Domain 3: Energy

Part 2

3.3: Organisms capture and store free energy for use in biological processes.

2. Photoautotrophic nutrition- light reactions

Photosynthesis

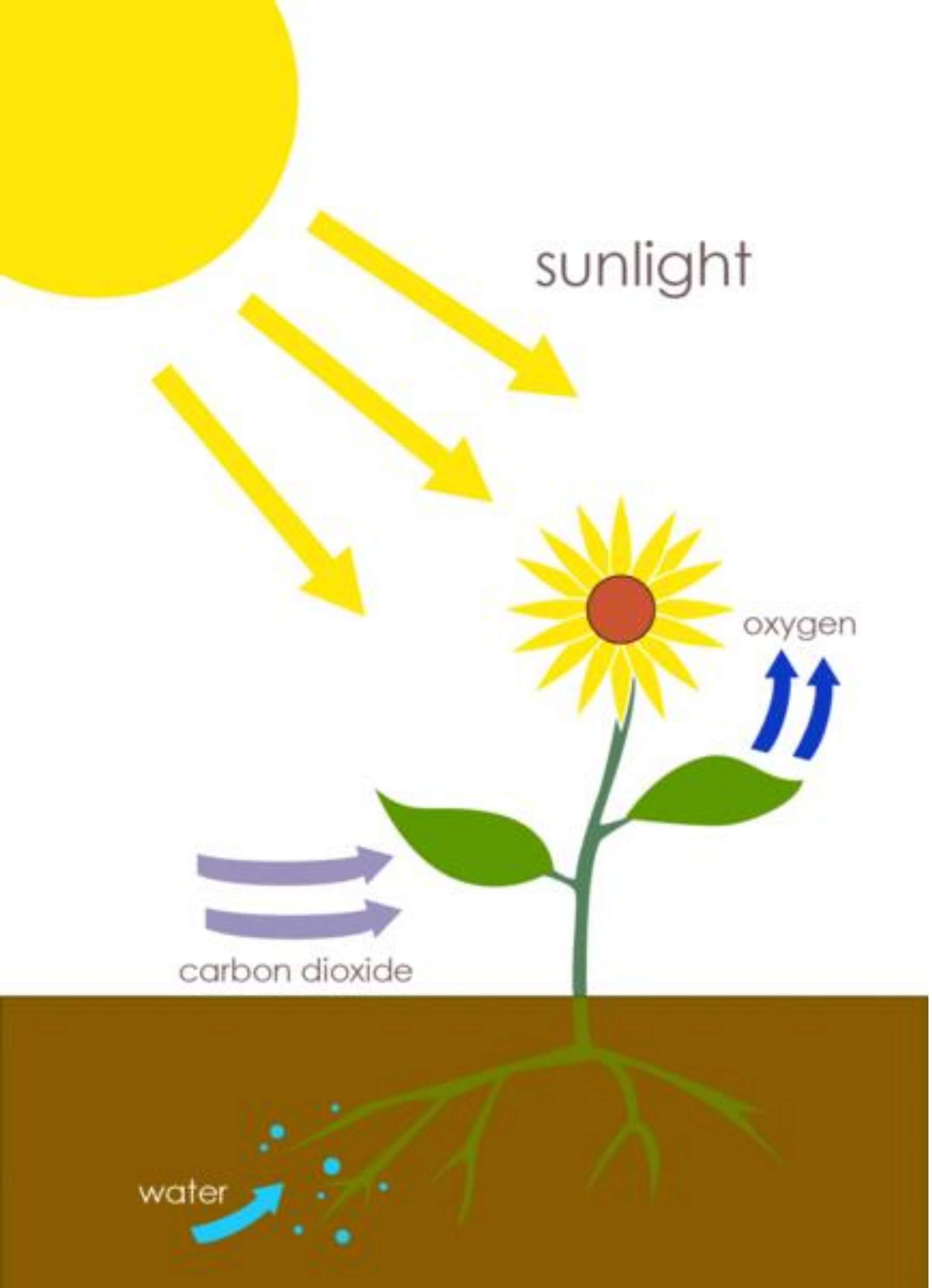
$$6CO_2 + 6H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2$$

Carbon dioxide + Water → Sugar + Oxygen

Photosynthesis is a two-part process.

1. The Light Reactions

2. Carbon Fixation (aka “The Calvin Cycle”)



Light is Energy

Photons of specific wavelengths of light are used in the light reactions.

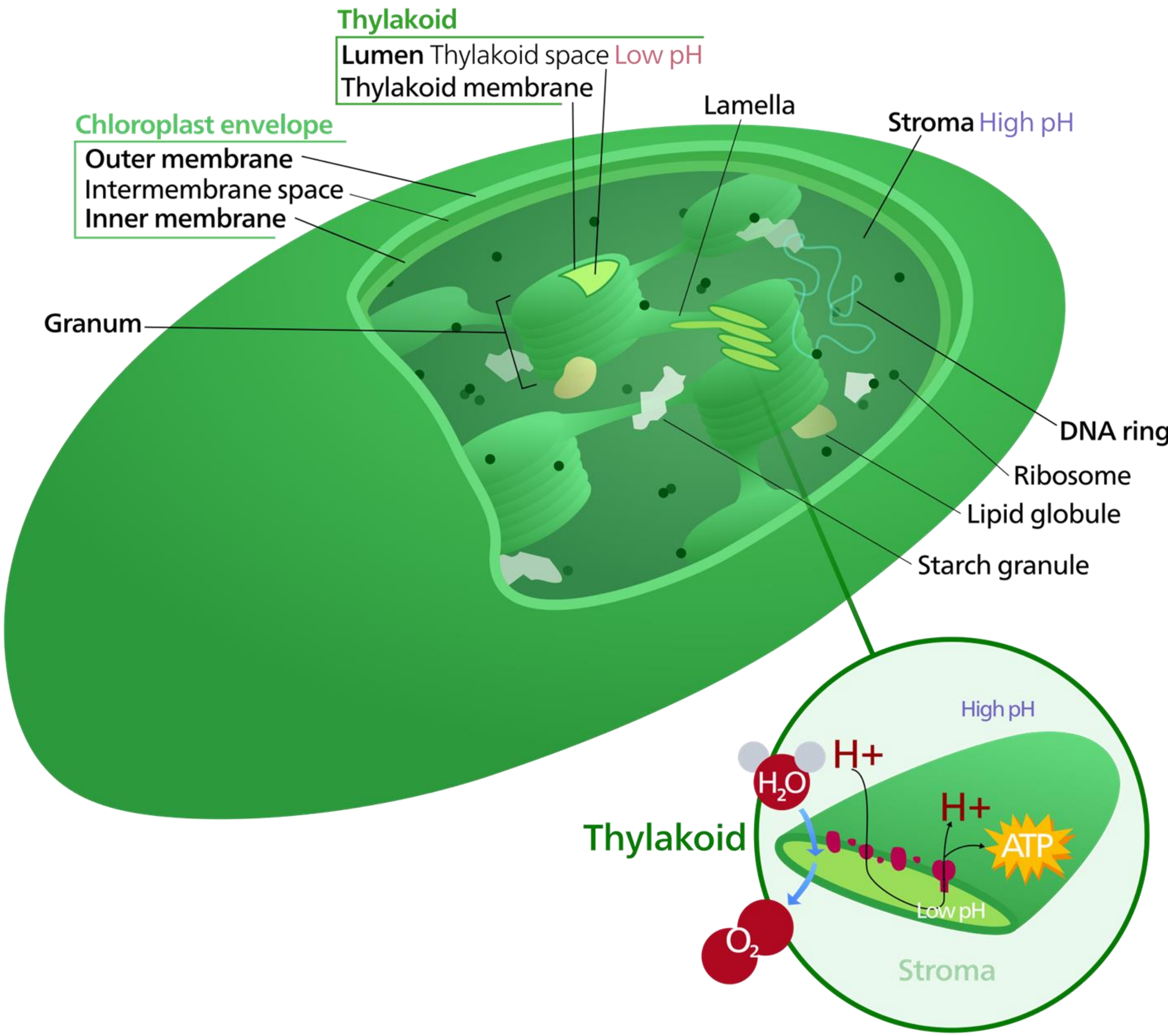
Light Reactions: Overview

Occurs: in photosystems in the thylakoid membrane of chloroplasts.

Uses: Water, light, $NADP^+$, and ADP

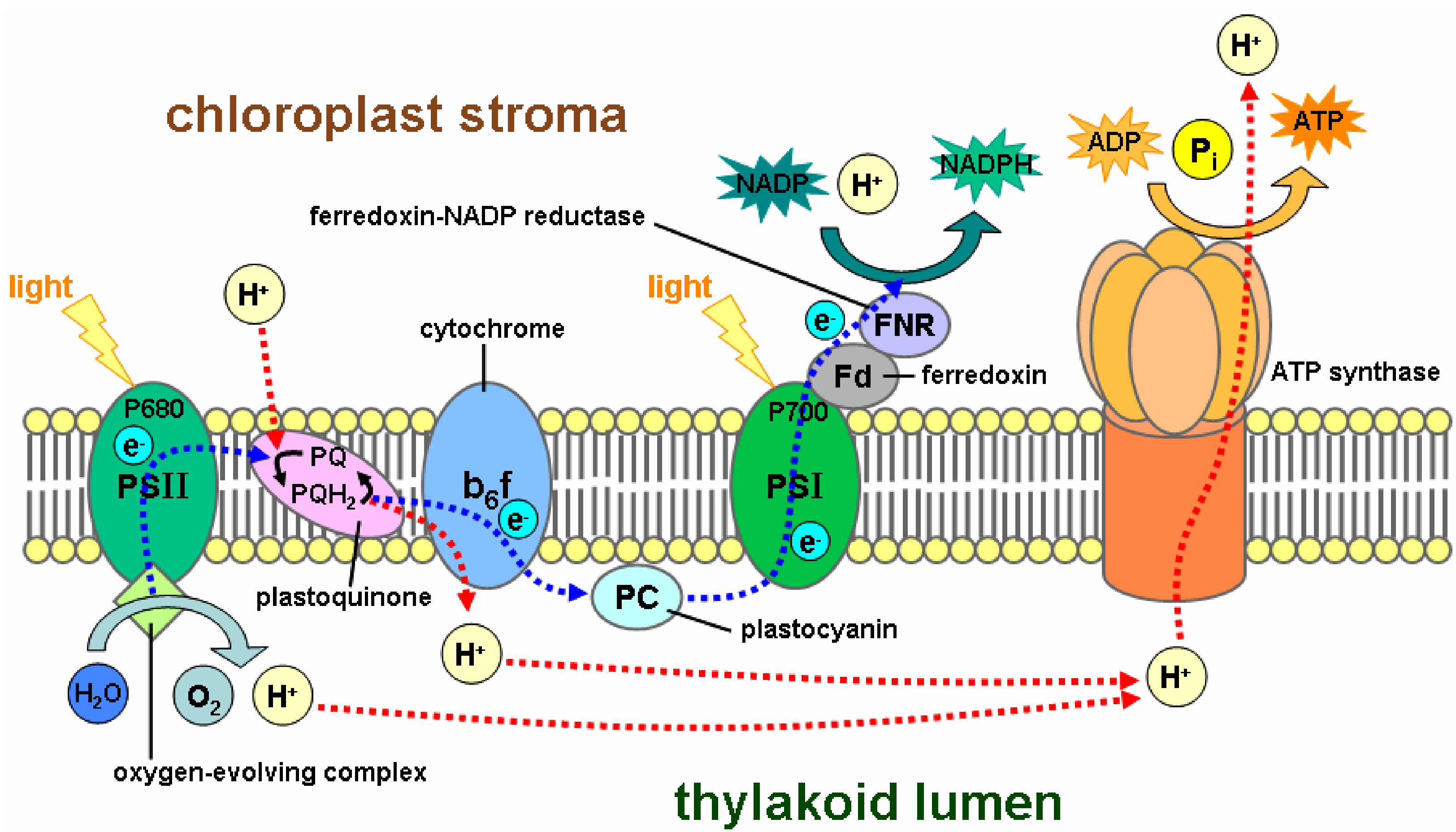
Produces: O_2 (waste), NADPH, and ATP

Chloroplasts are adapted to separate the light reactions from carbon fixation.

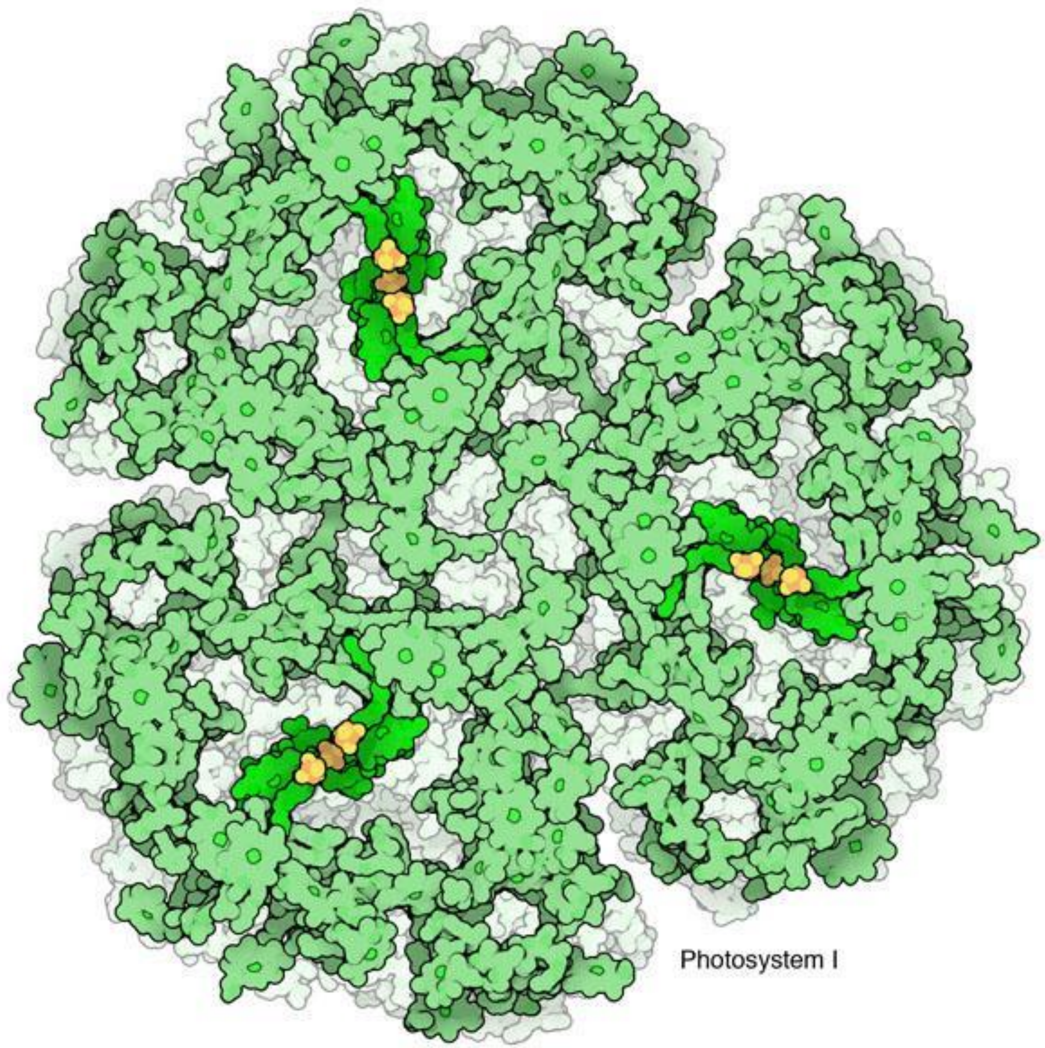


The light reactions occur at the **thylakoid membrane**.

Chlorophyll molecules in **photosystems** produce high energy electrons when exposed to photons.



Photosystem 1



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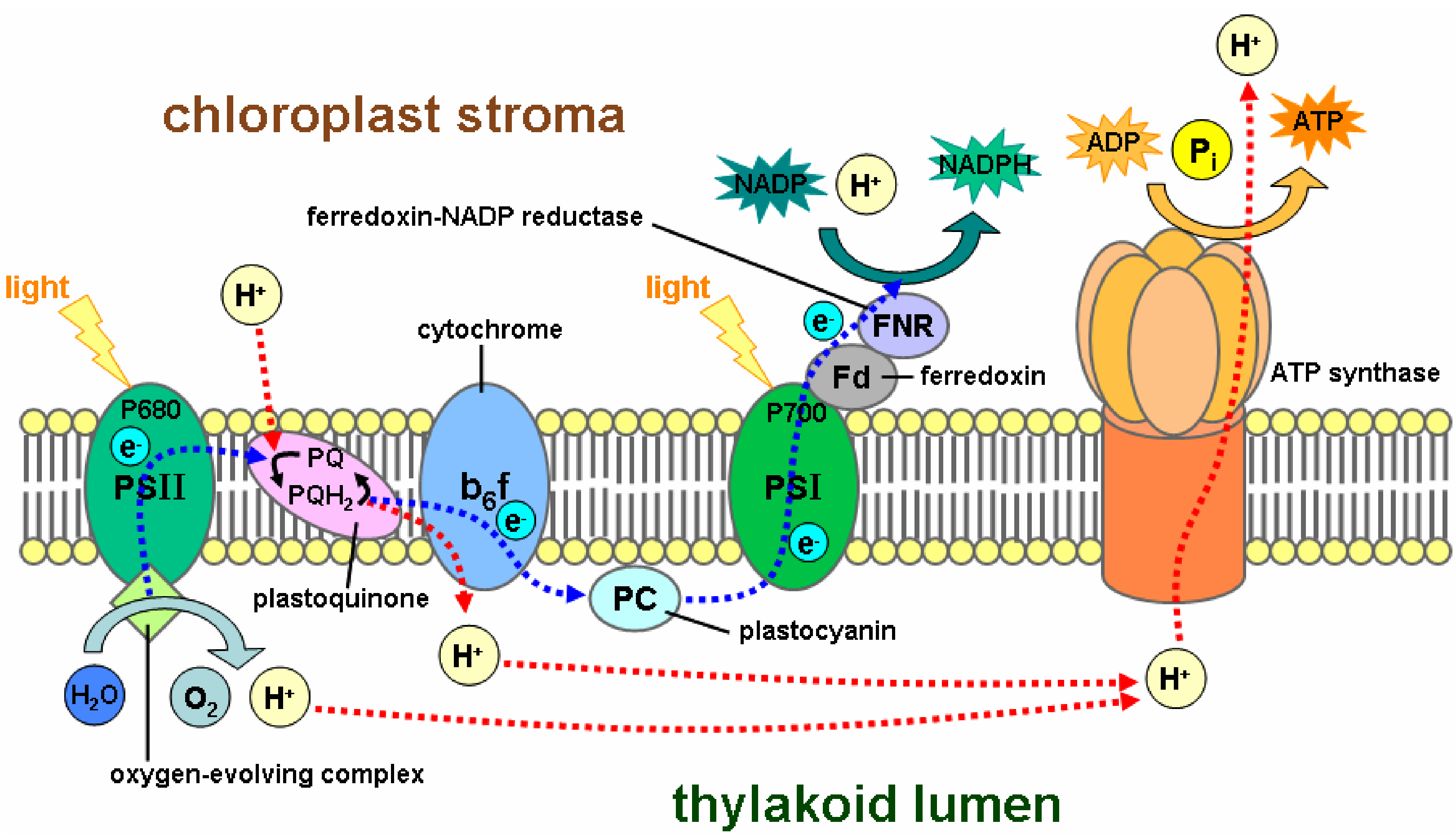
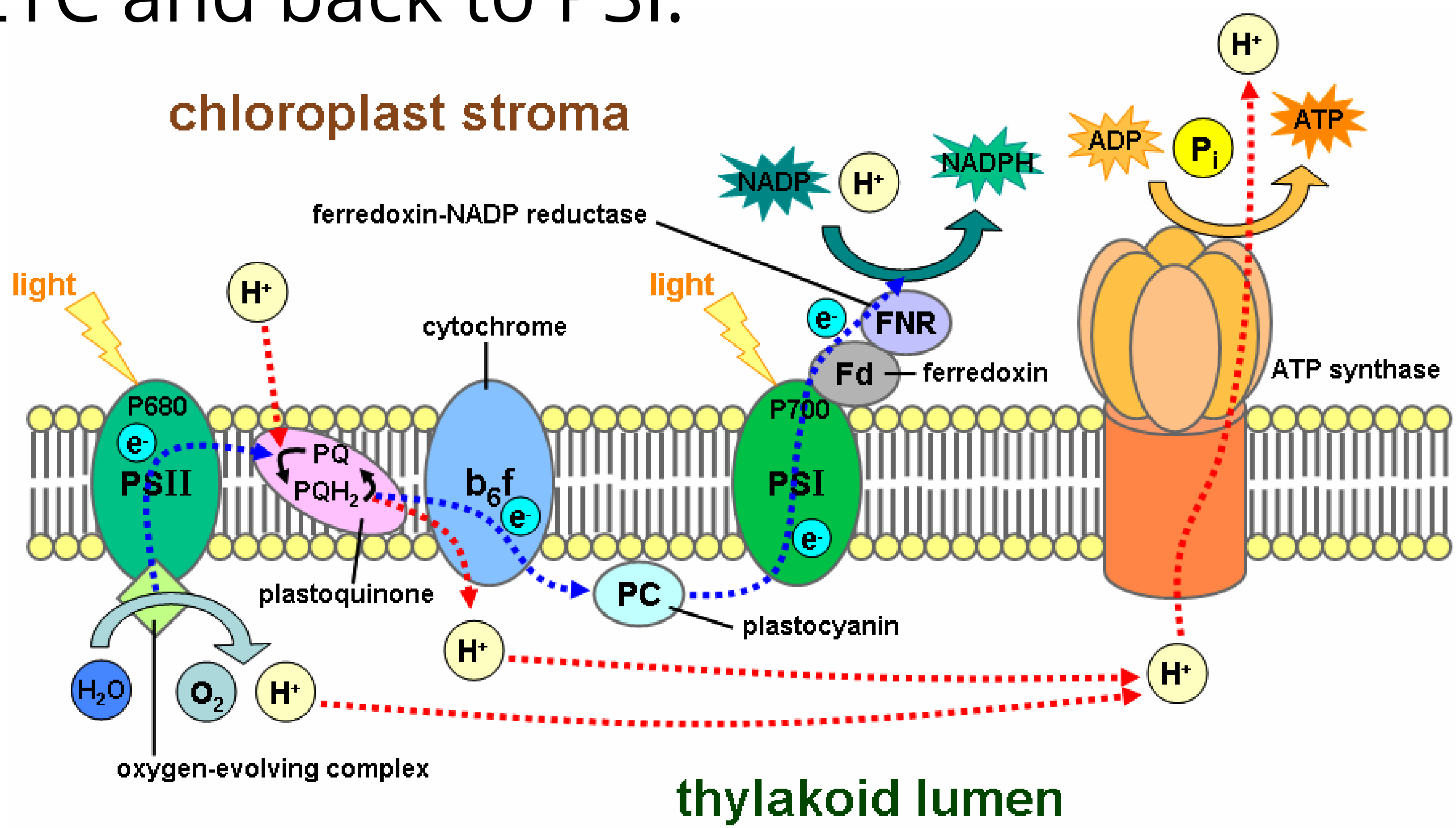
Electrons move through **electron transport chains** between photosystems. This releases free energy used to move protons across the thylakoid membrane.

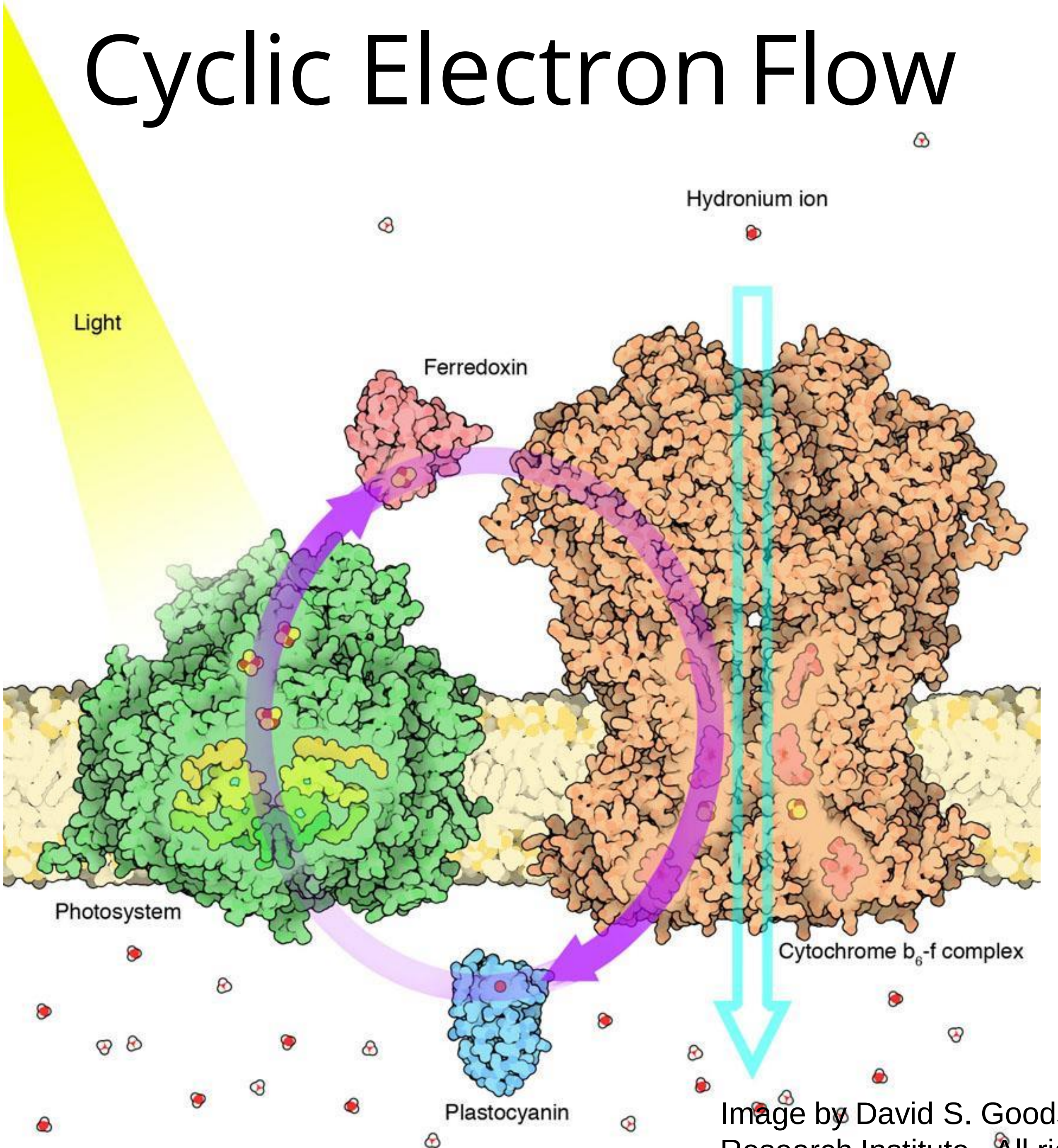


Non-Cyclic e$^-$ flow: e$^-$'s move from PSII to PS1, and are incorporated into **NADPH**.

Cyclic e- flow: e$^-$'s move from PSI into the ETC and back to PSI.



Cyclic Electron Flow



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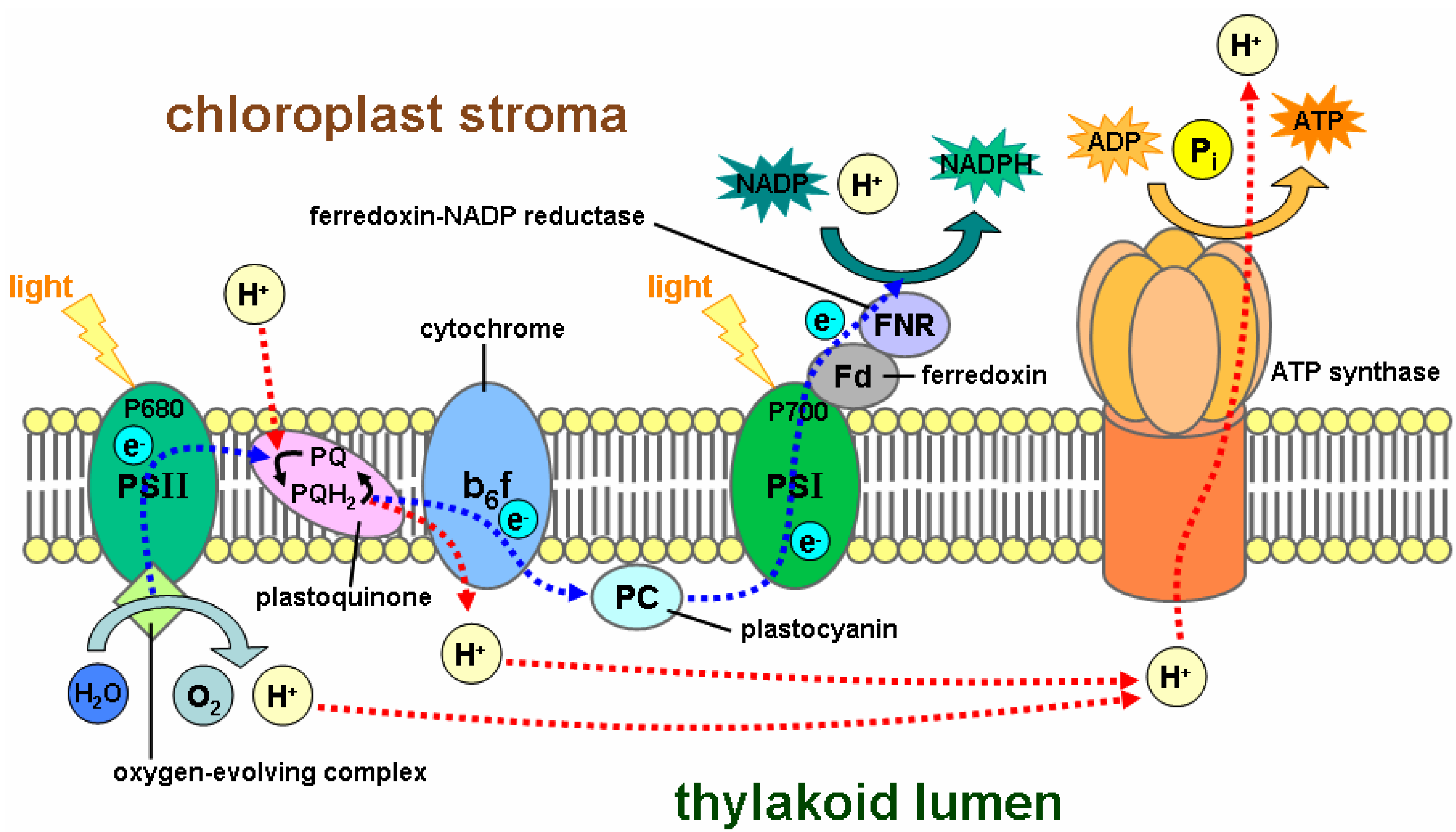
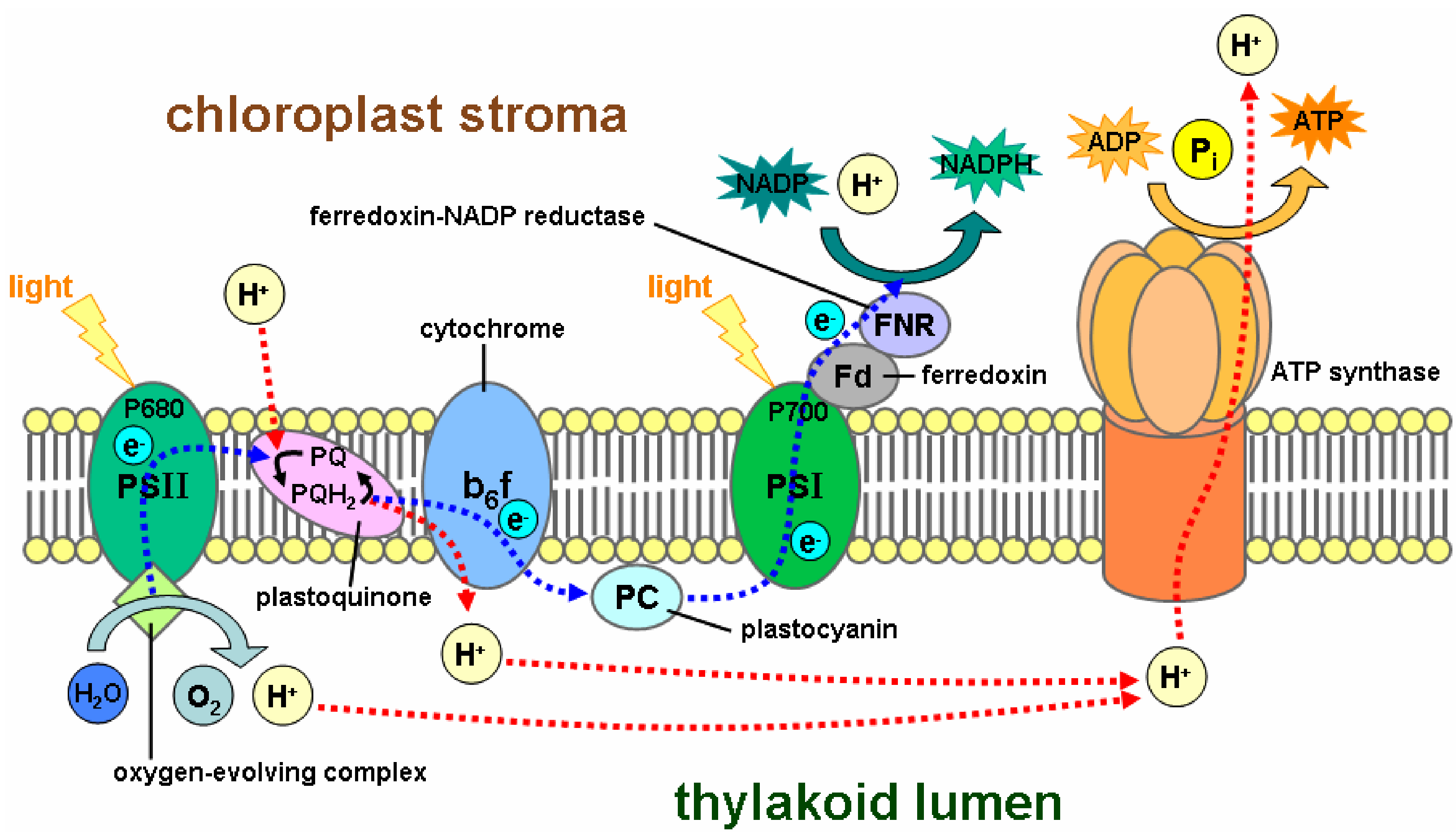
Water is decomposed at PSII to supply chlorophyll with replacement e^-'s.

This produces **waste O_2**



The high concentration of H^+ in the thylakoid space is used to produce ATP through **chemiosmosis**

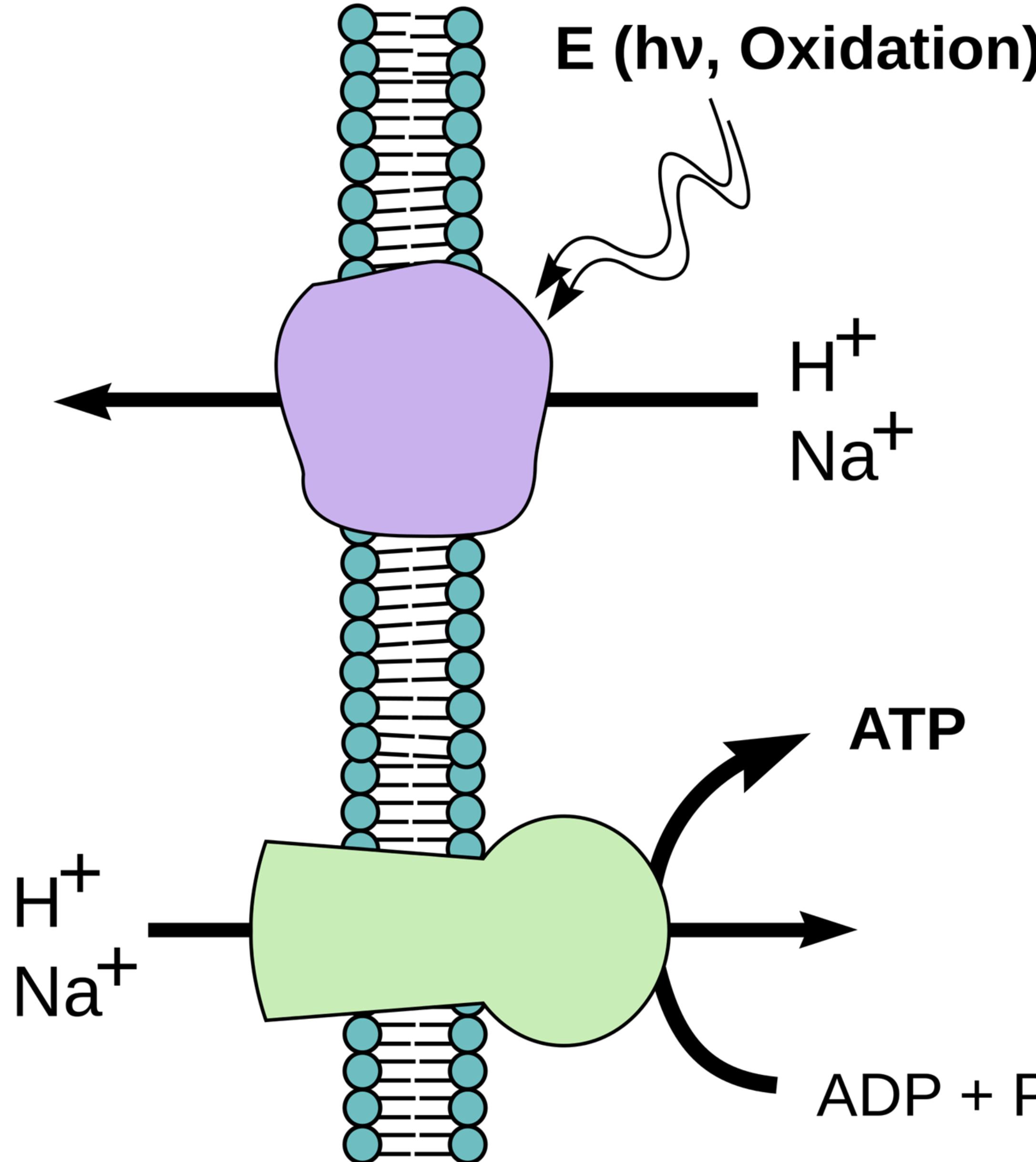


Chemiosmosis

H^+ can not diffuse through the bi-layer.

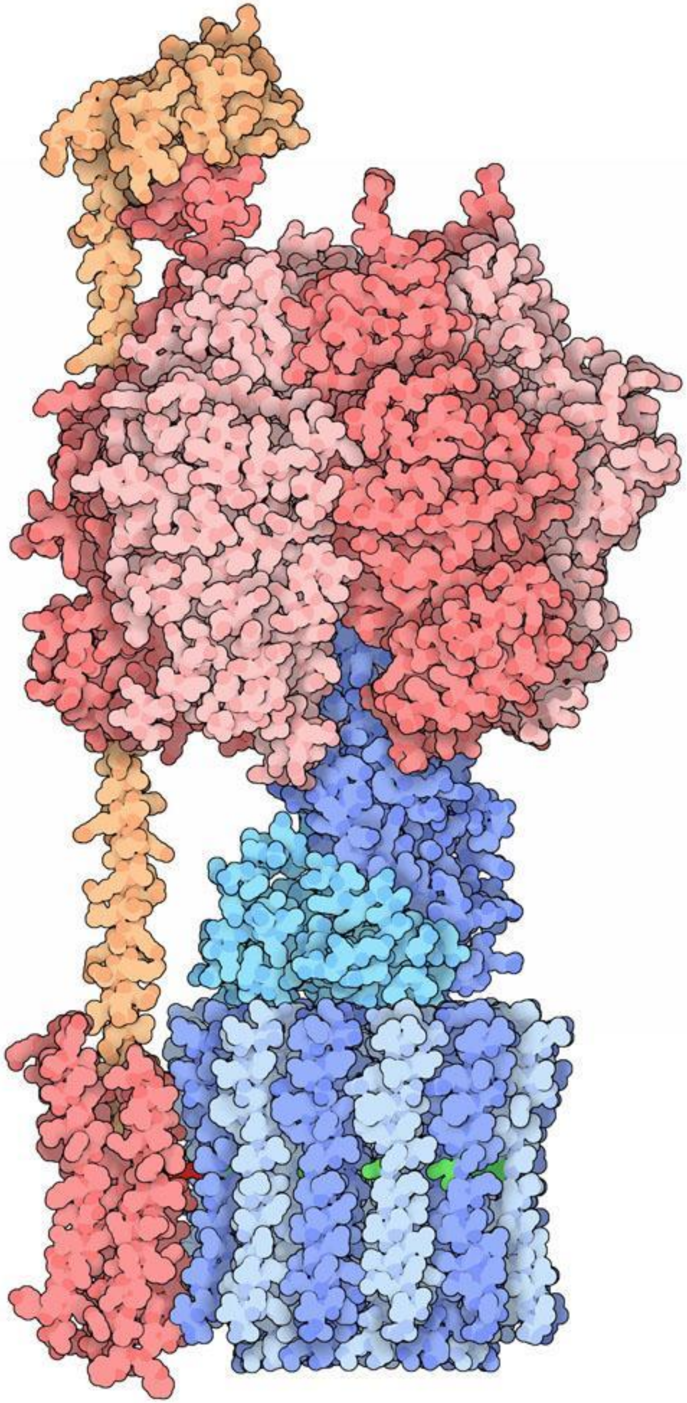
The only way that H^+ can diffuse is through the **ATP synthase** enzyme.

This diffusion produces ATP from ADP.



ATP Synthase

The diffusion of H^+ ions through one region of ATP Synthase provides the energy necessary to drive the catalytic conversion of ADP to ATP.



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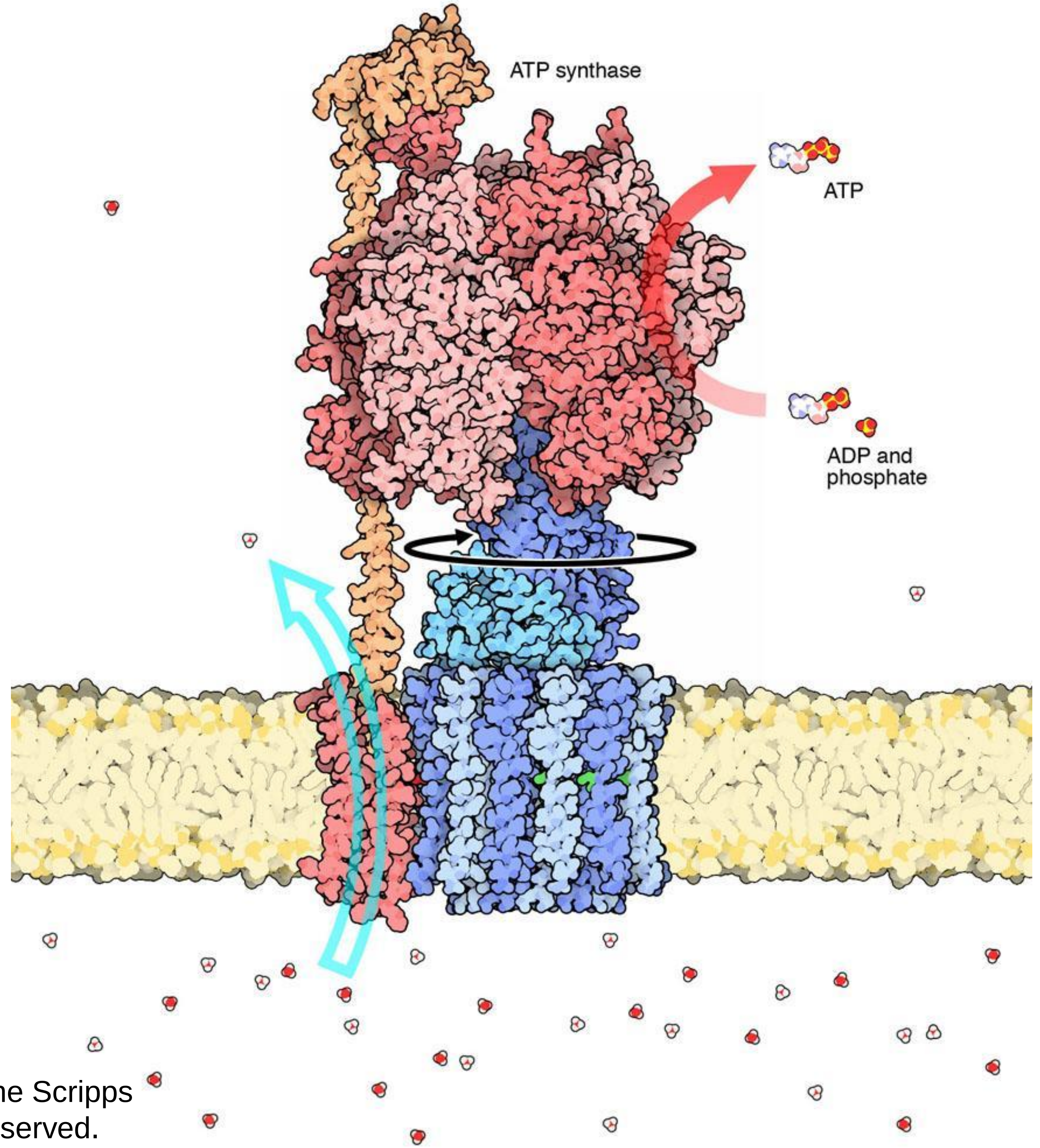

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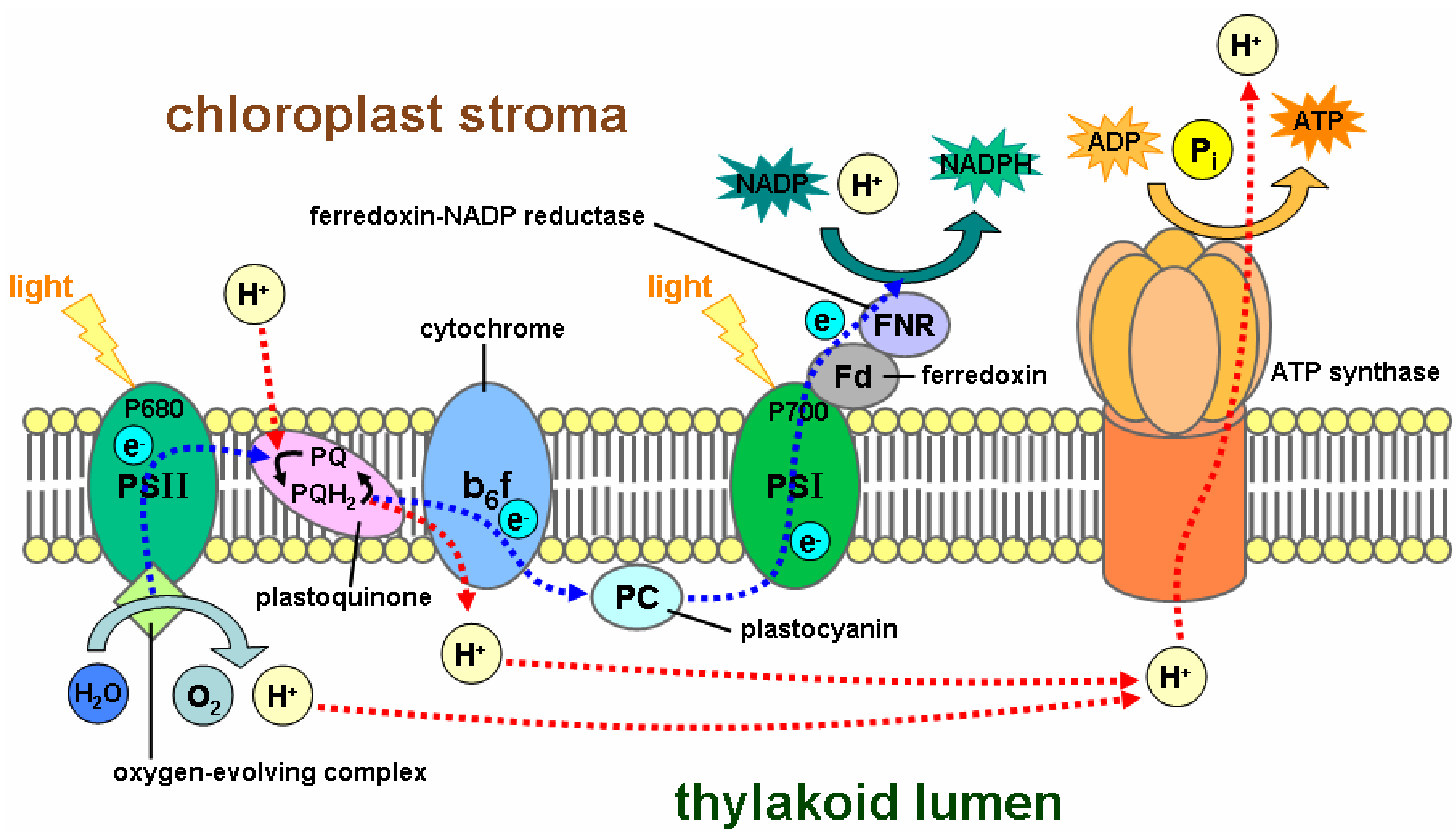
3.3: Organisms capture and store free energy for use in biological processes.

3. Photoautotrophic nutrition- Carbon Fixation

Review: The light reactions produced ATP and NADPH at the Thylakoid Membrane.



Carbon Fixation: Overview

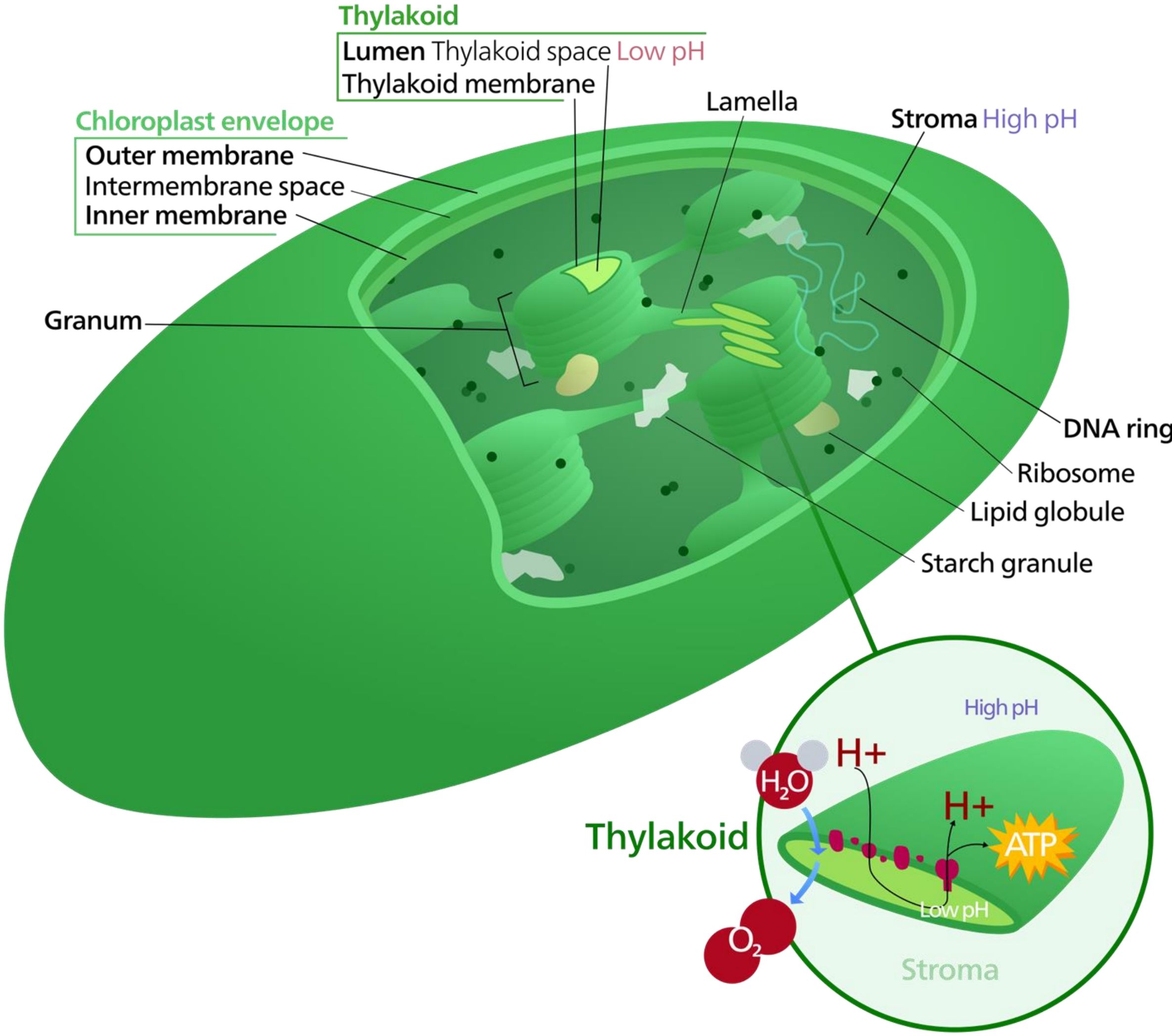
Occurs: in the stroma of the chloroplast.

Uses: CO_2, NADPH, and ATP

Produces: Organic Molecules (G3P), NADP, and ADP

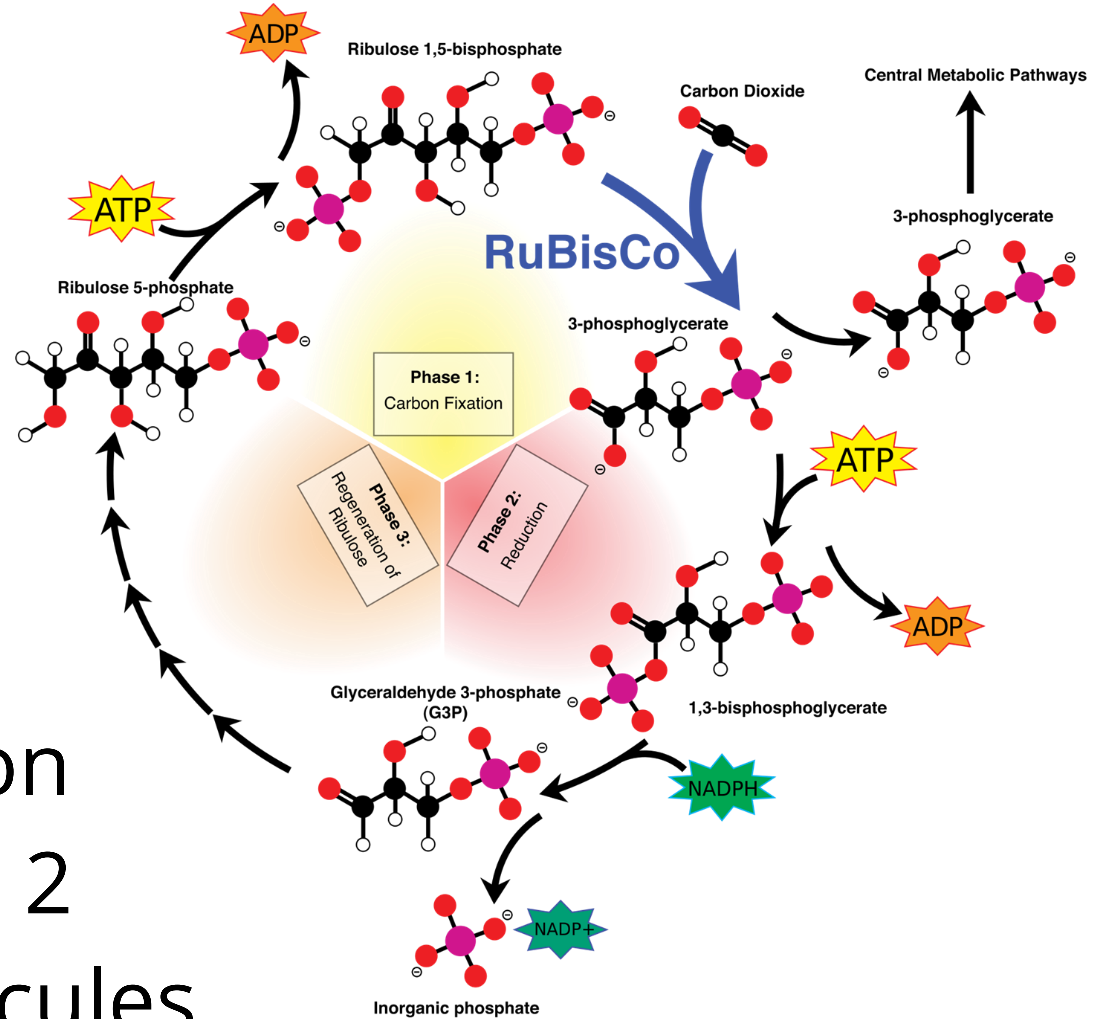
Chloroplasts are adapted to separate the light reactions from carbon fixation.

Carbon fixation occurs in the **stroma**.

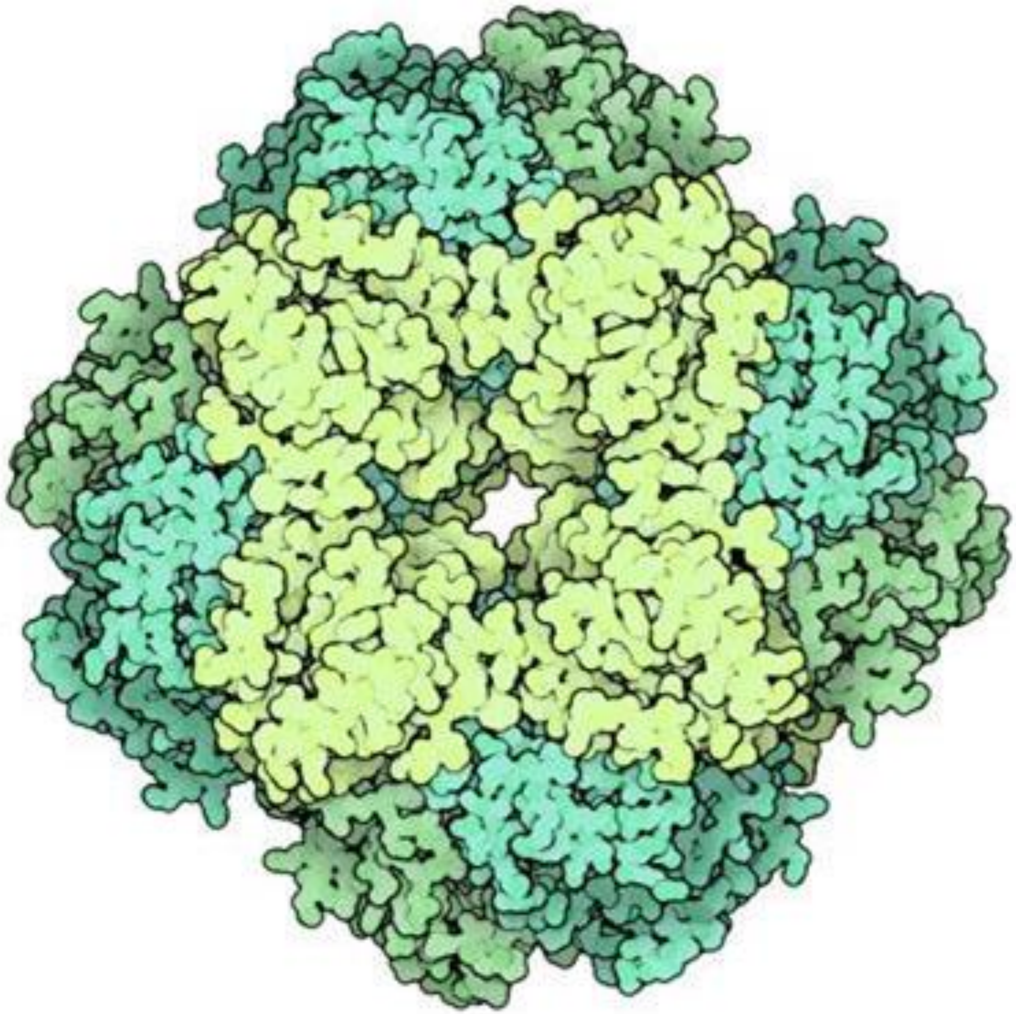


Carbon Dioxide is incorporated into the Calvin cycle by the enzyme **RuBisCo**.

This turns a 5-Carbon **RuBP** molecule into 2 3-Carbon **G3P** molecules (through a series of reactions NOT shown) using ATP and NADPH.



RuBisCo



Ribulose bisphosphate carboxylase/oxygenase

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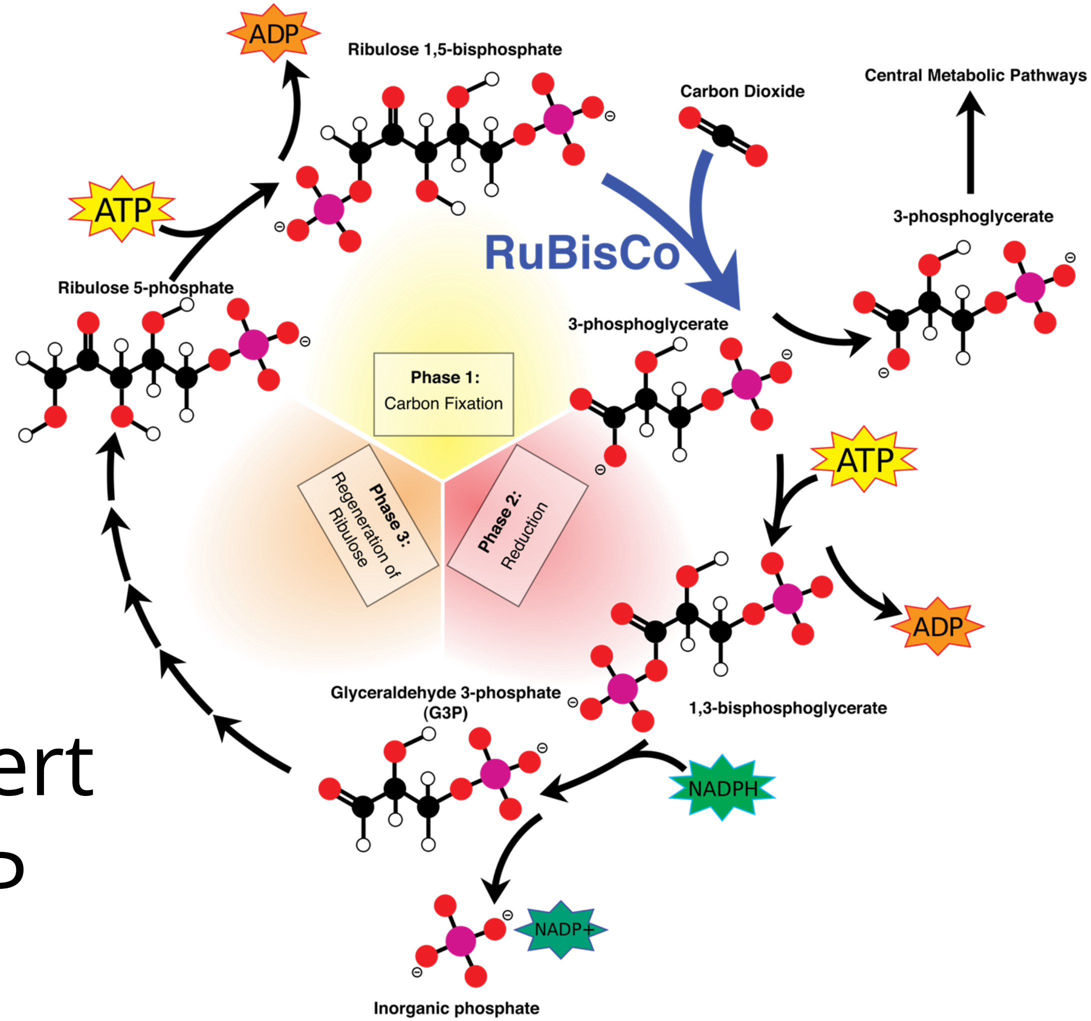
For every 3 “turns” of the Calvin Cycle, 1 net molecule of **G3P** is produced.



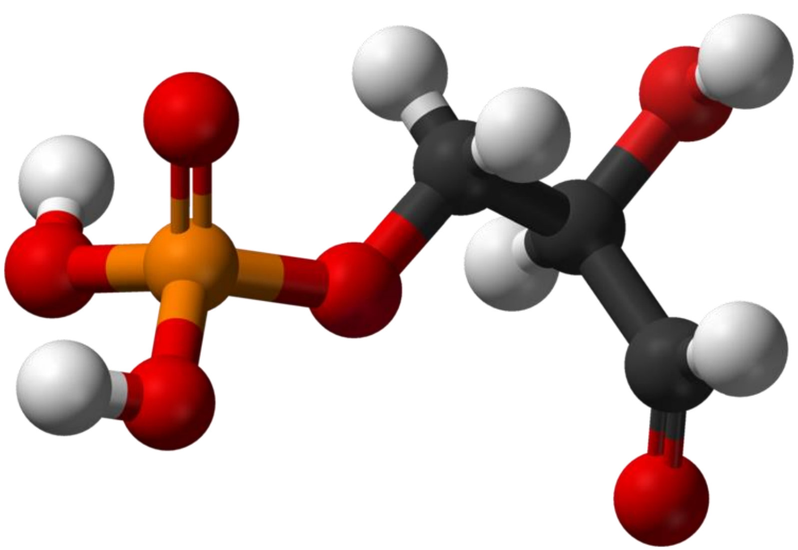
ATP is used to convert the remaining 5 G3P molecules back into 3 RuBP molecules.

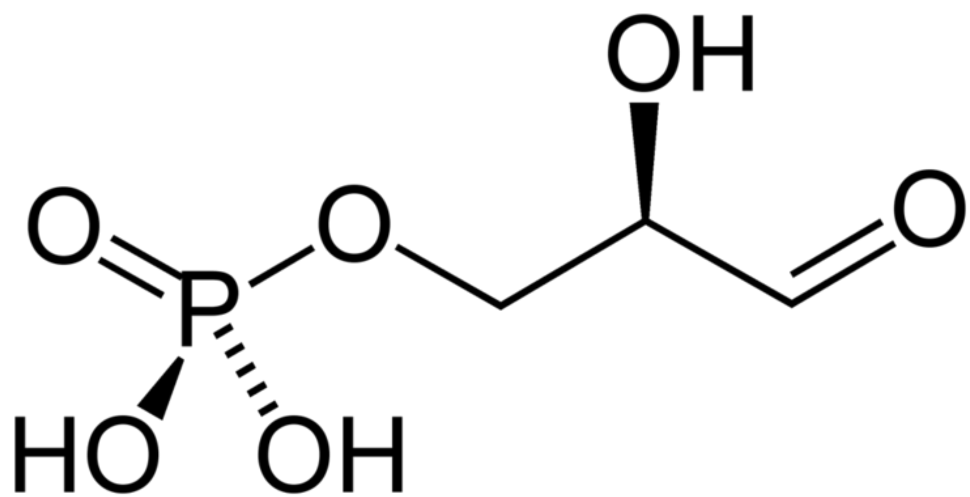
1 Net G3P requires 3 CO_2, 6 NADPH, & 9 ATP

G3P

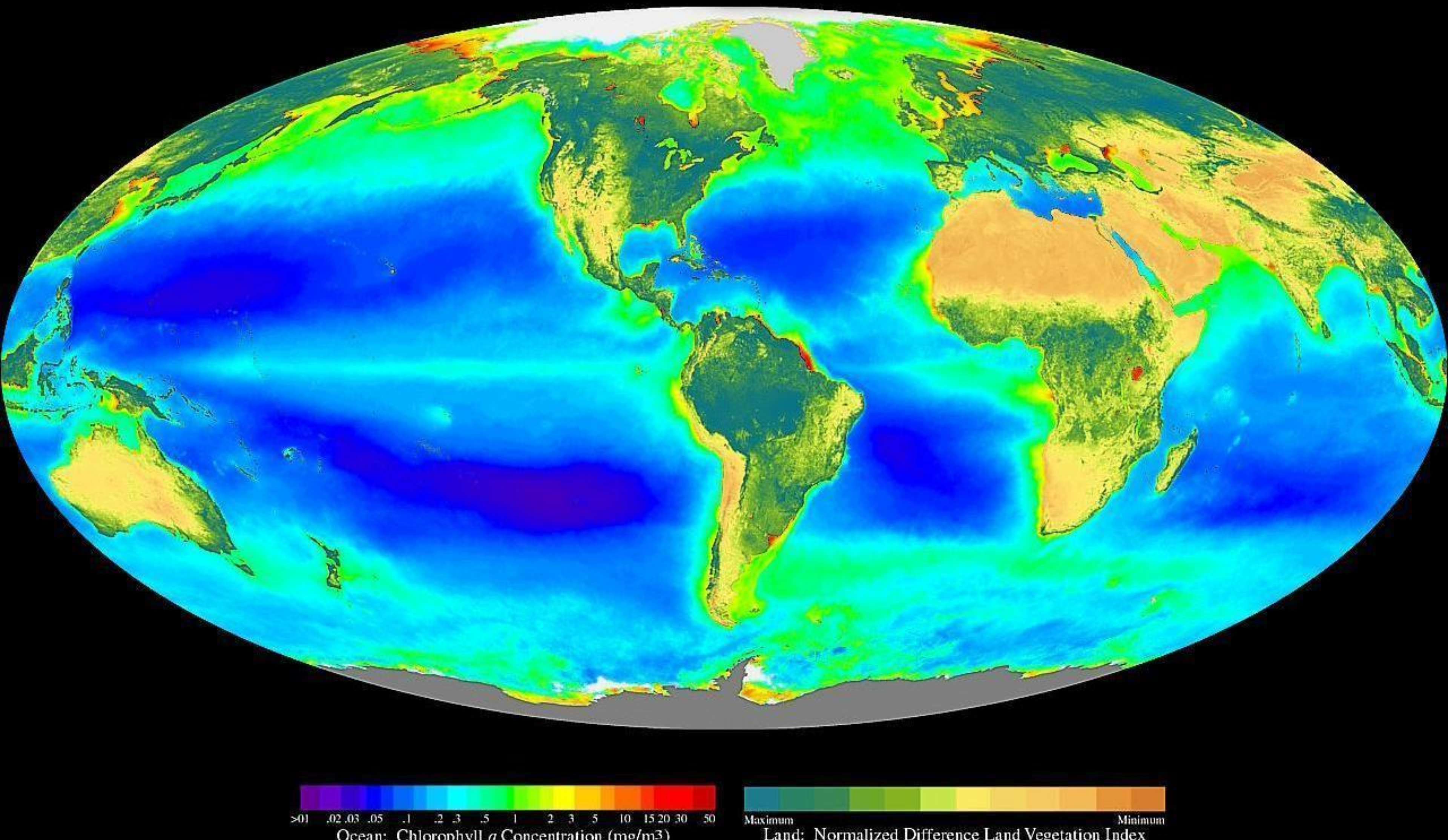
G3P is a sugar precursor.

2 G3Ps can make 1 glucose.





Photosynthesis determines **global productivity**.



3.3: Organisms capture and store free energy for use in biological processes.

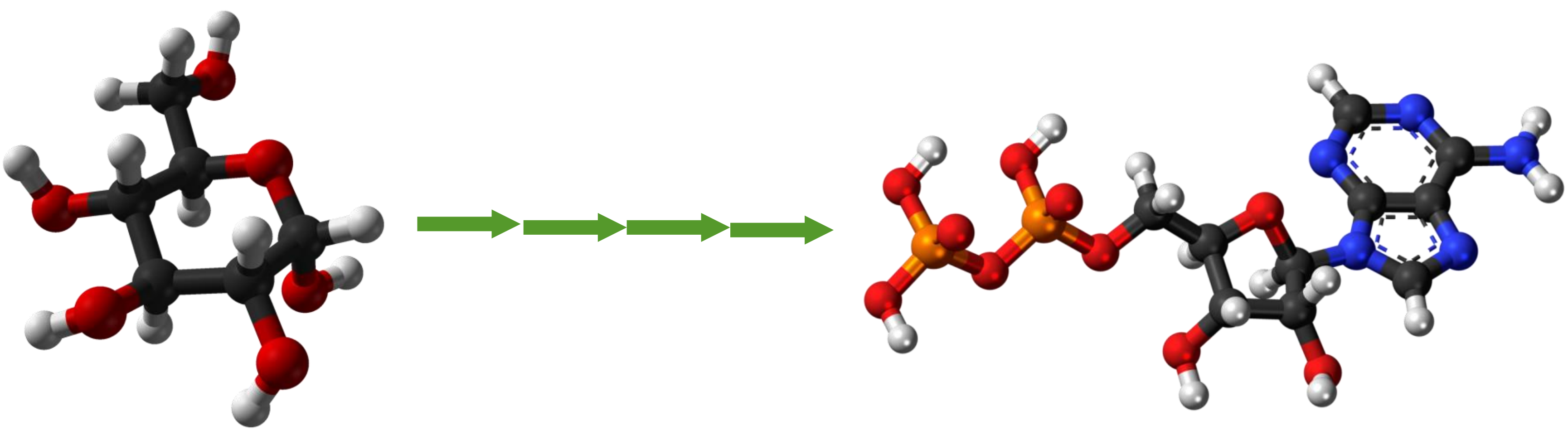
4. Chemoheterotrophic Nutrition- Anaerobic Cellular Respiration

Energy Transfer

Respiration pathways involve the transfer of energy from complex organic molecules (we look at glucose) into ATP.

This happens in a series of enzymatically controlled reactions that can require oxygen (**aerobic**) or not (**anaerobic**).

Both start the same way.



Glycolysis: Overview

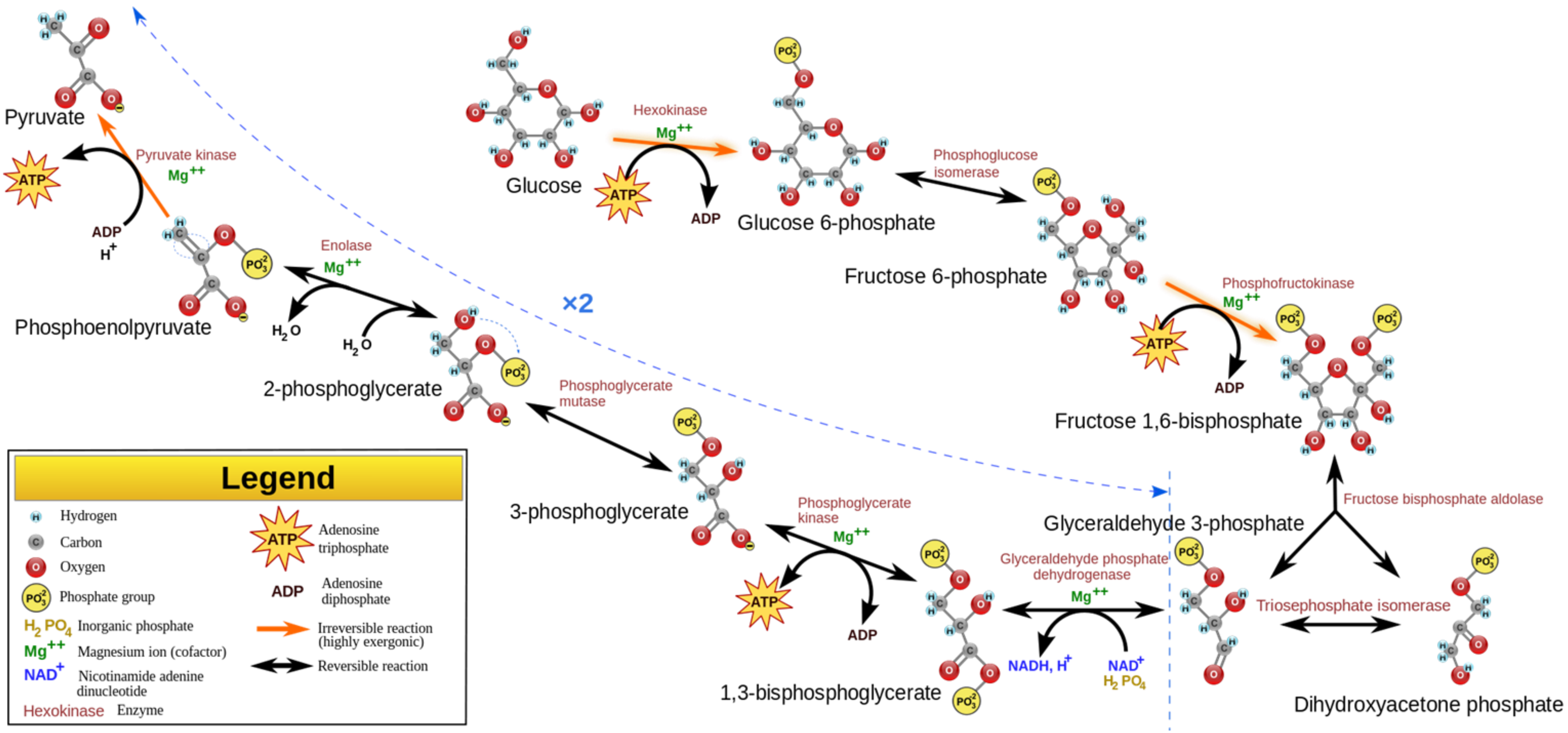
Occurs: in the cytoplasm of all cells on the planet

Uses: Glucose (6 Carbon), 2 ATP, 2NAD^+

Produces: 2 Pyruvate (3 Carbon), 4 ATP, 2 NADH

Glycolysis is universal among all living things.

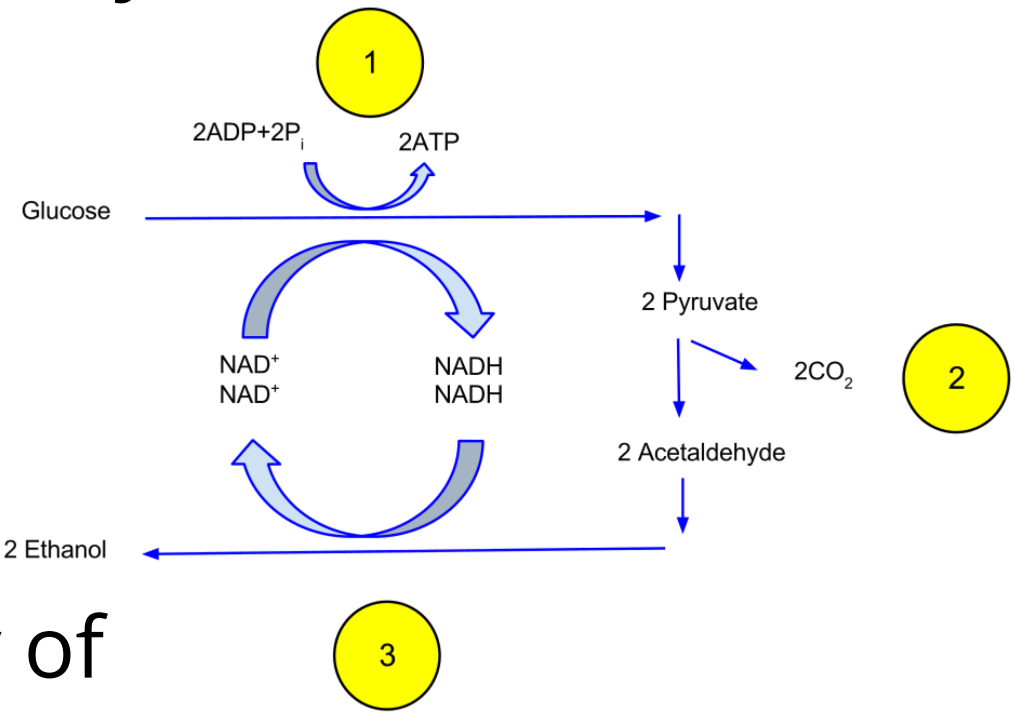
2 ATP are invested, but 4 are produced.



Fermentation

If a cell stops at glycolysis, it will run out of NAD^+.

Fermentation pathways allow cells to oxidize NADH back to NAD^+ in order to continue anaerobic cellular respiration. Pyruvate is reduced into one of a variety of molecules.



Fermentation: Overview

Occurs: in the cytoplasm of all anaerobically respiring cells

Uses: 2 Pyruvate, 2 NADH

Produces: A variety of organic molecules, and 2 NAD^+

- 2 Examples:
  - Yeast – ethanol (2 Carbon) and CO_2
  - Mammalian Muscle – Lactic Acid (3 Carbon)

3.3: Organisms capture and store free energy for use in biological processes.

5. Chemoheterotrophic Nutrition-Aerobic Cellular Respiration

Before We Begin…

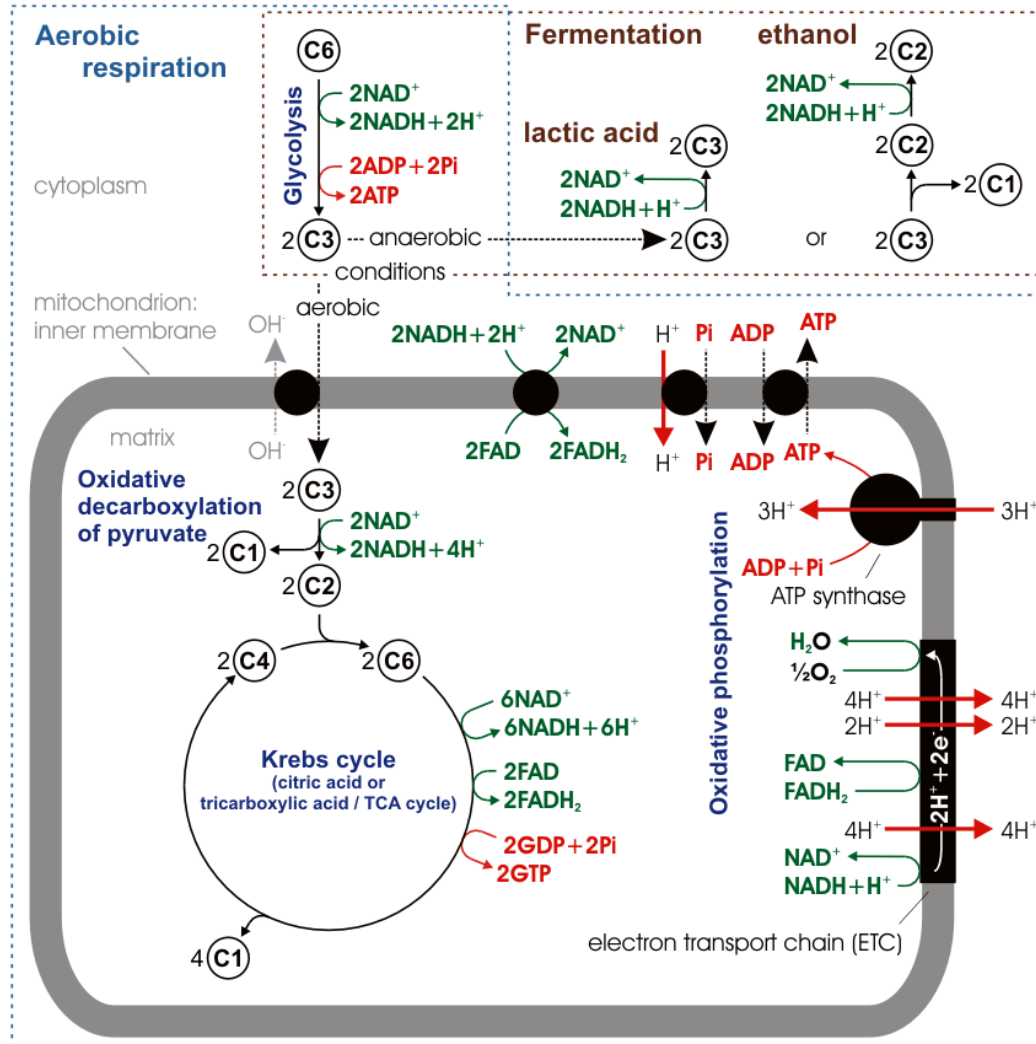
Let’s see who can hold his/her breath the longest!

There will be a prize!

Aerobic Cellular Machinery

Cells that carry out Aerobic Respiration need **mitochondria** or similar membrane compartments.

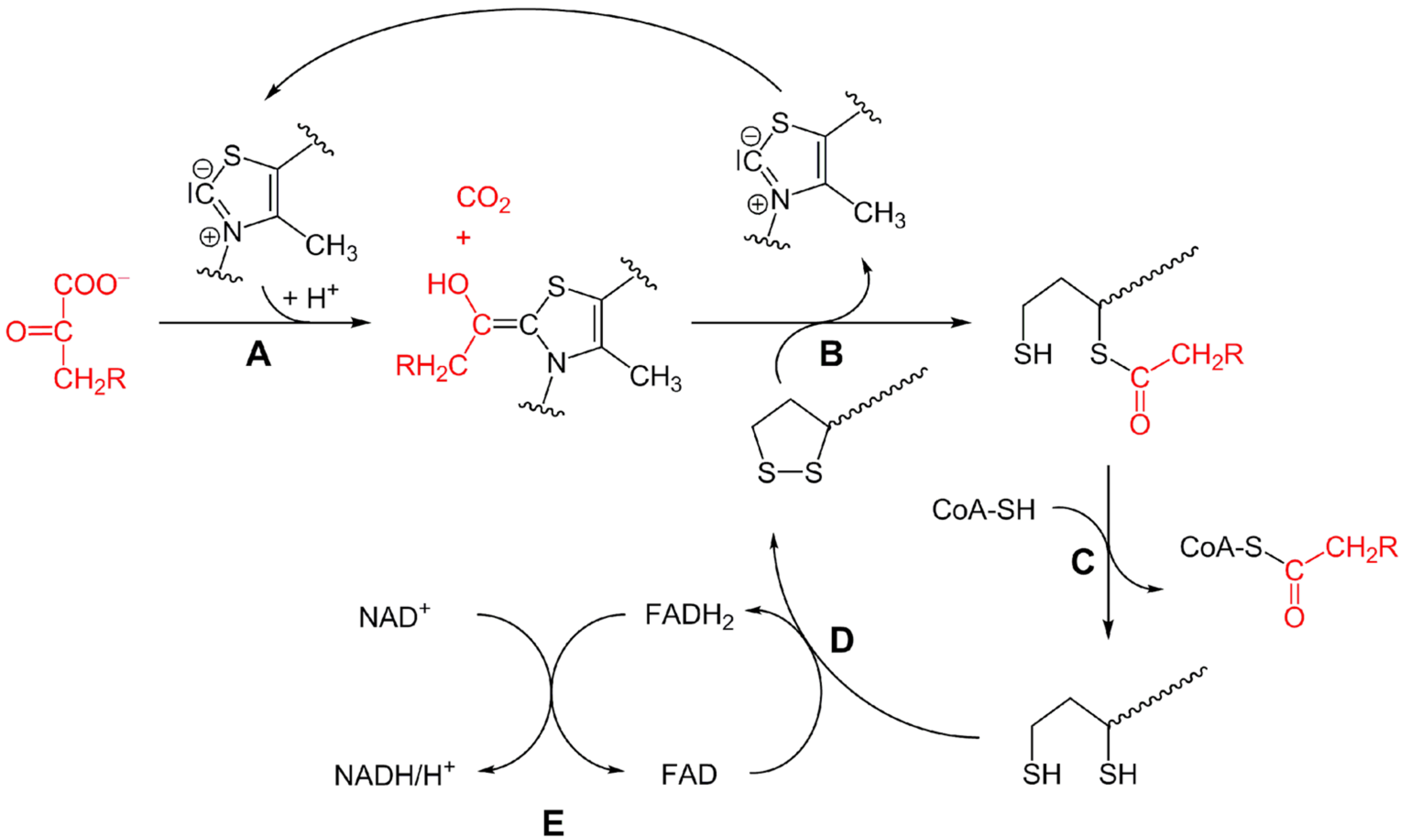
Aerobic Respiration is a 2-part process: **The Citric Acid Cycle**, followed by **Oxidative Phosphorylation**



But First…

Pyruvate is converted into a molecule of **acetyl-CoA**.

This process produces **1 NADH** per pyruvate, and also releases one of pyruvate's carbons as a molecule of **CO_2**



Citric Acid Cycle: Overview

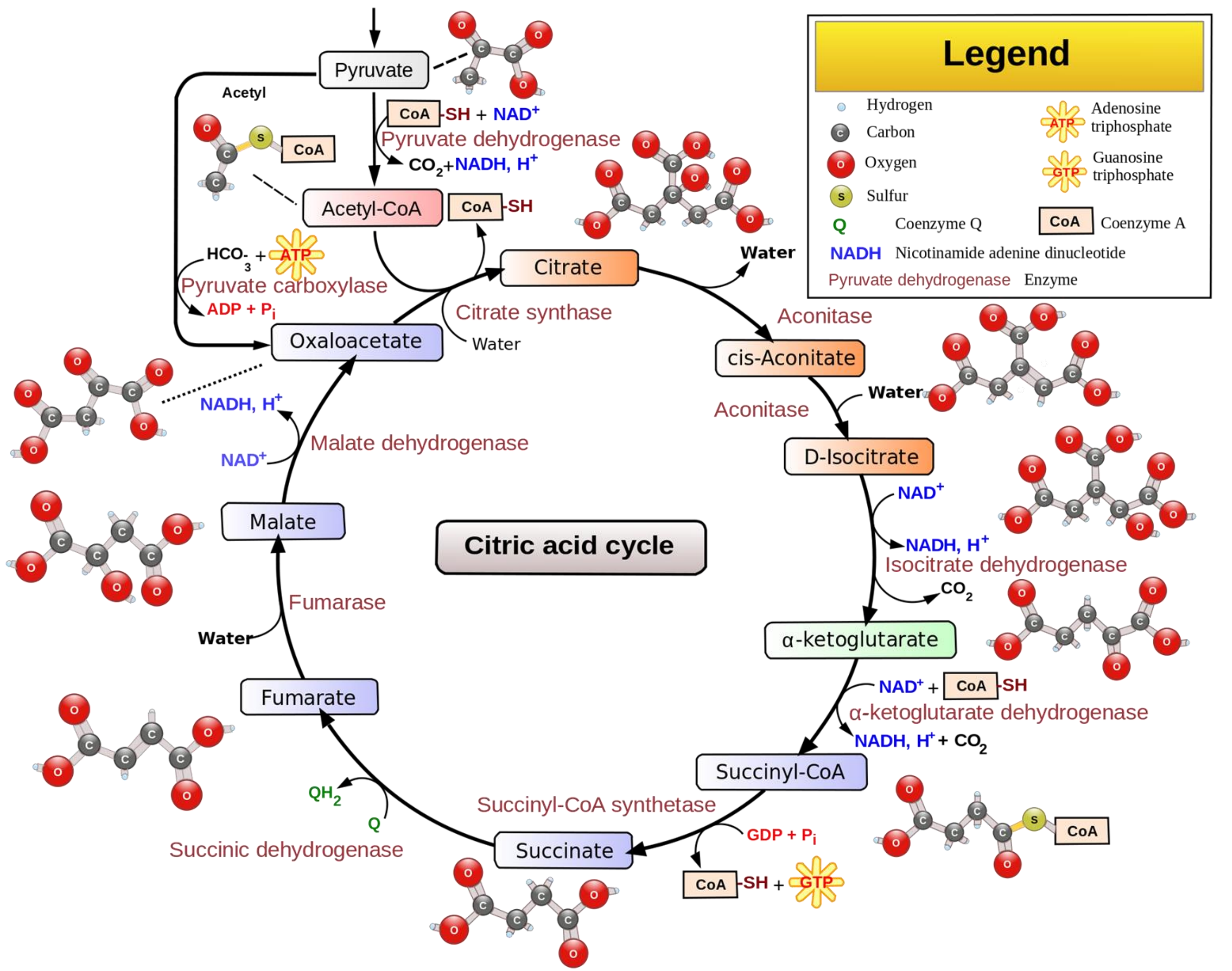
Occurs: In the matrix of the mitochondria.

Uses: A molecule of Acetyl-CoA (2 Carbon), 3 NAD^+, 1 FAD, and 1 ADP

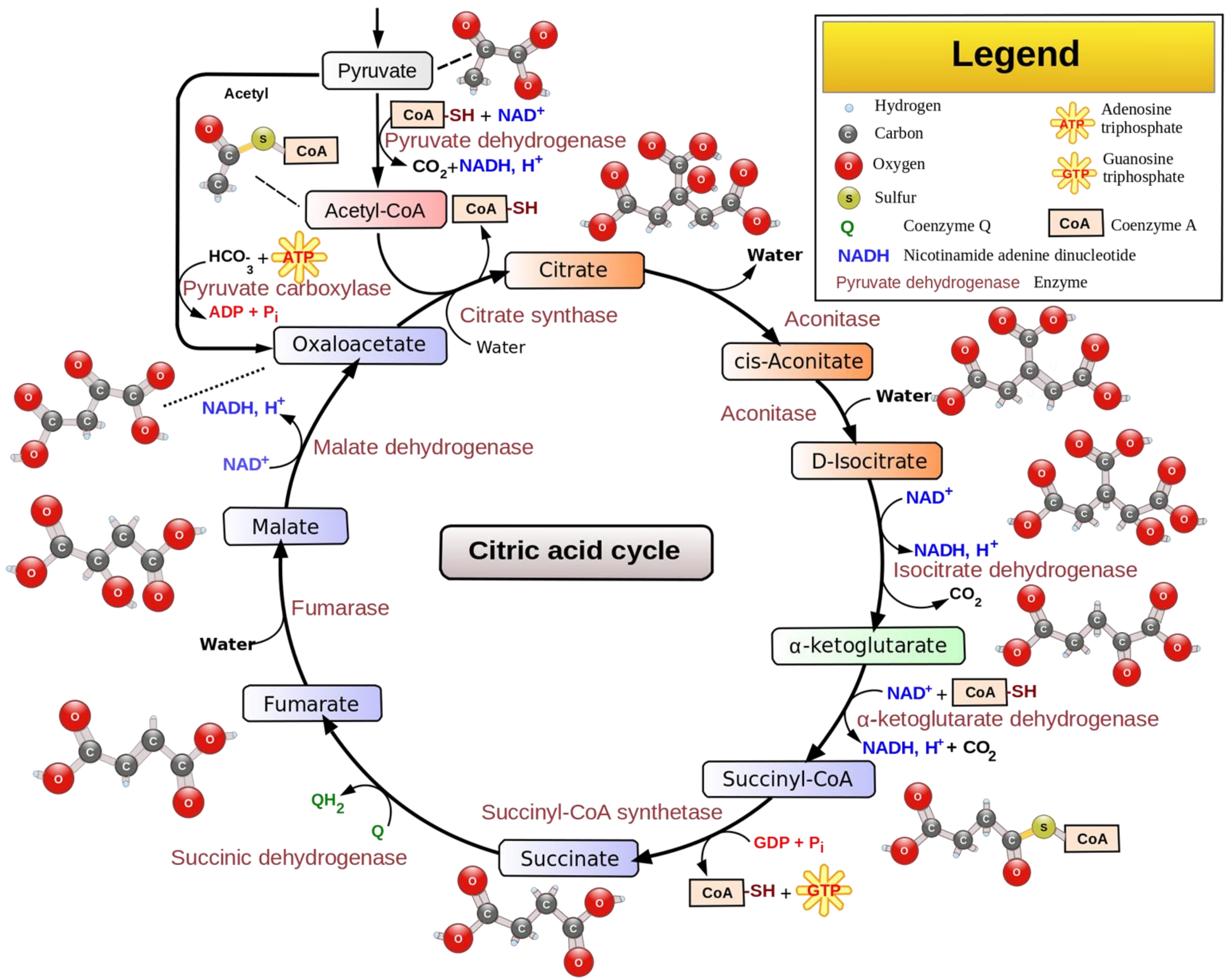
Produces: 2 CO_2, 3 NADH, 1 $FADH_2$, 1 ATP

Note: This happens twice per every 1 glucose.

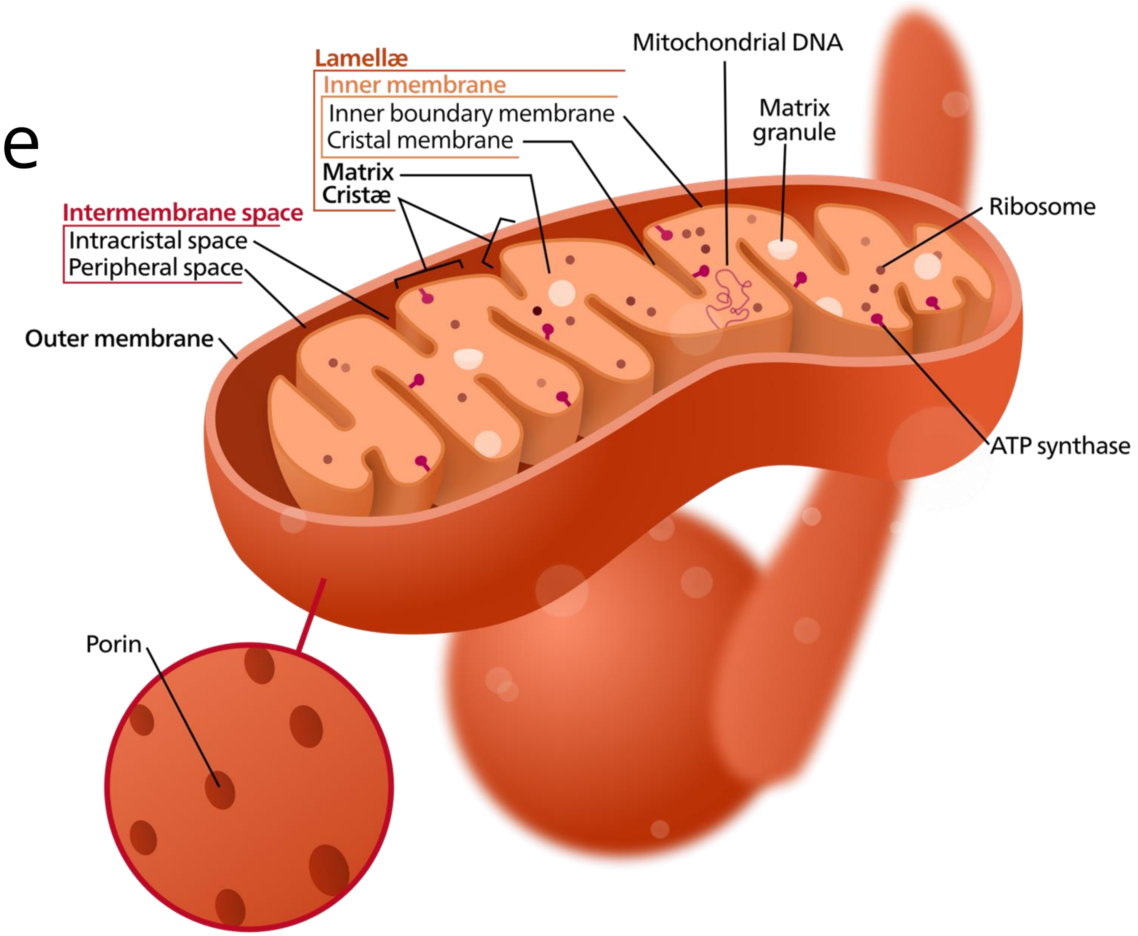
Though it doesn't use oxygen, the citric acid cycle stores more of the energy from glucose in electron shuttles (**NADH, $FADH_2$**). These will be used in the next step (Oxidative Phosphorylation)



The remaining 4 carbons from the original glucose will be released as CO_2 during this process.



Mitochondria are adapted to separate the citric acid cycle from oxidative phosphorylation.



The citric acid cycle occurs in the **mitochondrial matrix.**

Oxidative Phosphorylation occurs at the **inner membrane.**

Oxidative Phosphorylation: Overview

Occurs: At the inner membrane of the mitochondria

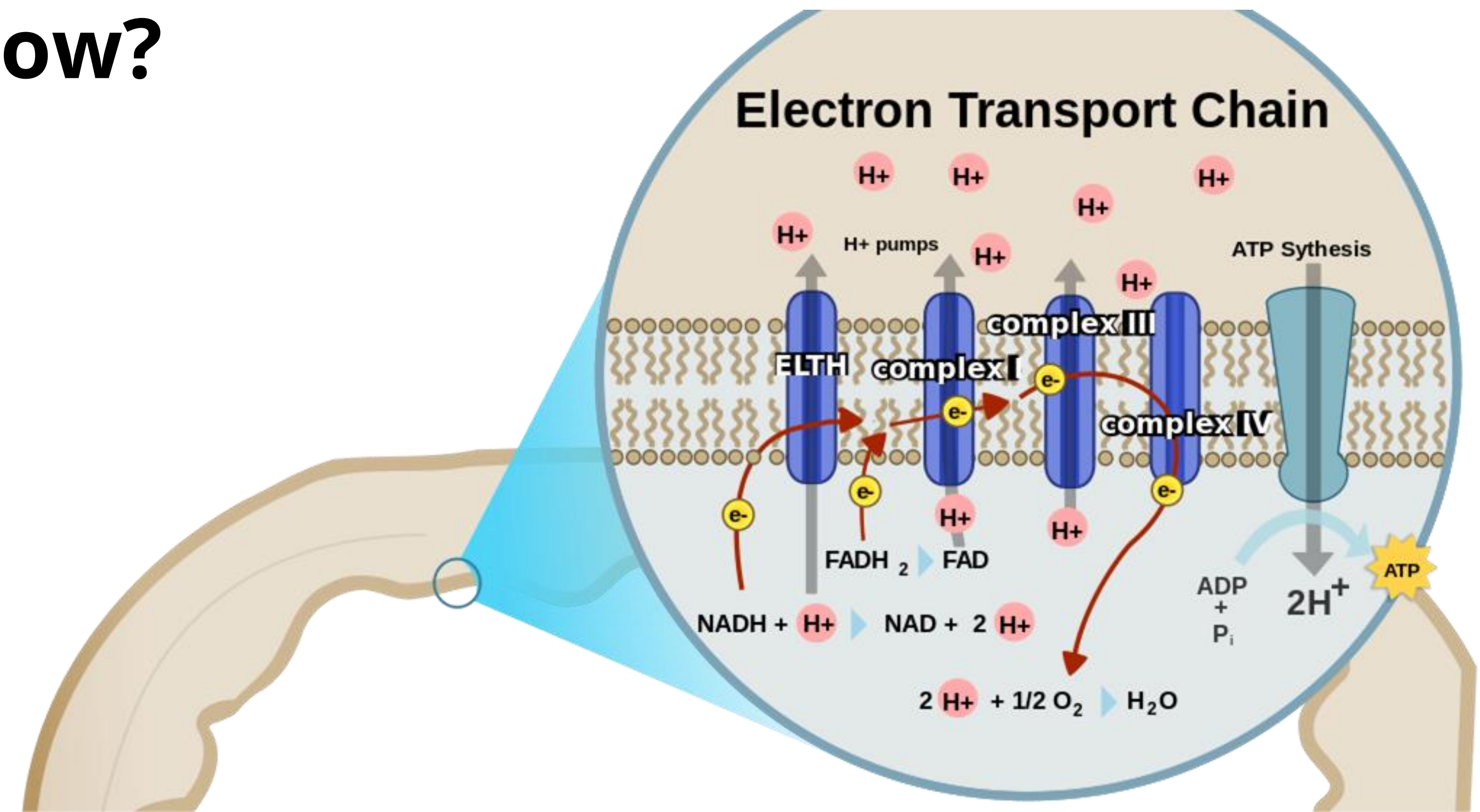
Uses: Oxygen, and all NADH and $FADH_2$ produced in glycolysis (2 NADH), acetyl-CoA conversion (2 NADH per glucose), and the citric acid cycle (6 NADH and 2 $FADH_2$ per glucose)

Produces: Water, NAD^+, FAD, and >30 ATP

Oxidative Phosphorylation

What's oxidized: NADH and $FADH_2$
What's produced: ATP and Water

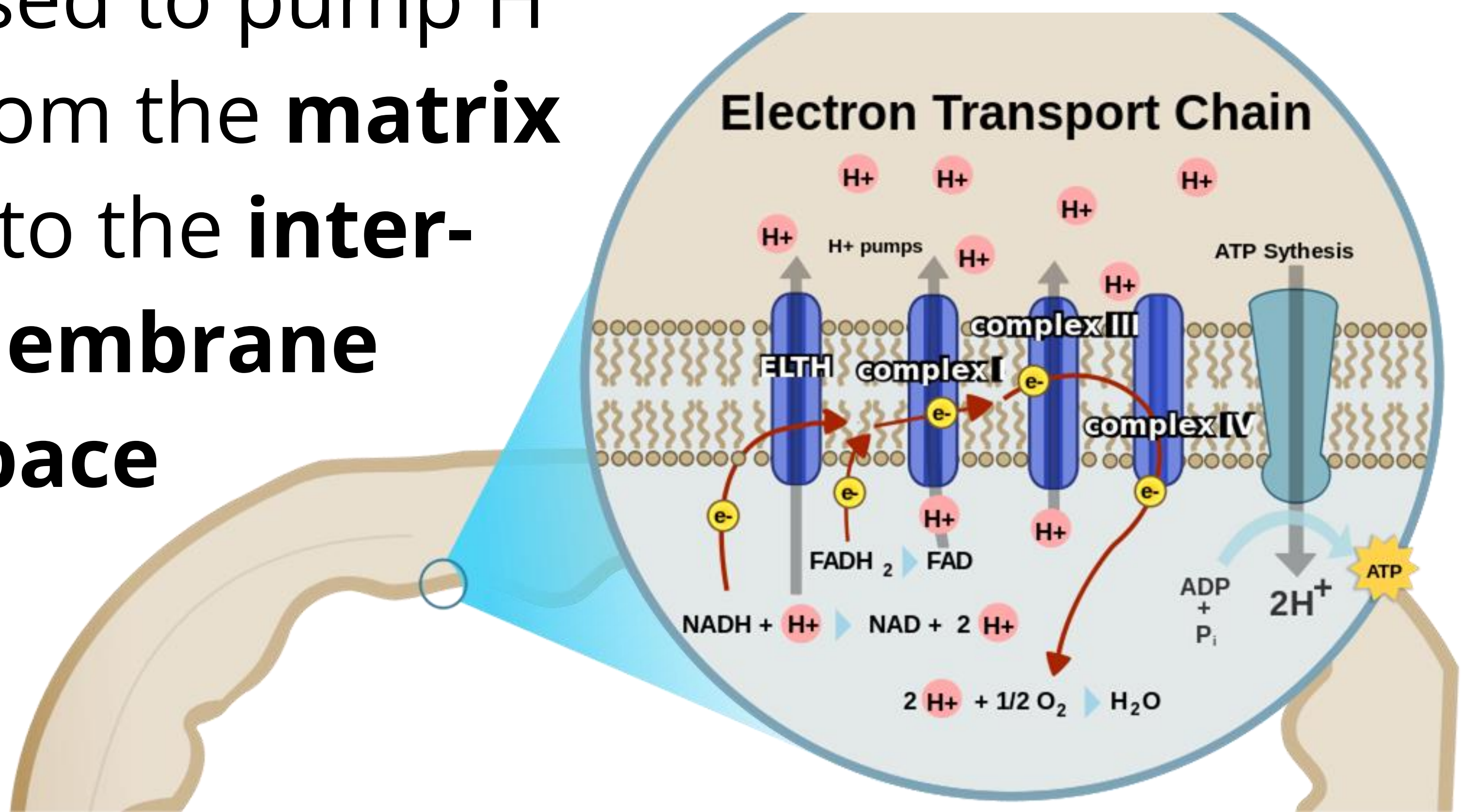
How?



Chemiosmosis

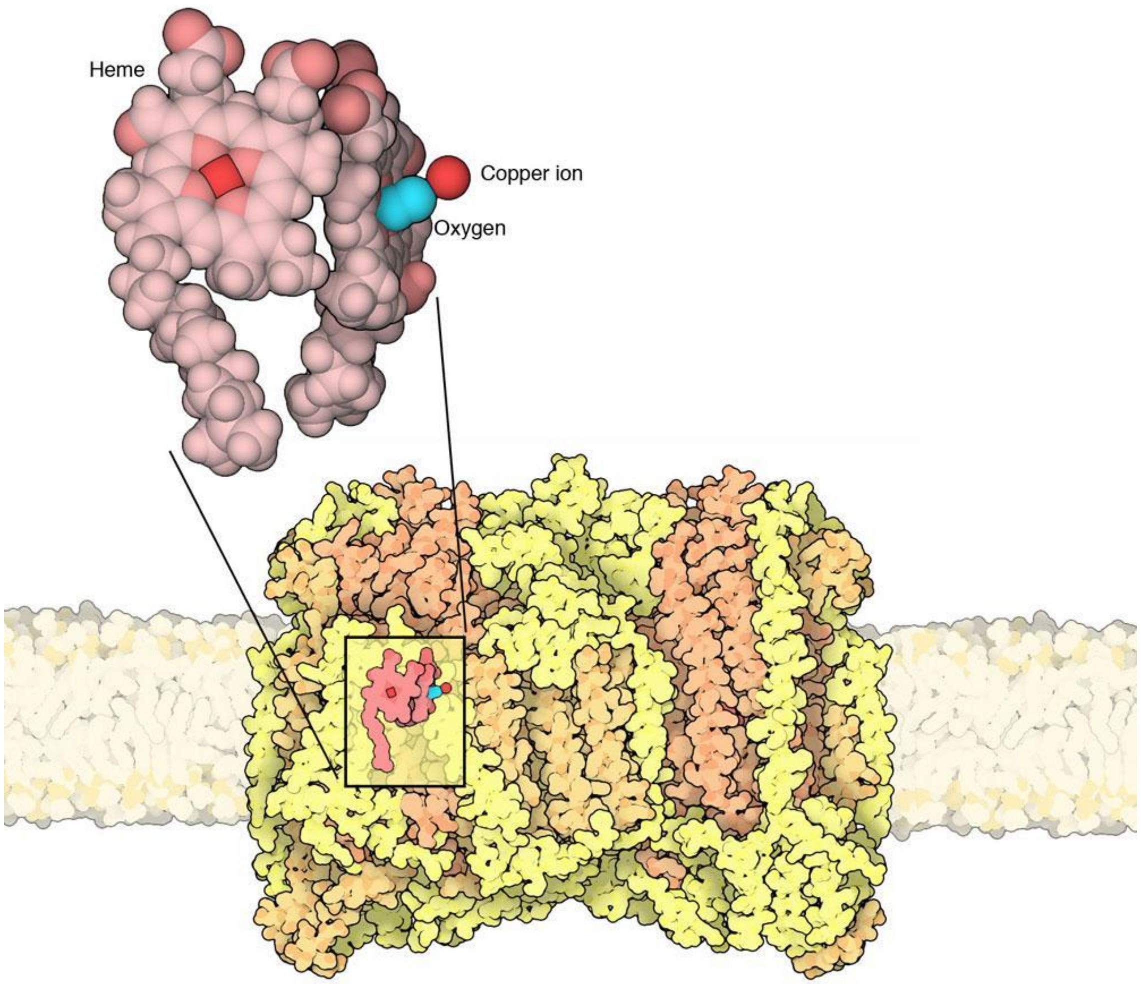
Similar to the light reactions.

The electrons move through an **electron transport chain**. The energy released is used to pump H^+ from the **matrix** into the **inter-membrane space**



Cytochrome C Oxidase

1 member of the mitochondrial ETC



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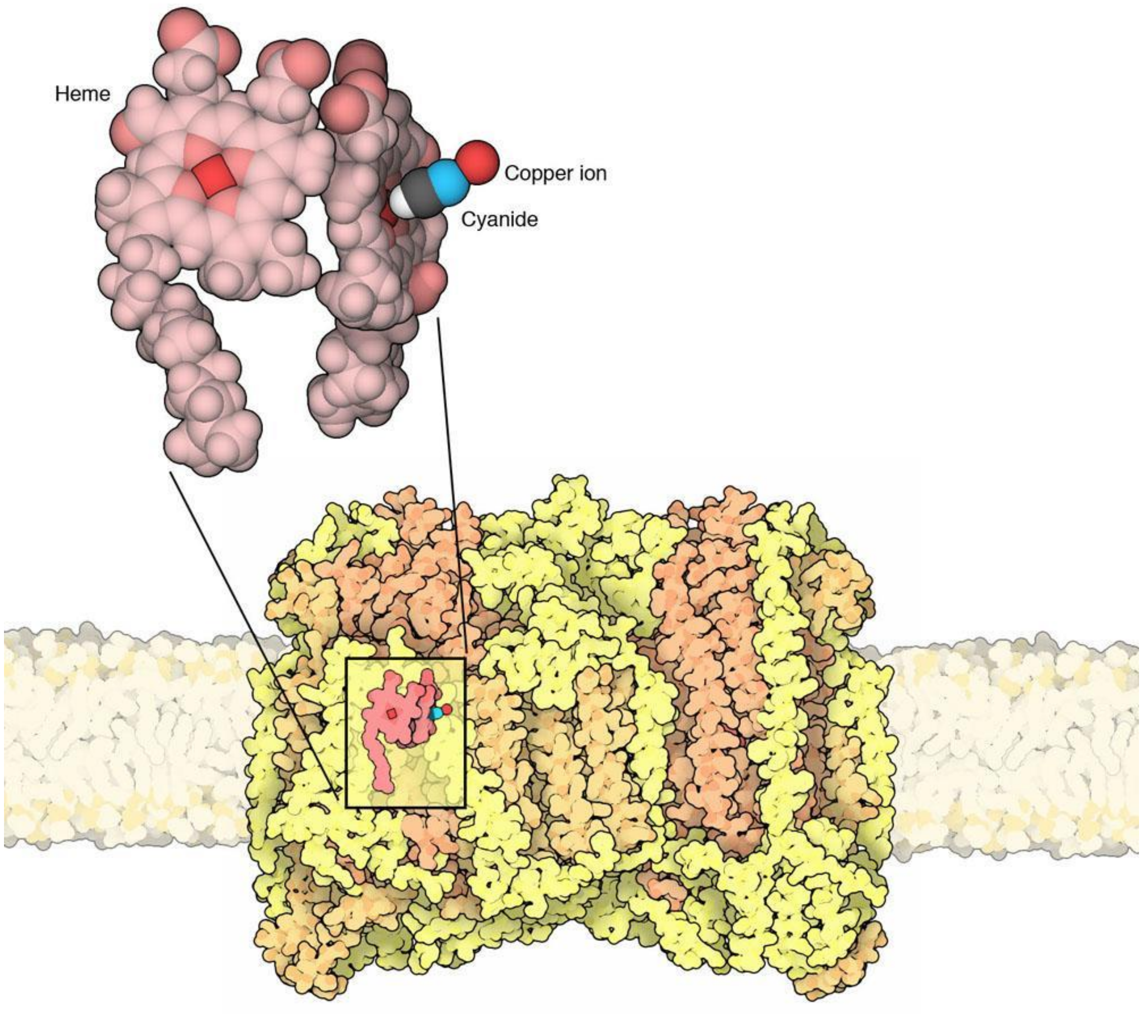
The Effect of Cyanide



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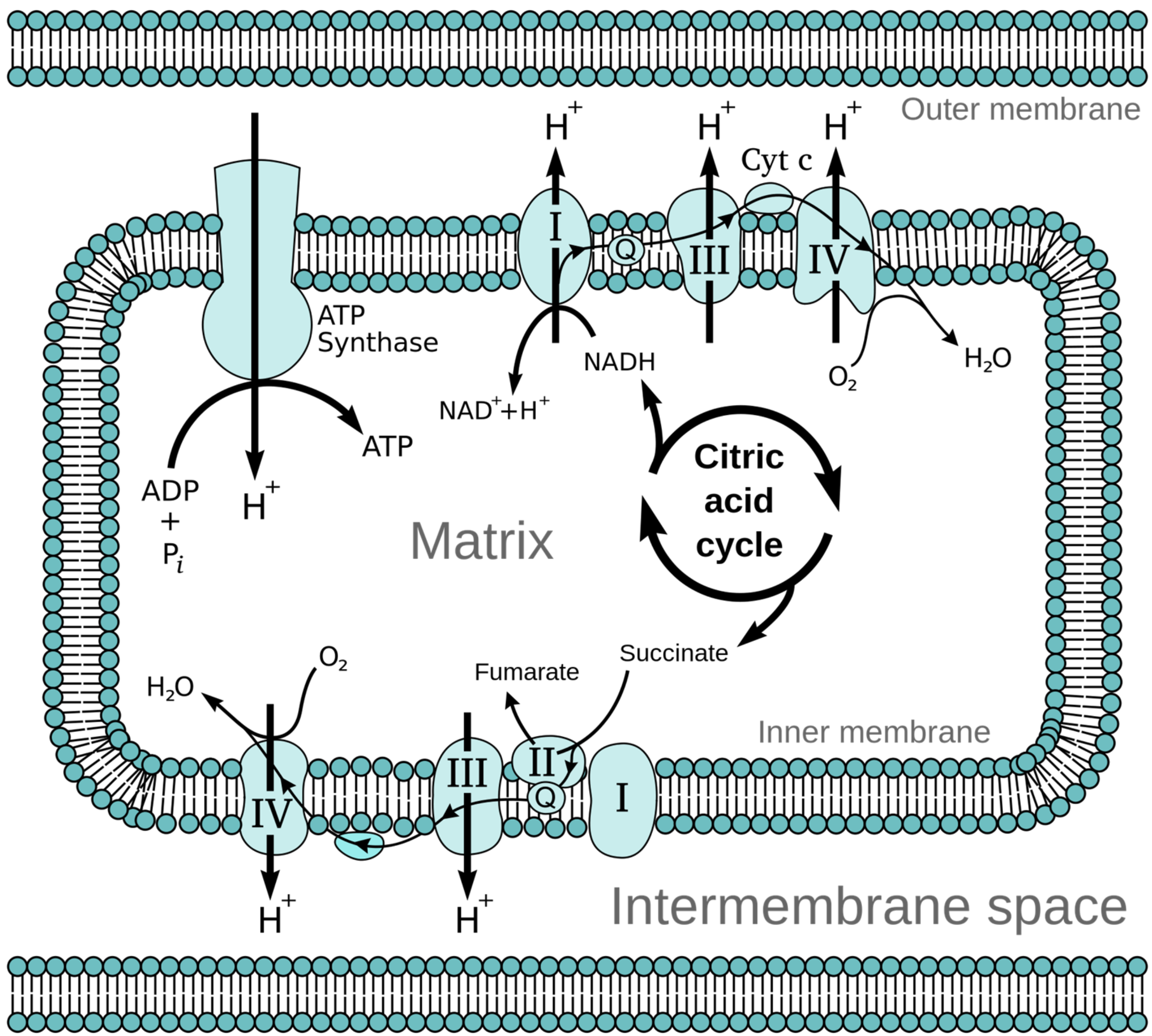
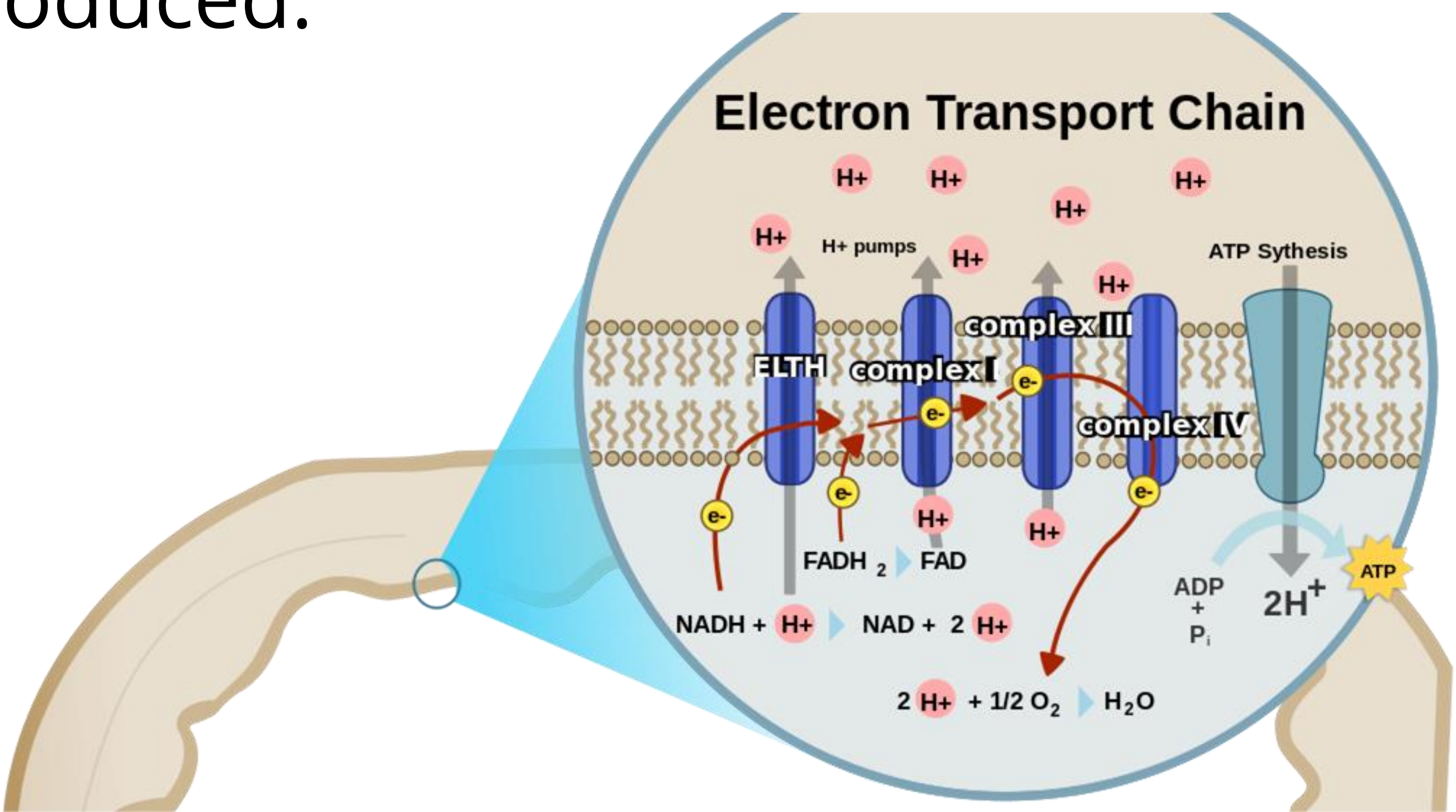
The only way for H^+ to diffuse back into the matrix is through **ATP Synthase**.



Where's Water?

Water is produced when electrons reach the end of the Electron Transport Chain.

They combine with oxygen, and water is produced.



Why >30 ATP?

We can't give an exact number because ATP synthesis and oxidation of electron carriers are not directly coupled.

~ 3 ATP per NADH, ~2 ATP per $FADH_2$

Certainly **MUCH MORE ATP** than in anaerobic cellular respiration.

Other Metabolites

All biological molecules are able to be metabolized through respiration pathways.

They are either converted in to glucose, or enter the process “downstream” of glycolysis, depending on the molecule.