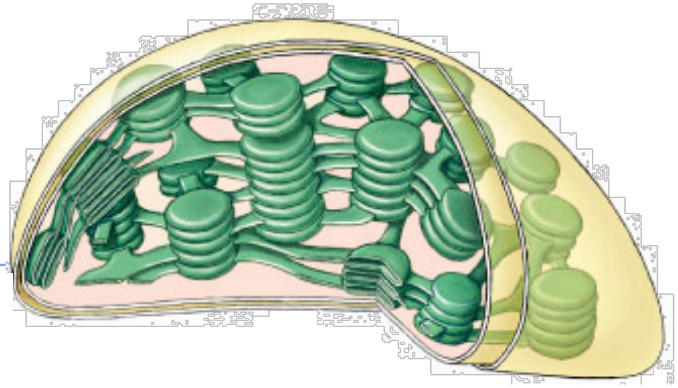
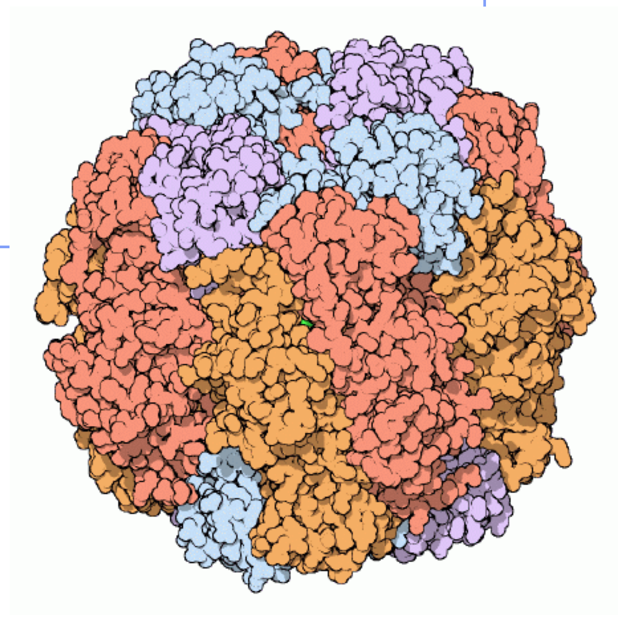


Photosynthesis:

The Calvin Cycle
Life from Air



1950s | 1961

Whoops! Wrong Calvin…

AP

Remember what it means to be a plant…

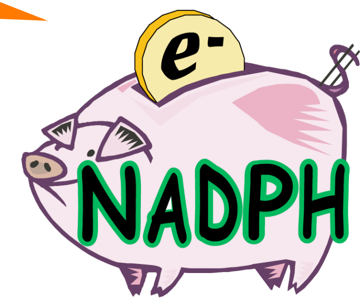
- Need to produce all organic molecules necessary for growth, repair, & reproduction
  - carbohydrates, lipids, proteins, nucleic acids
- Need to store chemical energy produced from light reactions
  - in a more stable form
  - that can be moved around the plant to non-photosynthetic cells
  - saved for a rainy day

carbon dioxide + water + energy → glucose + oxygen

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Light reactions

- Convert solar energy to chemical energy
  - ATP → energy
  - NADPH → reducing power



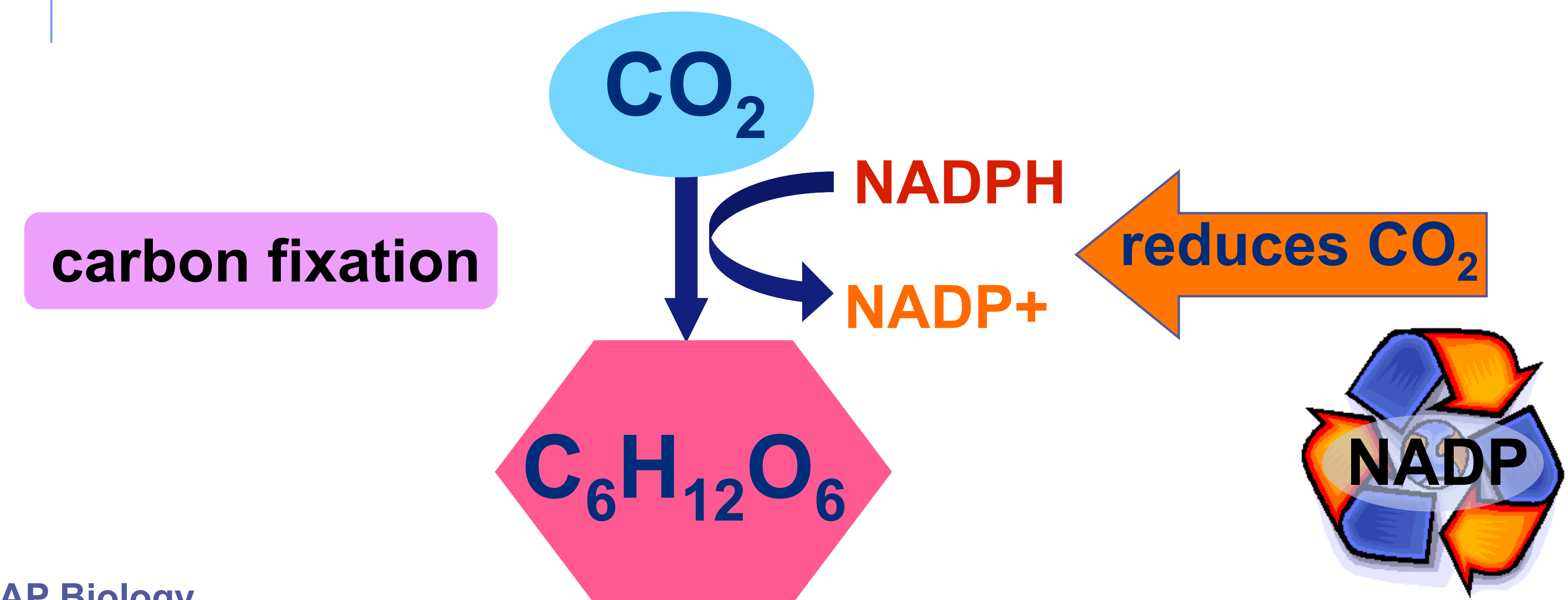
- What can we do now?

→ → build stuff !!

photosynthesis

How is that helpful?

- Want to make $C_6H_{12}O_6$
  - <u>Synthesis</u>
  - How? From what?
    What raw materials are available?



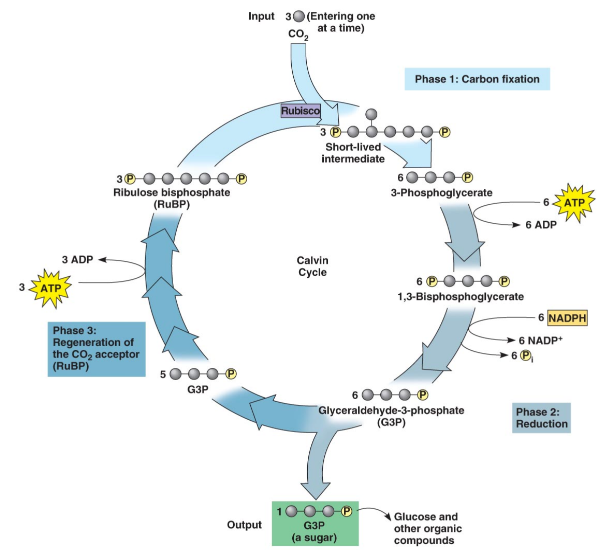
From $CO_2 \rightarrow C_6H_{12}O_6$

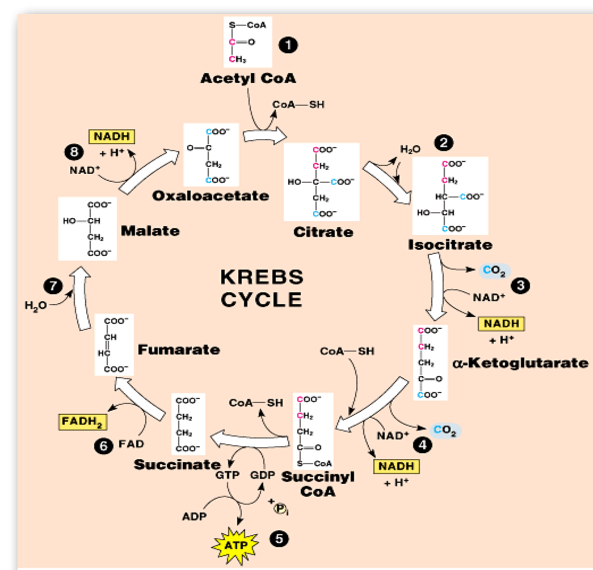
- CO_2 has very little stored chemical energy
  - it is a fully oxidized molecule
- $C_6H_{12}O_6$ contains a lot of chemical energy
  - it is a highly reduced molecule
- Synthesis is an endergonic process
  - building high energy organic molecules requires an input of a lot of ENERGY
- Reduction of $CO_2 \rightarrow C_6H_{12}O_6$ proceeds in many small uphill steps
  - each catalyzed by a specific enzyme
    - this endergonic biochemical process requires the energy stored in ATP & NADPH

Calvin vs. Krebs (Citric Acid) Cycle

- **Similar:**
  - Starting material is regenerated after molecules enter and leave the cycle

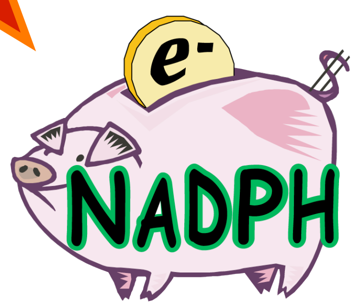
- **Difference:**
  - Citric Acid Cycle is catabolic, oxidizing glucose and using energy to make ATP
  - Calvin Cycle is anabolic, building carbohydrates from smaller molecules and using up energy

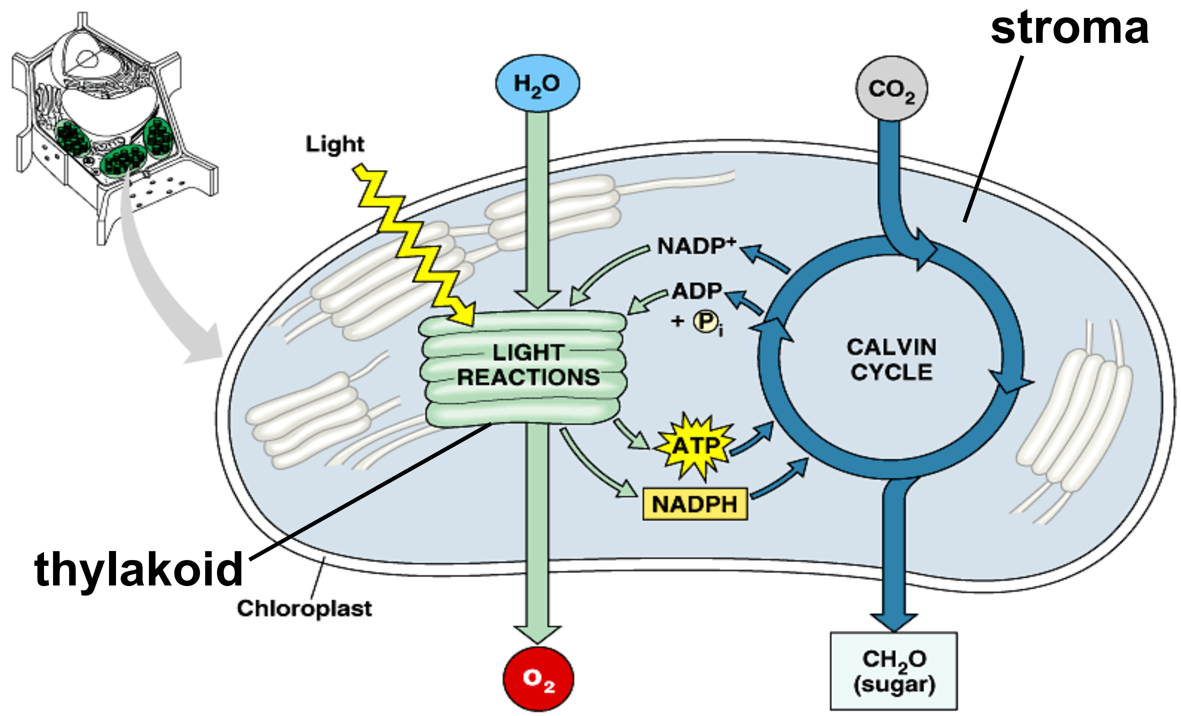




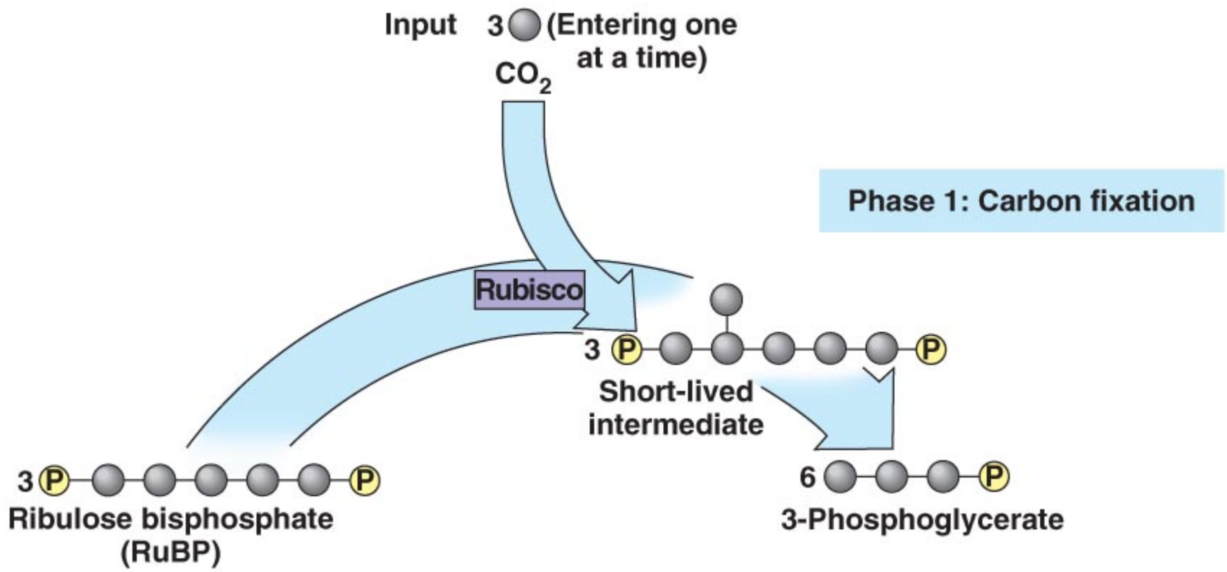
From Light reactions to Calvin cycle

- Calvin cycle
  - In chloroplast's stroma
- Need products of light reactions to drive synthesis reactions
  - ATP
  - NADPH





Calvin cycle - Overview



1. **CARBON FIXATION:**

   A five-carbon sugar molecule (ribulose bisphosphate, or RuBP) binds CO_2 dissolved in the stroma.

   CO_2 fixation = catalyzed by the enzyme RuBP carboxylase (RUBISCO), forming an unstable six-carbon molecule.

   This molecule quickly breaks down to give two molecules of the three-carbon 3-phosphoglycerate (3PG), also called phosphoglyceric acid (PGA).

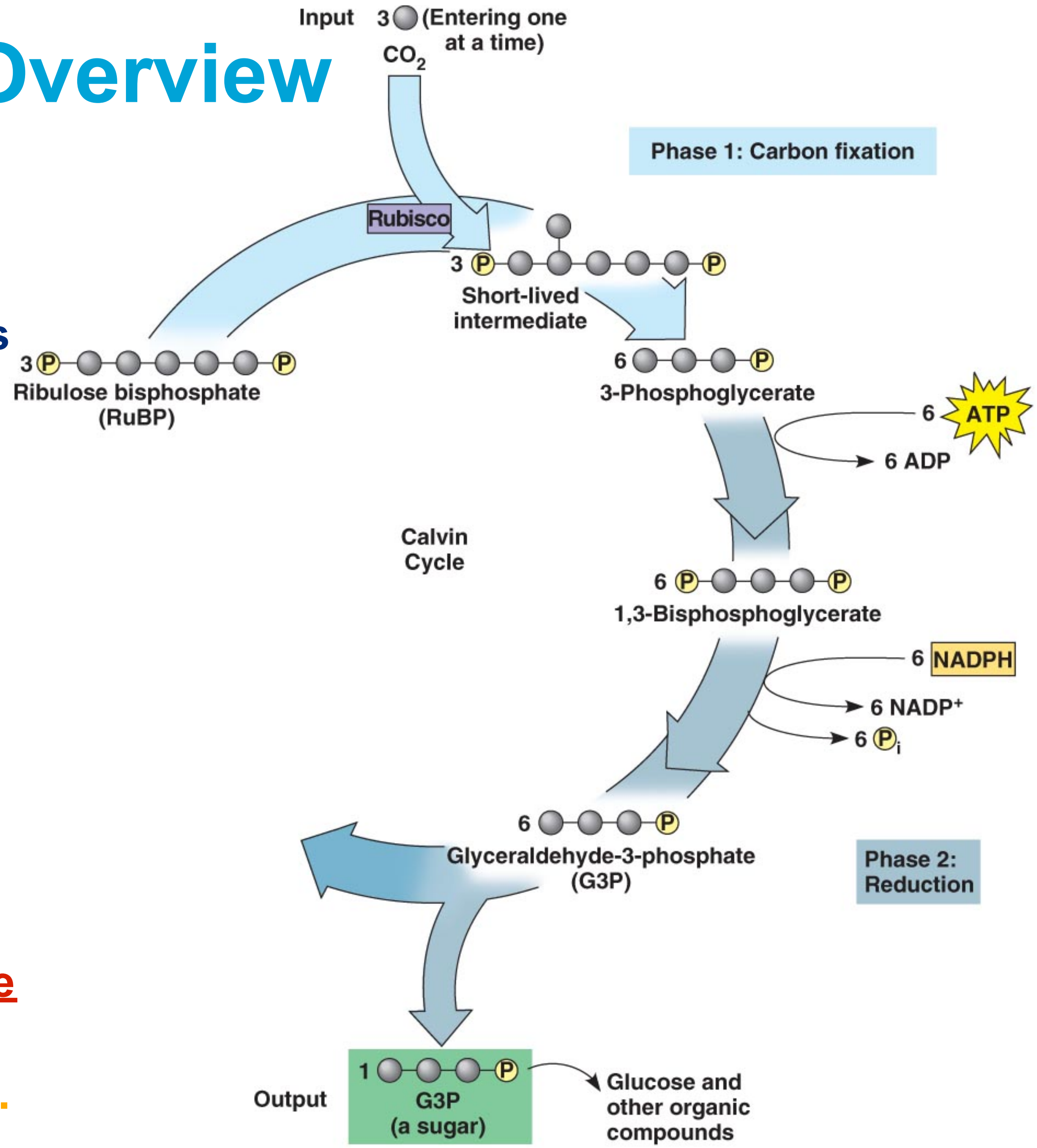
Calvin cycle - Overview

2. REDUCTION:

The two 3PG molecules are converted into glyceraldehyde 3-phosphate (G3P) molecules, a three-carbon sugar phosphate.

How?

By adding a high-energy phosphate group from ATP then breaking the phosphate bond and adding hydrogen from NADPH.



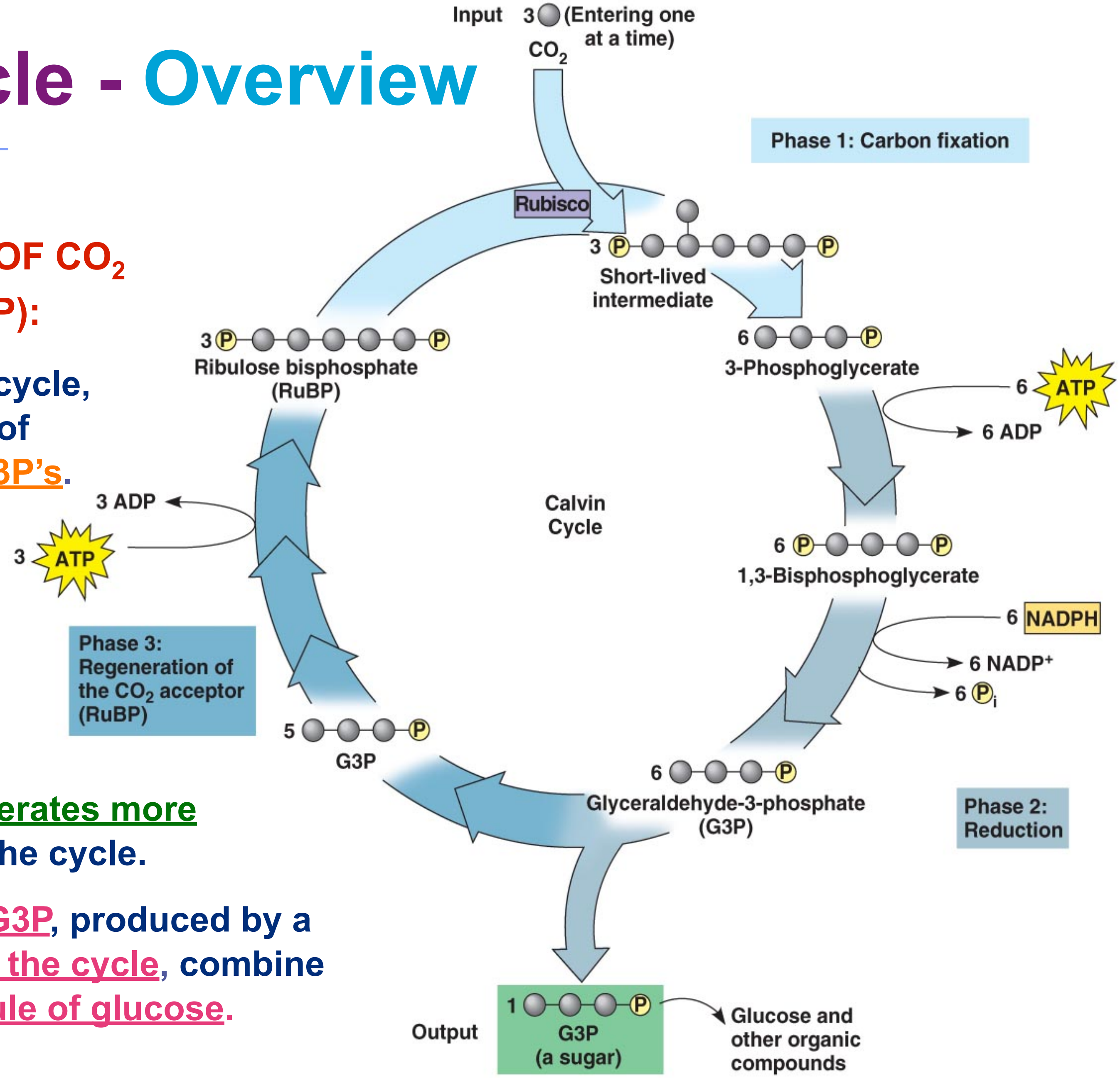
Calvin cycle - Overview

3. REGENERATION OF CO_2 ACCEPTOR (RuBP):

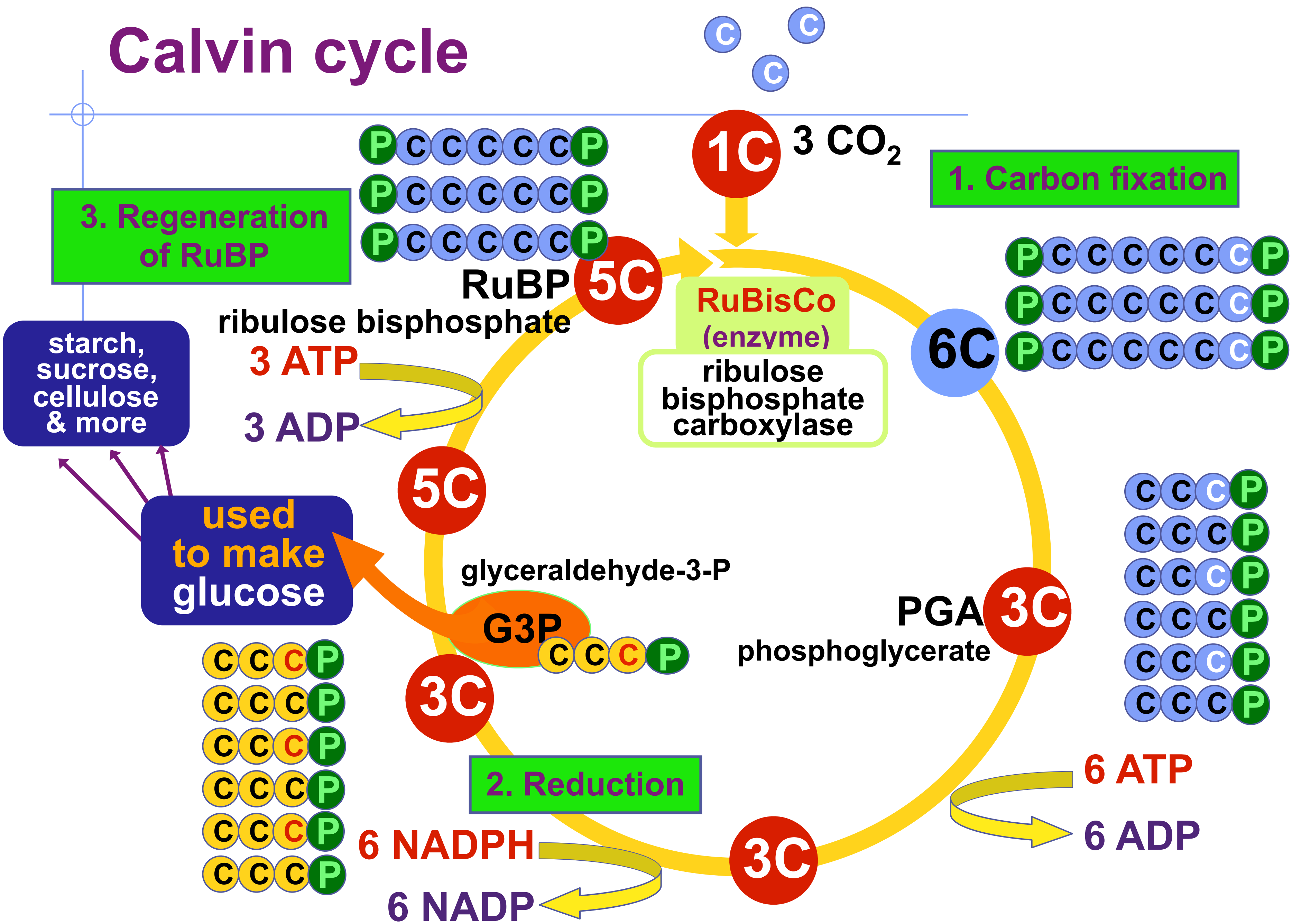
Three turns of the cycle, using 3 molecules of CO_2, produces 6 G3P's.

However, only one of the 6 molecules exits the cycle as an output, while the remaining 5 enter a complex process that regenerates more RuBP to continue the cycle.

Two molecules of G3P, produced by a total of six turns of the cycle, combine to form one molecule of glucose.

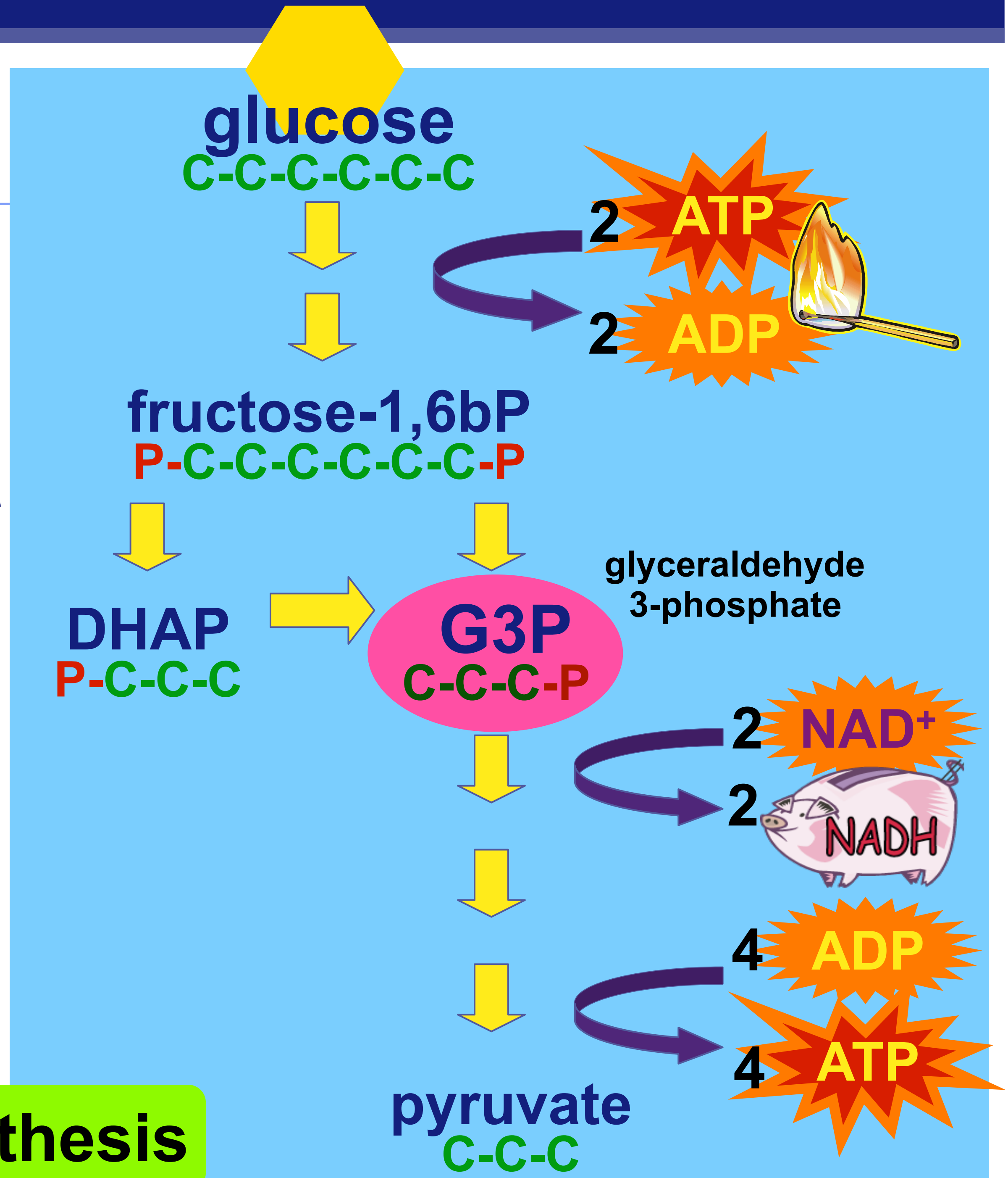


Calvin cycle



Remember G3P?

glycolysis



Photosynthesis

The value of G3P!

- **Glyceraldehyde-3-P**
  - end product of Calvin cycle
  - energy rich <u>3 carbon sugar</u>
  - "C<u>3</u> photosynthesis"

- **G3P is an important intermediate:**

G3P → → glucose → → carbohydrates

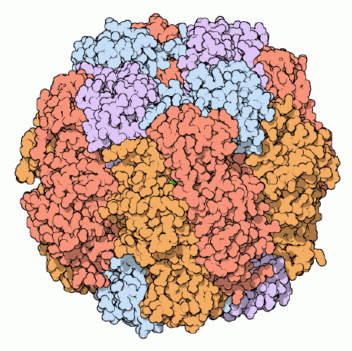
→ → lipids → → phospholipids, fats, waxes

→ → amino acids → → proteins

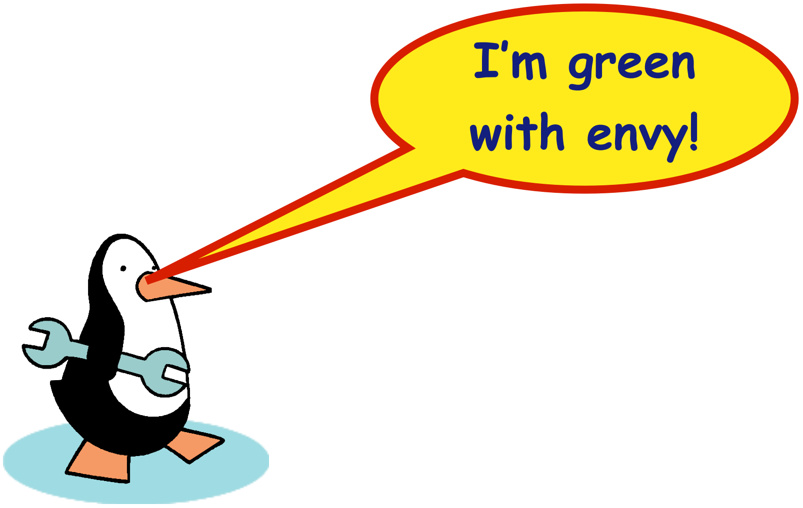
→ → nucleic acids → → DNA, RNA

RuBisCo

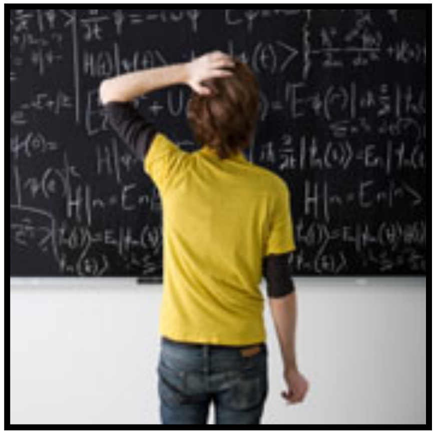
- Enzyme which fixes carbon (converts



  - ribulose bisphosphate carboxylase
  - the most important enzyme in the world!
    - it makes life out of air!
  - definitely the most abundant enzyme



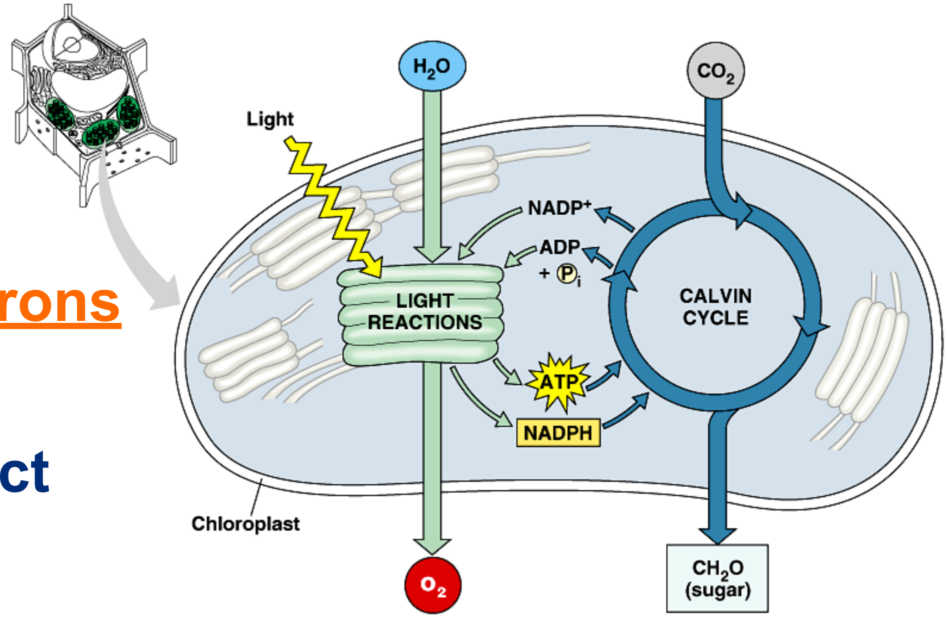
Accounting



- The accounting is complicated:
  - 3 turns of Calvin cycle produces 1 net G3P
    - 3 CO_2 → 1 G3P (3C)
    - 9 ATP + 6 NADPH → 1 G3P
  - 6 turns of Calvin cycle produces 1 $C_6H_{12}O_6$ (6C)
    - 6 CO_2 → 1 $C_6H_{12}O_6$ (6C)
    - 18 ATP + 12 NADPH → 1 $C_6H_{12}O_6$
- any ATP left over from light reactions will be used elsewhere by the cell for doing work
  - This is why during daylight hours, photosynthetic cells may not need to perform much cellular respiration reactions to make ATP (like they do have to do at night)

Photosynthesis summary

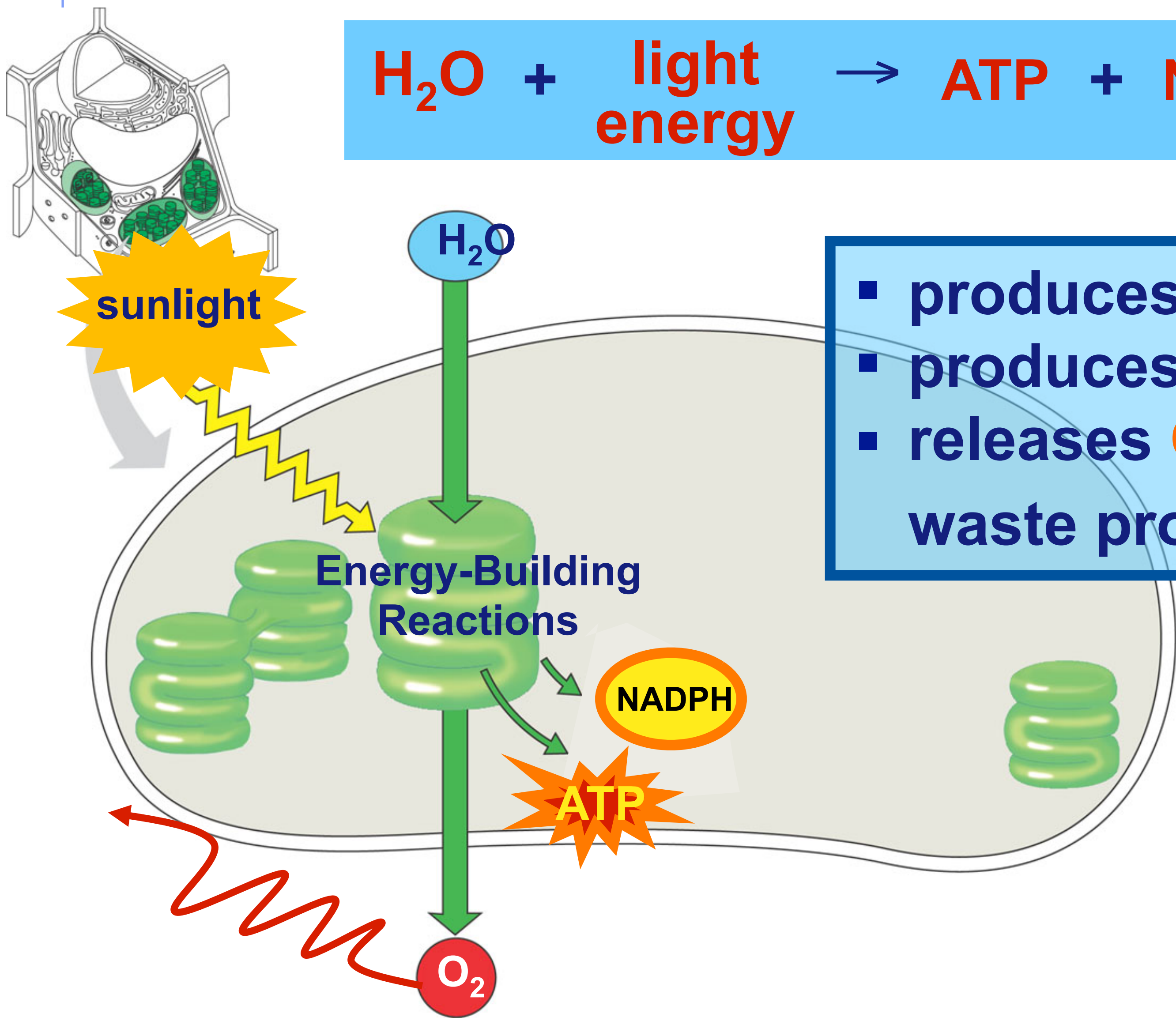
- Light reactions
  - produced ATP, which stores potential energy
  - produced NADPH, which carries high-energy electrons
  - consumed H_2O
  - produced O_2 as by-product



- Calvin cycle
  - consumed CO_2
  - produced high-energy, organic G3P (sugar)
  - regenerated ADP + Pi
  - regenerated $NADP^+$

Light Reactions

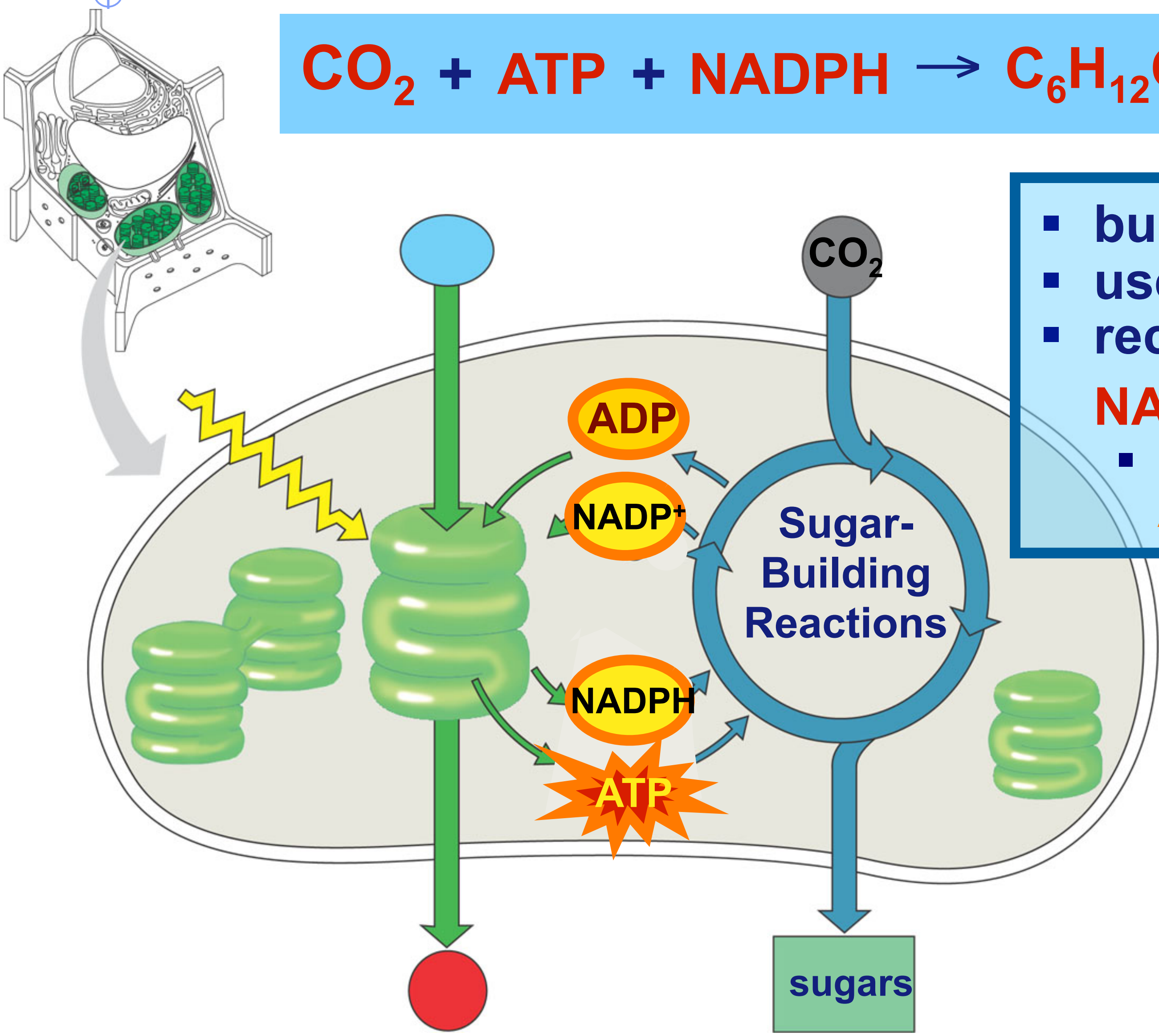
H_2O + light energy $\rightarrow$ ATP + NADPH + O_2



- produces ATP
- produces NADPH
- releases O_2 as a waste product

Calvin Cycle

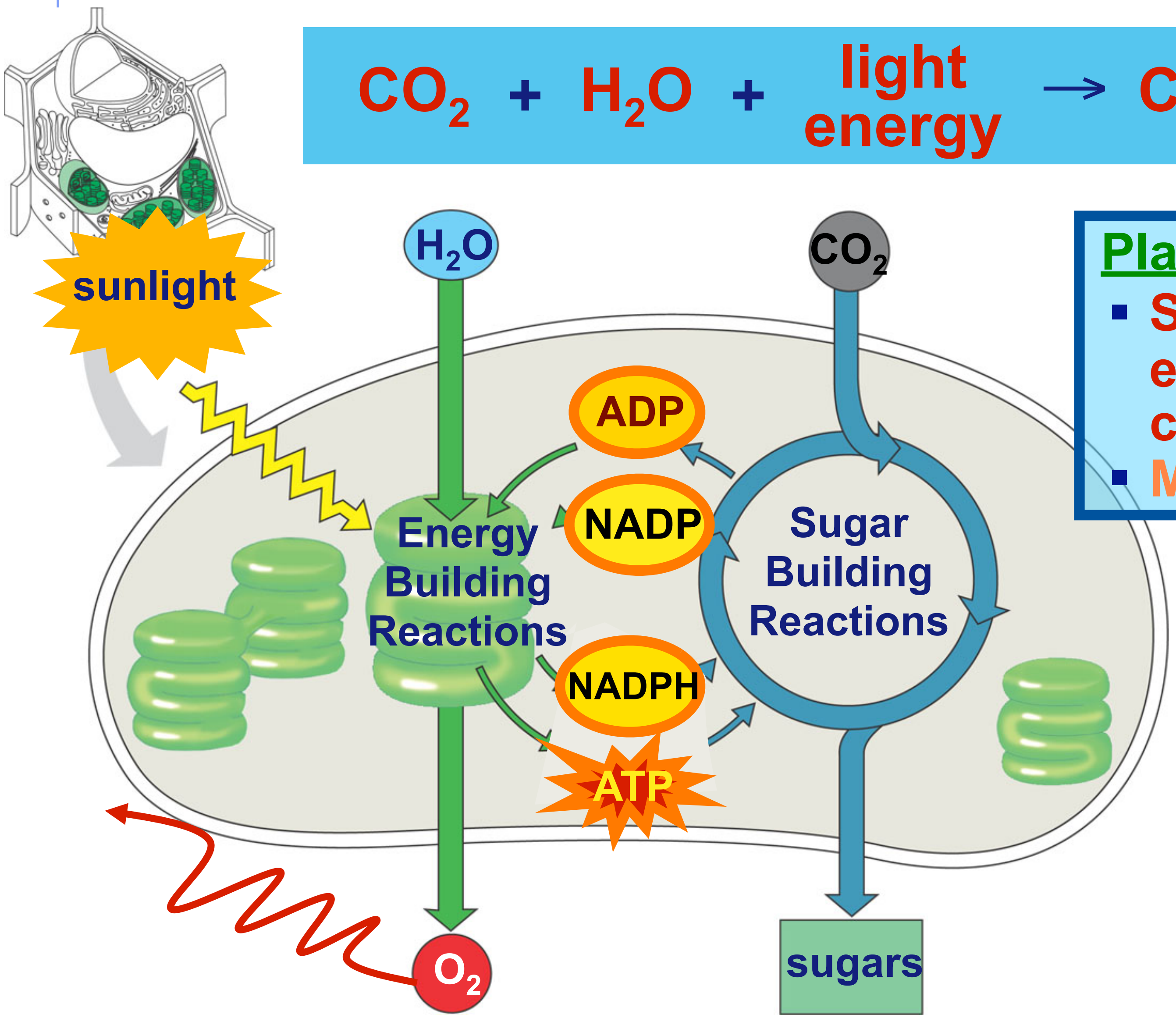
CO_2 + ATP + NADPH → $C_6H_{12}O_6$ + ADP + $NADP^+$



- builds sugars
- uses ATP & NADPH
- recycles ADP + Pi & $NADP^+$
  - back to make more ATP & NADPH

Putting it all together - Photosynthesis

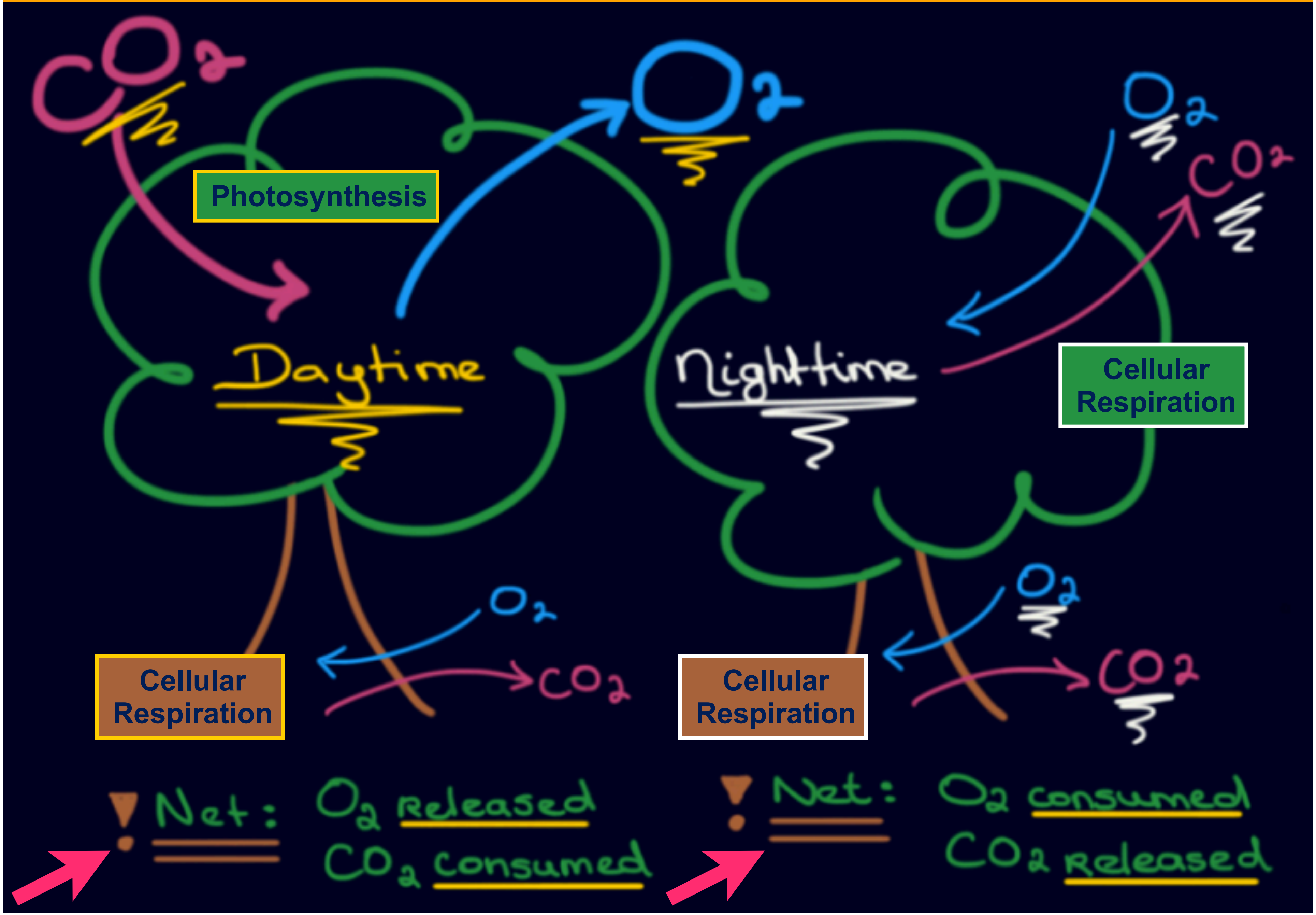
$$CO_2 + H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + O_2$$

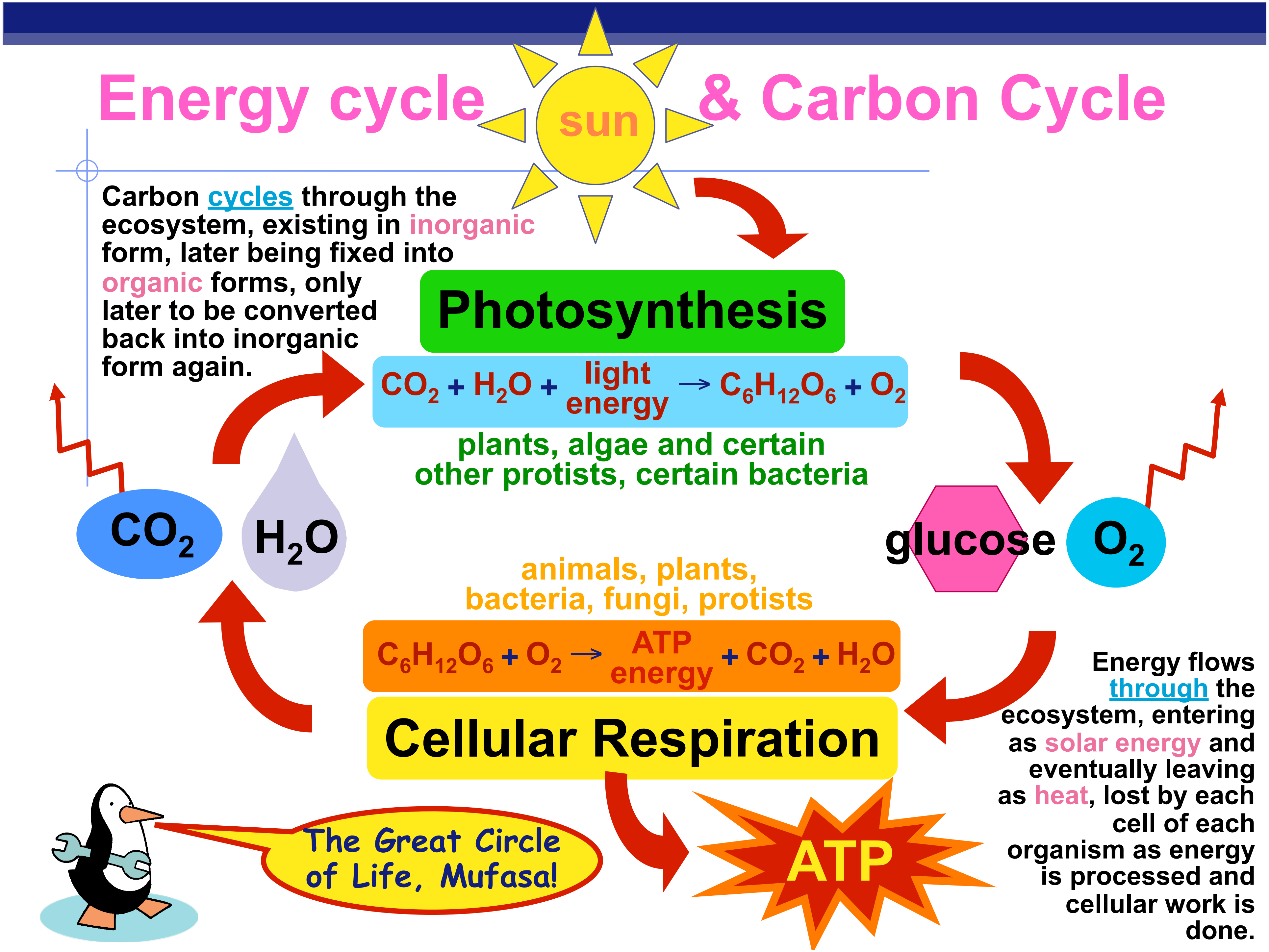


Plants:

- Store light energy as chemical energy
- Make sugars

Remember, plants do cellular respiration too!




Energy cycle
sun
& Carbon Cycle
Carbon cycles through the ecosystem, existing in inorganic form, later being fixed into organic forms, only later to be converted back into inorganic form again.
Photosynthesis
$CO_2 + H_2O +$ light energy $\rightarrow C_6H_{12}O_6 + O_2$
plants, algae and certain other protists, certain bacteria
CO_2
H_2O
glucose
O_2
animals, plants, bacteria, fungi, protists
$C_6H_{12}O_6 + O_2 \rightarrow$ ATP energy $+ CO_2 + H_2O$
Cellular Respiration
ATP
The Great Circle of Life, Mufasa!
Energy flows through the ecosystem, entering as solar energy and eventually leaving as heat, lost by each cell of each organism as energy is processed and cellular work is done.

Summary of photosynthesis

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

- Where did the CO_2 come from?
- Where did the CO_2 go?
- Where did the H_2O come from?
- Where did the H_2O go?
- Where did the energy come from?
- What's the energy used for?
- What will the $C_6H_{12}O_6$ be used for?
- Where did the O_2 come from?
- Where will the O_2 go?

Answer Key

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

- **Where did the CO_2 come from?** *Diffusion into the leaf space and then photosynthetic cells from the air.*
- **Where did the CO_2 go?** *It got reduced into glucose.*
- **Where did the H_2O come from?** *The soil, brought into the plant by roots.*
- **Where did the H_2O go?** *It was split as a source of new (low energy) electrons.*
- **Where did the energy come from?** *The sun.*
- **What's the energy used for?** *To drive the endergonic reactions that build G3P and thus glucose.*
- **What will the $C_6H_{12}O_6$ be used for?** *It is a source of chemical energy for cells and a source of organic carbons for the cell to use to make all other organic molecules needed.*
- **Where did the O_2 come from?** *From the splitting of water in the light reactions.*
- **Where will the O_2 go?** *It will diffuse out of the chloroplast and photosynthesizing cell, entering the air.*

Supporting a biosphere

- On global scale, photosynthesis is the most important process for the continuation of life on Earth
  - each year photosynthesis…
    - captures 121 billion tons of CO_2
    - synthesizes 160 billion tons of carbohydrate
  - heterotrophs are dependent on plants, algae, cyanobacteria and alike as food source for fuel & raw building material
    - A basic ecosystems can be formed if is has photosynthetic organisms (producers) to fix carbon and capture solar energy and decomposers - bacteria and fungi - that eventually convert the organic molecules of all living cells back into inorganic ions and molecules, later returned to the air, soil, and water where producers will obtain them again)

The poetic perspective…

- All the solid material of every plant and photosynthetic protist and bacterium was built by sunlight out of 'thin air'
- All the solid organic material of every animal, fungus, bacterium, plant, and protist was built from carbon fixed by photosynthesizing organisms

air

sun

Then all the plants, cats, dogs, elephants & people … are really particles of air woven together by strands of sunlight!

If plants can do it…

You can learn it*!*

Ask Questions*!!*

Why you ask?

You can grow if you Ask Questions*!*

Duh!