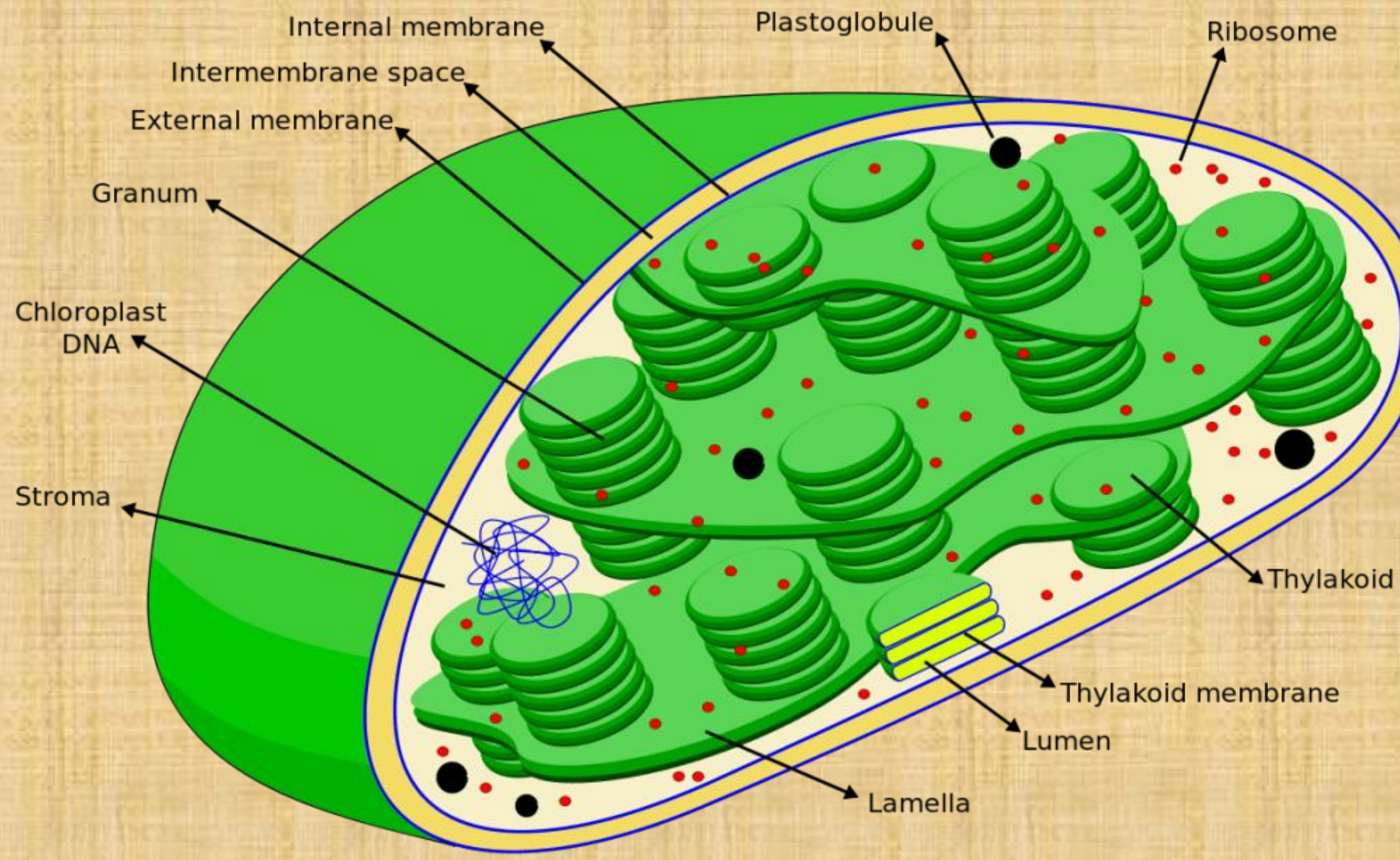
Structure and Functions of Chloroplast

Structure of Chloroplast



Chloroplast structure

- **chloroplast**, structure within the cells of plants and green algae that is the site of photosynthesis, the process by which light energy is converted to chemical energy, resulting in the production of oxygen and energy-rich organic compounds. Photosynthetic cyanobacteria are free-living close relatives of chloroplasts; endosymbiotic theory posits that chloroplasts and mitochondria (energy-producing organelles in eukaryotic cells) are descended from such organism.
- Chloroplasts are roughly 1–2 μm (1 μm = 0.001 mm) thick and 5–7 μm in diameter. They are enclosed in a chloroplast envelope, which consists of a double membrane with outer and inner layers, between which is a gap called the intermembrane space. A third, internal membrane, extensively folded and characterized by the presence of closed disks (or thylakoids), is known as the thylakoid membrane. In most higher plants, the thylakoids are arranged in tight stacks called grana (singular granum). Grana are connected by stromal lamellae, extensions that run from one granum, through the stroma, into a neighbouring *granum*. The thylakoid membrane envelops a central aqueous region known as the thylakoid lumen. The space between the inner membrane and the thylakoid membrane is filled with stroma, a matrix containing dissolved enzymes, starch granules, and copies of the chloroplast genome.

Introduction

- **Photosynthesis**, the process by which green plants and certain other organisms transform light energy into chemical energy.
- The process of photosynthesis in plants is based on two reactions that are carried out by separate parts of the chloroplast.
- The light reactions occur in the chloroplast thylakoid membrane and involve the splitting of water into oxygen, protons and electrons.
- The protons and electrons are then transferred through the thylakoid membrane to create the energy storage molecules adenosine triphosphate (ATP) and nicotinomide–adenine dinucleotide phosphate (NADPH).
- The ATP and NADPH are then utilized by the enzymes of the Calvin–Benson cycle (the dark reactions), which converts CO_2 into carbohydrate in the chloroplast stroma.

Oxygenic photosynthesis is written as follows

- $6CO_2 + 12H_2O$ + Light Energy $\rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$

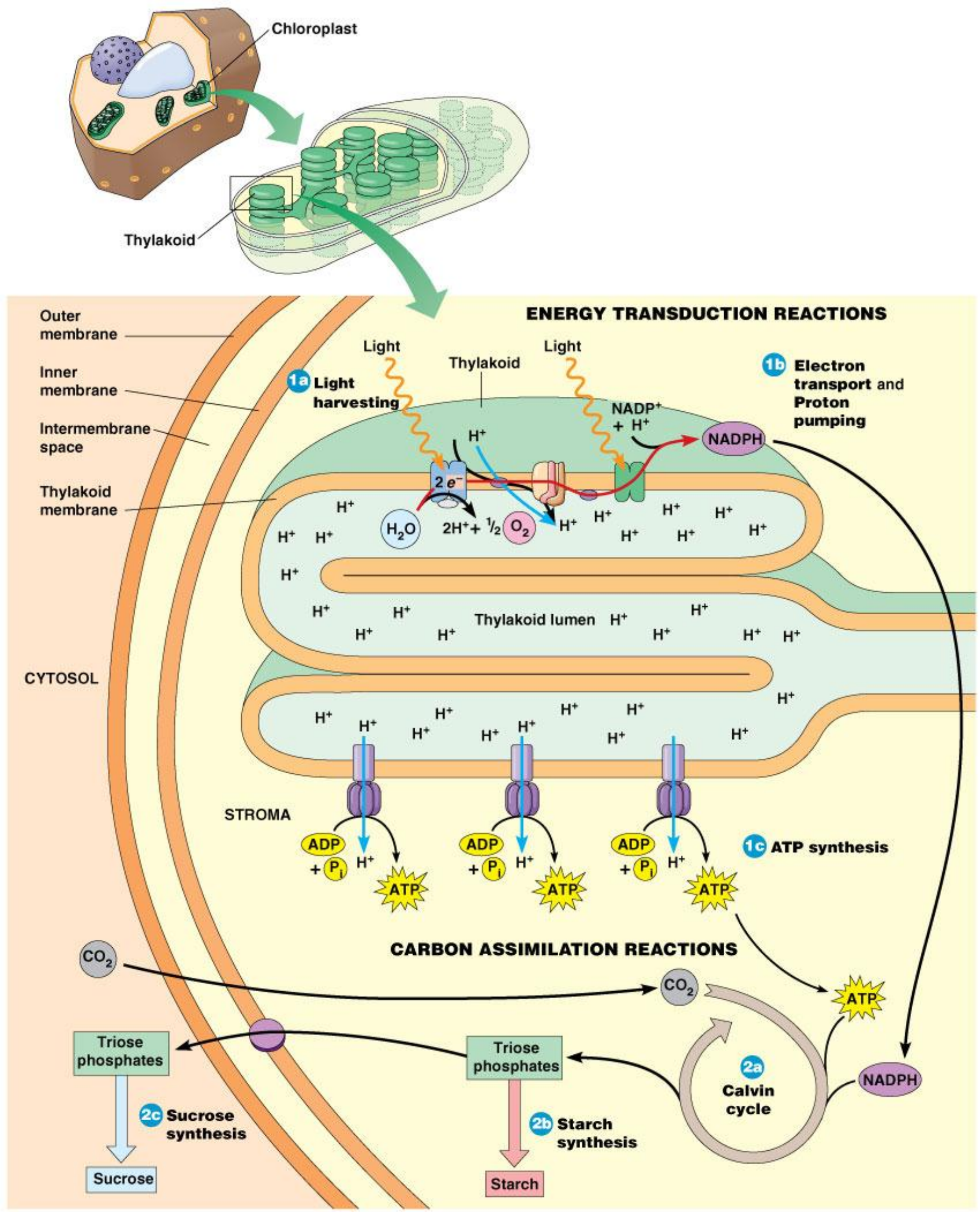
Here, six molecules of carbon dioxide (CO_2) combine with 12 molecules of water (H_2O) using light energy. The end result is the formation of a single carbohydrate molecule ($C_6H_{12}O_6$, or glucose) along with six molecules each of breathable oxygen and water.

Oxygenic Photosynthesis:

$6CO_2 + 12H_2O$ + Light Energy $\longrightarrow C_6H_{12}O_6$ (Glucose) + 6O2 + $6H_2O$

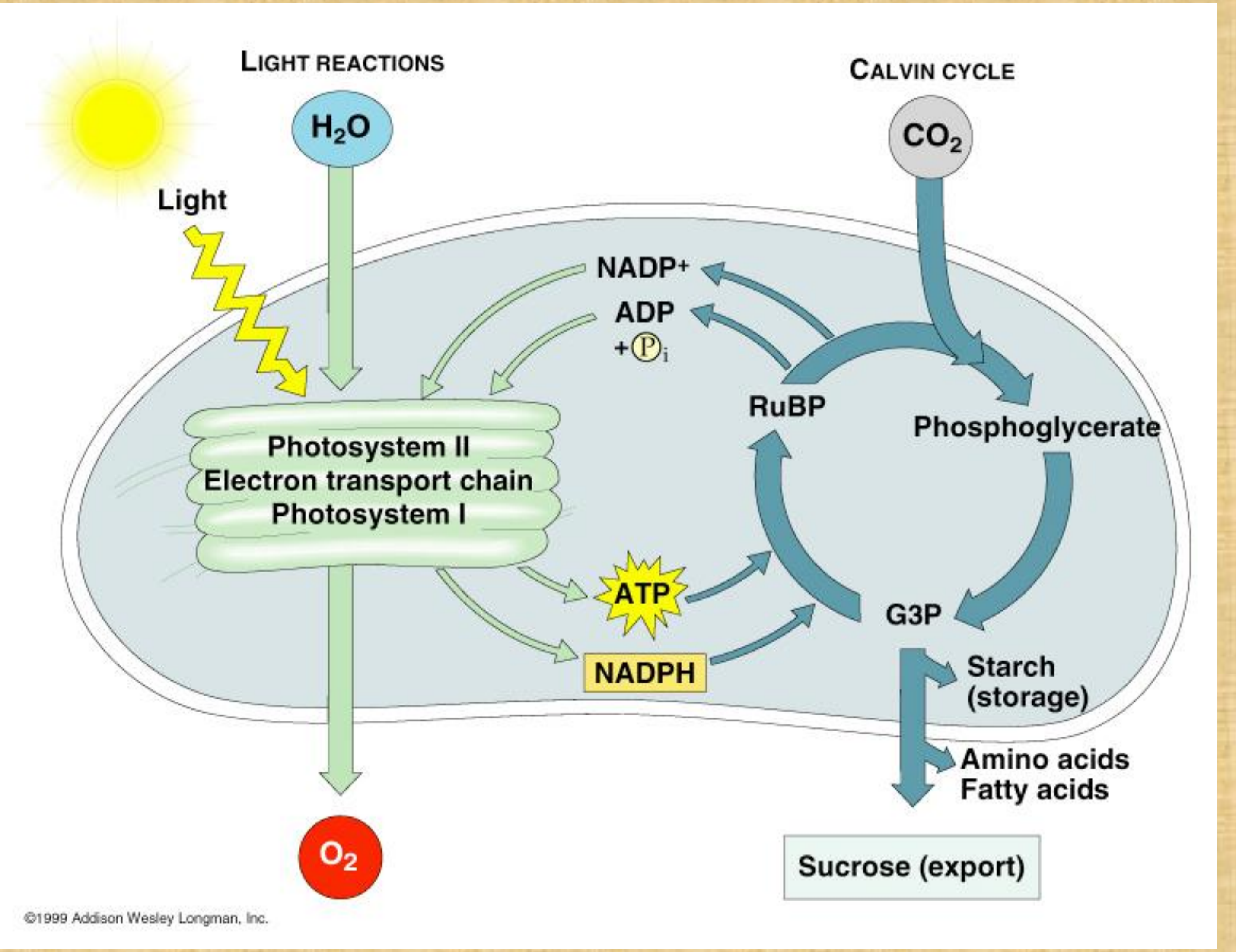
Anoxygenic Photosynthesis:

$CO_2 + 2H_2S$ + Light Energy $\longrightarrow [CH_2O] + 2S + H_2O$



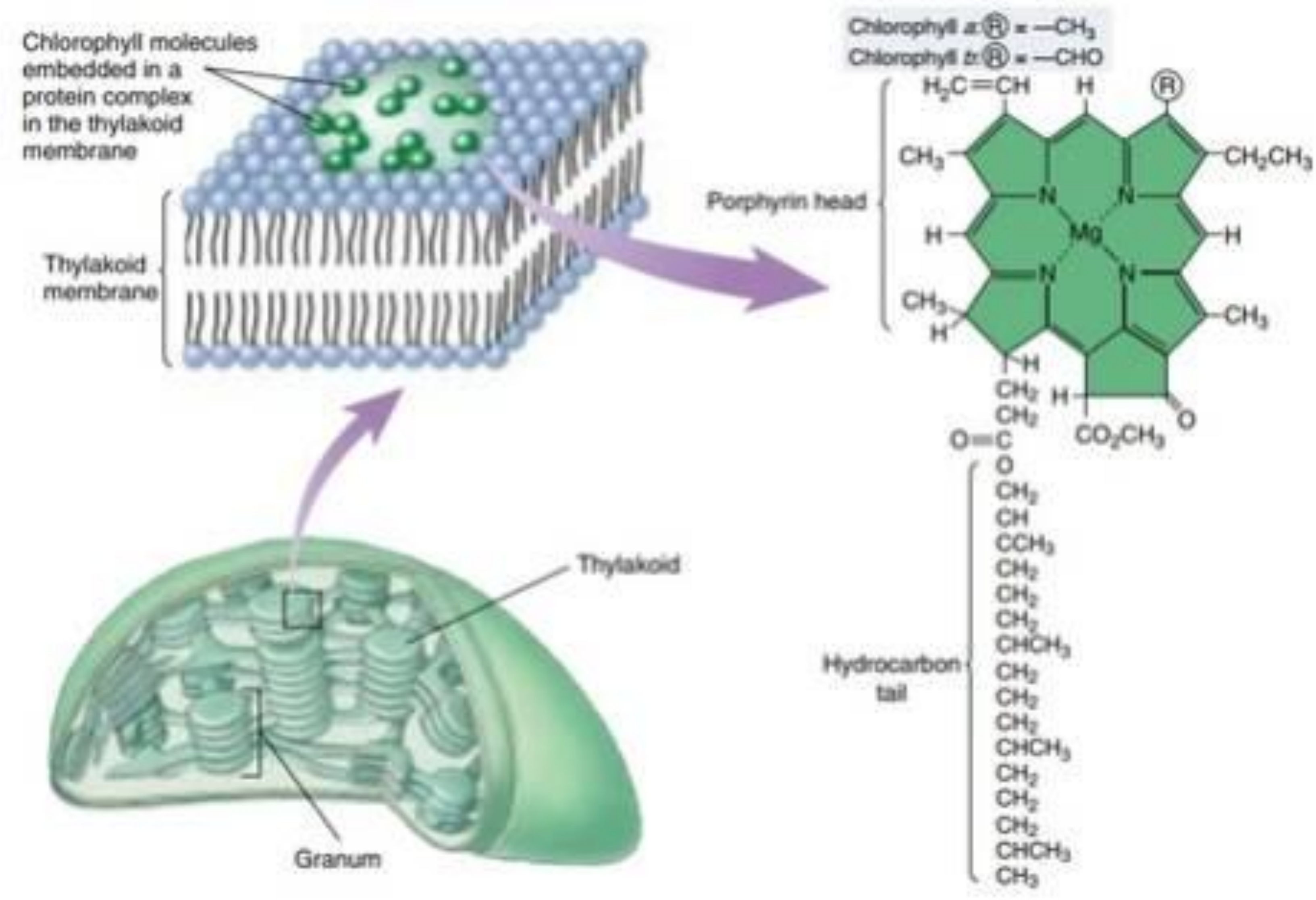
Chloroplast
Thylakoid
ENERGY TRANSDUCTION REACTIONS
Outer membrane
Inner membrane
Intermembrane space
Thylakoid membrane
Light
Thylakoid
Light
1a Light harvesting
1b Electron transport and Proton pumping
NADP+ + H+
NADPH
H+
2 e−
H2O
2H+ + ½ O2
Thylakoid lumen
CYTOSOL
STROMA
ADP + Pi
ATP
1c ATP synthesis
CARBON ASSIMILATION REACTIONS
CO2
CO2
ATP
NADPH
Triose phosphates
Triose phosphates
2a Calvin cycle
2b Starch synthesis
2c Sucrose synthesis
Sucrose
Starch

Photosynthesis

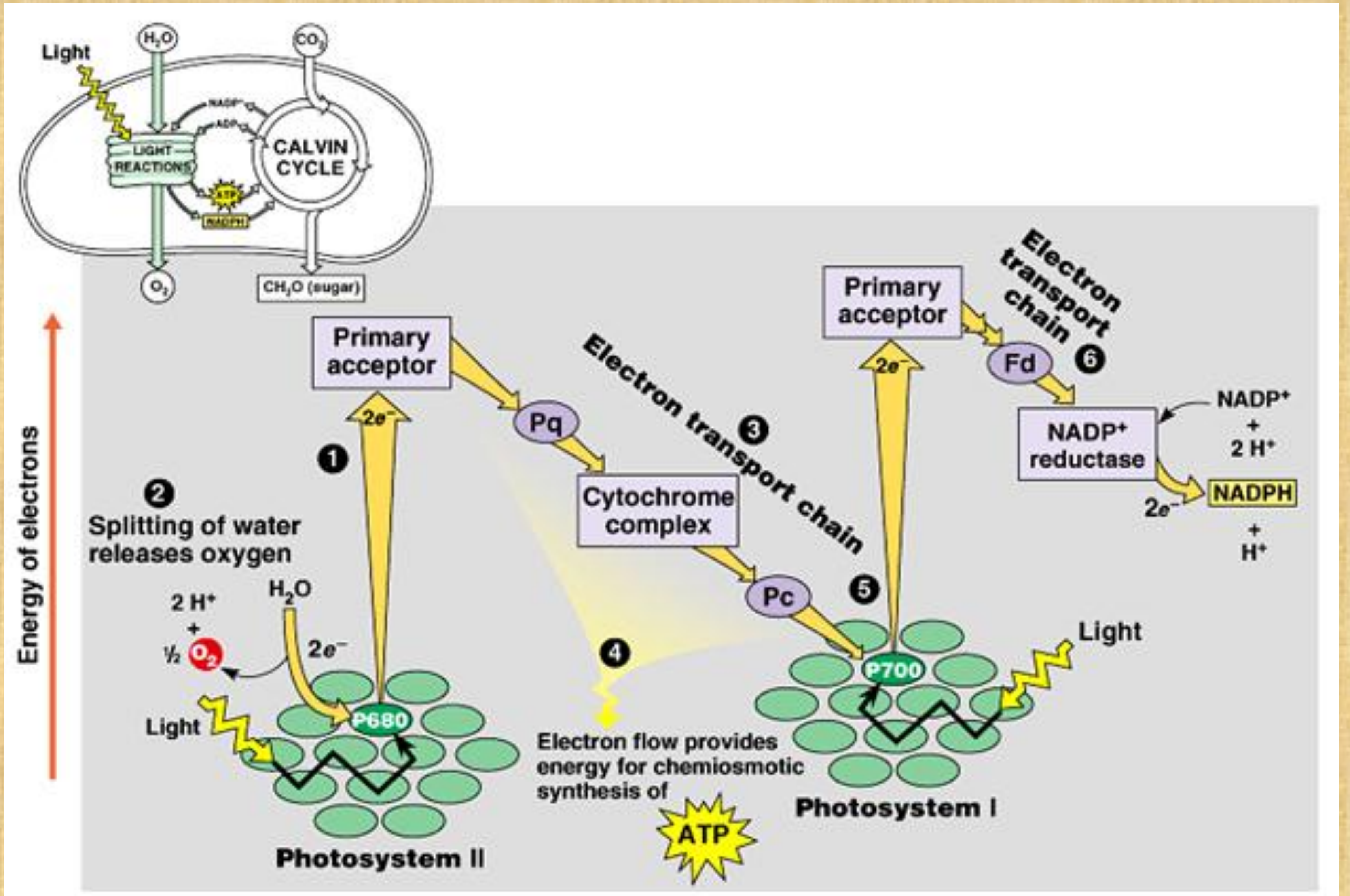


Light reaction

- The light reactions happen in the *thylakoid membranes* of the chloroplasts of plant cells. The thylakoids have densely packed protein and enzyme clusters known as *photosystems*.
- A photosystem is comprised of various proteins that surround and connect a series of *pigment molecules*. Pigments are molecules that absorb various photons, allowing their electrons to become excited. *Chlorophyll a* is the main pigment used in these systems, and collects the final energy transfer before releasing an electron.
- Photosystem II (PSII, P_{680}) starts this process of electrons by using the light energy to split a water molecule, which releases the hydrogen while siphoning off the electrons. The electrons are then passed through plastoquinone, an enzyme complex that releases more hydrogens into the *thylakoid space*.
- The electrons then flow through a cytochrome complex and plastocyanin to reach photosystem I (PSI, P_{700}). These three complexes form an *electron transport chain*, much like the one seen in mitochondria. Photosystem I then uses these electrons to drive the reduction of $NADP^+$ to NADPH.
- ATP synthesis : The high-energy electron travels down an electron transport chain, losing energy as it goes. Some of the released energy drives pumping of H^+ , H^+ ions from the stroma into the thylakoid interior, building a gradient. (H^+ from the splitting of water also add to the gradient.) As H^+ ions flow down their gradient and into the stroma, they pass through ATP synthase, driving ATP production in a process known as chemiosmosis.


Chlorophyll molecules embedded in a protein complex in the thylakoid membrane
Thylakoid membrane
Thylakoid
Granum
Chlorophyll a: Ⓡ = —CH_3
Chlorophyll b: Ⓡ = —CHO
Porphyrin head
$H_2C=CH$
H
Ⓡ
CH_3
CH_2CH_3
N
Mg
H
CH_3
H
CH_2
CH_2
$O=C$
O
CO_2CH_3
Hydrocarbon tail
CH_2
CH
CCH_3
CH_2
CH_2
CH_2
$CHCH_3$
CH_2
CH_2
CH_2
$CHCH_3$
CH_2
CH_2
CH_2
$CHCH_3$
CH_3

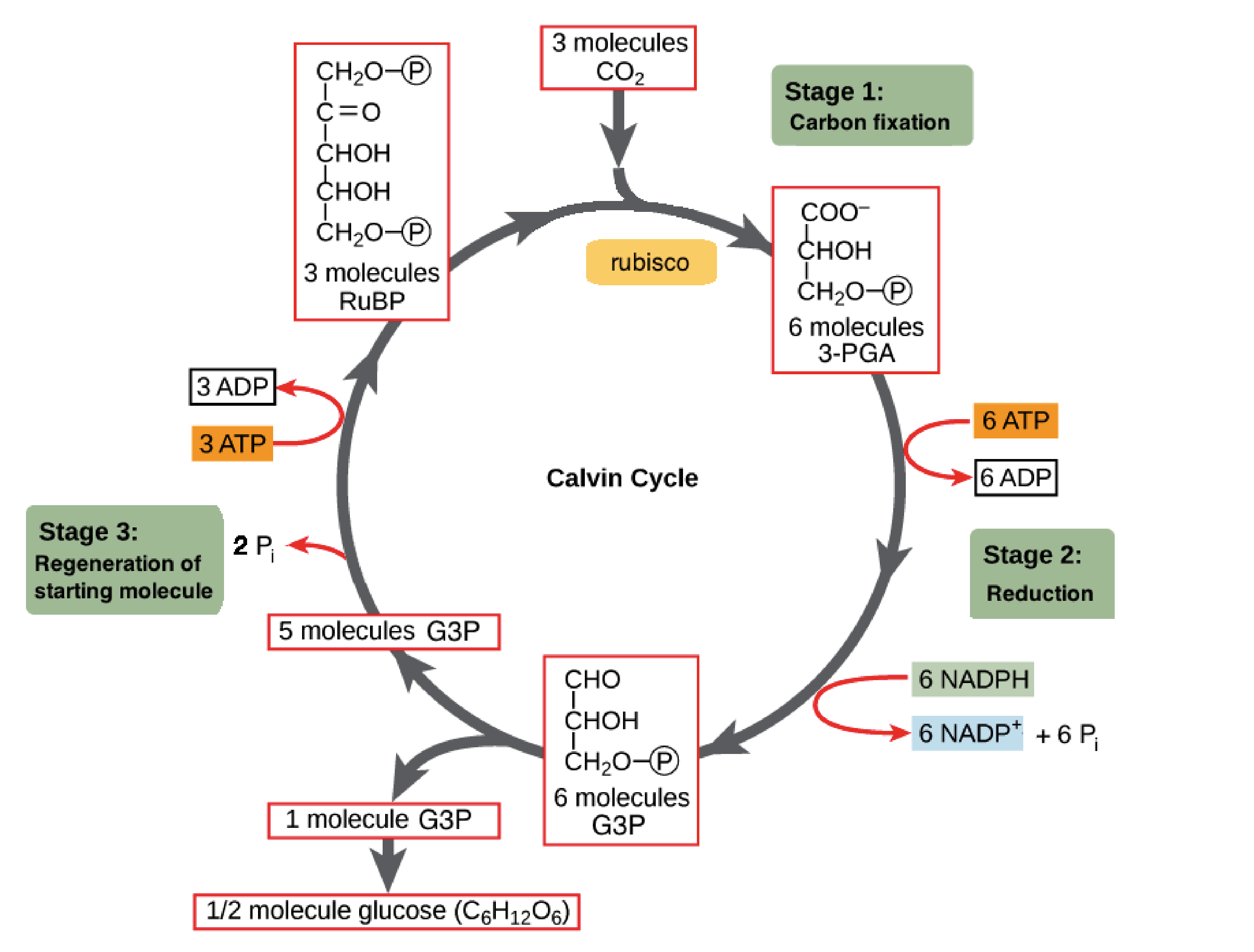
Light reaction



Dark Reactions

- Carbon-Fixing Reactions are also known as the Dark Reactions (or Light Independent Reactions) consists of three phases. The reaction occurs in the stroma of the chloroplast.
- **Fixation**: The first enzyme that intervenes in the Calvin Cycle is called RuBisCO, which fixes three atmospheric CO_2 atoms, binding them to three units of ribulose bisphosphate. The result of this binding is six molecules of 3-phosphoglycerate.
- **Reduction**: The previous molecule transforms into 1,3-Bisphosphoglycerate through the action of six ATPs (generated in the light phase), and this compound transforms into G3P through the action of six NADPHs. One of these two molecules of G3P passes to the plant's metabolic pathways to produce superior compounds such as glucose or starch.
- **Regeneration**: Finally, the addition of phosphorus through three ATPs ends up generating a new molecule of ribulose-1,5-bisphosphate, which sets the process off again. For more detail, see the following diagram that shows the Calvin Cycle steps:

Calvin cycle



Photophosphorylation

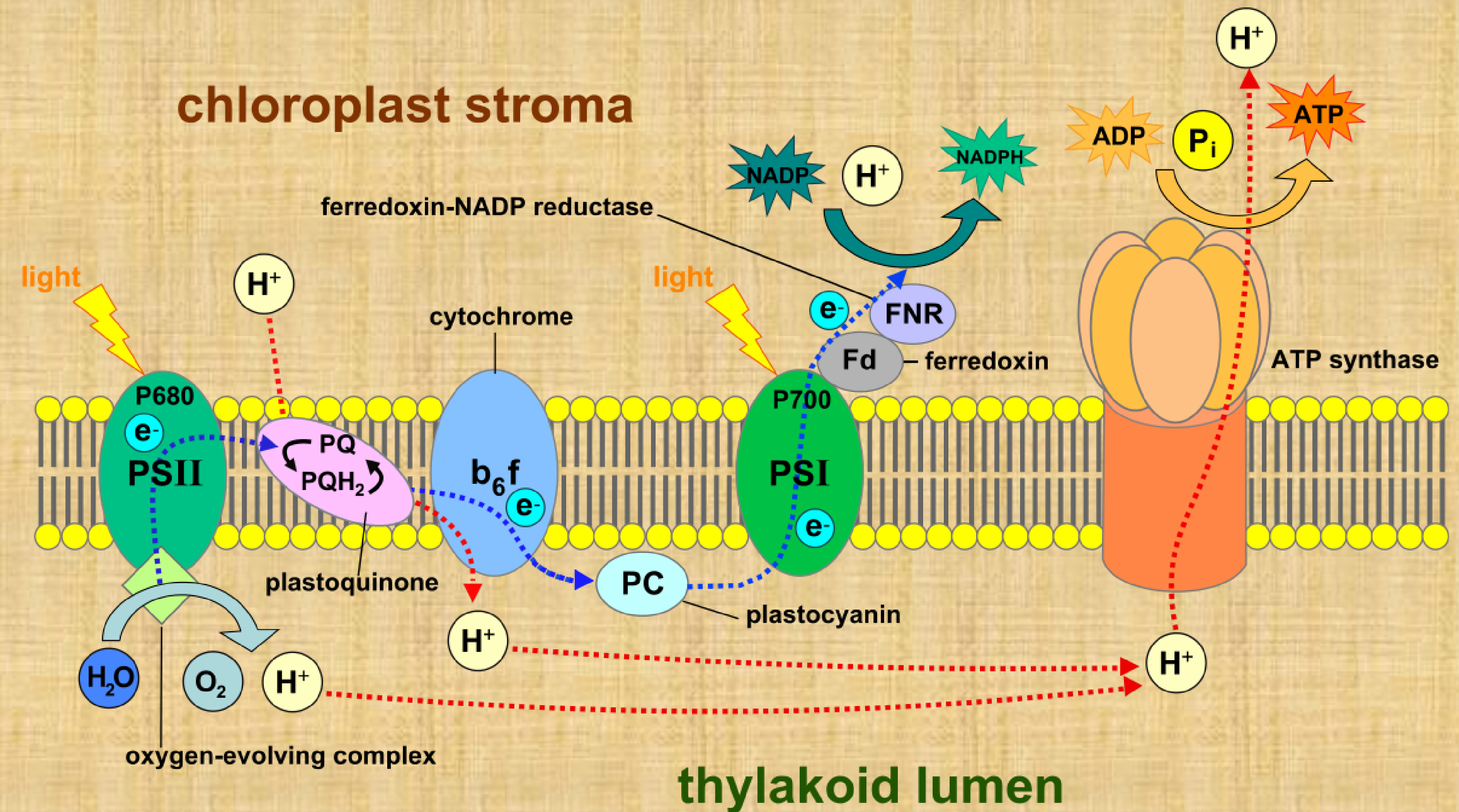
Cyclic Photophosphorylation

- Cyclic photophosphorylation involves the use of only **one** photosystem (PS I) and does **not** involve the reduction of $NADP^+$
- When light is absorbed by Photosystem I, the excited electron may enter into an electron transport chain to produce ATP
- Following this, the de-energised electron returns to the photosystem, restoring its electron supply (hence: cyclic)
- As the electron returns to the photosystem, $NADP^+$ is not reduced and water is not needed to replenish the electron supply

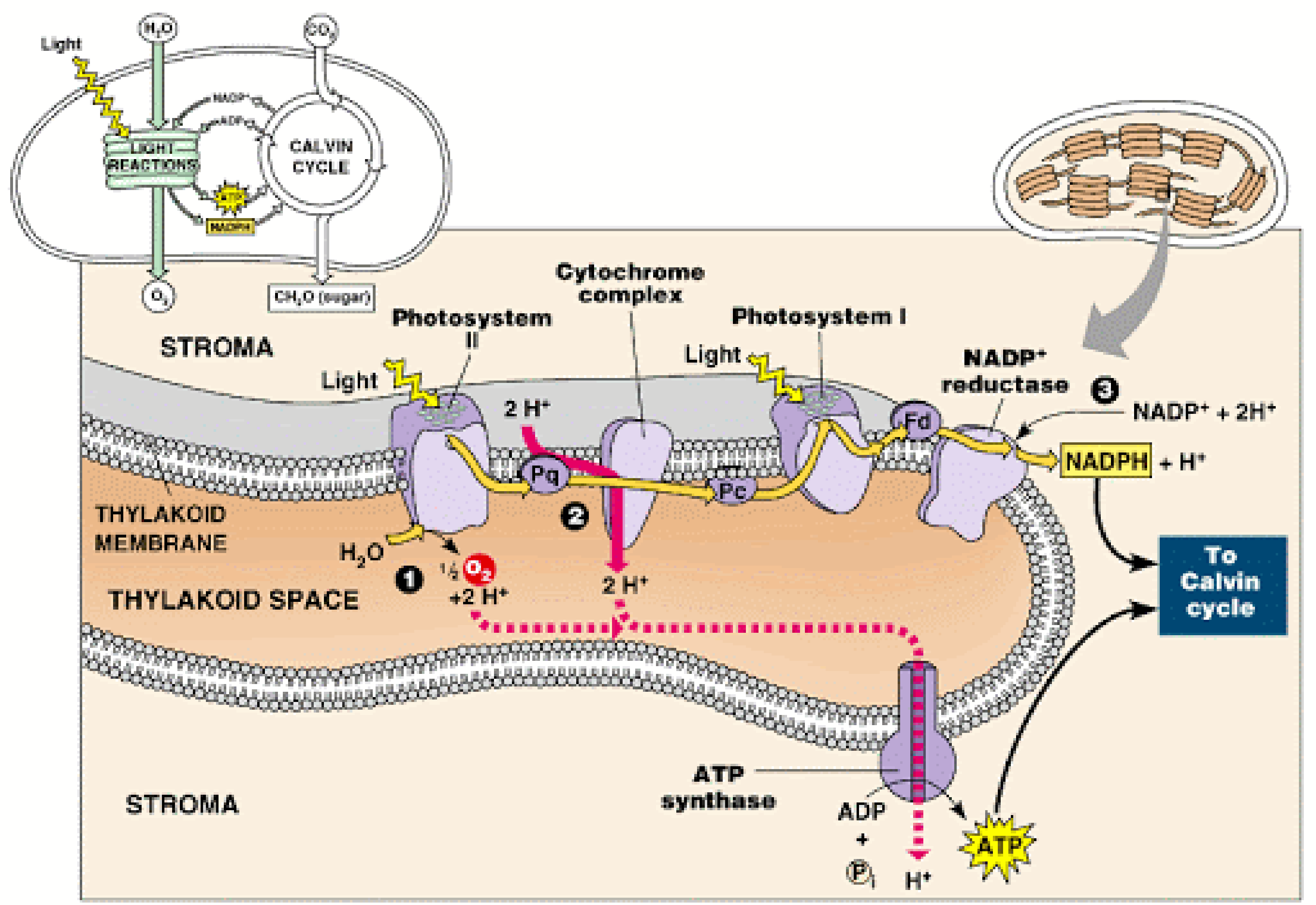
Non-Cyclic Photophosphorylation

- Non-cyclic photophosphorylation involves **two** photosystems (PS I and PS II) and **does** involve the reduction of $NADP^+$
- When light is absorbed by Photosystem II, the excited electrons enter into an electron transport chain to produce ATP
- Concurrently, photoactivation of Photosystem I results in the release of electrons which reduce $NADP^+$ (forms NADPH)
- The photolysis of water releases electrons which replace those lost by Photosystem II (PS I electrons replaced by PS II)

Photophosporylation



Photophosporylation



Cyclic Photophosphorylation	Non-Cyclic Photophosphorylation
Only PS I is involved	PS I and PS II are both involved
Water is not required	Photolysis of water is required
Oxygen is not evolved	Oxygen is evolved
NADPH is not synthesized	NADPH is synthesized
Used to produce additional ATP in order to meet cell energy demands	Products can be used for the light independent reactions

C4 pathway

- The C4 pathway acts as a mechanism to build up high concentrations of carbon dioxide in the chloroplasts of the bundle sheath cells. The resulting higher level of internal carbon dioxide in these chloroplasts serves to increase the ratio of carboxylation to oxygenation, thus minimizing photorespiration.
- The carbon-fixation pathway begins in the mesophyll cells, where carbon dioxide is converted into bicarbonate, which is then added to the three-carbon acid phosphoenolpyruvate (PEP) by an enzyme called phosphoenolpyruvate carboxylase.PEP carboxylase, which is located in the mesophyll cells, is an essential enzyme in C4 plants [Eg. Sugarcane (*Saccharum officinarum*) Maize (*Zea mays*).

C4 photosynthetic pathway

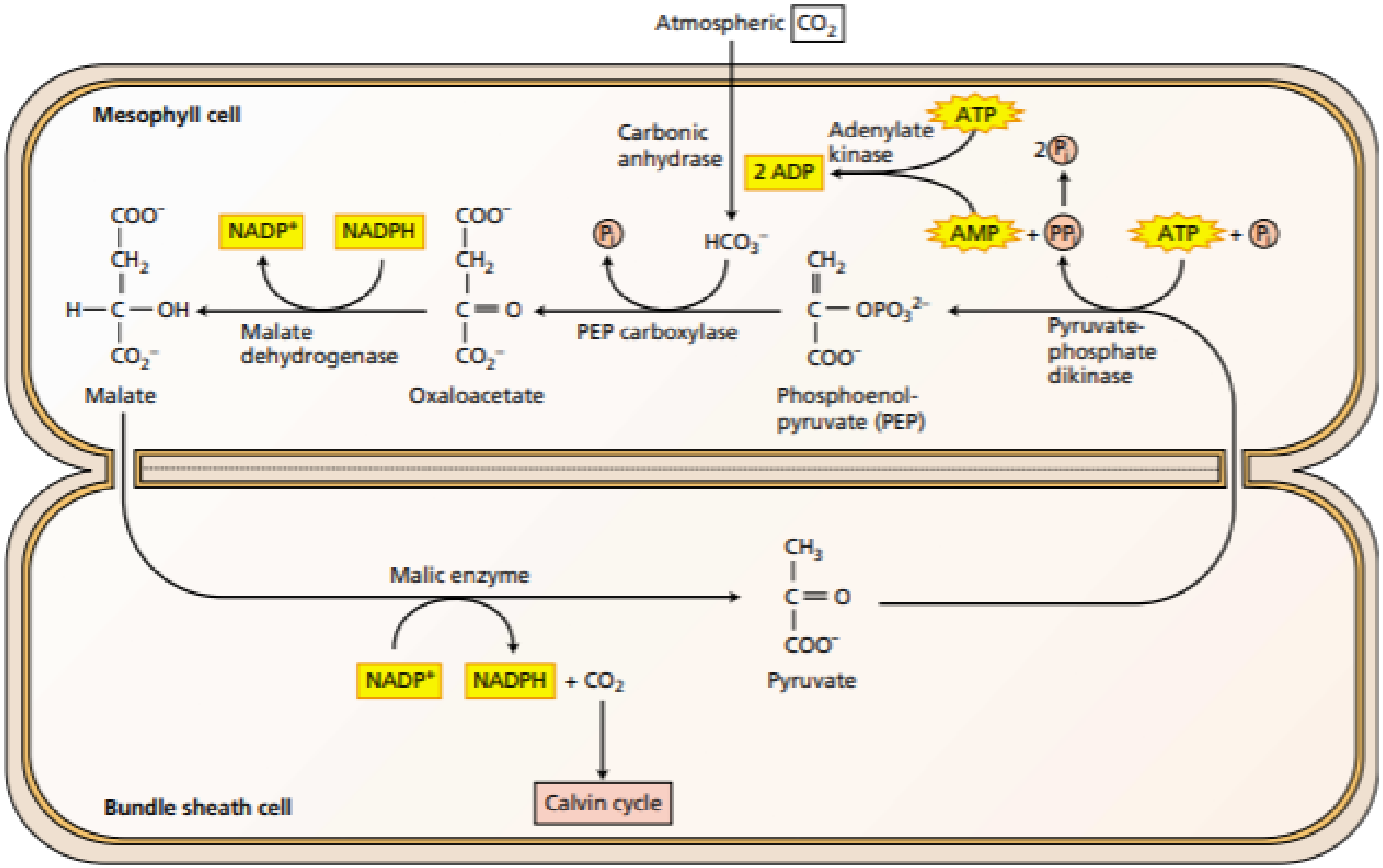
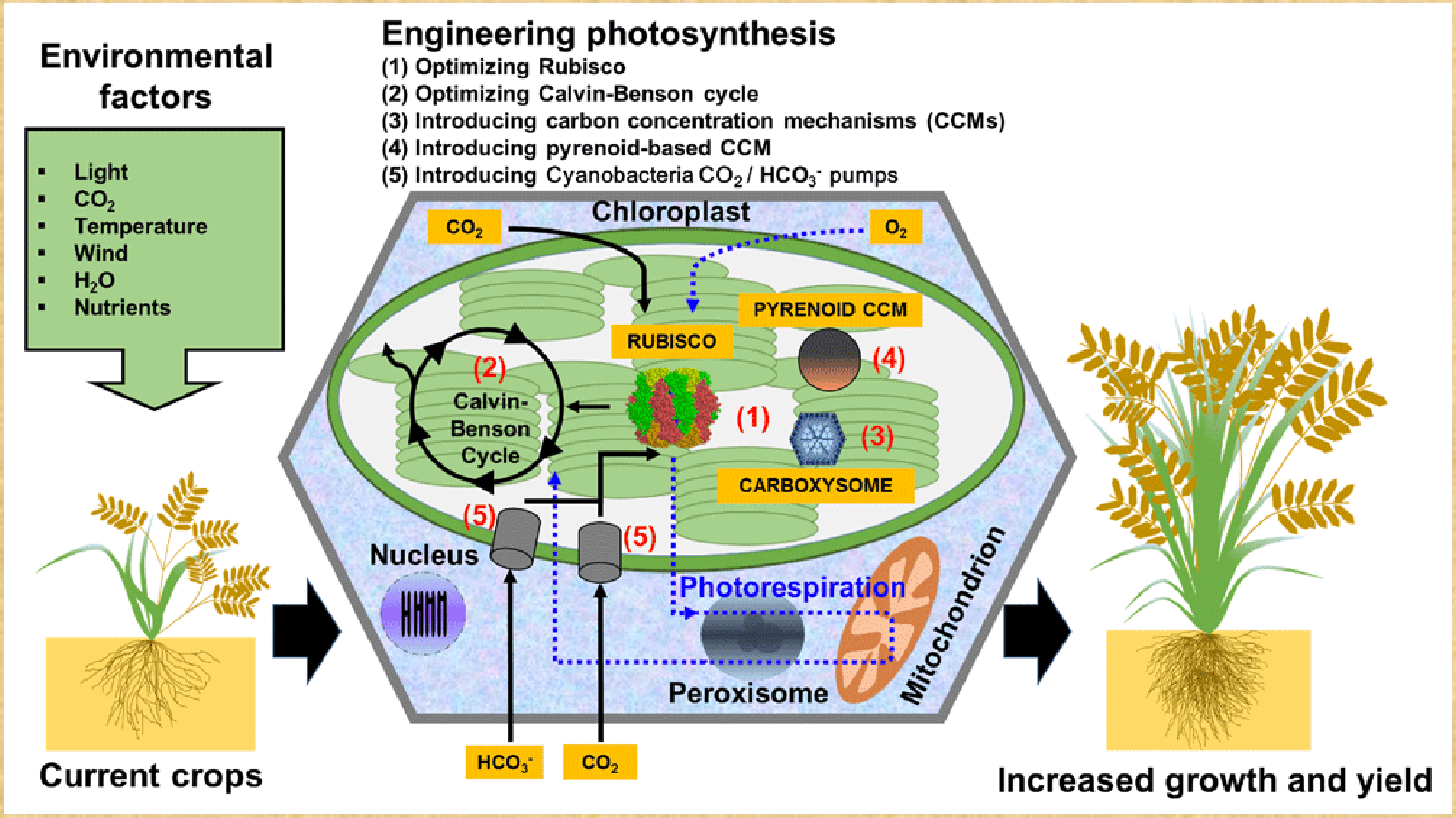


FIGURE 8.11 The C_4 photosynthetic pathway. The hydrolysis of two ATP drives the cycle in the direction of the arrows, thus pumping CO_2 from the atmosphere to the Calvin cycle of the chloroplasts from bundle sheath cells.

Engineering Photosynthesis



Douglas et al., 2019

- Photosynthesis is the basis of primary productivity on the planet. Crop breeding has sustained steady improvements in yield to keep pace with population growth increases.
- Yet these advances have not resulted from improving the photosynthetic process per se but rather of altering the way carbon is partitioned within the plant.
- Mounting evidence suggests that the rate at which crop yields can be boosted by traditional plant breeding approaches is wavering, and they may reach a “yield ceiling” in the foreseeable future.
- Further increases in yield will likely depend on the targeted manipulation of plant metabolism.
- Improving photosynthesis poses one such route, with simulations indicating it could have a significant transformative influence on enhancing crop productivity.
- The above figure summarize recent advances of alternative approaches for the manipulation and enhancement of photosynthesis and their possible application for crop improvement

References

F1000Research F1000Research 2017, 6(F1000 Faculty Rev):1891 Last updated: 17 JUL 2019

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REVIEW

Engineering photosynthesis: progress and perspectives [version 1; peer review: 2 approved]

Douglas J. Orr [1], Auderlan M. Pereira[2,3], Paula da Fonseca Pereira[2,3], Ítalo A. Pereira-Lima[2,3], Agustin Zsögön[3], Wagner L. Araújo [2,3]

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Photosynthesis

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