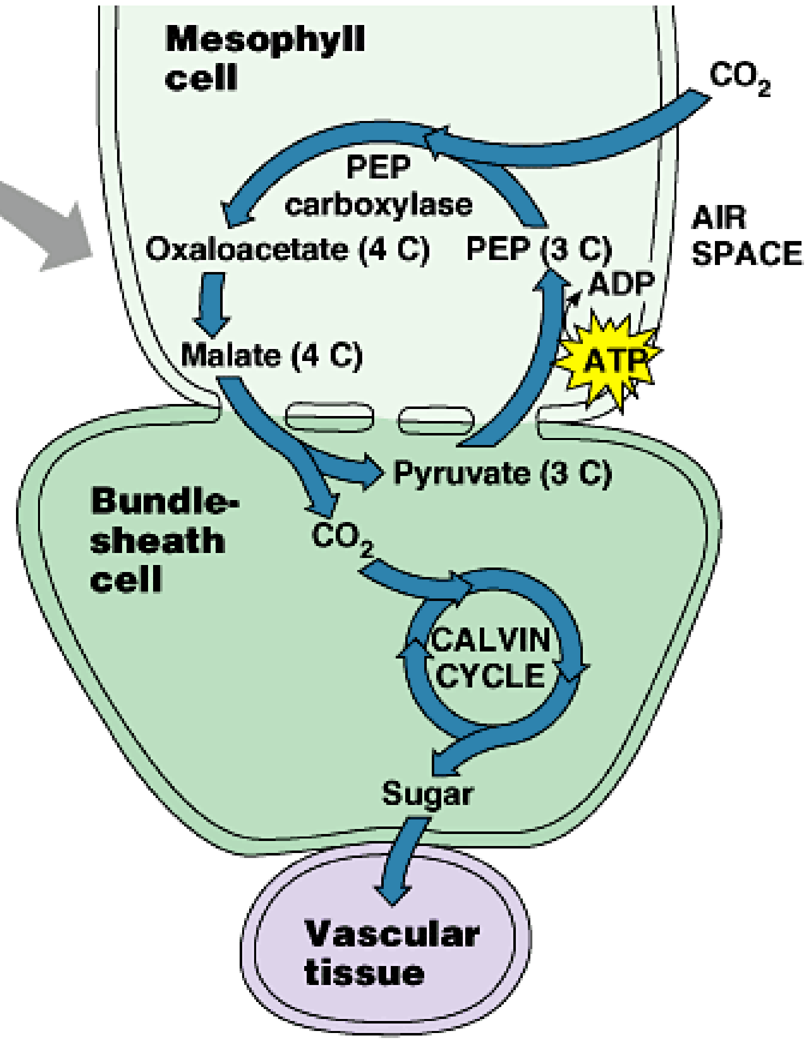
With stomata closed, rubisco accepts O_2 making a product that does **not** generate ATP or make food



How do C_4 plants solve this problem?



C_4 leaf anatomy



The C_4 pathway

PEP carboxylase has much higher affinity for CO_2 than O_2

On hot dry days, stomata close, PEP-C uses all remaining CO_2, transports it to Calvin cycle.

Result relative to C_3 plants?:

- transpirational water loss?
- sugar production?

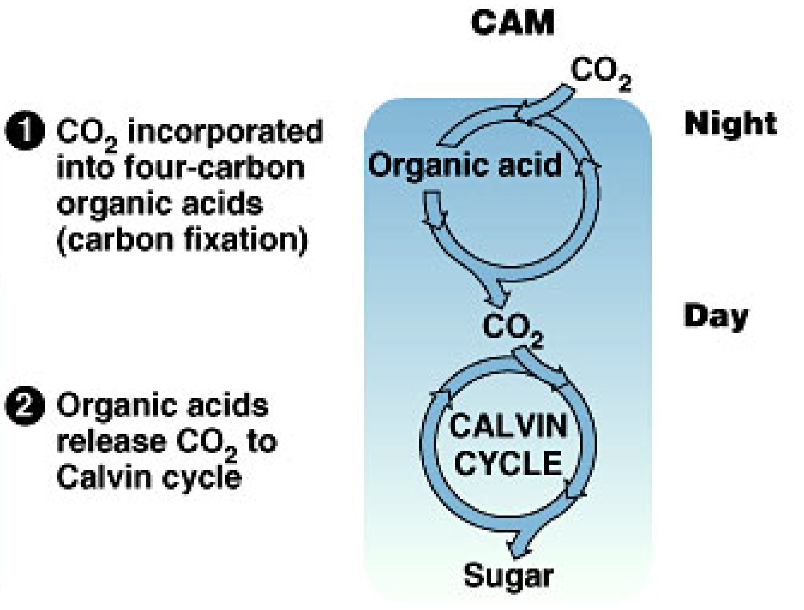
A different way to solve the same problem….. CAM photosynthesis

Stomata closed during hot dry days, open at night

CO_2 fixed during the night only
(stored as organic acids - malate)

Calvin cycle runs during the day. Why?

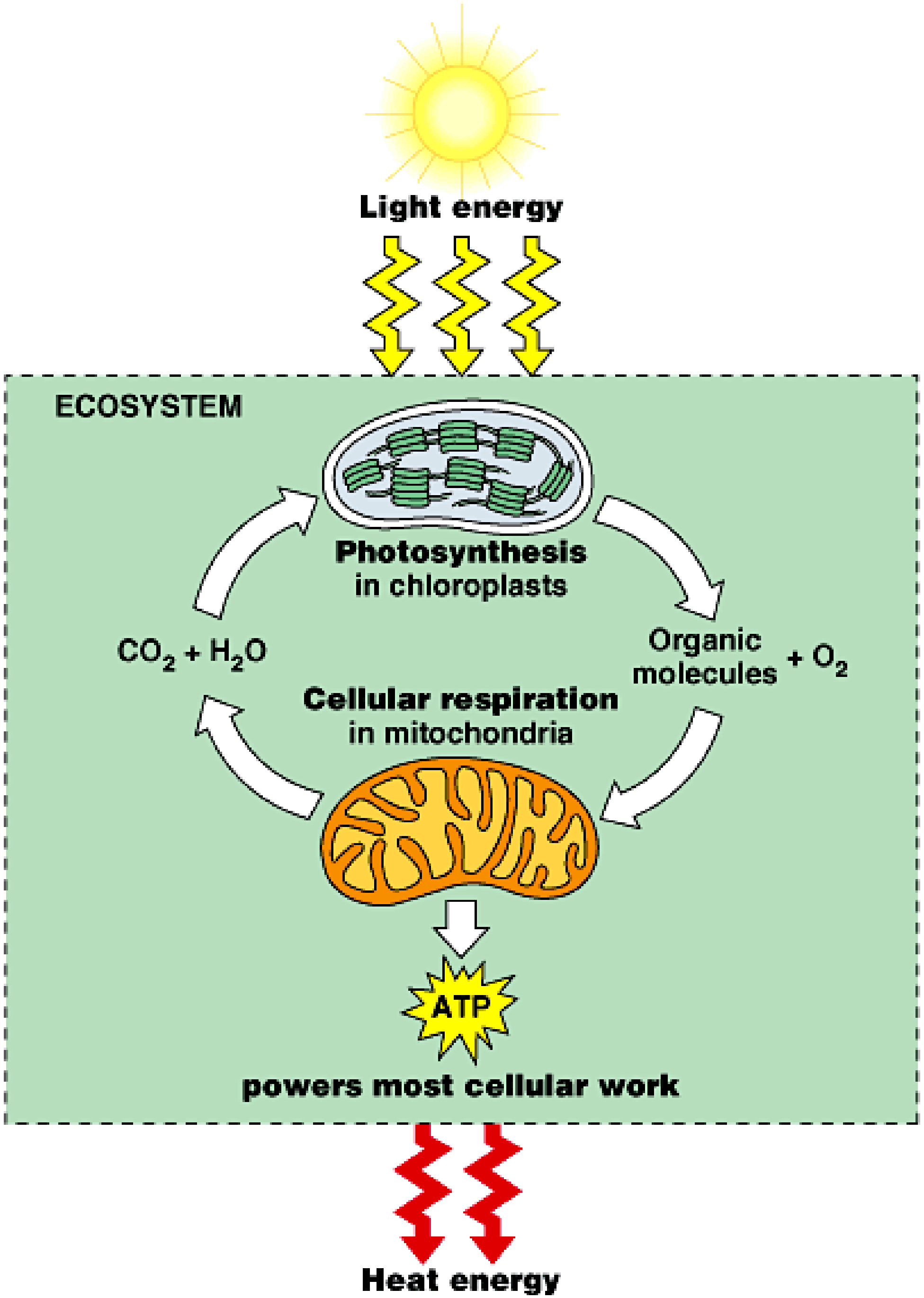
ATP and NADPH needed to fuel Calvin cycle comes from light reactions



(b) Temporal separation of steps

Crassulacean acid metabolism

Why is photosynthesis so important to us?



Sugar products become:

body of living plant: macromolecules.. organs

fuel for cellular respiration in plants

stored sugar – starch in roots, tubers, seeds, fruits

Any other reasons why photosynthesis matters?

Source of oxygen

Sink for carbon dioxide

Primary production fuels all heterotrophic life

What effects might current trends in climate change have on photosynthesis?

Warming?

Enzymatic processes involved

Membranes involved

Higher atmospheric CO_2?

Increased primary production?

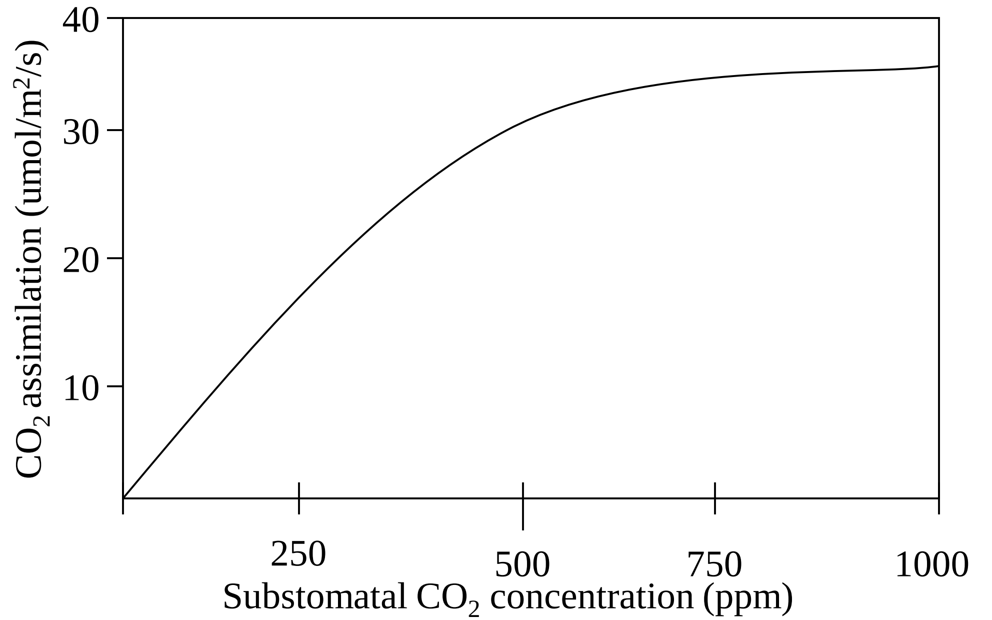


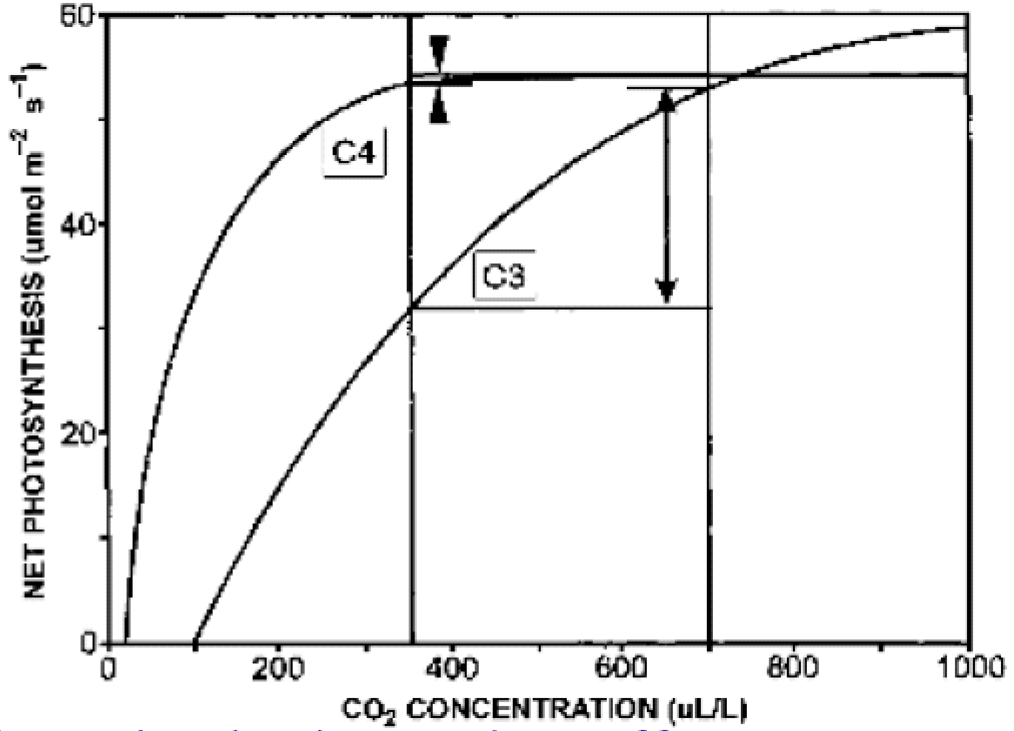
Fig. 1. The effect of CO_2concentration on the rate of photosynthesis in a potato leaf

C_3 vs C_4 plant response?

Water use efficiency? WUE = $\frac{CO_2 \text{ assimilated}}{\text{water lost}}$

- 2 scenarios for how WUE might increase with increasing CO_2

Photosynthetic response to CO_2 levels

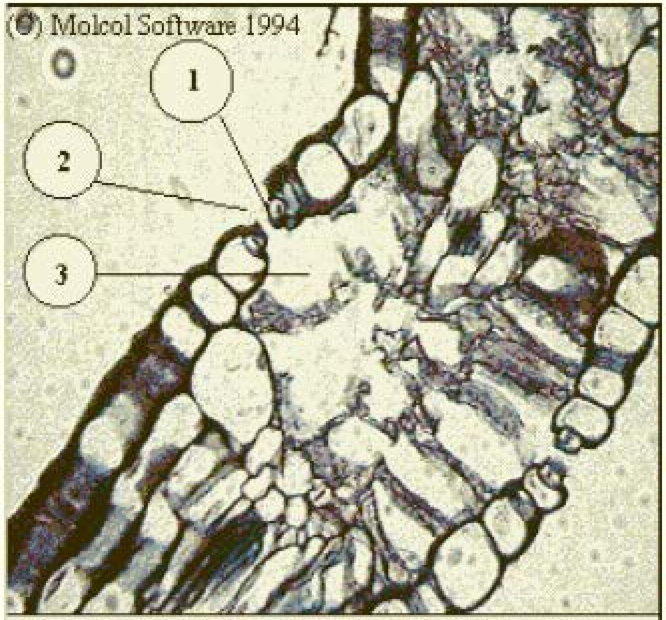


C3 plants (most plants) - photosynthetic efficiency continues rising at high (3-4x preindustrial) CO_2 levels

C4 plants (warm-climate grasses) - photosynthetic efficiency levels off about at modern CO_2 levels

Stomata

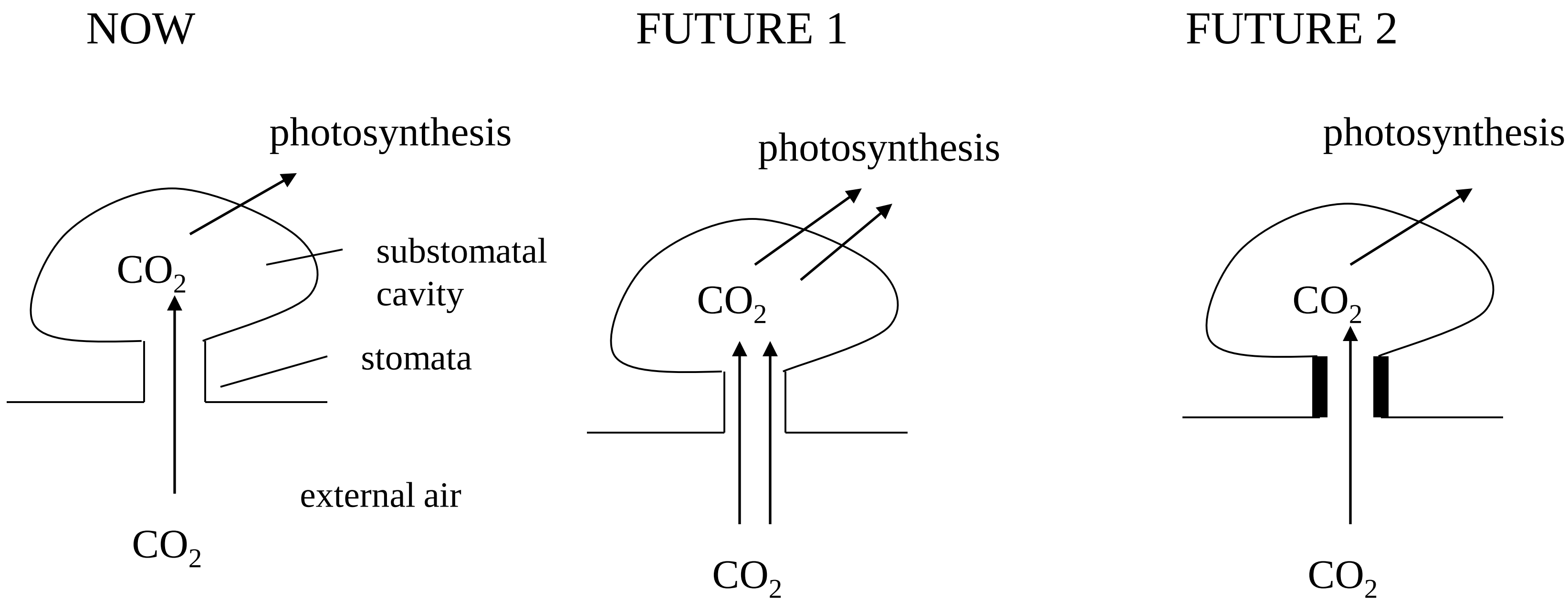
Leaf openings through which CO_2 is taken in and water is lost



Two stomata are visible - one on each side of this leaf section. A Stoma consists of the pore itself -(2) and the two surrounding guard cells - only 1 indicated -(1). The air space -(3) is also visible. (Image from Molcol Software)

Leaf X-section

Leaf surface



Increase in atmospheric CO_2 will increase WUE of a plant:

$$\textbf{WUE} = \frac{\textbf{CO2 assimilated}}{\textbf{water lost}}$$

In FUTURE 1: photosynthesis increases because stomata are unaffected,

CO_2 assimilated increases,

water loss stays constant

In FUTURE 2: stomata close partially, (reacting to higher atmospheric CO_2)

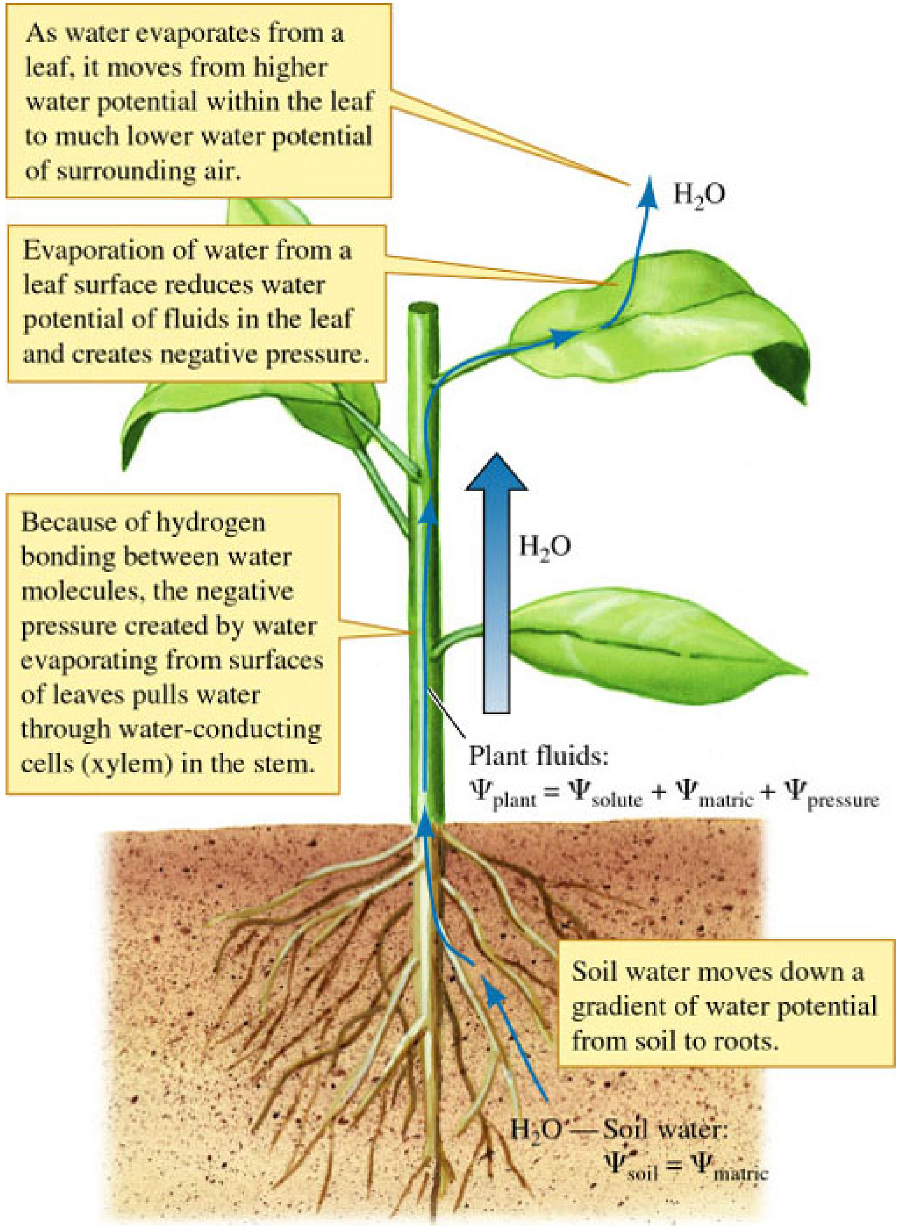
CO_2 assimilated stays constant,

water loss decreases

Plant Water Relations…

- Xylem potential…

- Leaf conductance…


As water evaporates from a leaf, it moves from higher water potential within the leaf to much lower water potential of surrounding air.
H_2O
Evaporation of water from a leaf surface reduces water potential of fluids in the leaf and creates negative pressure.
H_2O
Because of hydrogen bonding between water molecules, the negative pressure created by water evaporating from surfaces of leaves pulls water through water-conducting cells (xylem) in the stem.
Plant fluids:
$\Psi_{plant} = \Psi_{solute} + \Psi_{matric} + \Psi_{pressure}$
Soil water moves down a gradient of water potential from soil to roots.
H_2O — Soil water:
$\Psi_{soil} = \Psi_{matric}$

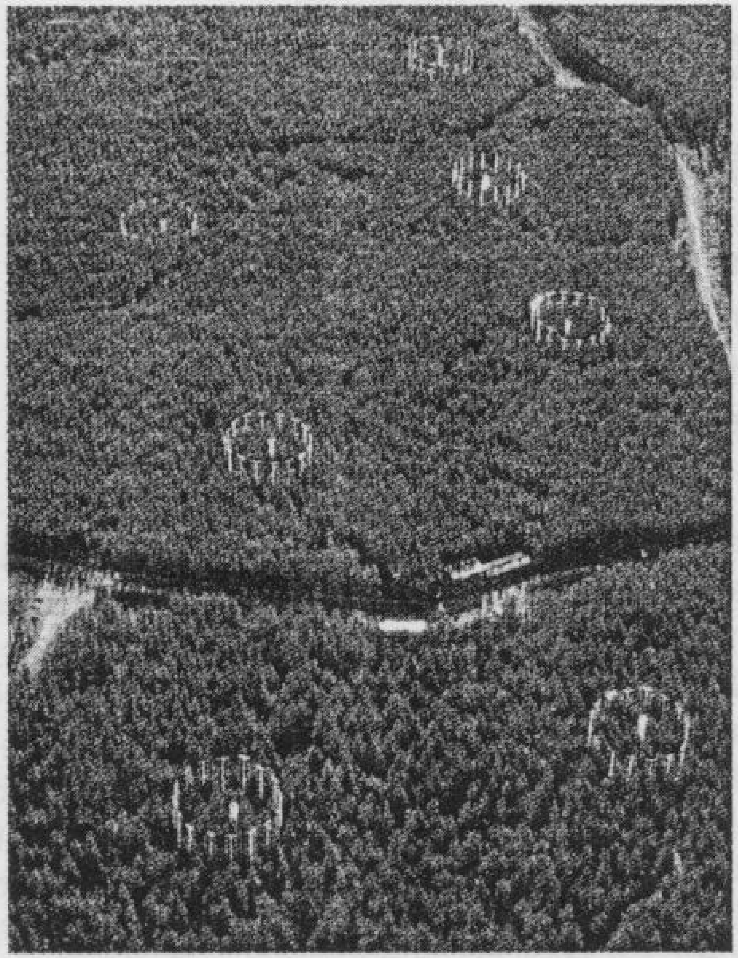


Fig. 1. Free-air CO_2 enrichment (FACE) rings in a pine plantation in North Carolina, USA. Each ring is 30 m in diameter and circumscribes about 100 trees. The distance from the single ring in the southwest (top right) to the two rings in the north (bottom) is ~500 m. The single ring in the background is a prototype. There are six experimental rings; three rings receive ambient air and three receive ambient plus 200 μl liter^{-1} CO_2 (photo: Will Owens).

Table 1. The mean (±1 SD) relative basal area increment (RBAI; $cm^2\ cm^{-2}\ year^{-1}$) for loblolly pine trees growing in ambient and elevated atmospheric CO_2 plots. The average RBAI was calculated for 30 to 40 trees in each plot. The RBAI for ambient and elevated plots for each year was compared with a paired-sample t test (one-tailed, $N = 3$).

Year	Mean RBAI ($cm^2\ cm^{-2}\ year^{-1}$)		Percent CO_2 effect	P
	Ambient	Elevated		
1996	0.094 ± 0.024	0.098 ± 0.011	4.2	0.342
1997	0.076 ± 0.020	0.095 ± 0.010	25.0	0.044
1998	0.054 ± 0.011	0.068 ± 0.012	25.9	0.007

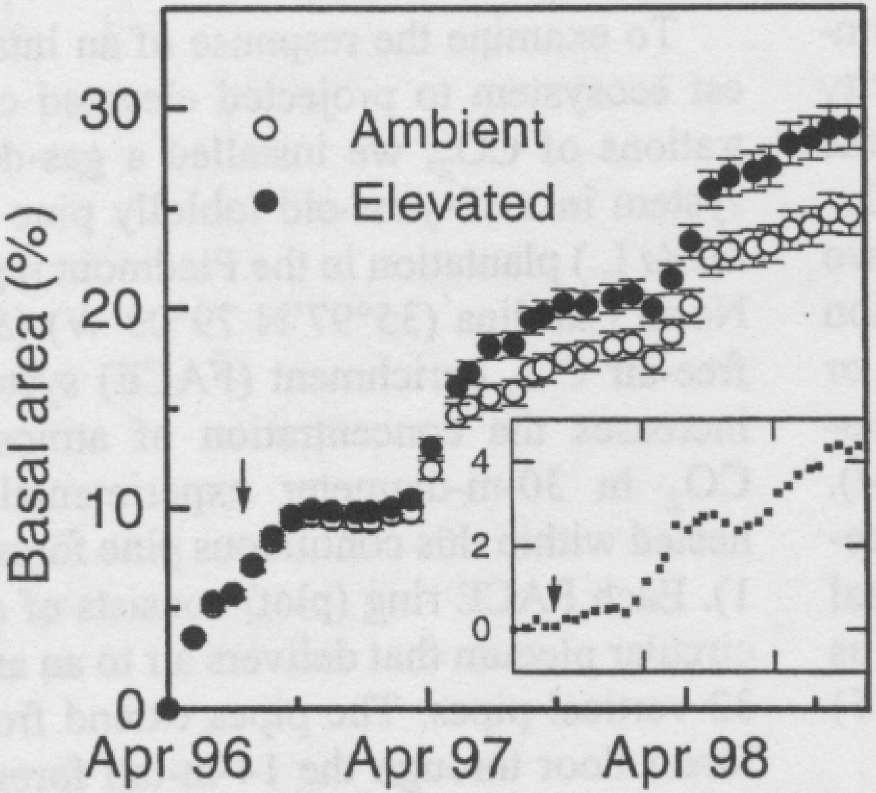


Fig. 2. Average basal area (±1 SE) for loblolly pine trees growing in ambient (N = 102) and elevated (N = 101) CO_2. Values are expressed as the percentage of the initial basal area. The insert shows the absolute difference between the basal area of elevated and ambient trees, and the arrows indicate when the CO_2 fumigation was initiated.

Table 2. Net primary production (production of dry matter; g m^{-2} year^{-1}) for a pine ecosystem under ambient or elevated atmospheric CO_2 during fumigation in 1997 and 1998. Subcanopy hardwoods are trees with a diameter ≥2.5 cm. The "sapling" category includes trees (<2 m tall), shrubs, and vines. Litterfall is the amount of dead biomass in foliage, branches, and reproductive structures falling to the ground annually. Net primary production ("Production") is the sum of all components. For years where data were not available for one or more components, they were not included in the calculation of NPP (for example, fine roots in 1996 and 1997 and subcanopy hardwoods and sapling production in 1996). The "Percent CO_2 effect" is the percentage difference between the elevated and ambient plots. Values for ambient and elevated plots were compared with a paired-sample t test (one-tailed, N = 3).

Category	Year	NPP (g m^{-2} year^{-1}) Ambient	Elevated	Percent CO_2 effect	P
		Increments			
Canopy pines	1996	976	1002	3	0.40
	1997	879	1087	24	0.14
	1998	685	857	25	0.09
Subcanopy hardwoods	1997	75	105	40	0.14
	1998	118	155	31	0.16
Saplings, shrubs, and vines	1997	8	4	−100	0.26
	1998	9	7	−22	0.29
Fine roots	1998	43	80	86	0.02
		Turnover			
Litterfall	1996	660	588	−11	0.13
	1997	529	533	1	0.45
	1998	613	739	21	0.08
Fine roots	1998	195	245	26	0.21
		Production			
	1996	1637	1590	−3	0.30
	1997	1491	1727	16	0.11
	1998	1662	2082	25	0.01

Picture 17. Aerial photo of an elevated CO_2 ring in 2005