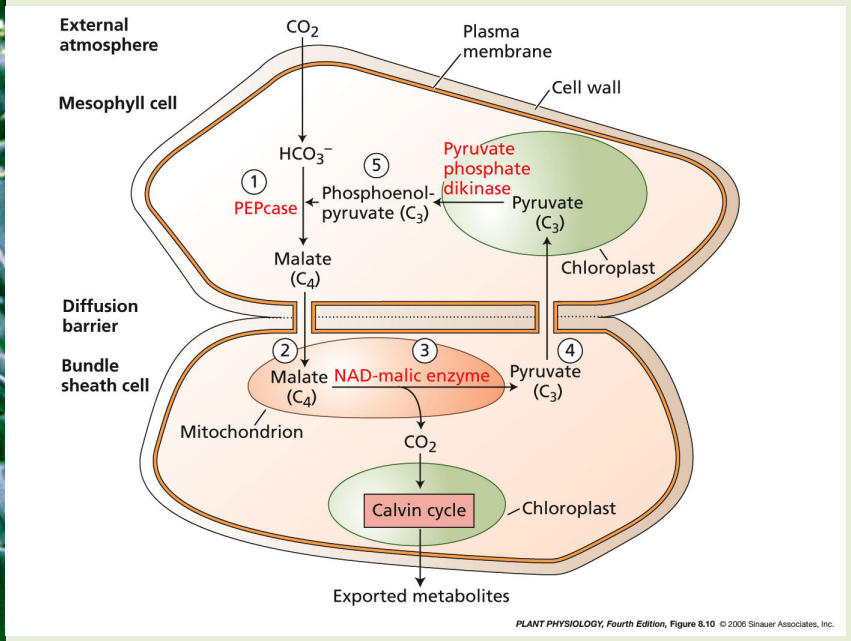


The Amazing (C_4) Photosynthesis of Maize

C4 Photosynthesis

Most of the grass species in the Tall Grass Prairie ecosystem are C_4 plants

Andropogon gerardii
[Big Bluestem]

-the dominant plant of of the Tall Grass Prairie ecosystem

My research:

Two enzymes that participate in the C4 photosynthesis process:

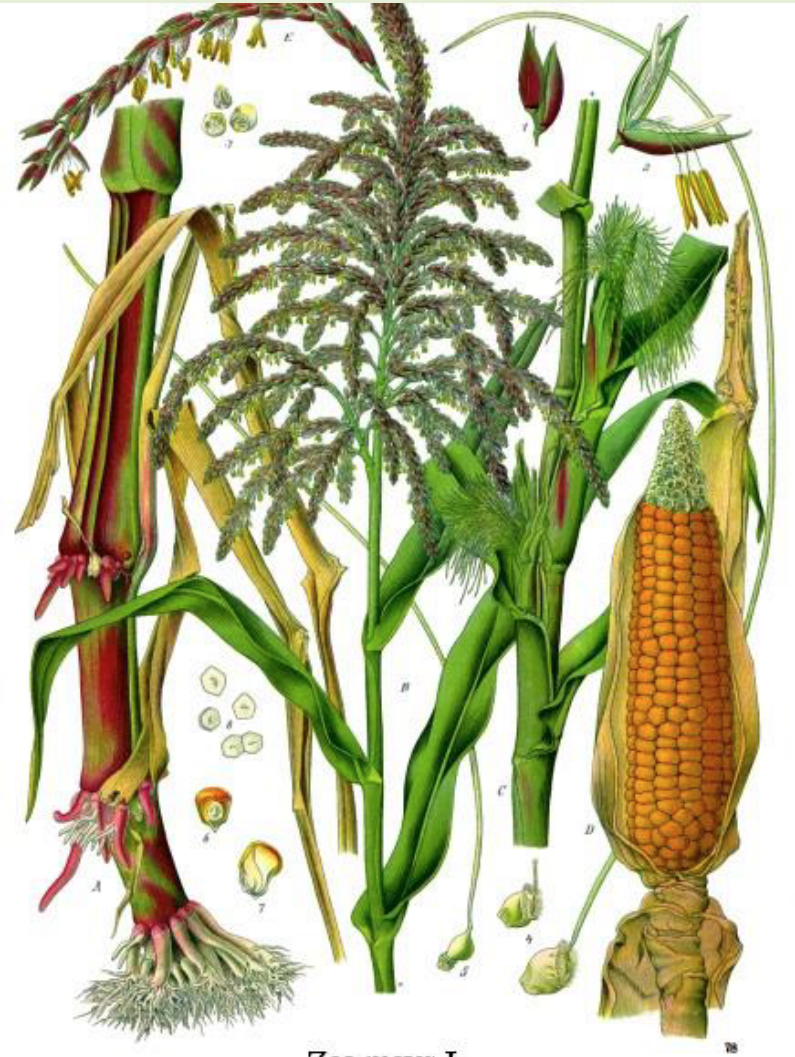
✓Pyruvate Phosphate Dikinase..... (PPDK)

✓Pyruvate Phosphate Dikinase Regulatory Protein .....(PDRP)

-Biochemistry
-Molecular Biology

✓My research has utilized maize for exploring regulation of the C_4 metabolic pathway

✓Maize is the sole model plant organism that utilizes the C_4 photosynthetic mechanism



Zea mays L.
Image processed by Thomas Schoepke
www.plant-pictures.de

<u>maize vs. corn</u>

Corn is the American vernacular for maize.

The rest of the world uses maize as the common word for corn.

In Europe, Australia, New Zealand, and India, the word corn is used for the grain crop barely, as in "barely corn".

The botanical name for corn is *Zea mays*

Part I: What is C_4 photosynthesis and why is it so amazing.

Part II: My research into the biochemistry and molecular biology of the C_4 photosynthesis enzymes, PPDK and PDRP

WHY is C_4 photosynthesis so amazing?

✓C_4 plants yield twice as much grain and biomass than C_3 plants

✓C_4 plants are twice as drought hardy as C_3 plants

✓C_4 crop plants: maize, sugarcane, Sorghum, millet, Amaranth.....in fact only 0.1 % of all plant species are C_4 plants

✓C_3 crop plants: Wheat, Rice, Soybeans, Sugar beets, etc. [and all other crops]

✓C_4 weeds: foxtail, pigweed, crabgrass – worst weeds in agriculture

What is the 4 in C_4 photosynthesis?

What is the 3 in C_3 photosynthesis?

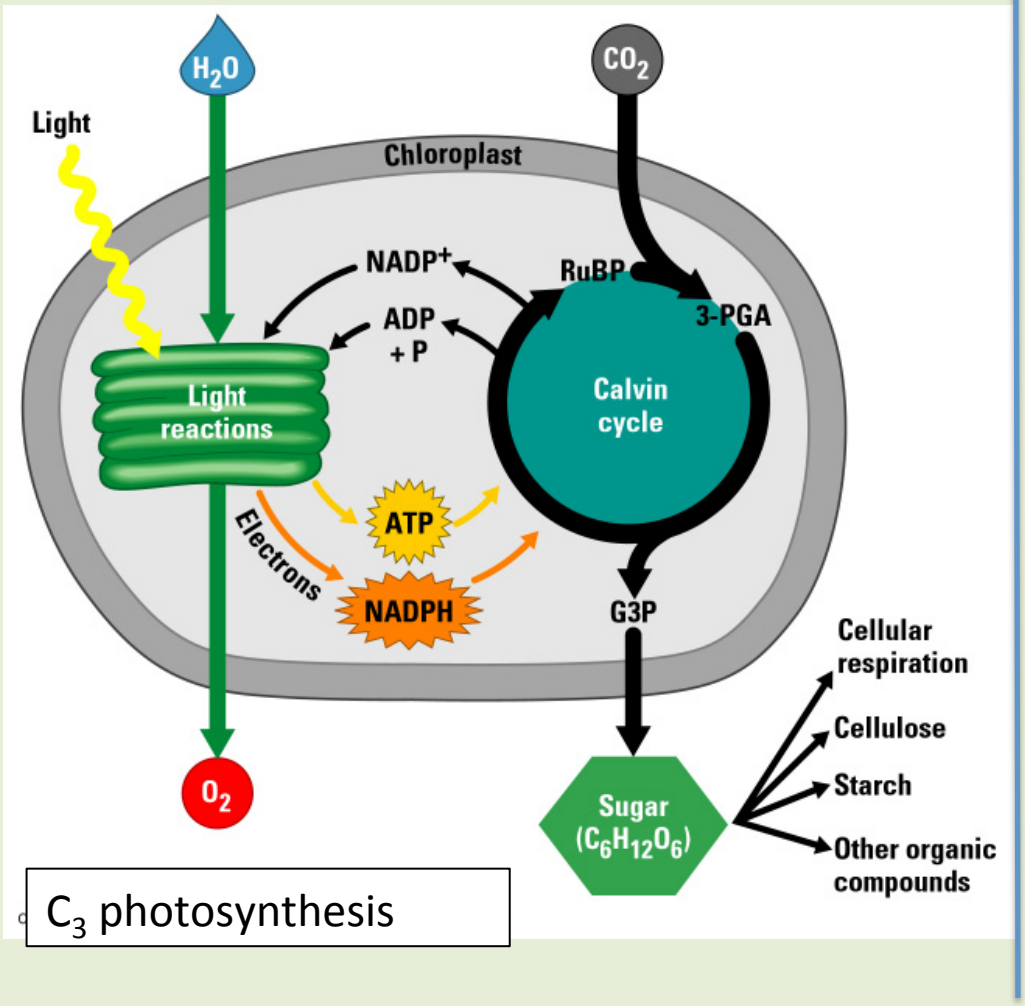
The numbers 3 and 4 refer to the number of carbons in the first stable compound produced when CO_2 from the air is assimilated into the leaf

C_3: phosphoglyceric acid – a 3 carbon compound

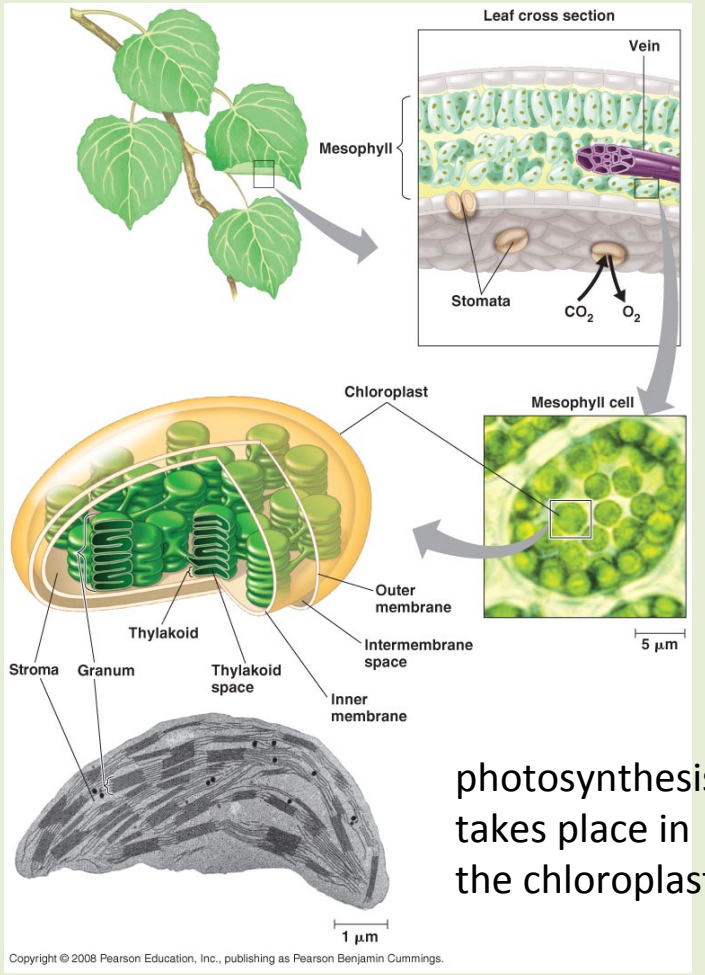
C_4: oxaloacetic acid – a 4 carbon compound

To understand what C_4 your have to first know what C_3 photosynthesis is.

C_3 PS is the "original" photosynthetic process...first appears in bluegreen alga around 2.5 billion years ago



C_3 photosynthesis

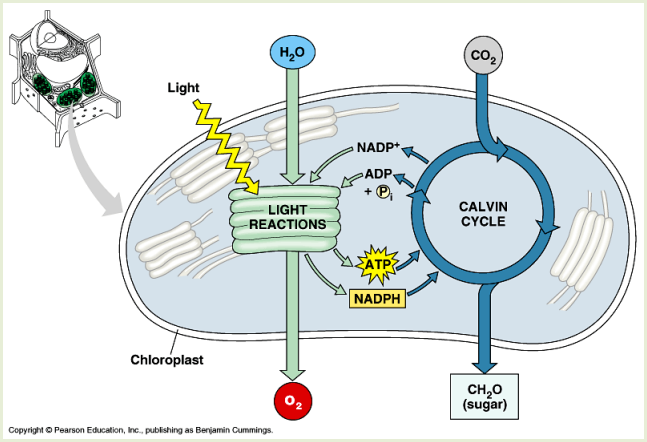


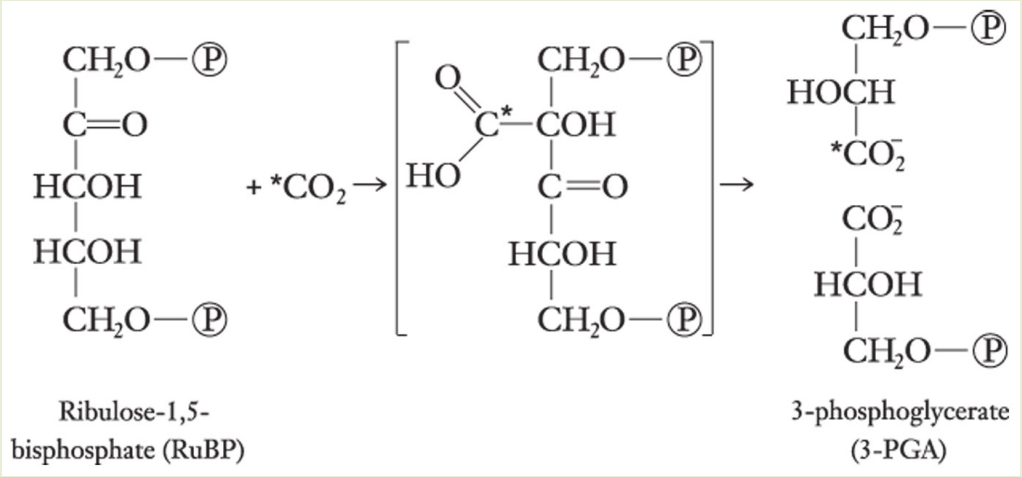
photosynthesis takes place in the chloroplast

C_3 Photosynthesis

98% of all plant species use the ancient (first evolved) C_3 photosynthetic process for fixing CO_2 into sugars in the leaf.

These are referred to as C_3 plants.

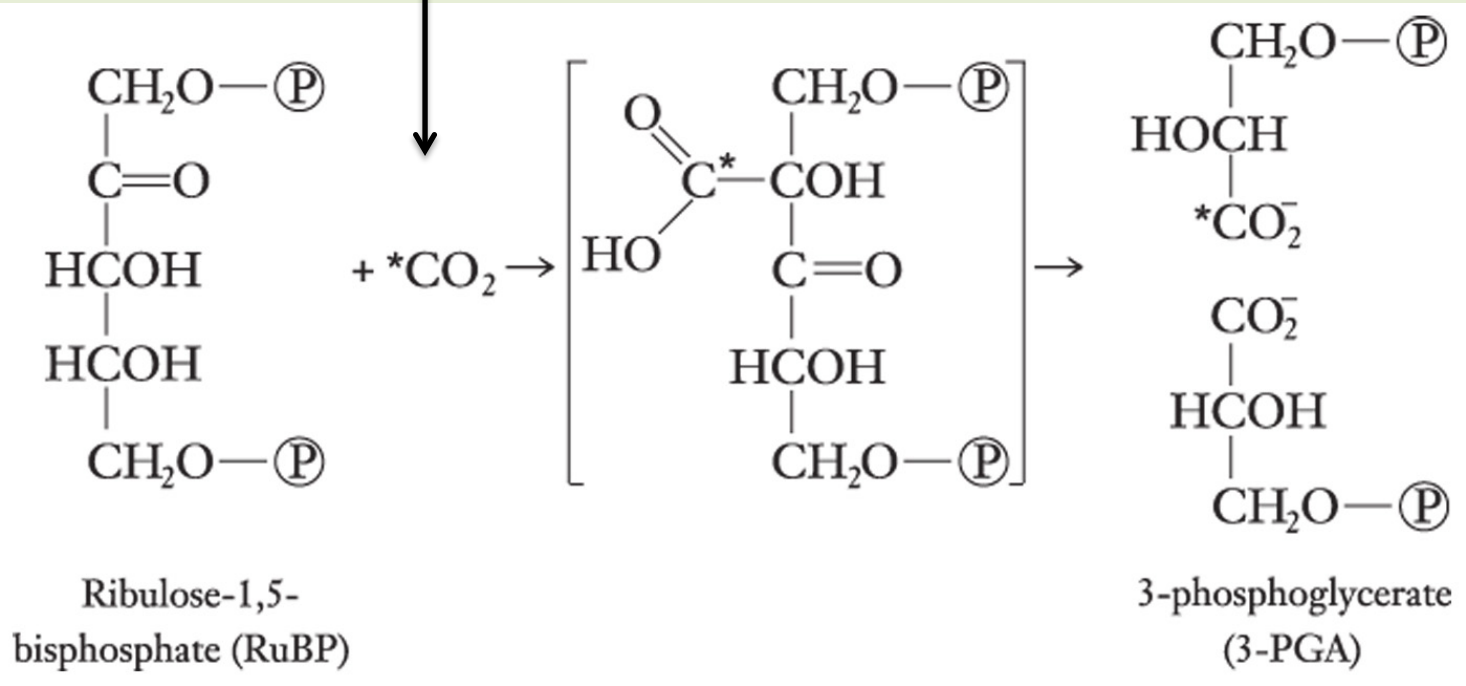




The C_3 in the C_3 photosynthetic process refers to the number of carbon atoms in the first stable compound formed after CO_2 fixation in the leaf.

C_3 Photosynthesis

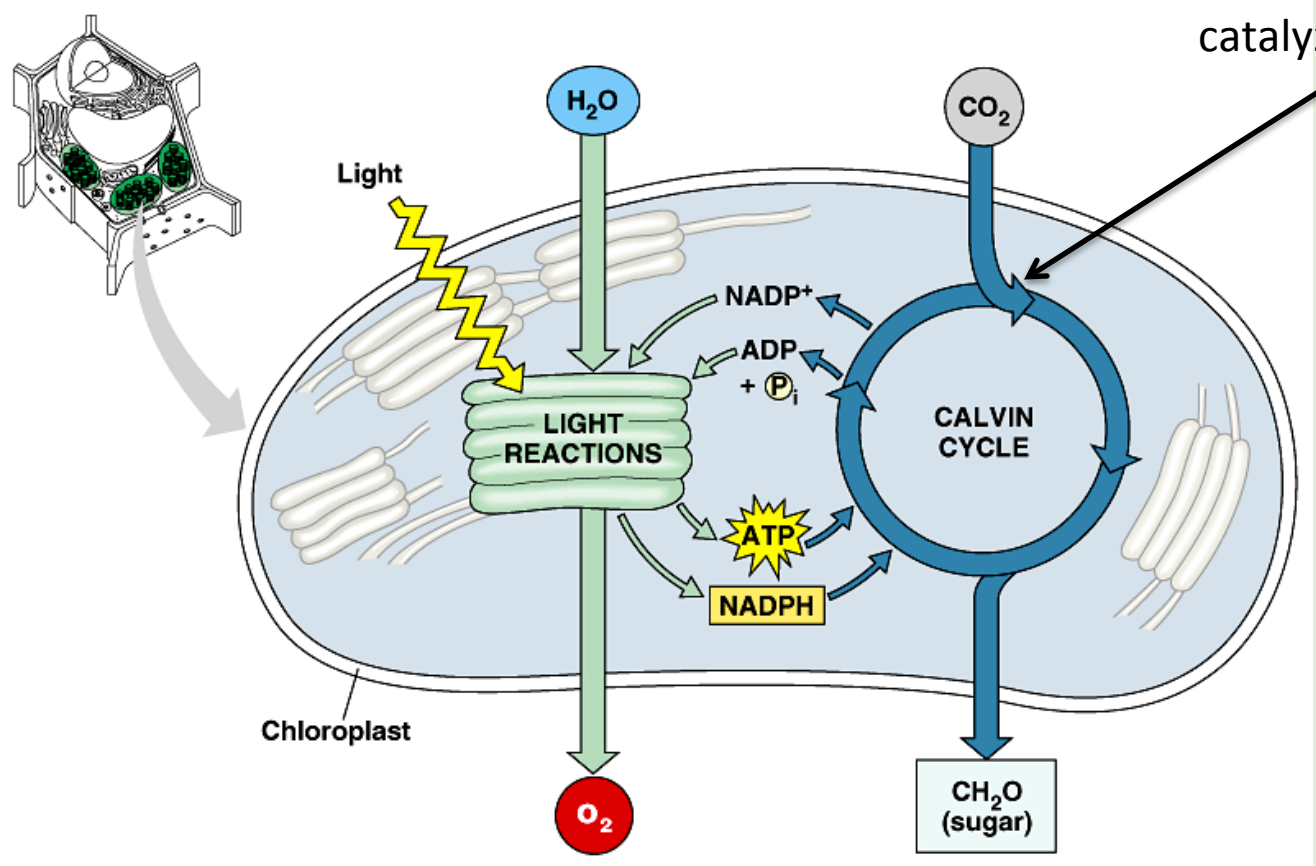
Rubisco enzyme catalyzes this step



Rib**u**lose **Bis**phosphate **C**arboxylase **O**xygenase = RuBisco

C_3 Photosynthesis

Rubisco enzyme catalyzes this step



C_3 Photosynthesis – why it is inferior to C_4 photosynthesis

C3 photosynthesis and Rubisco first evolved 2.5 billion years ago

Air at 2 billion years ago — 10% CO_2 and 1 % O_2

plants "terraform" the earth

Air at 50 million years ago — 0.03% CO_2 and 20% O_2

C_3 Photosynthesis – why it is inferior to C_4 photosynthesis

The dramatic change in atmosphere over time exposed a "design" flaw in Rubisco

The exposed flaw?

Rubisco sometimes mistakes O_2 for CO_2

molecular structure of O_2

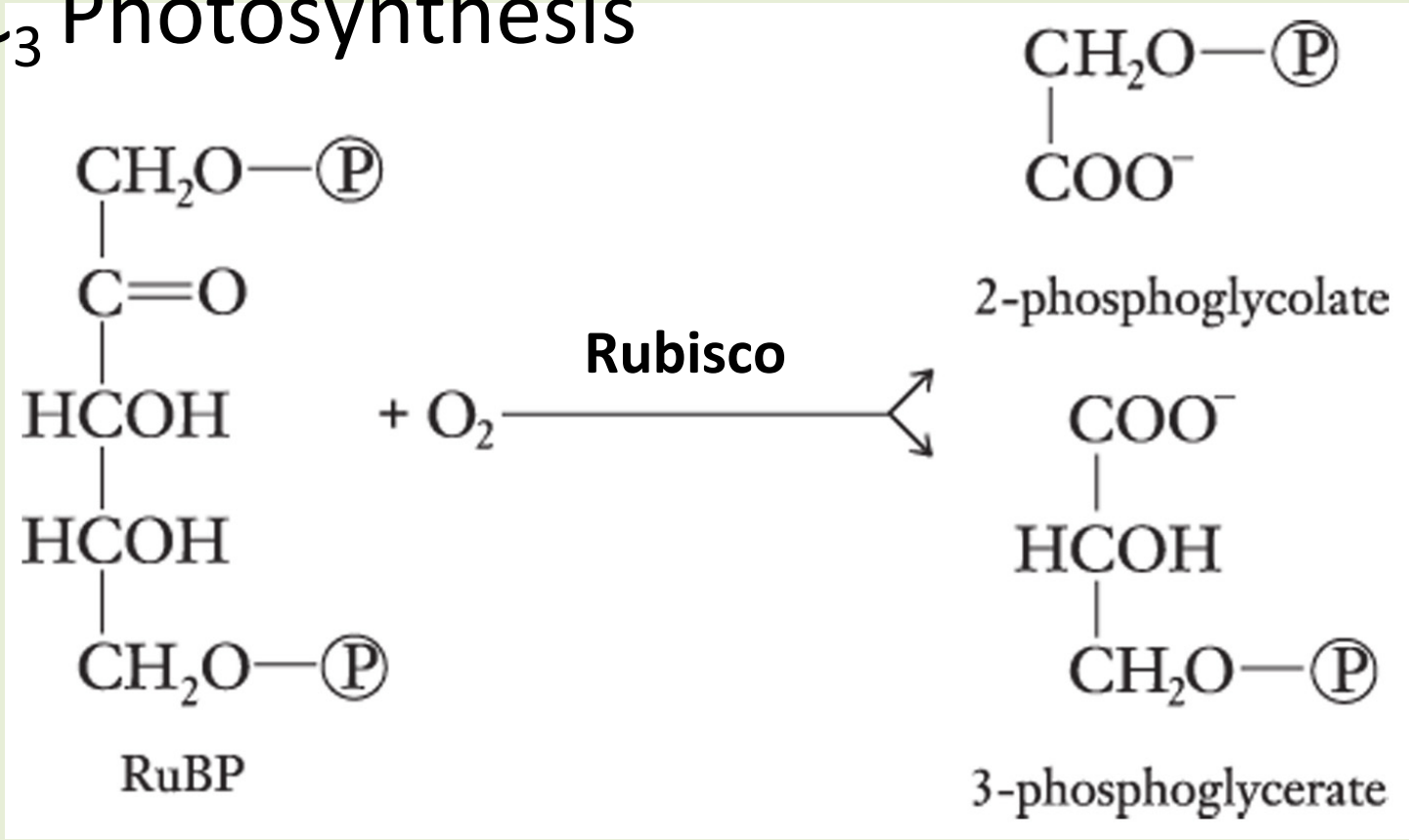
O=O

molecular structure of CO_2

O=C=O

O_2 can fit into the active-site of the Rubisco enzyme, displacing CO_2

C_3 Photosynthesis



Around 30% of the time, Rubisco makes the mistake of fixing O_2 instead of CO_2.

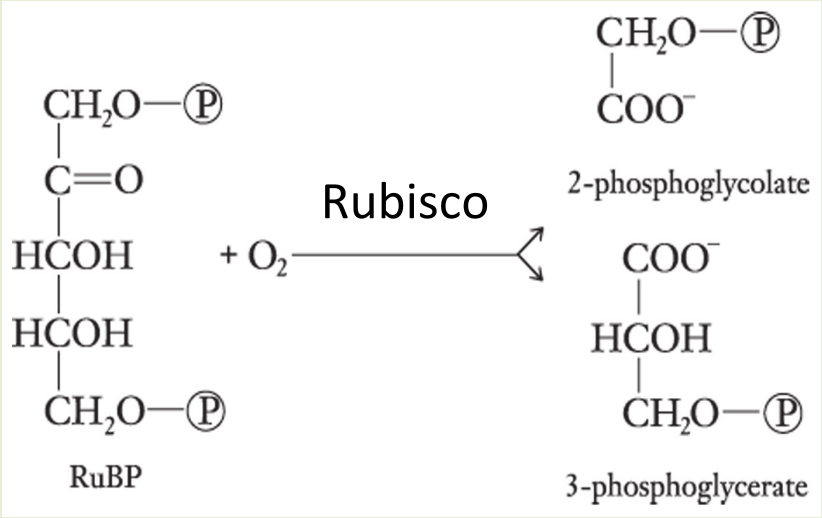
C_3 Photosynthesis

…….this is very bad for the plant. Why?

ANSWER: the plant just "ate" a molecule of O_2…….there is no food value to oxygen, no calories!....

O_2 fixation…… 5-carbons before fixation and 5-carbons after fixation.

.....NO NET FIXATION of CO_2!



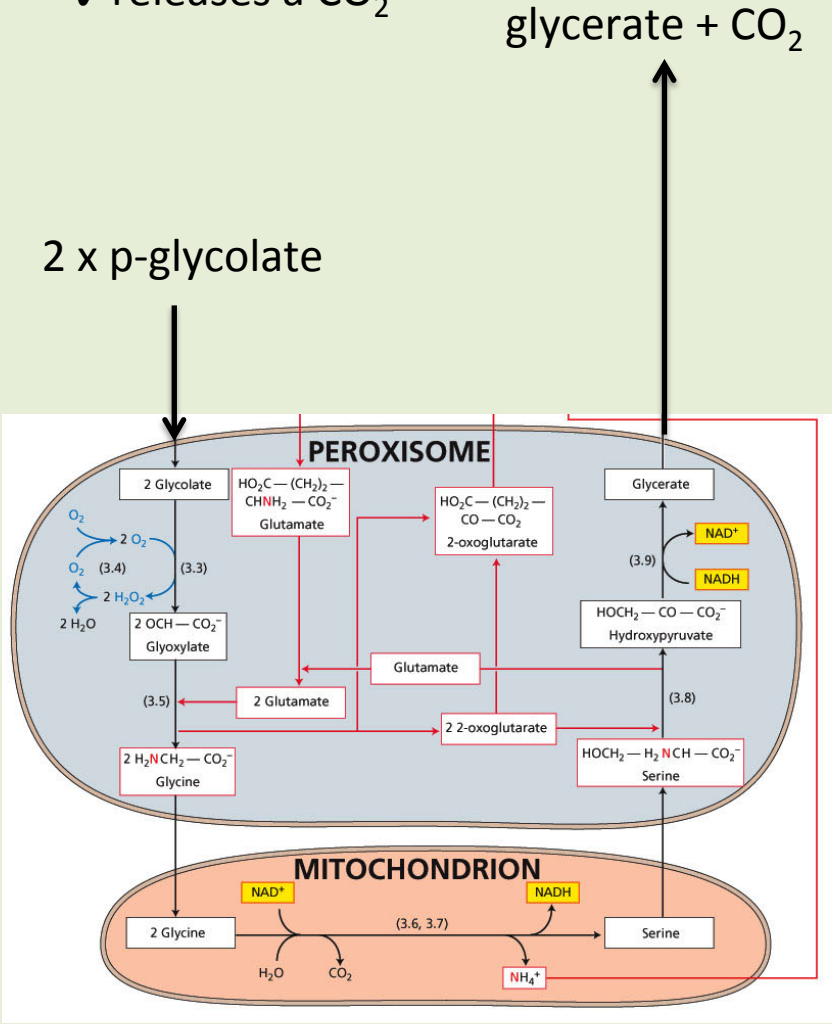
Photorespiration

- uptake of O_2 by leaves in the light

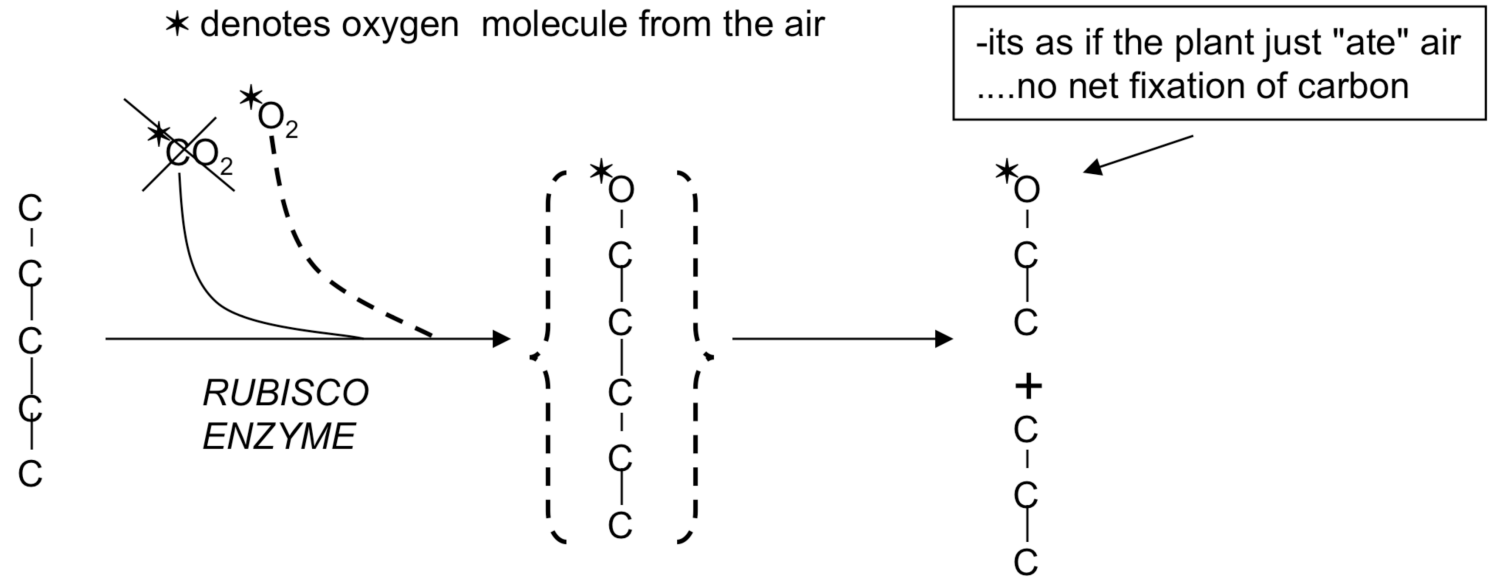
The molecule resulting from Rubisco's O_2 fixation, phosphoglycolate, cannot be used directly for making sugars……it must be "reprocessed" by an energy consuming biochemical pathway

Photorespiration Biochemical Pathway

✓consumes ATP
✓releases a CO_2



The Rubisco defect and why this reduces the efficiency of C3 photosynthesis



The net loss of potential carbohydrate is 40%.

The flaw in Rubisco is the direct cause for the loss of 40% of plant biomass and grain yield

The secret of C_4 photosynthesis' success:

No O_2 fixation by Rubisco!

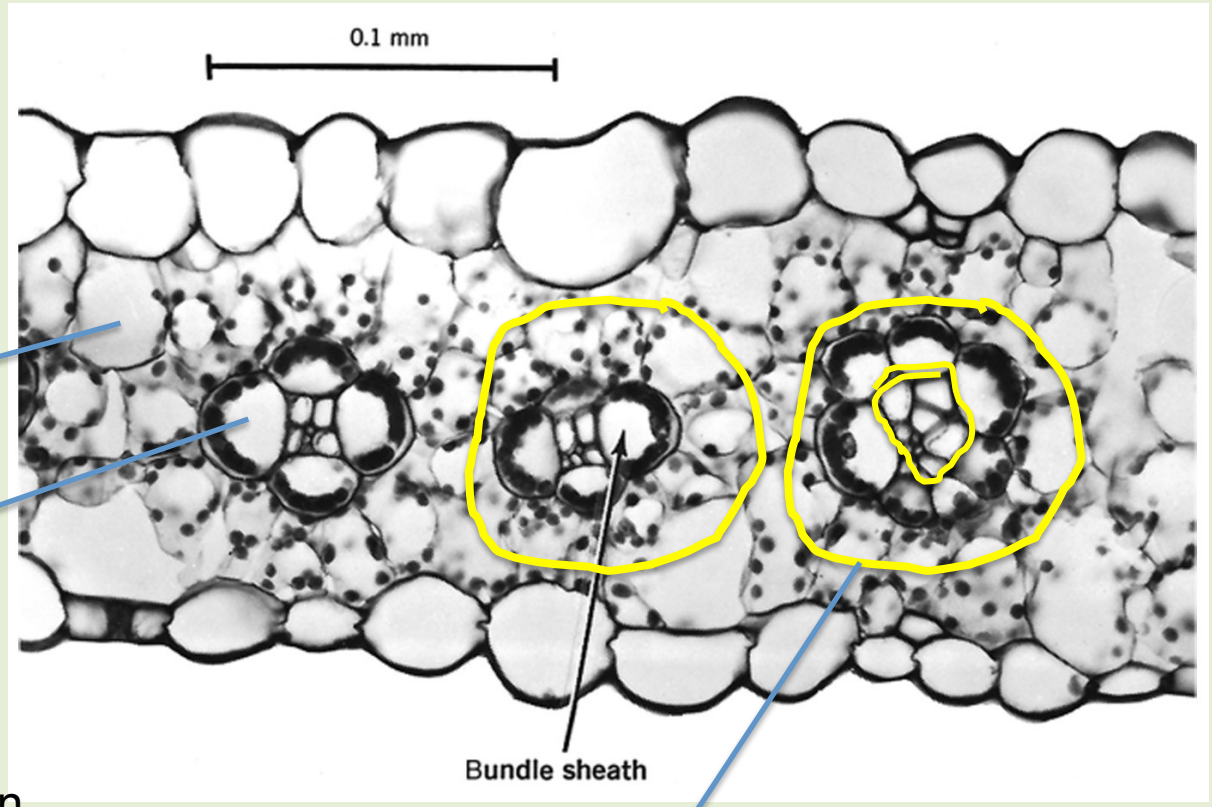
C_4 plants fix only CO_2 so it they never "eat" a calorie-less O_2 molecule

How does Rubisco in C_4 plants avoid the same fatal flaw that Rubisco in C_3 plants makes?

Nature did not correct the flaw of Rubisco

Instead, it confined Rubisco enzyme to a layer of cells deep inside the leaf

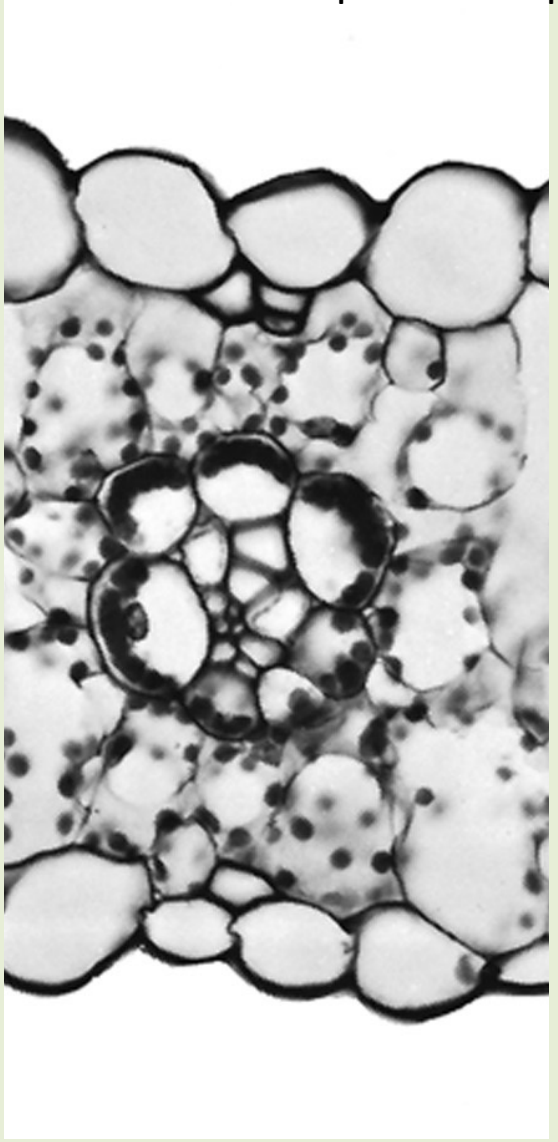
-these cells contain a layer of rubber on the outside that seals in gaseous molecules such as CO_2.

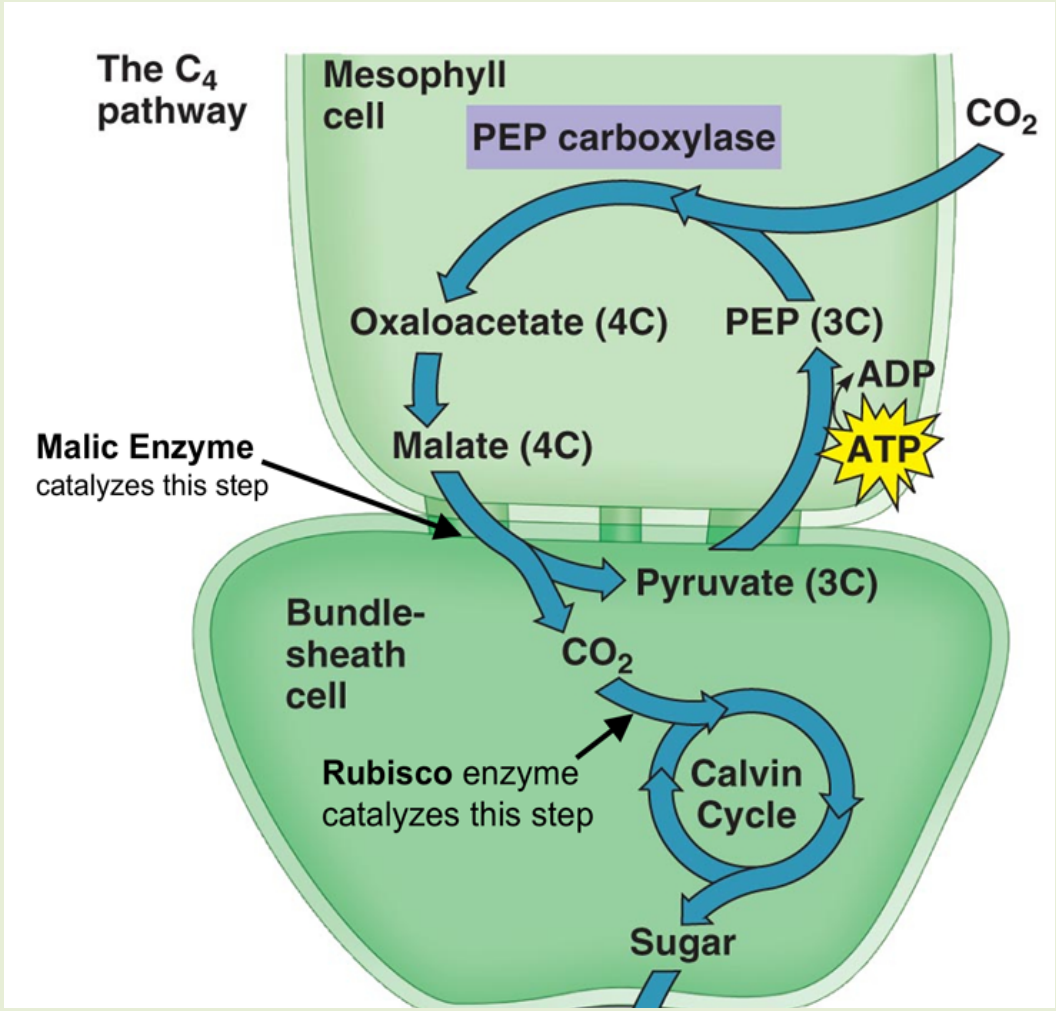


Corn leaf cross section

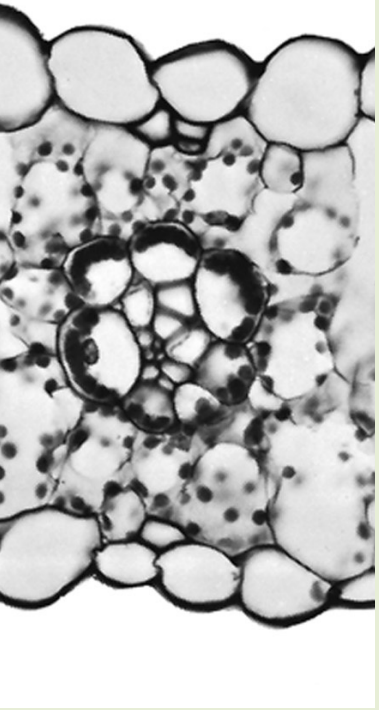
interior leaf cells
-Rubisco enzyme is concentrated here

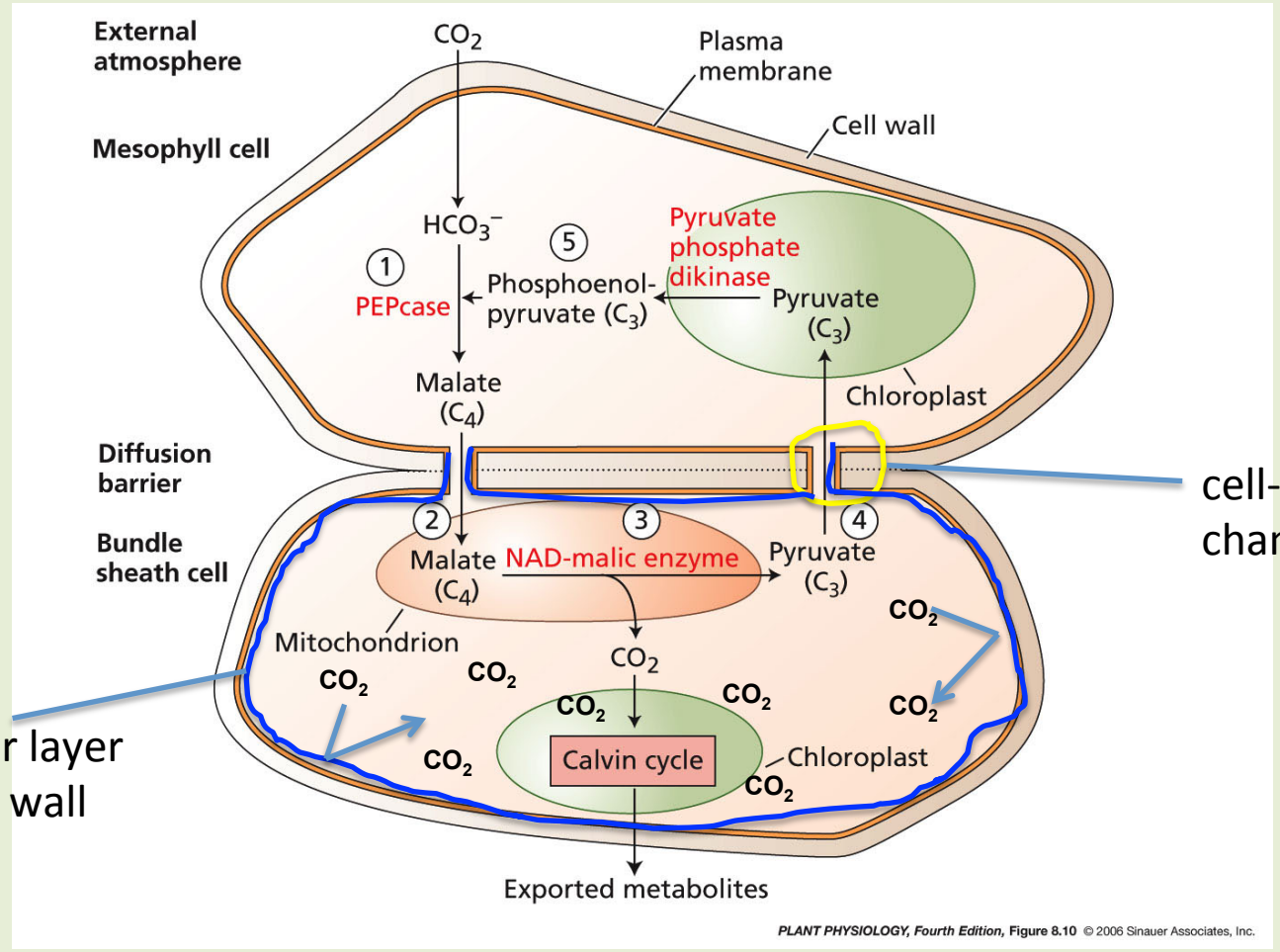
The C4 photosynthetic biochemical pathway was evolved to "pump" CO_2 in the form of a C4 compound deep into the interior cells where Rubisco is confined





Intracellular Biochemical CO_2 pump





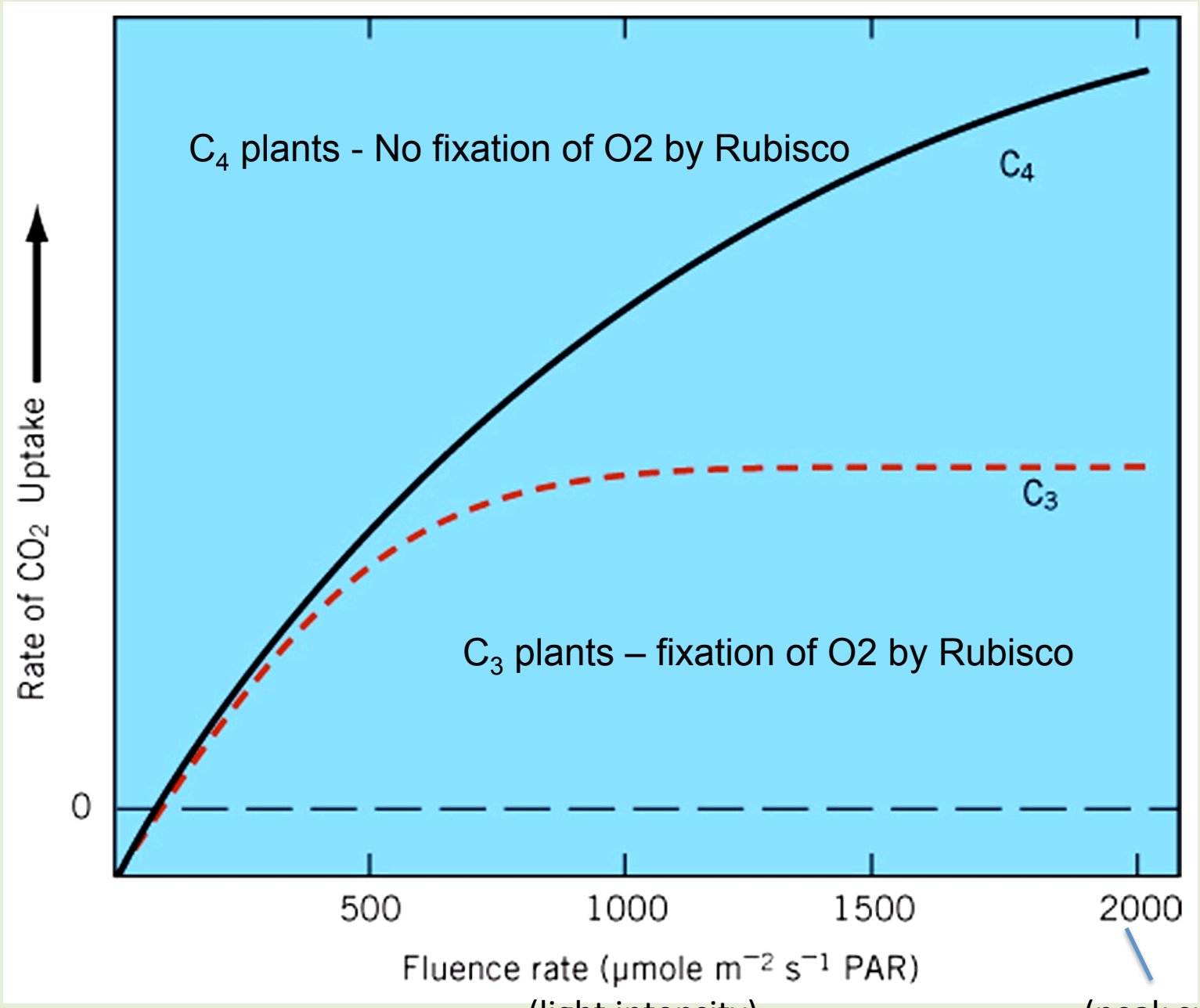
cell-cell channel

rubber layer in cell wall

CO_2 is concentrated 400 times the level of CO_2 air

✓Rubisco enzyme is "force-fed" CO_2

✓never is allowed to fix O_2


C_4 plants - No fixation of O2 by Rubisco
C_4
C_3
C_3 plants – fixation of O2 by Rubisco
Rate of CO_2 Uptake
(photosynthesis rate)
0
500
1000
1500
2000
Fluence rate (μmole m^{-2} s^{-1} PAR)
(light intensity)
(peak sunlight)

My C_4 photosynthesis research:

Two enzymes that participate in the C4 photosynthesis process:

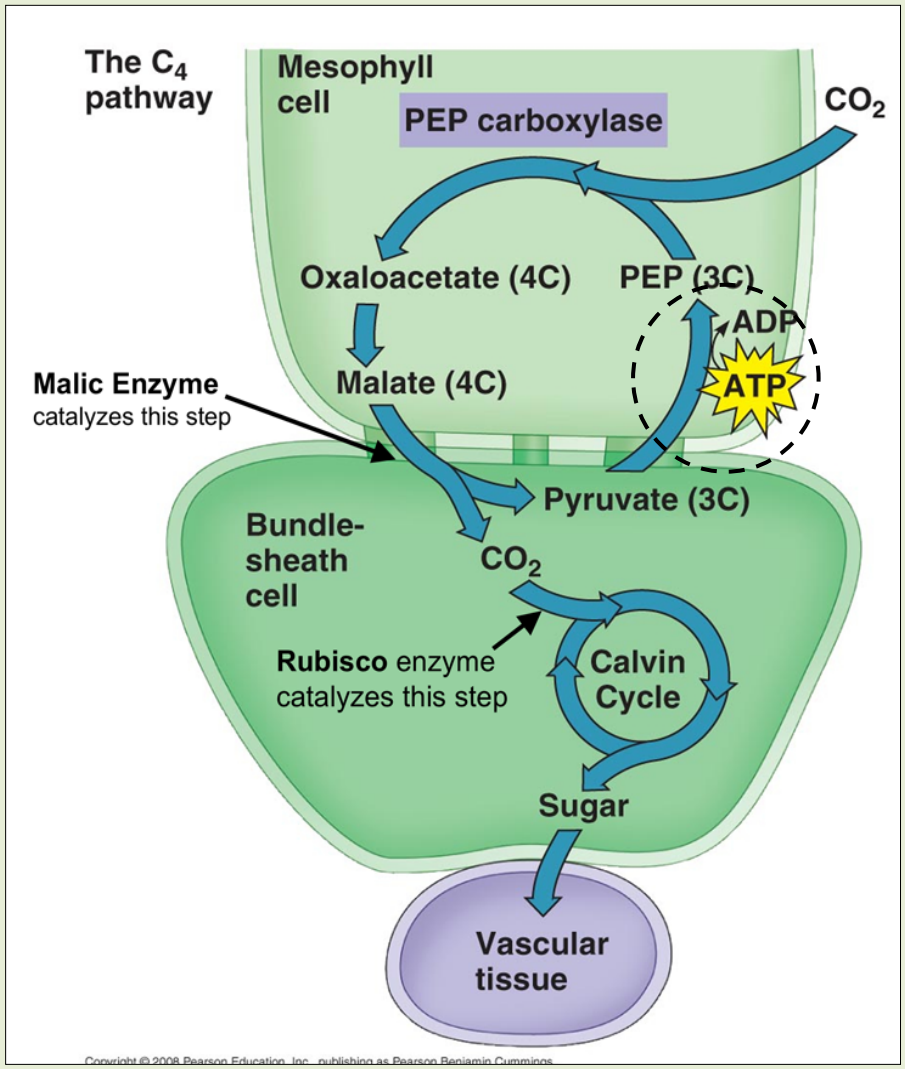
✓Pyruvate Phosphate Dikinase..... (PPDK)

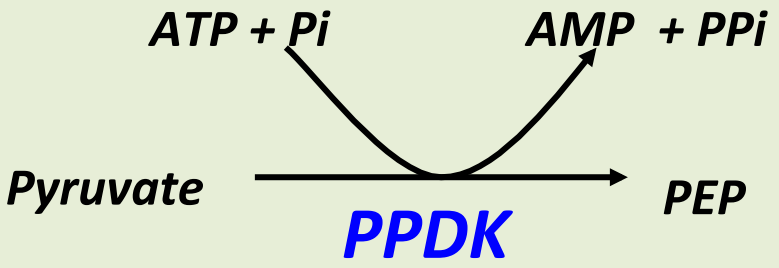
✓Pyruvate Phosphate Dikinase Regulatory Protein .....(PDRP)

-Biochemistry
-Molecular Biology

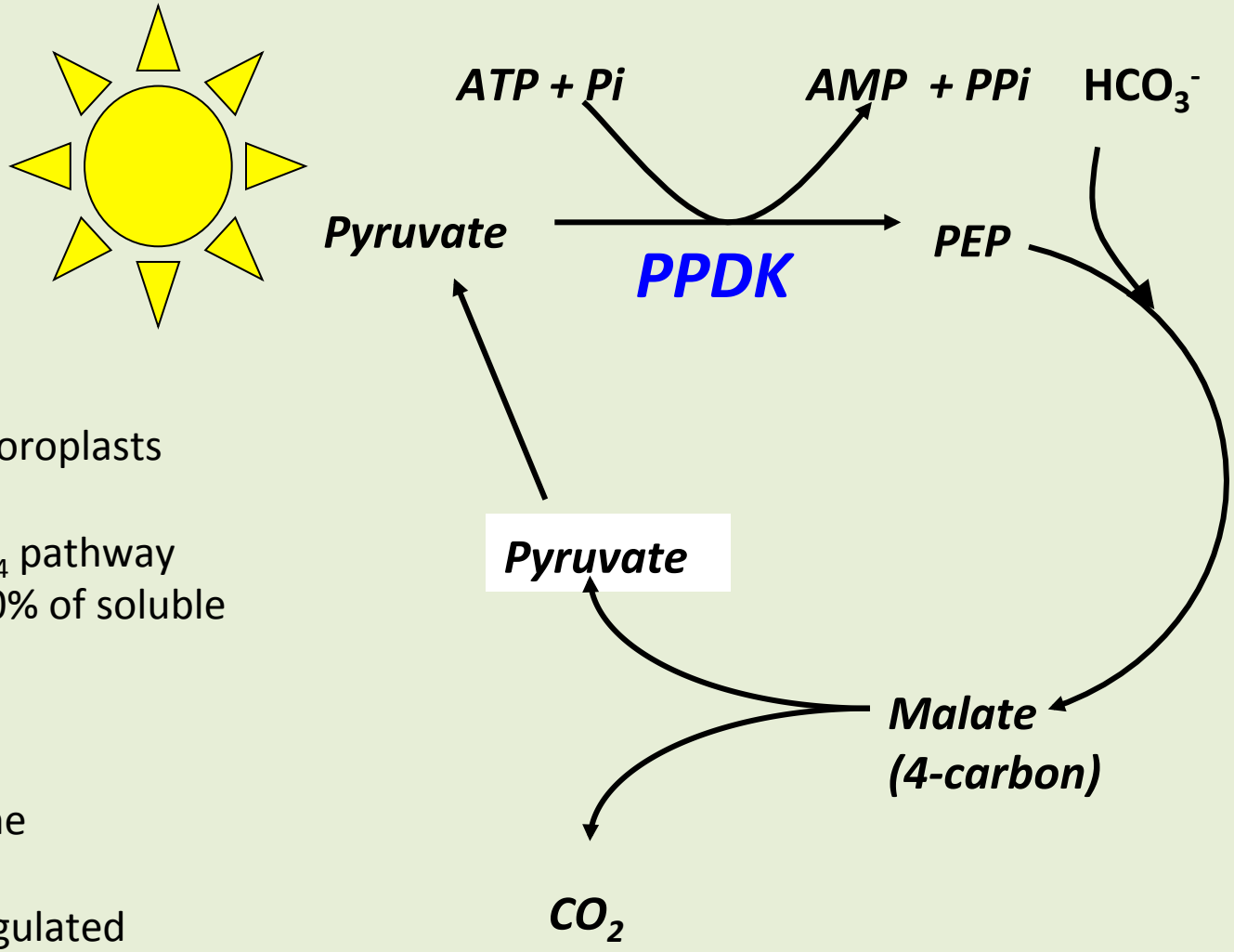
Pyruvate Phosphate Dikinase (PPDK) – a metabolite kinase

-catalyzes the conversion of pyruvate to PEP in the C_4 pathway





PPDK in the C_4 Photosynthetic Cycle



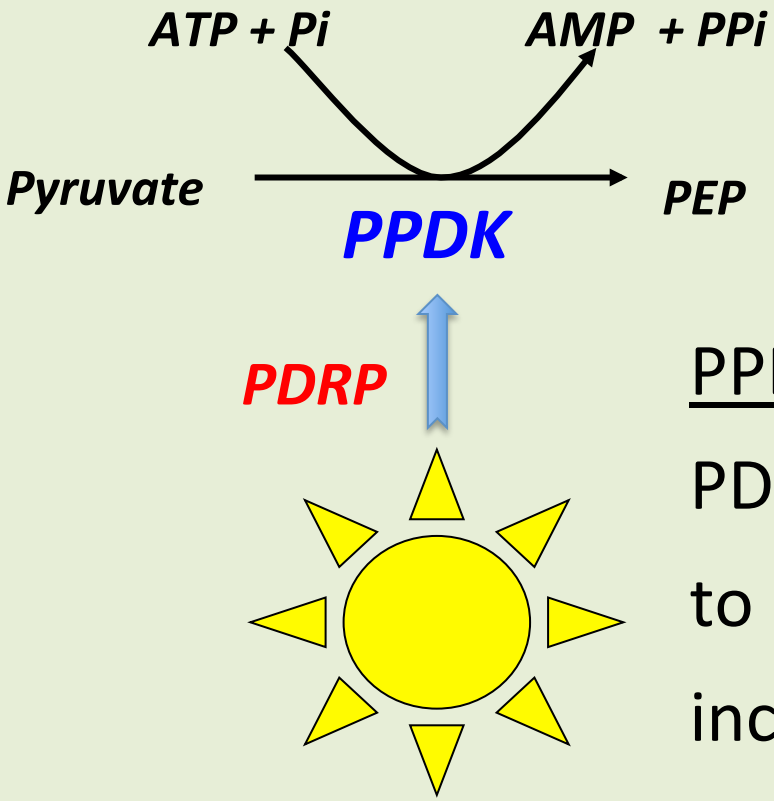
-located in the chloroplasts

-most abundant C_4 pathway enzyme....up to 10% of soluble leaf protein

- co-limiting C_4 pathway enzyme

-activity is light regulated

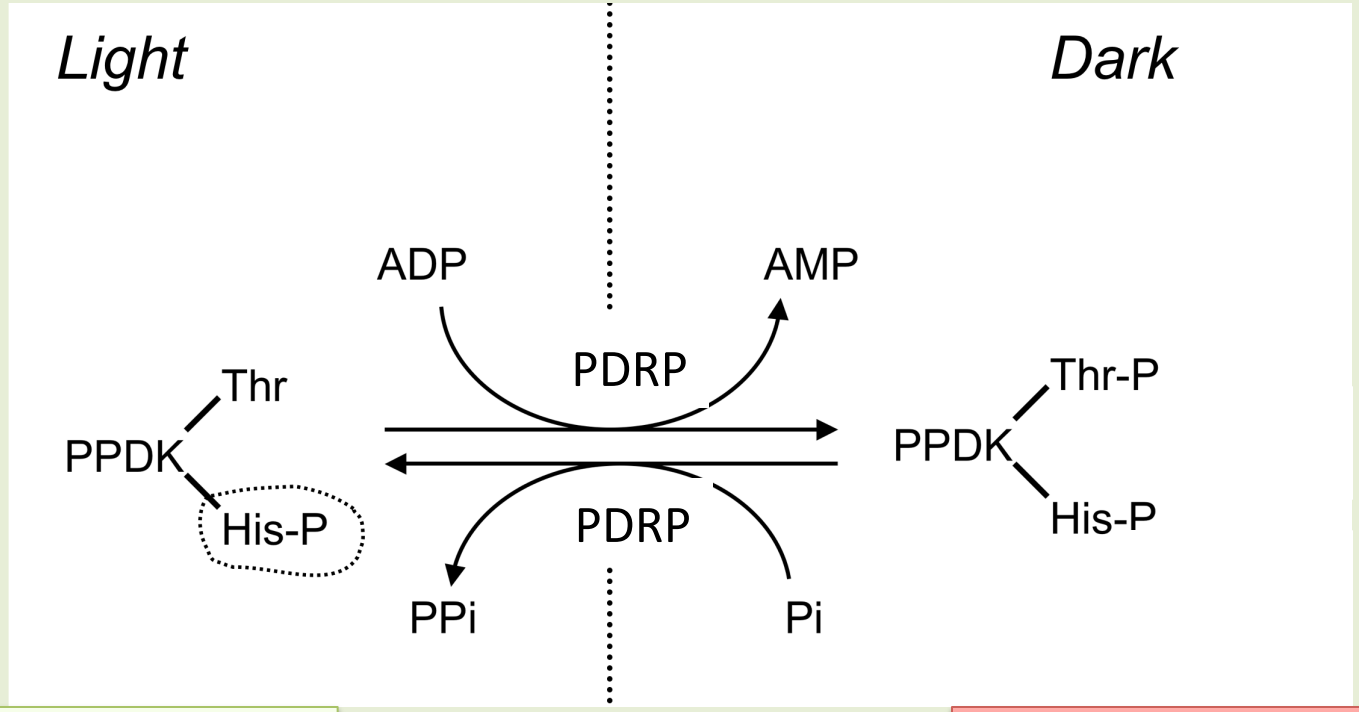
Pyruvate Phosphate Dikinase Regulatory Protein – PDRP



<u>PPDK is light regulated by PDRP</u>

PDRP adjusts the rate of PPDK to match the level of sunlight incident on the leaf

The PPDK regulatory protein (PDRP)



PPDK is Active

PPDK is Inactive

-catalyzes reversible phosphorylation of an active-site Thr
-functions as the light sensing component of the PPDK regulation cycle

C4-rice project. Based in the Phillipines, sponsered by the Gates foundation.

Goal: to genetically engineer C4 photosynthesis into rice, a C3 plant....predicted to double rice yields

BILL & MELINDA GATES foundation

IRRI
INTERNATIONAL RICE RESEARCH INSTITUTE

Past breakthrough highlights of Chastain research into PPDK and PDRP

∞ first ones to clone the maize PPDK gene into a plasmid for synthesis in bacteria

∞ studies of mutated PPDK revealed workings of how PPDK is inactivated by PDRP

∞ created antibodies for detection of phosphorylated PPDK in maize leaves
.... lead to discovery of the speed by which PDRP can increase or decrease PPDK activity in leaves
.....lead to creation of a new and improved biochemical assay of PDRP

∞breakthrough cloning of the PDRP from maize and Arabidopsis: one of a kind enzyme in tree of life

∞gene expression studies of PDRP and PPDK in maize leaves: genes are not co-regulated; PPDK mRNA level dwarfs PDRP mRNA level in C4 plant leaves.

The End