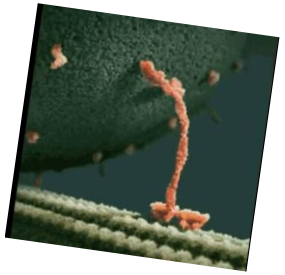
OSHER LIFELONG LEARNING INSTITUTE



NanoMachines:

The Tiny Biological Gadgets that Animate Life

The Lemonade Machine
(Sprice Machines 2019)

Session 2
Energy: Powering Life

OLLI at Illinois
Spring 2023

D. H. Tracy
DavidHTracy@gmail.com

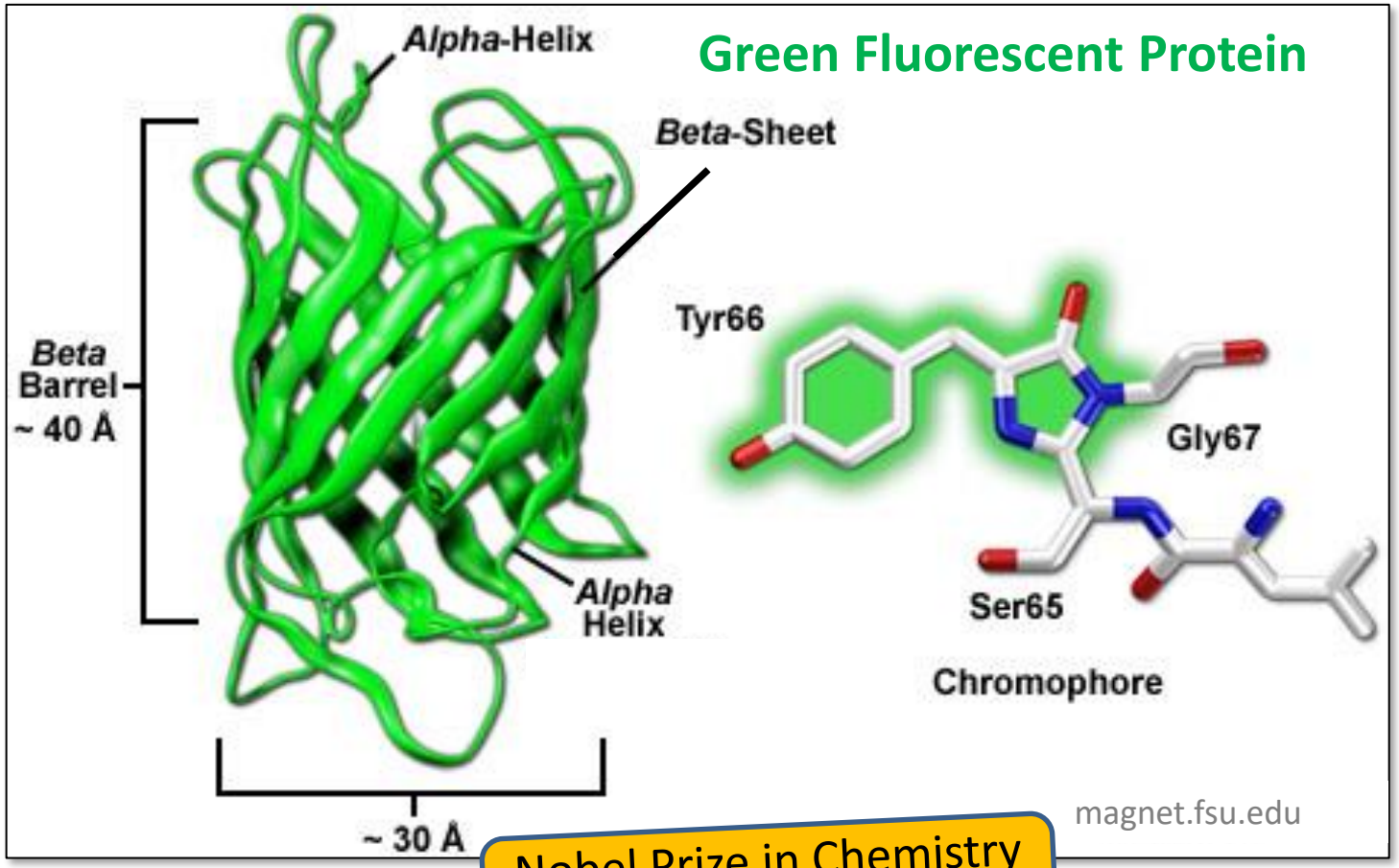
Course Outline

1. Overview
   Building blocks, energy flow, how we know
2. **nanoMachines in energy flow**
3. Motors and locomotion
4. DNA & RNA processing, protein manufacturing, Sensory

From last week….

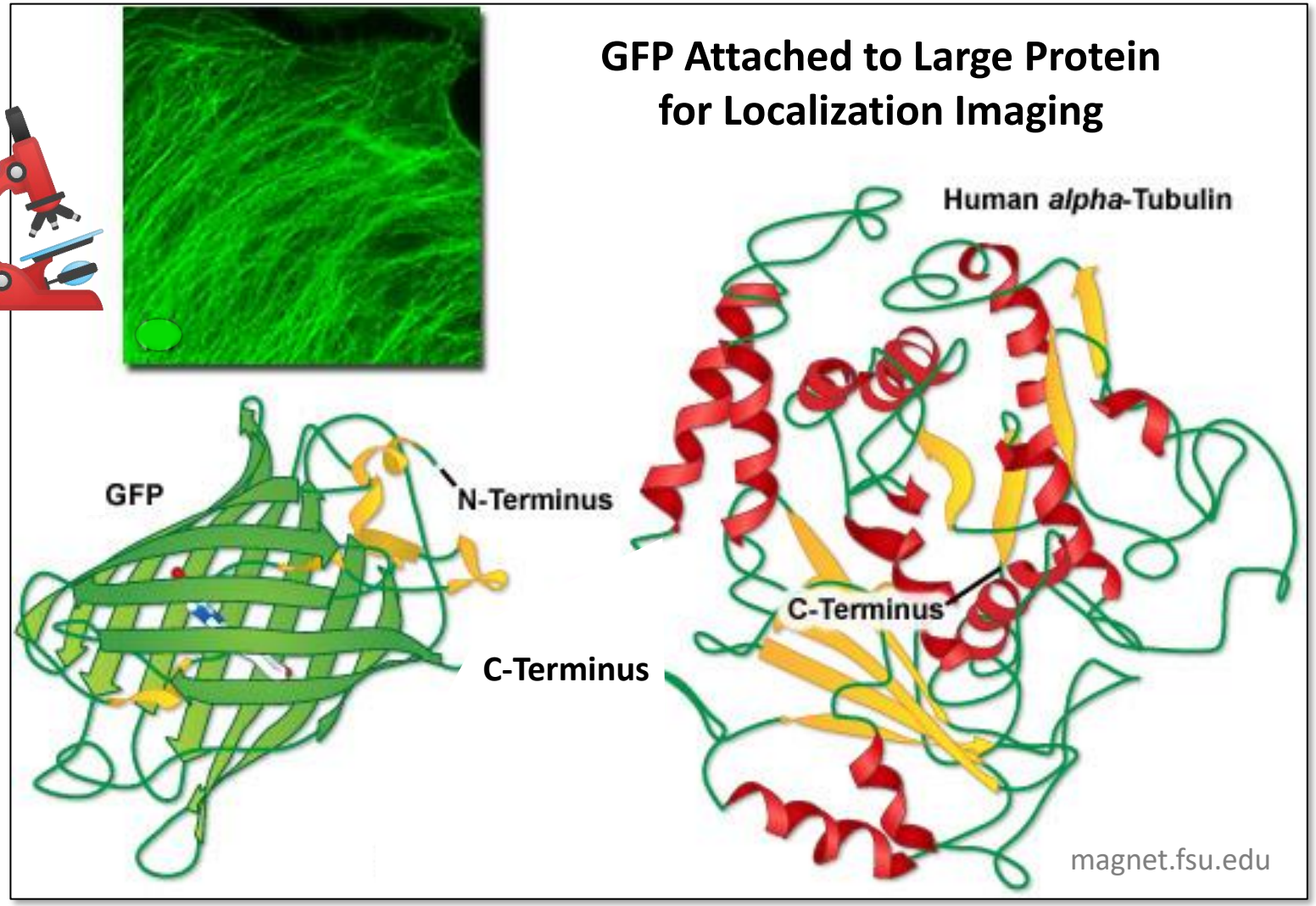
Visible microscopy has a role – motion detection

Bioluminescent



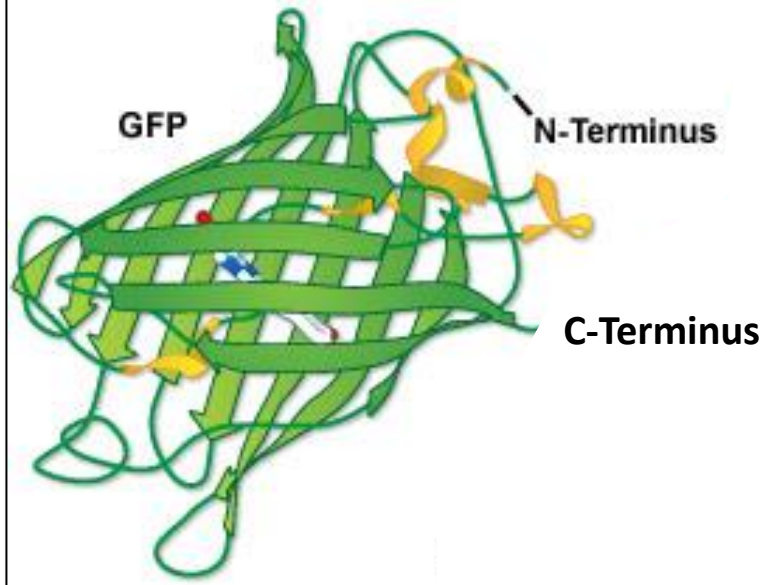
Nobel Prize in Chemistry 2008

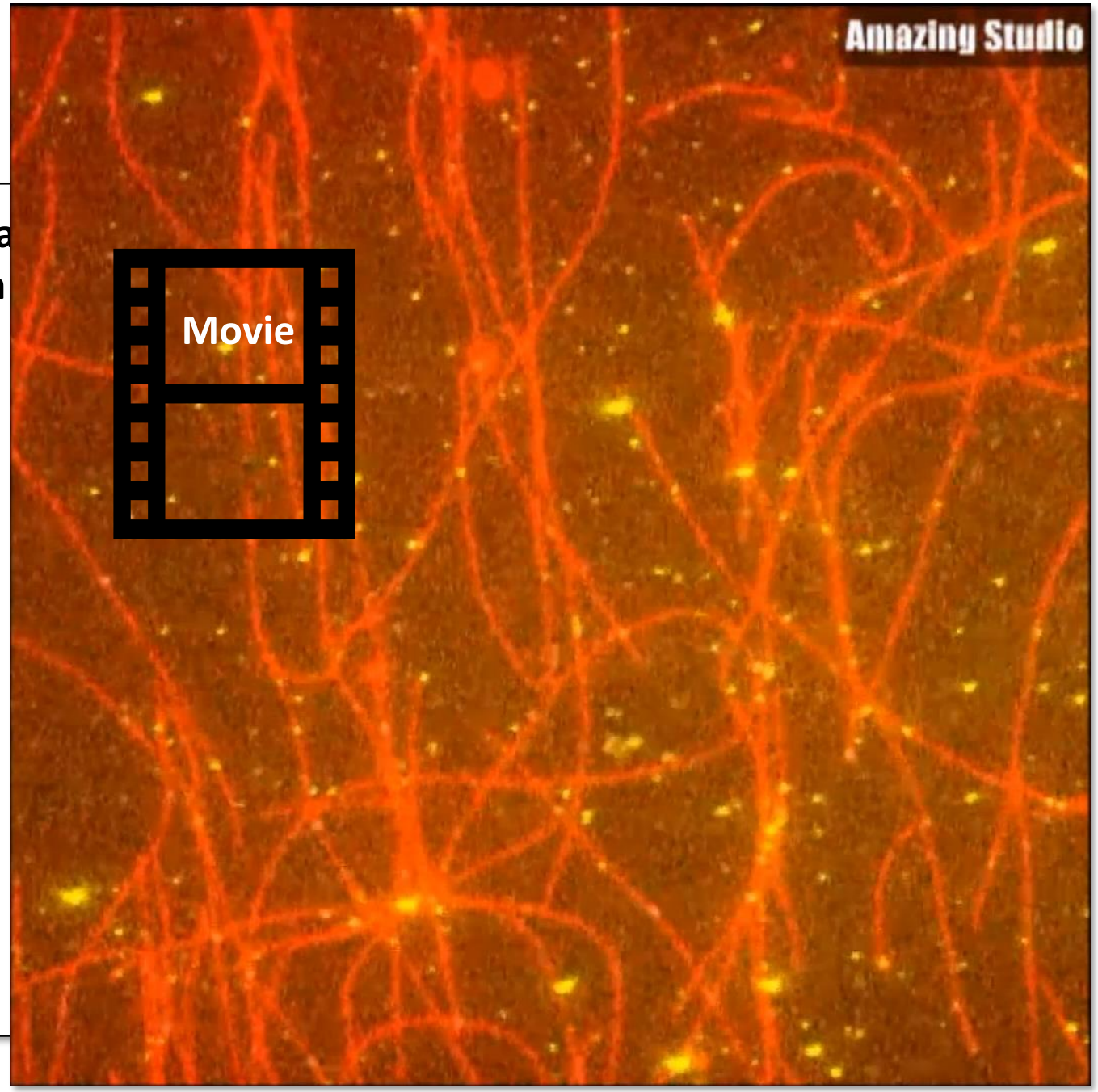
Visible microscopy has a role – motion detection



Visible microscopy has a role – motion detection

GFP Attached to La
for Localization

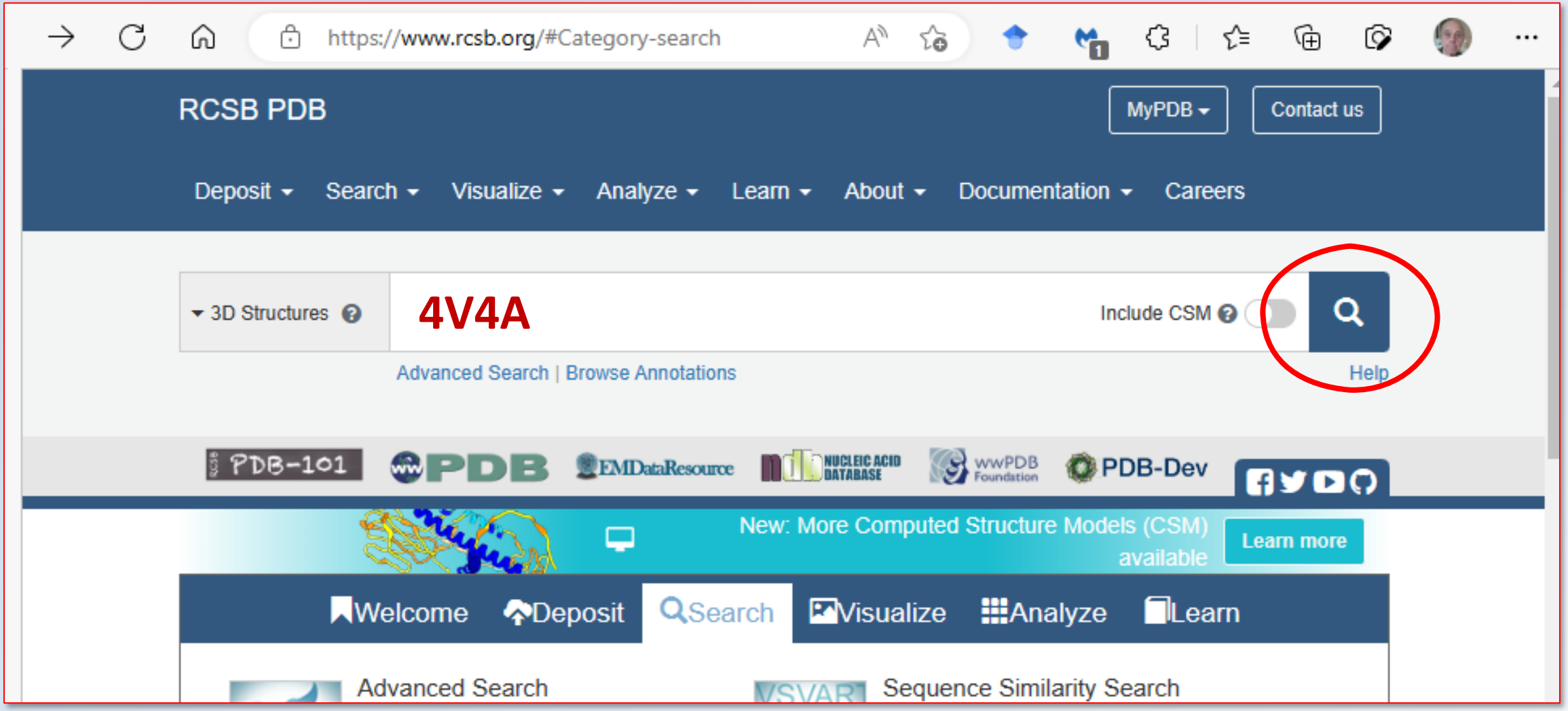




A note about visualizing nanoMachines

- Last week: Free visualization software
- Another way:
  - Web based visualization at www.RCSB.org

www.RCSB.org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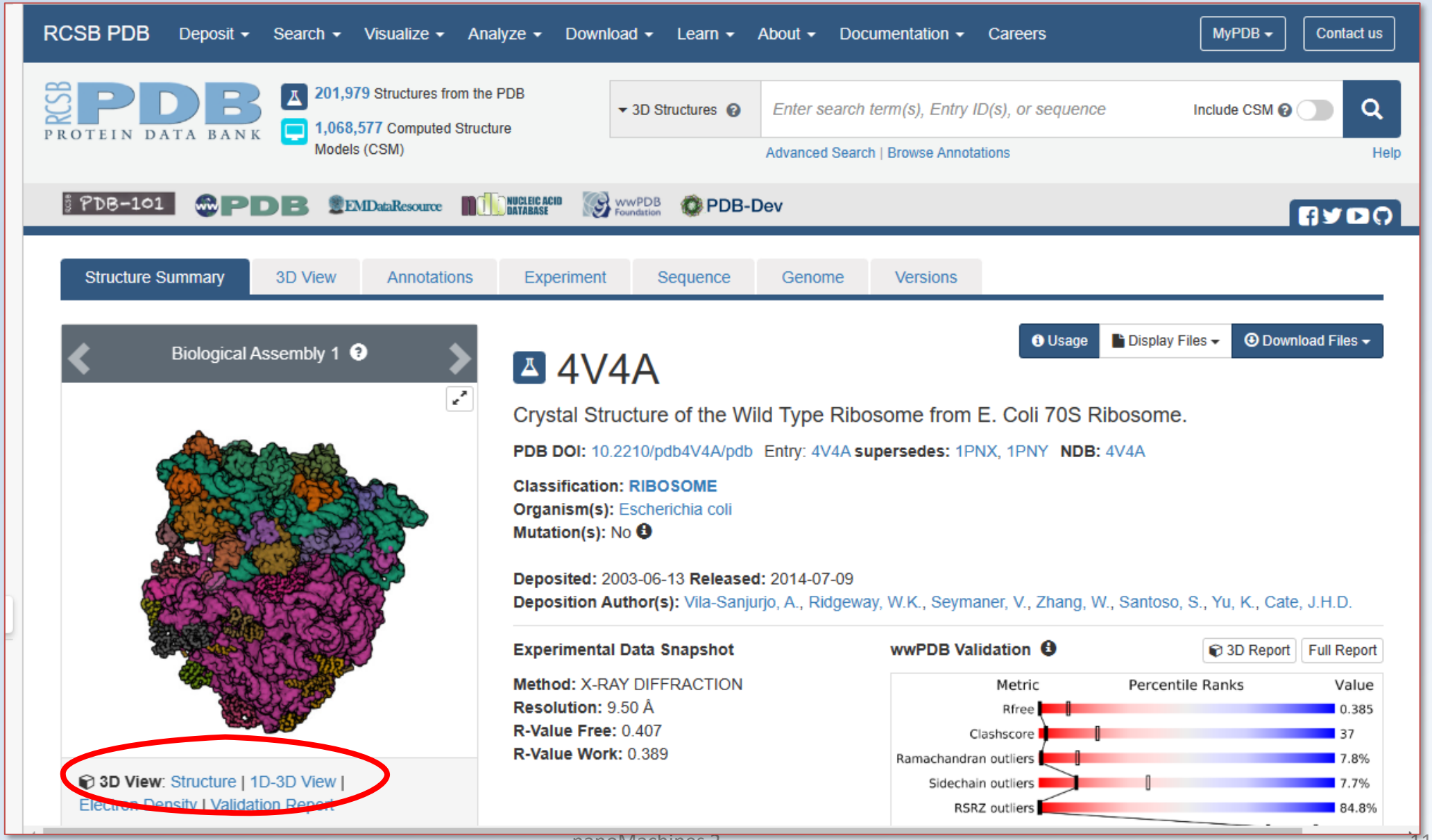
www.RCSB.org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PDB-Dev
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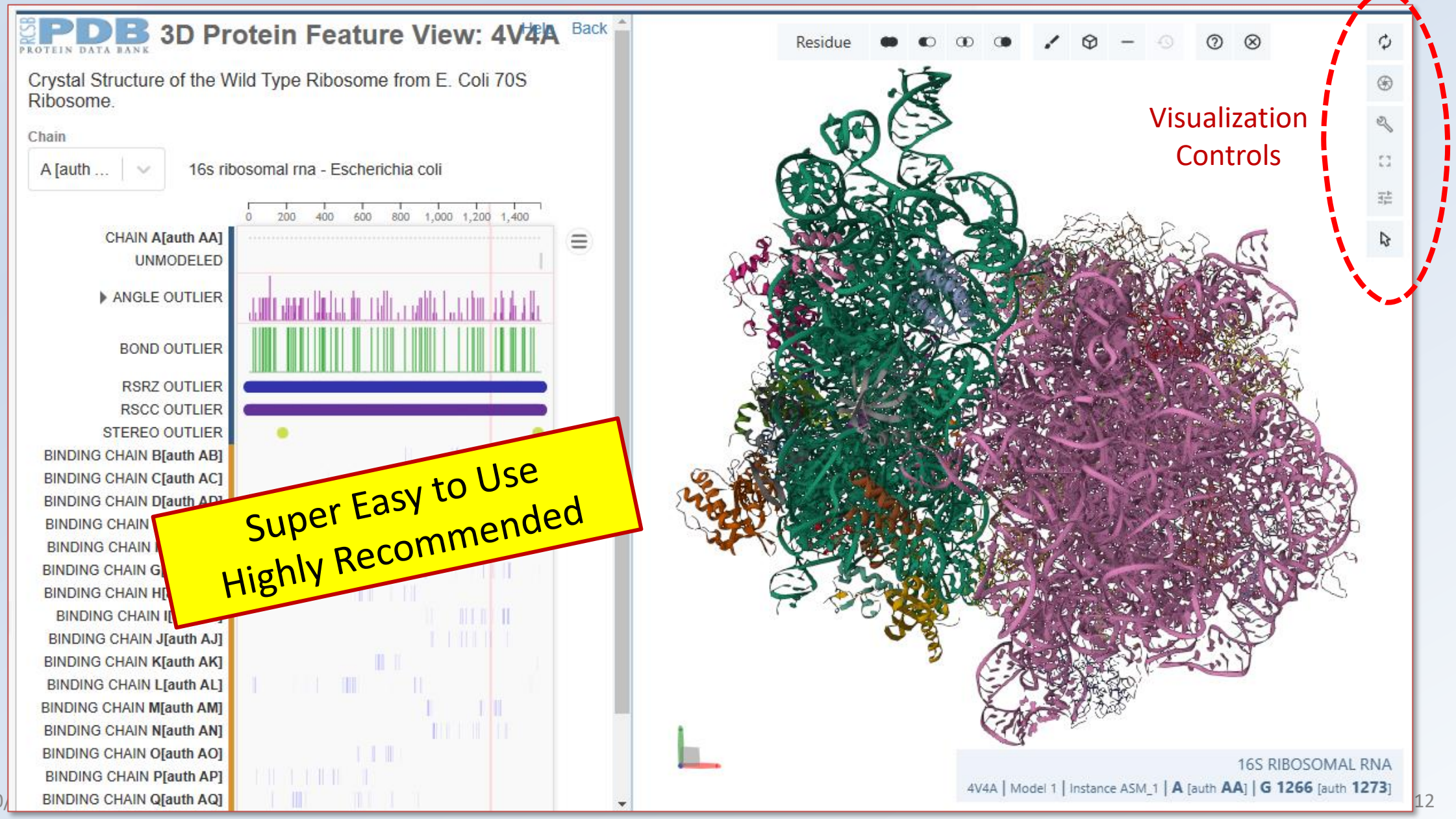
Annotations
Experiment
Sequence
Genome
Versions
Biological Assembly 1
Usage
Display Files
Download Files
4V4A
Crystal Structure of the Wild Type Ribosome from E. Coli 70S Ribosome.
PDB DOI: 10.2210/pdb4V4A/pdb Entry: 4V4A supersedes: 1PNX, 1PNY NDB: 4V4A
Classification: RIBOSOME
Organism(s): Escherichia coli
Mutation(s): No
Deposited: 2003-06-13 Released: 2014-07-09
Deposition Author(s): Vila-Sanjurjo, A., Ridgeway, W.K., Seymaner, V., Zhang, W., Santoso, S., Yu, K., Cate, J.H.D.
3D View: Structure | 1D-3D View |
Experimental Data Snapshot
Method: X-RAY DIFFRACTION
Resolution: 9.50 Å
R-Value Free: 0.407
R-Value Work: 0.389
wwPDB Validation
3D Report
Full Report
Metric
Percentile Ranks
Value
Rfree
0.385
Clashscore
37
Ramachandran outliers
7.8%
Sidechain outliers
7.7%
RSRZ outliers
84.8%

www.RCSB.org


PDB PROTEIN DATA BANK
3D Protein Feature View: 4V4A
Help
Back
Crystal Structure of the Wild Type Ribosome from E. Coli 70S Ribosome.
Chain
A [auth ...
16s ribosomal rna - Escherichia coli
0 200 400 600 800 1,000 1,200 1,400
CHAIN A[auth AA]
UNMODELED
ANGLE OUTLIER
BOND OUTLIER
RSRZ OUTLIER
RSCC OUTLIER
STEREO OUTLIER
BINDING CHAIN B[auth AB]
BINDING CHAIN C[auth AC]
BINDING CHAIN D[auth AD]
BINDING CHAIN
BINDING CHAIN
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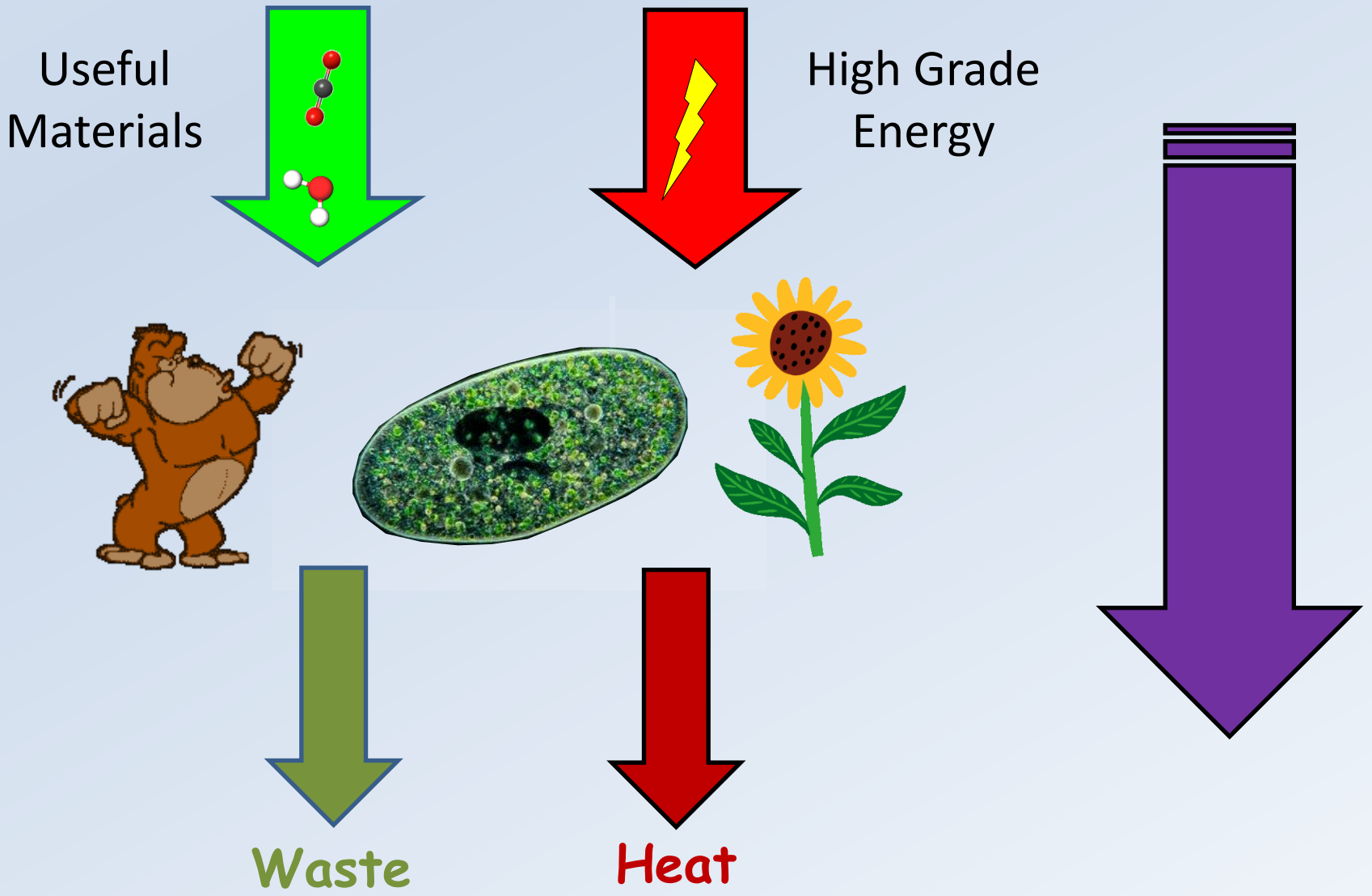
BINDING CHAIN I
BINDING CHAIN J[auth AJ]
BINDING CHAIN K[auth AK]
BINDING CHAIN L[auth AL]
BINDING CHAIN M[auth AM]
BINDING CHAIN N[auth AN]
BINDING CHAIN O[auth AO]
BINDING CHAIN P[auth AP]
BINDING CHAIN Q[auth AQ]
Super Easy to Use
Highly Recommended
Residue
Visualization Controls
16S RIBOSOMAL RNA
4V4A | Model 1 | Instance ASM_1 | A [auth AA] | G 1266 [auth 1273]

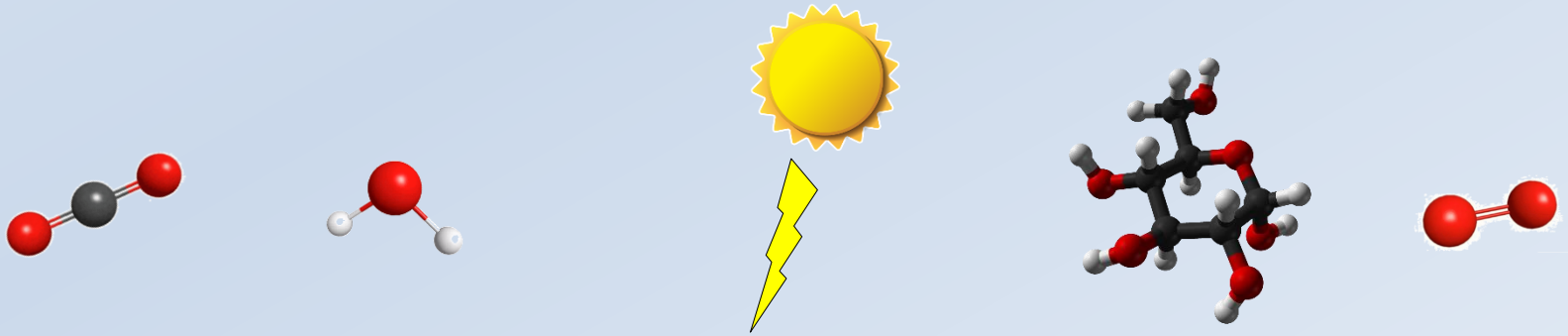
Outline of Session 2

- Photosynthesis
  - Harnessing sunlight to make the fuel that powers life
- Respiration
  - Converting that fuel to usable energy

Energy and Material Flow Animates All Life



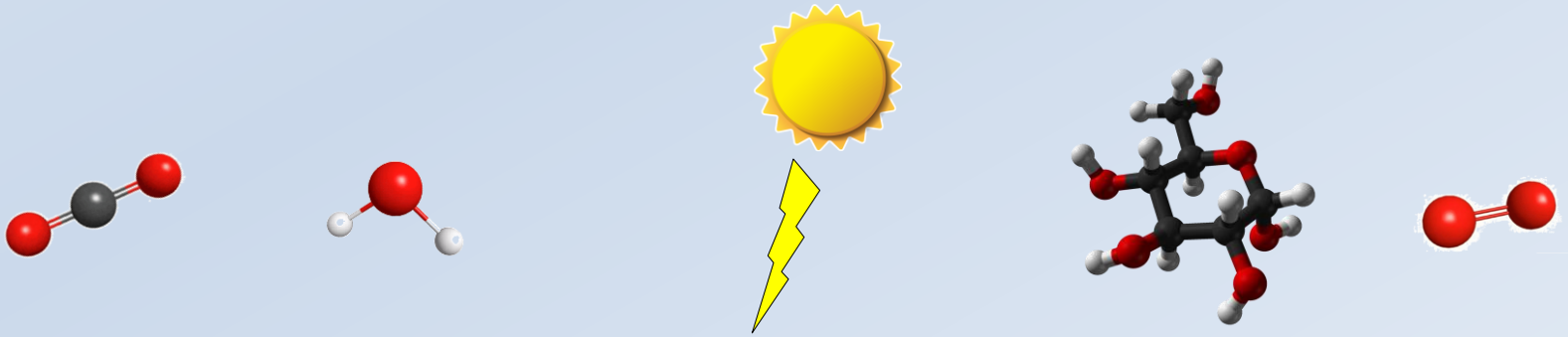
For the last few billion years, the main source of Energy for living things has been Sunlight



$CO_2 + H_2O + Energy \rightarrow Carbs + O_2$

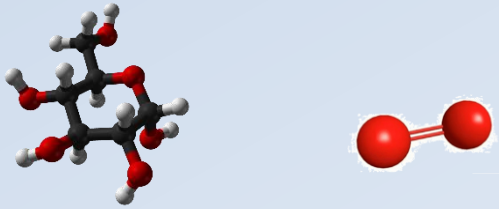
Photosynthesis

For the last few billion years, the main source of Energy for living things has been Sunlight



$CO_2 + H_2O + Energy \rightarrow Carbs + O_2$

Photosynthesis



$Carbs + O_2$

Respiration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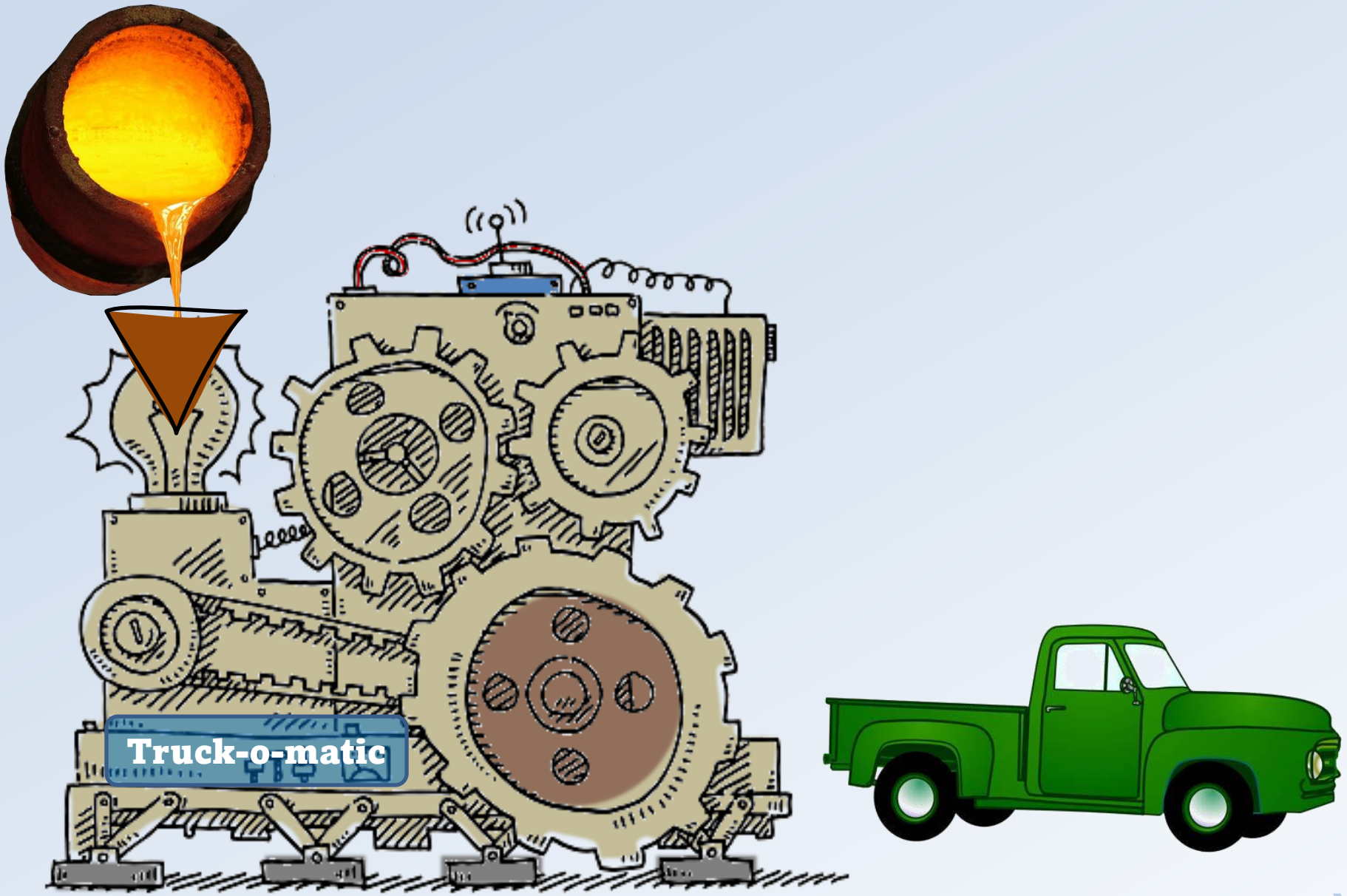
Twin Tangye Type
Model Steam Engine
Movie
www.mainsteam.co.uk
Keith Appleton
Steam Enthusiast

Results in a single step?



Ford F-150 Pickup Assembly:
more than 1 step

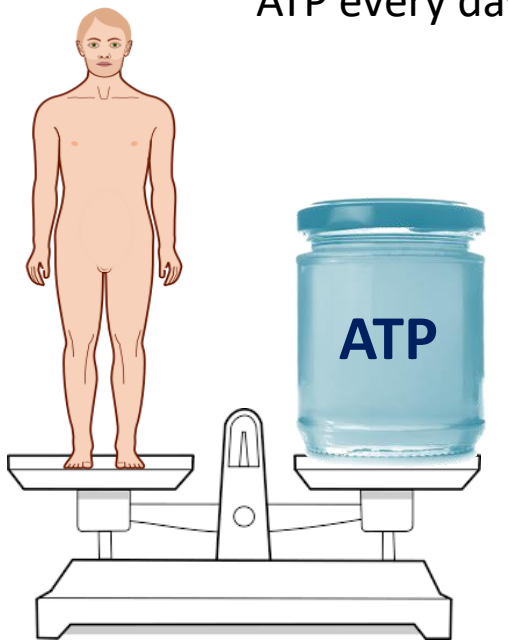

Movie

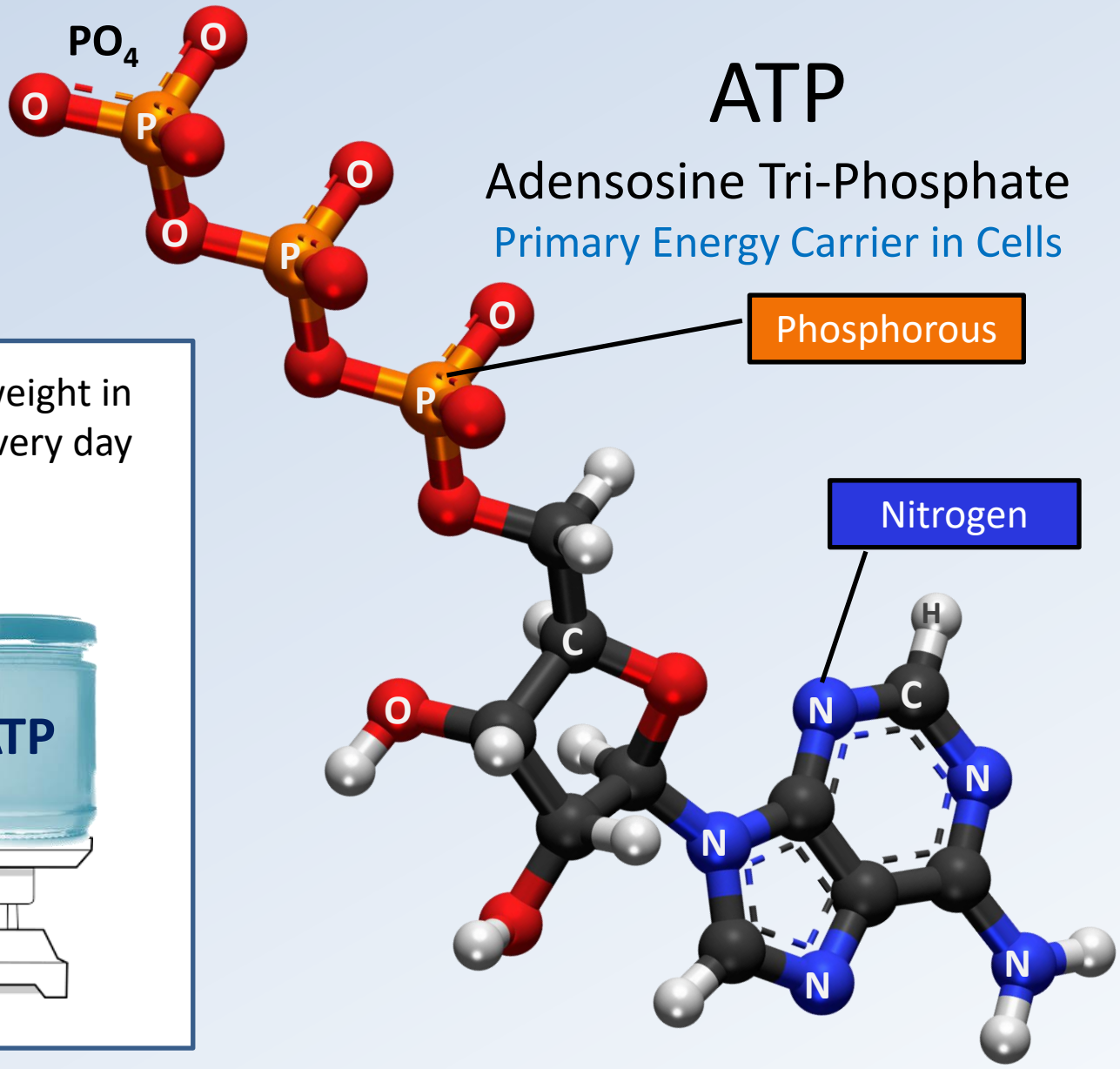
Lesson: A Big Job may have to be divided into many small steps

Remember ATP?

Energy "Tokens"

You use your own weight in ATP every day





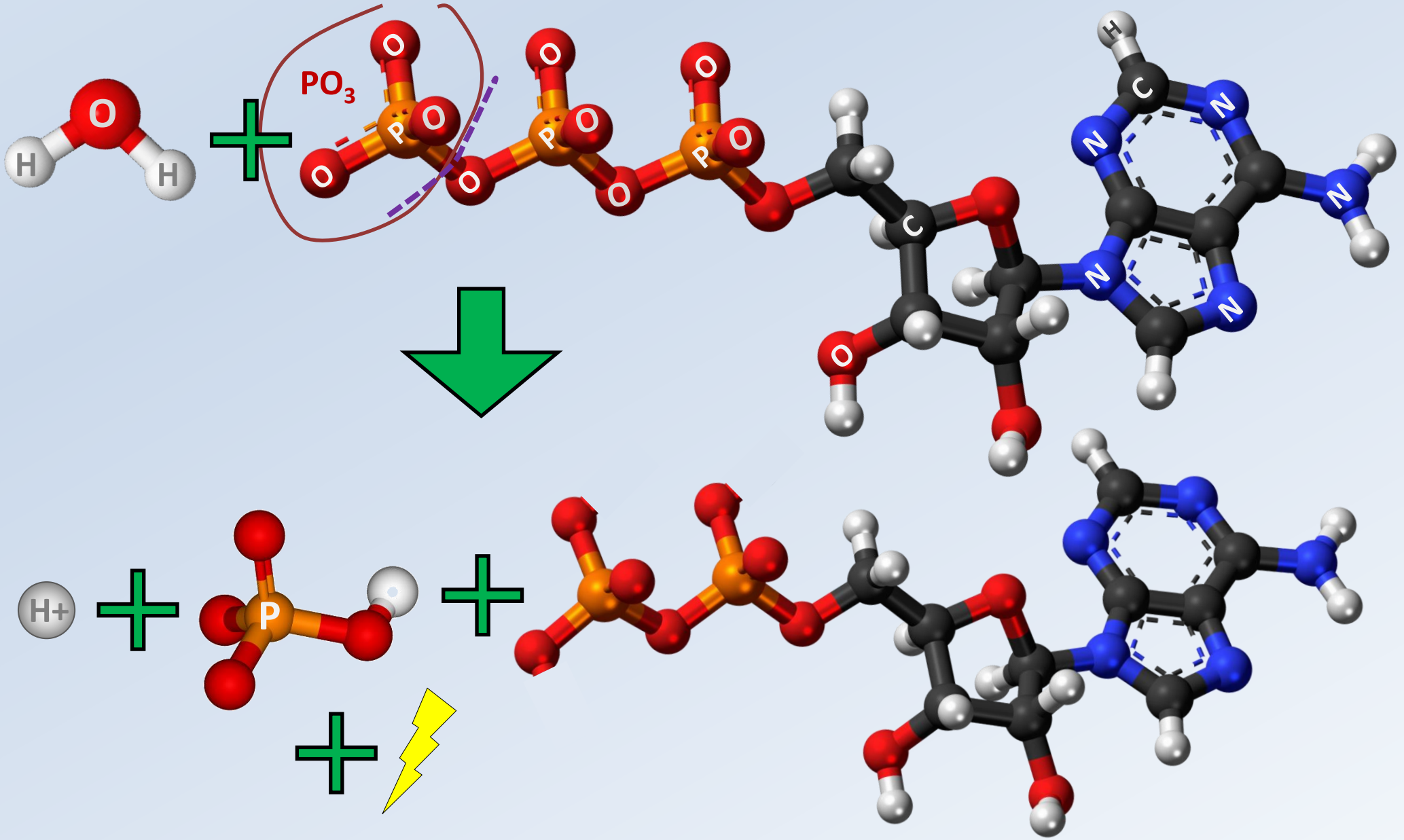
ATP

Adensosine Tri-Phosphate

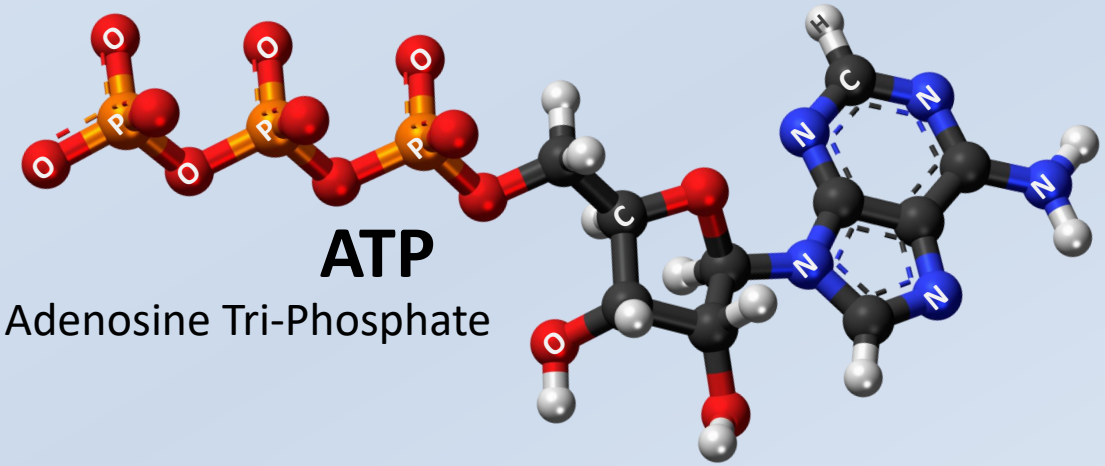
Primary Energy Carrier in Cells

Wikipedia

Short Term Energy Storage ATP from ADP



Short Term Energy Storage Molecules like ATP

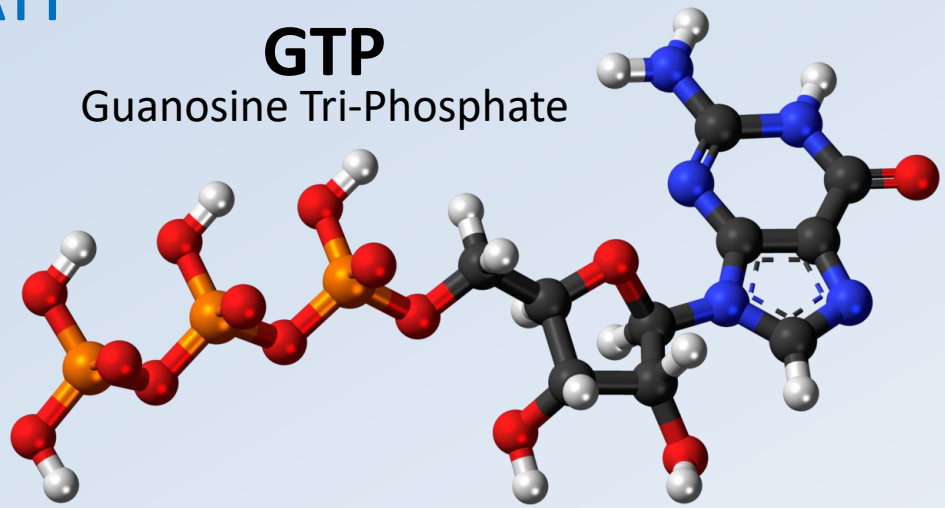


ATP

Adenosine Tri-Phosphate

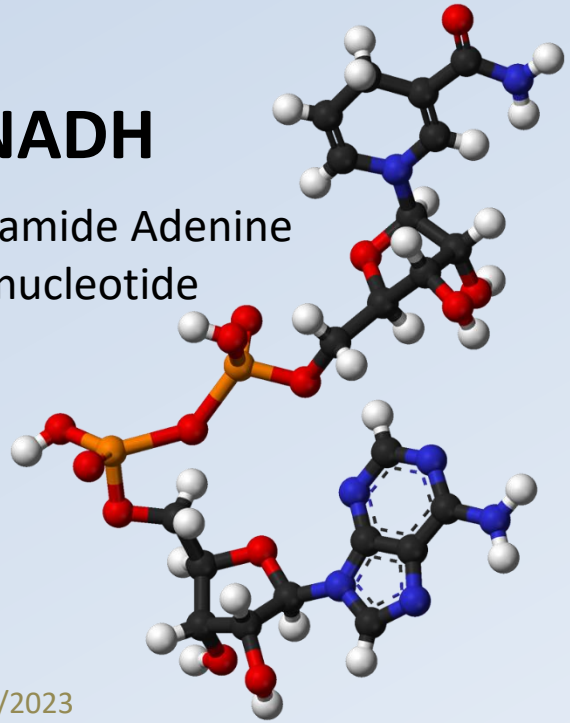
GTP

Guanosine Tri-Phosphate



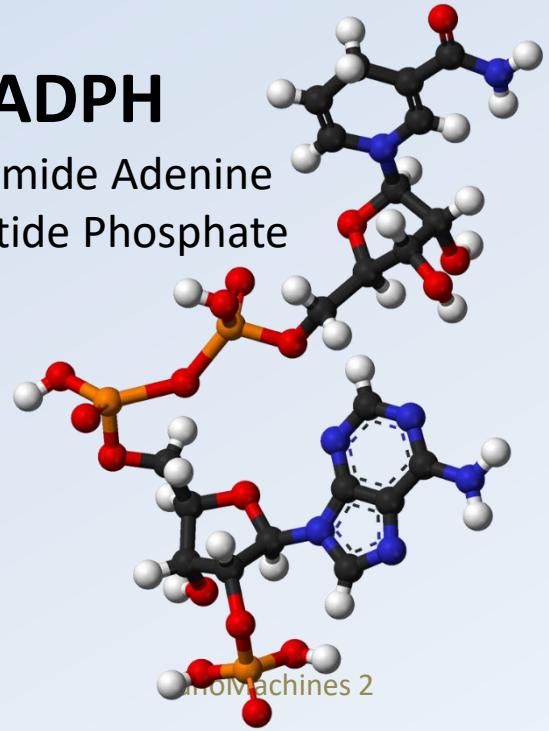
NADH

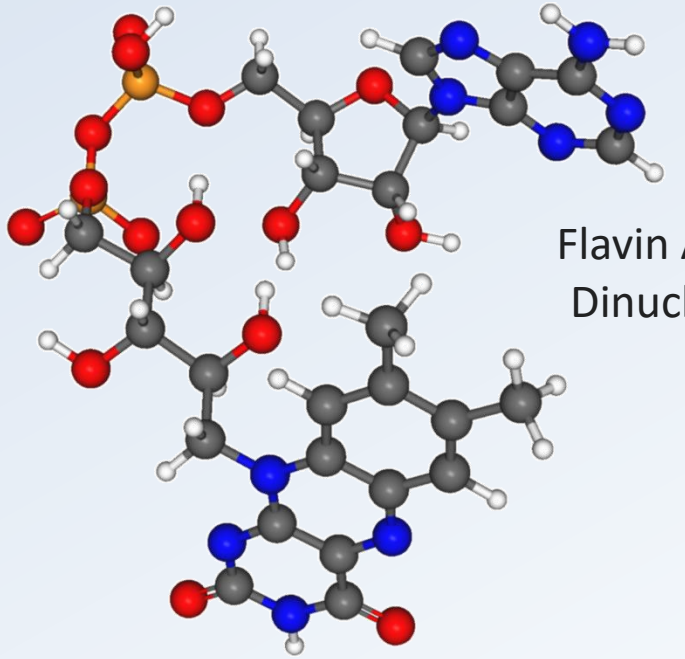
Nicotinamide Adenine Dinucleotide



NADPH

Nicotinamide Adenine Dinucleotide Phosphate



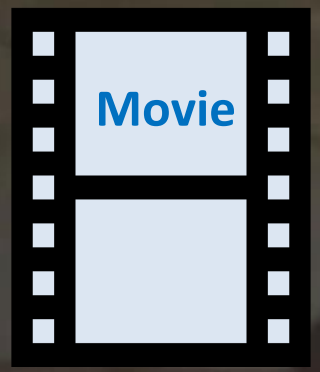


FAD

Flavin Adenine Dinucleotide

Flight of the Phoenix (1965)

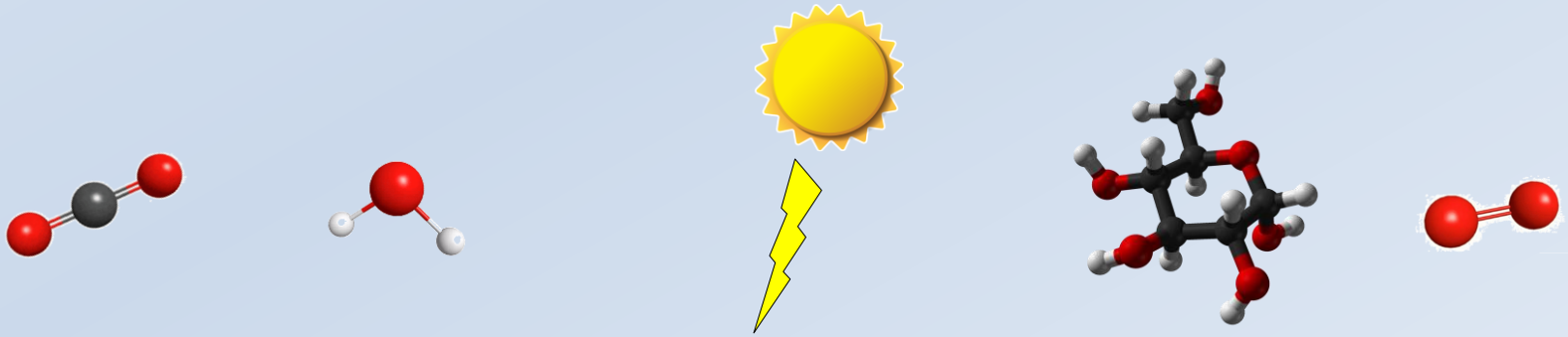
Our hardy crew is stranded in the Libyan desert with only one hope of survival ...



Jimmy Stewart

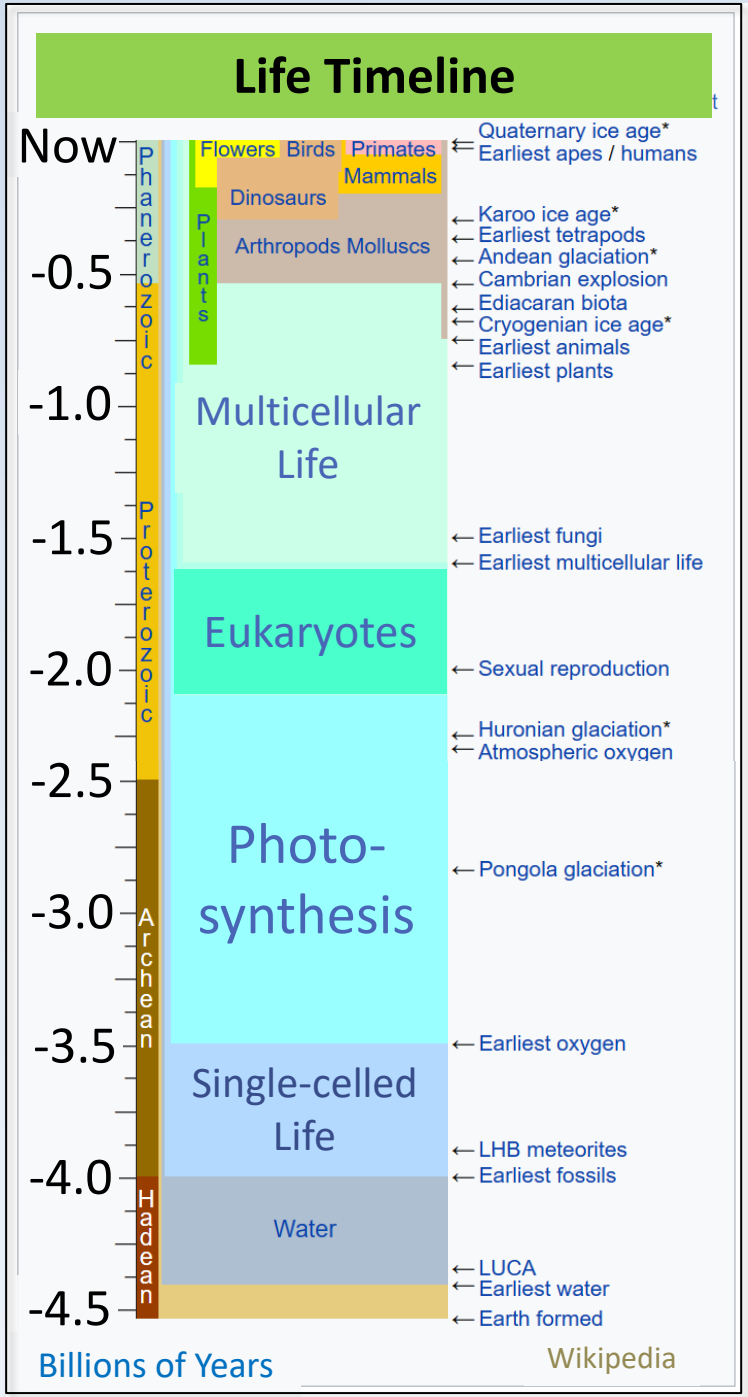
Coffman Cartridges

For the last few billion years, the main source of Energy for living things has been Sunlight



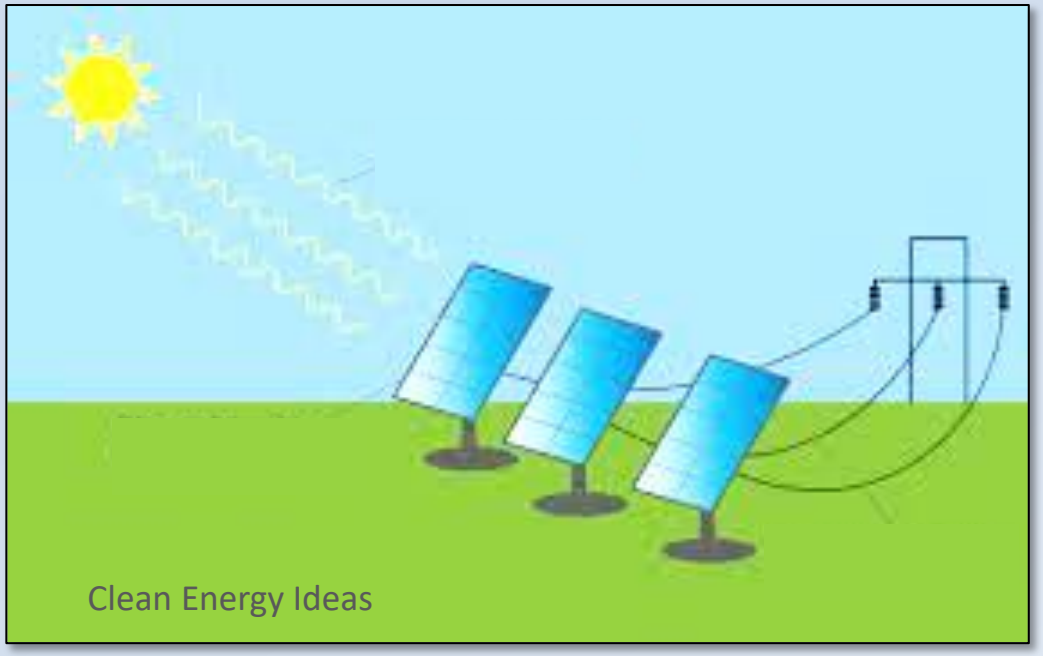
$CO_2 + H_2O + Energy \rightarrow Carbs + O_2$

Photosynthesis

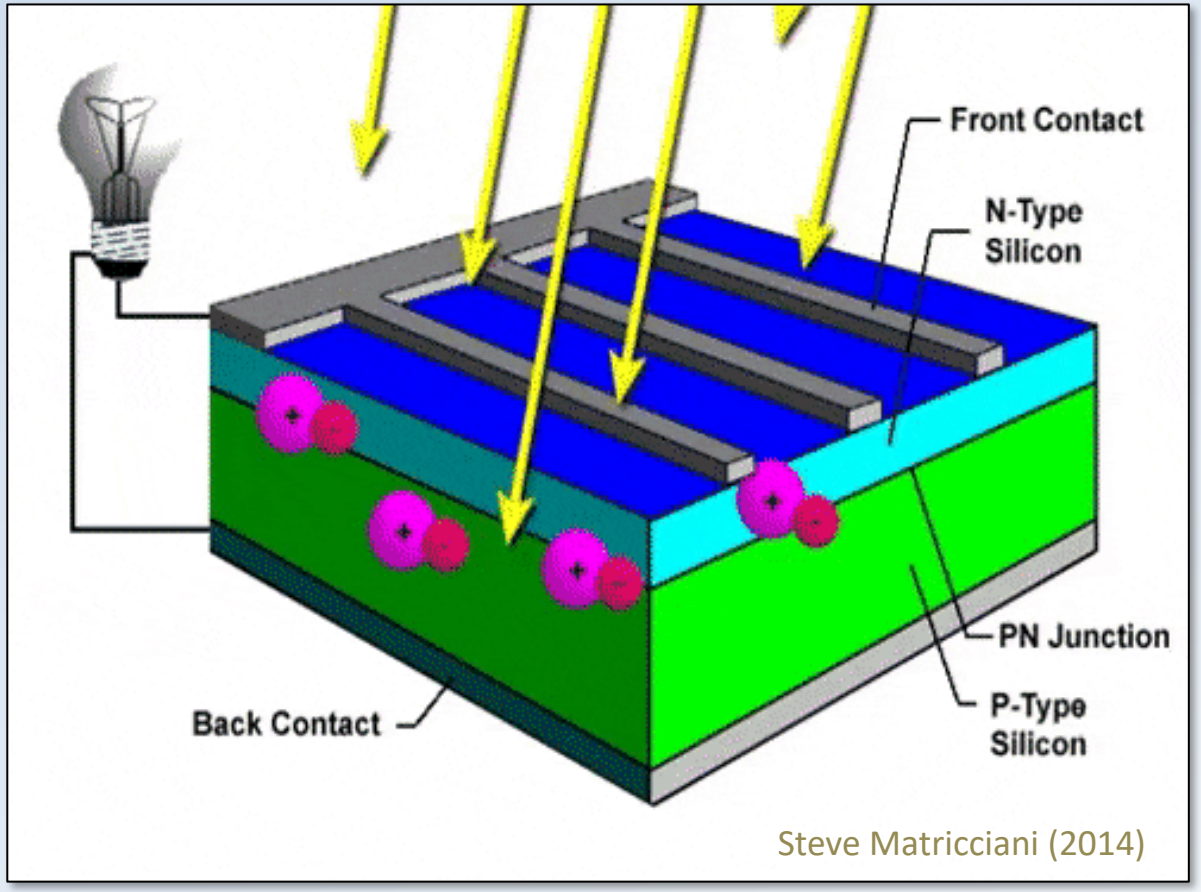


Photosynthesis

The way we do it….

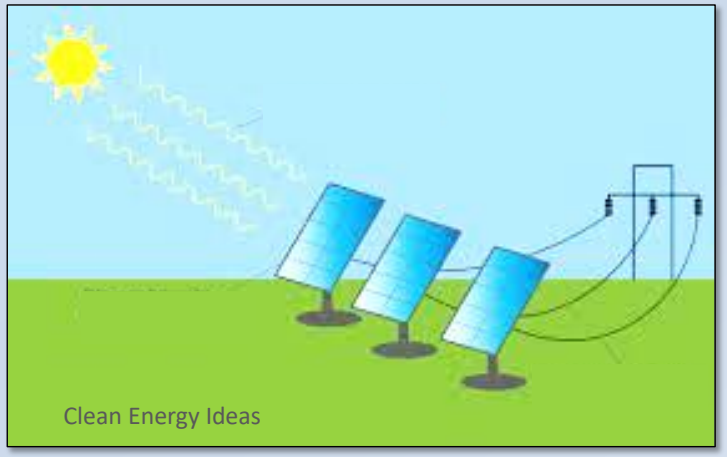


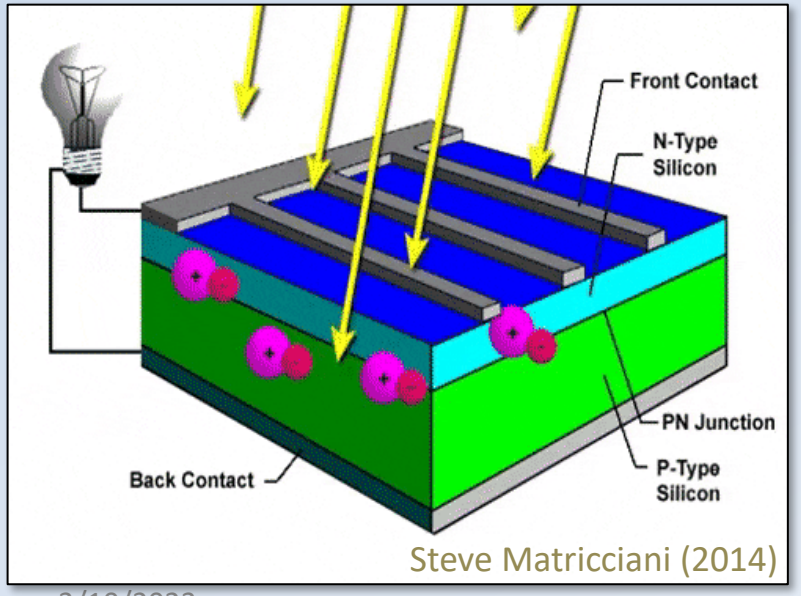
Silicon PhotoVoltaic Cell: 0.5V



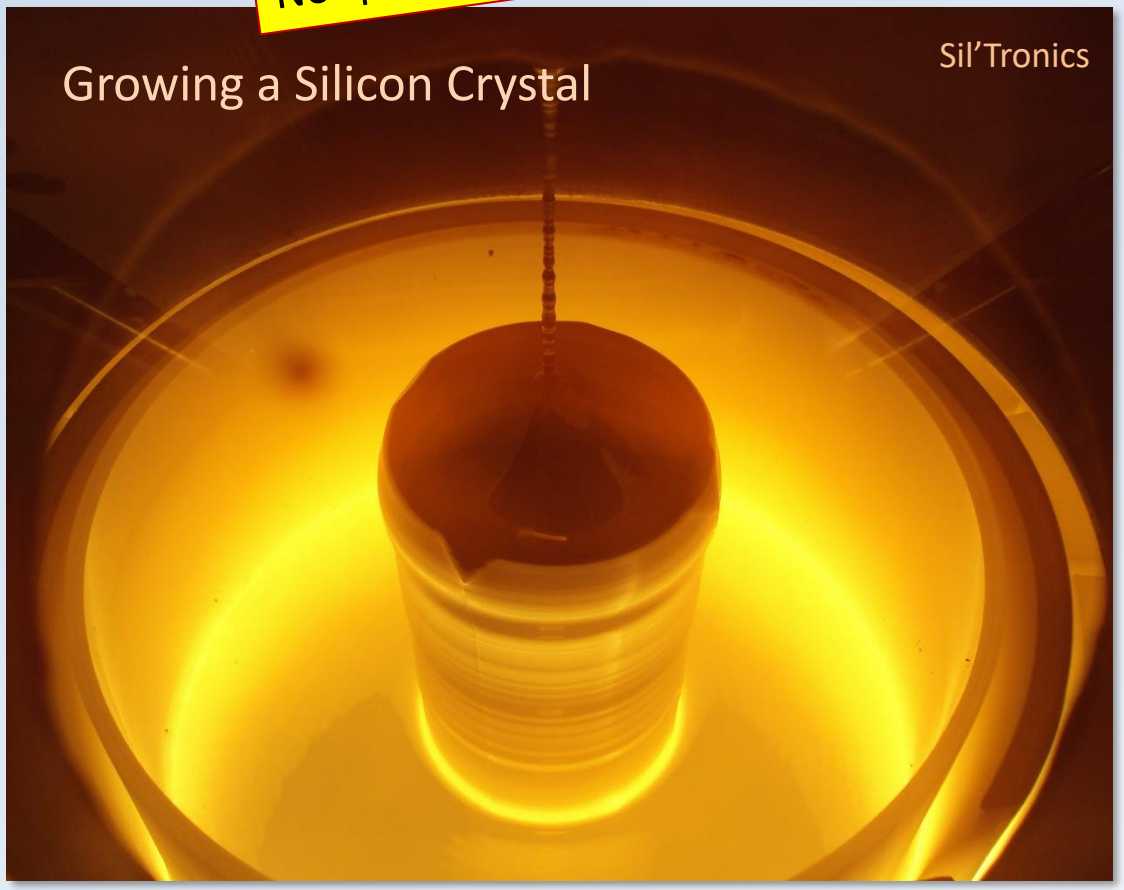
Photosynthesis

The way we do it….



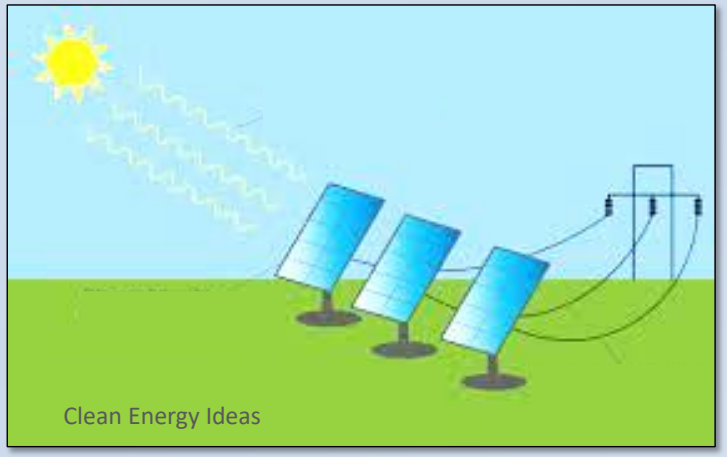


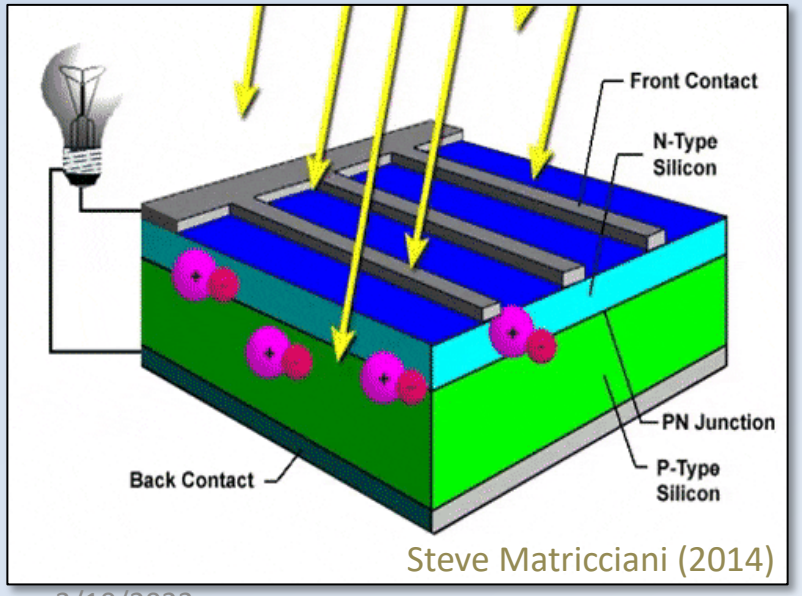
Not practical for biology….



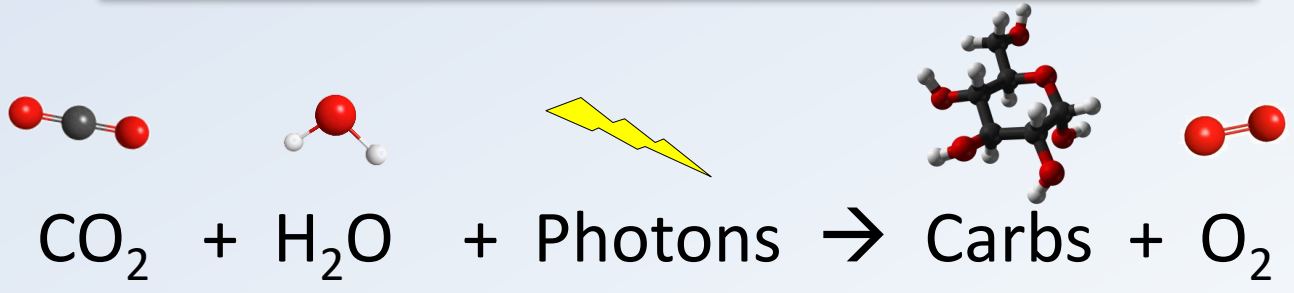
Photosynthesis

The way we do it….

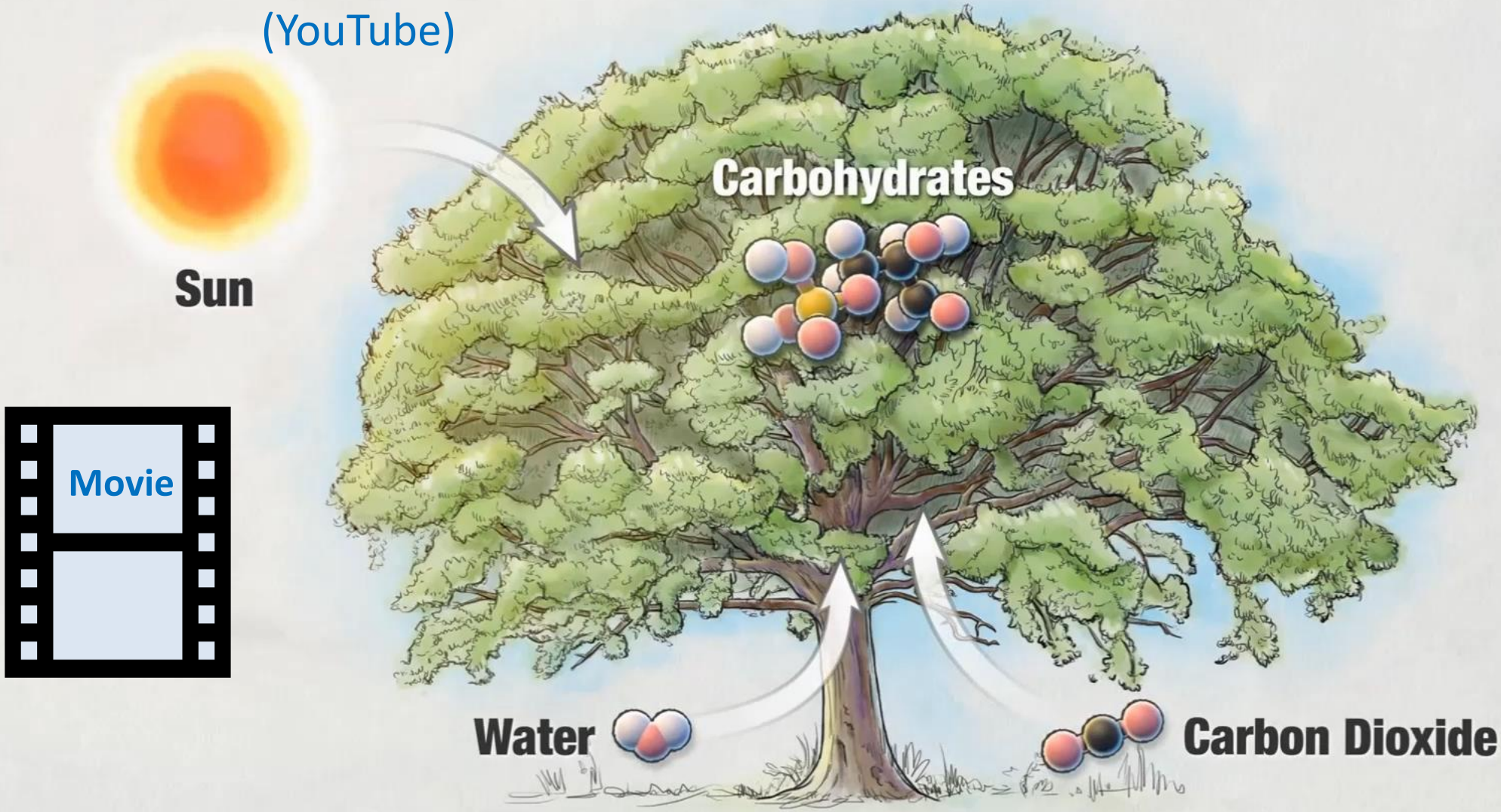




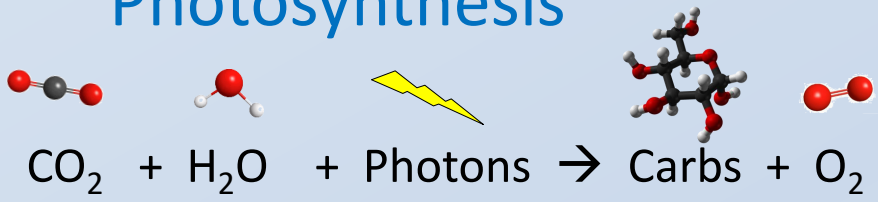
The way nature does it….



Photosynthesis | HHMI BioInteractive Video (YouTube)



Photosynthesis



CO_2 + H_2O + Photons → Carbs + O_2

① Photon Absorber

Problem:

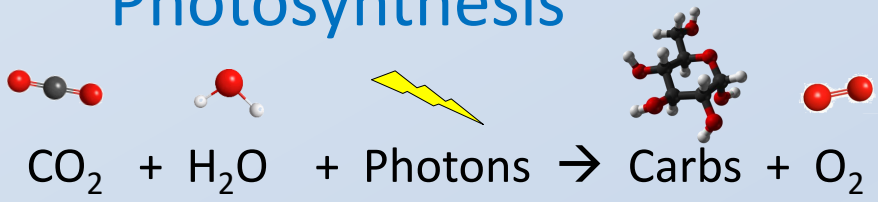
Most organic molecules do <u>not</u> absorb light

Those that do are called **pigments** or **dyes**

Beta Carotene

Chlorophyll a

Photosynthesis



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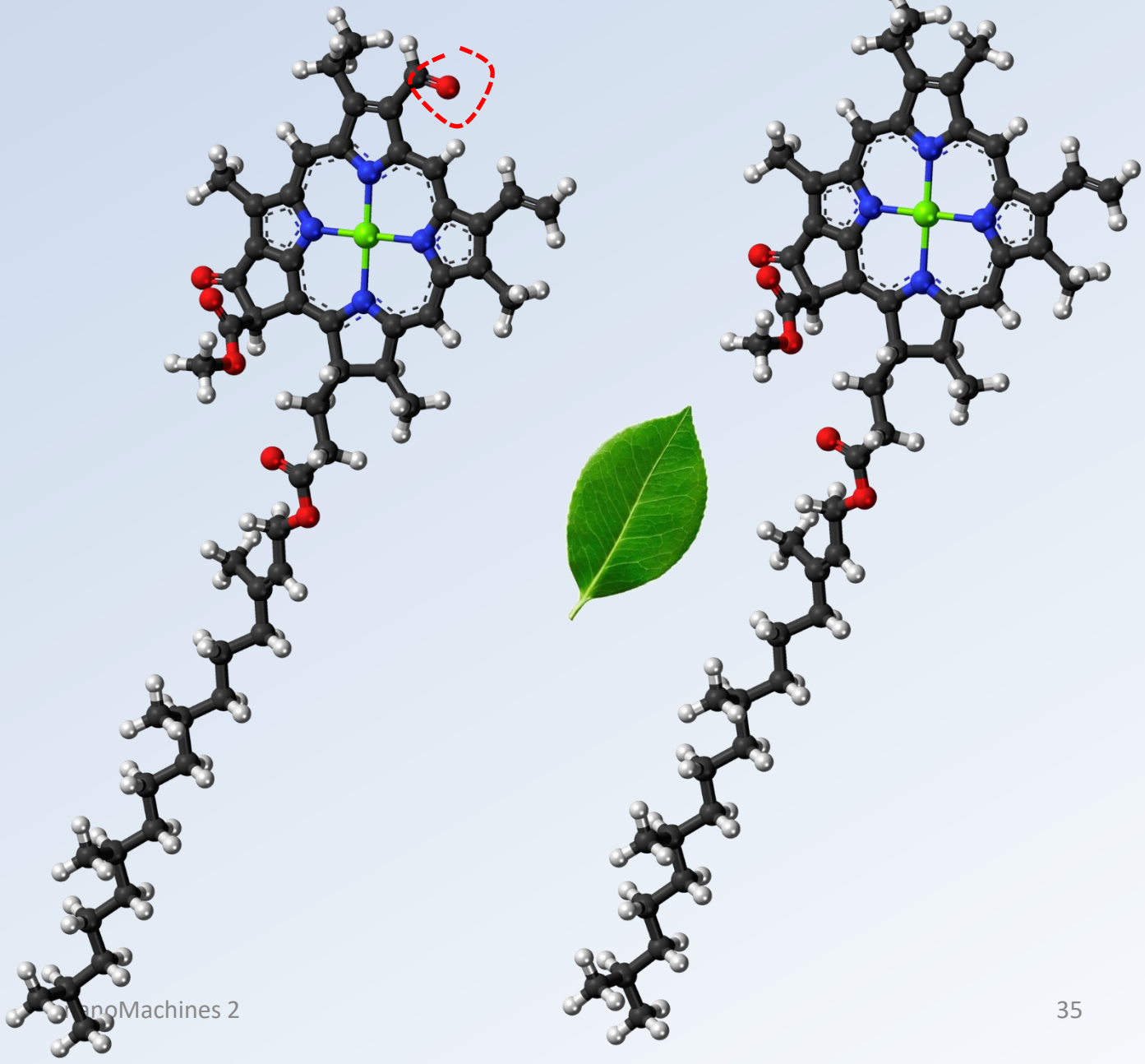
Chlorophyll b

Chlorophyll a



Photosynthesis

$CO_2 + H_2O + Photons \rightarrow Carbs + O_2$

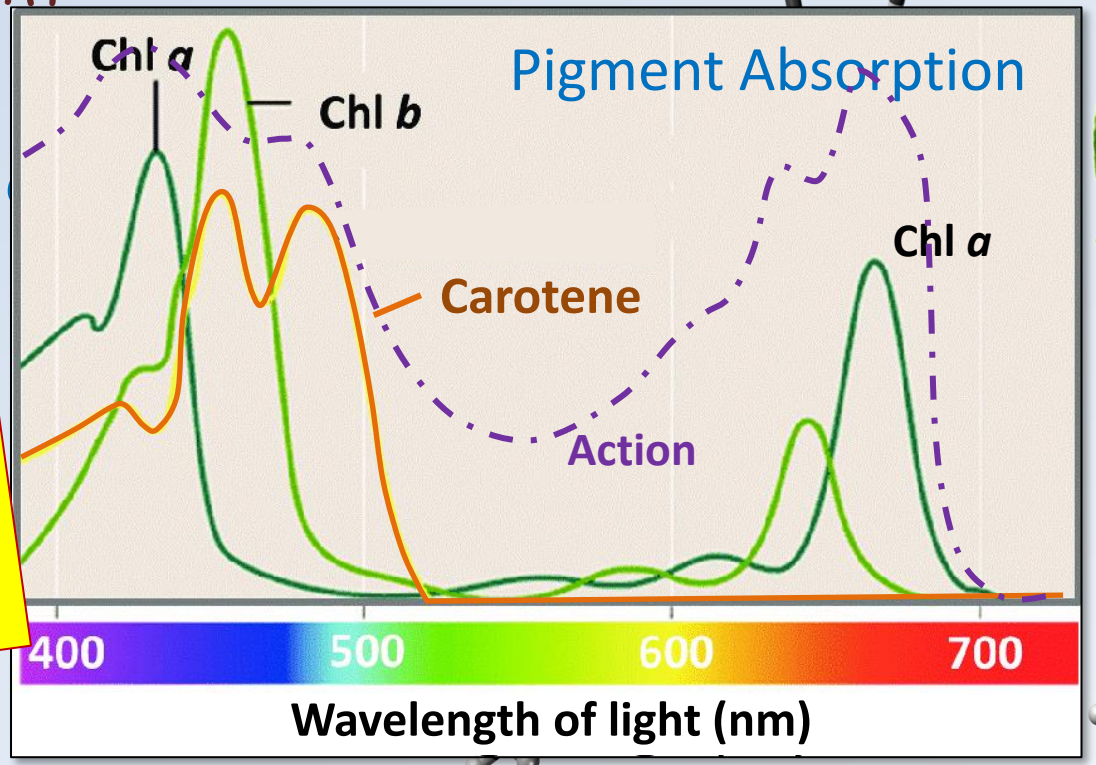
① Photon Absorber

Problem:

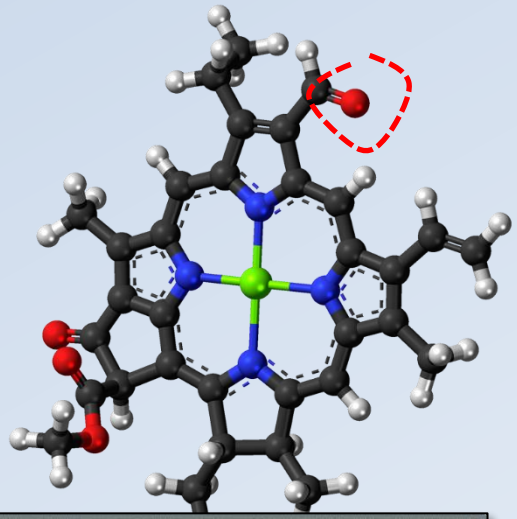
Most organic molecules do not absorb light

Those that do are called pigments or

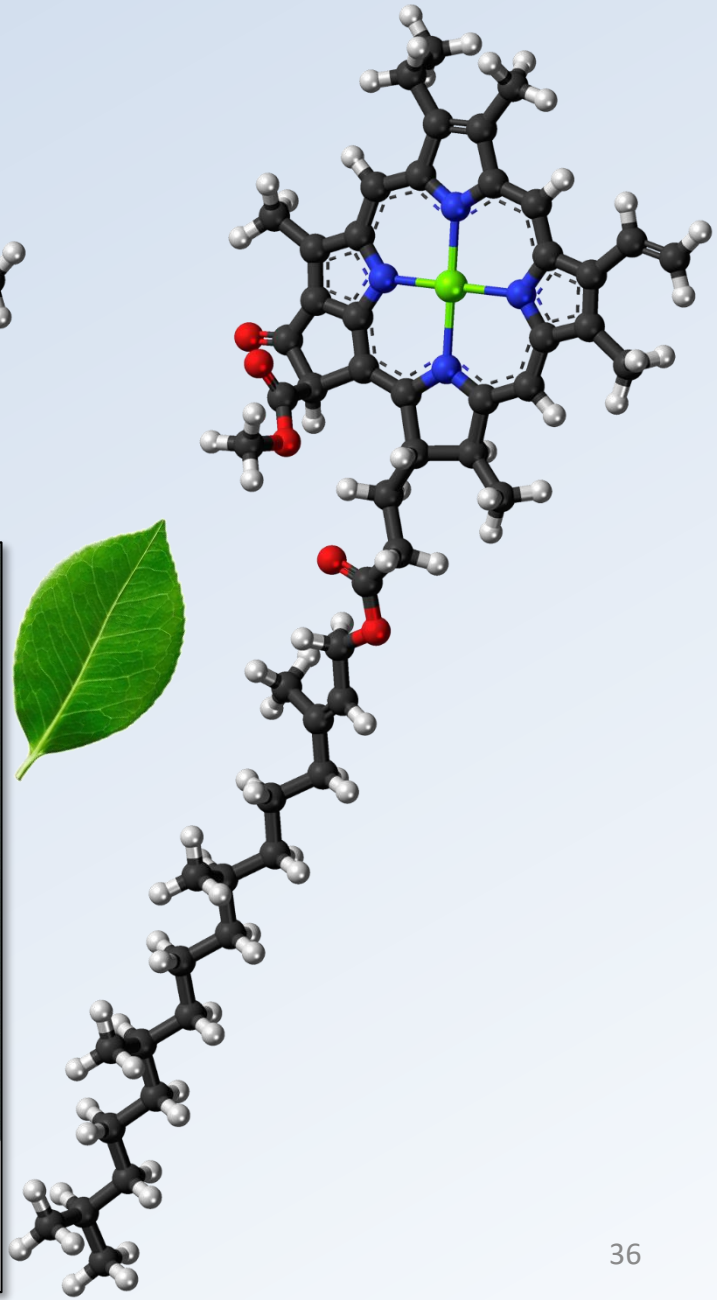
Action spectrum shows how effective each color is for promoting photosynthesis and growth.
Even green light can give photosynthesis, though more weakly.



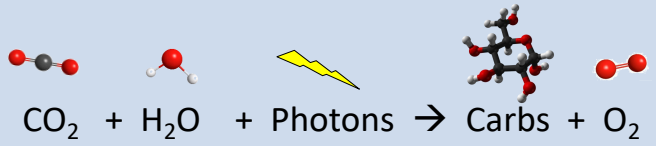
Chlorophyll b



Chlorophyll a

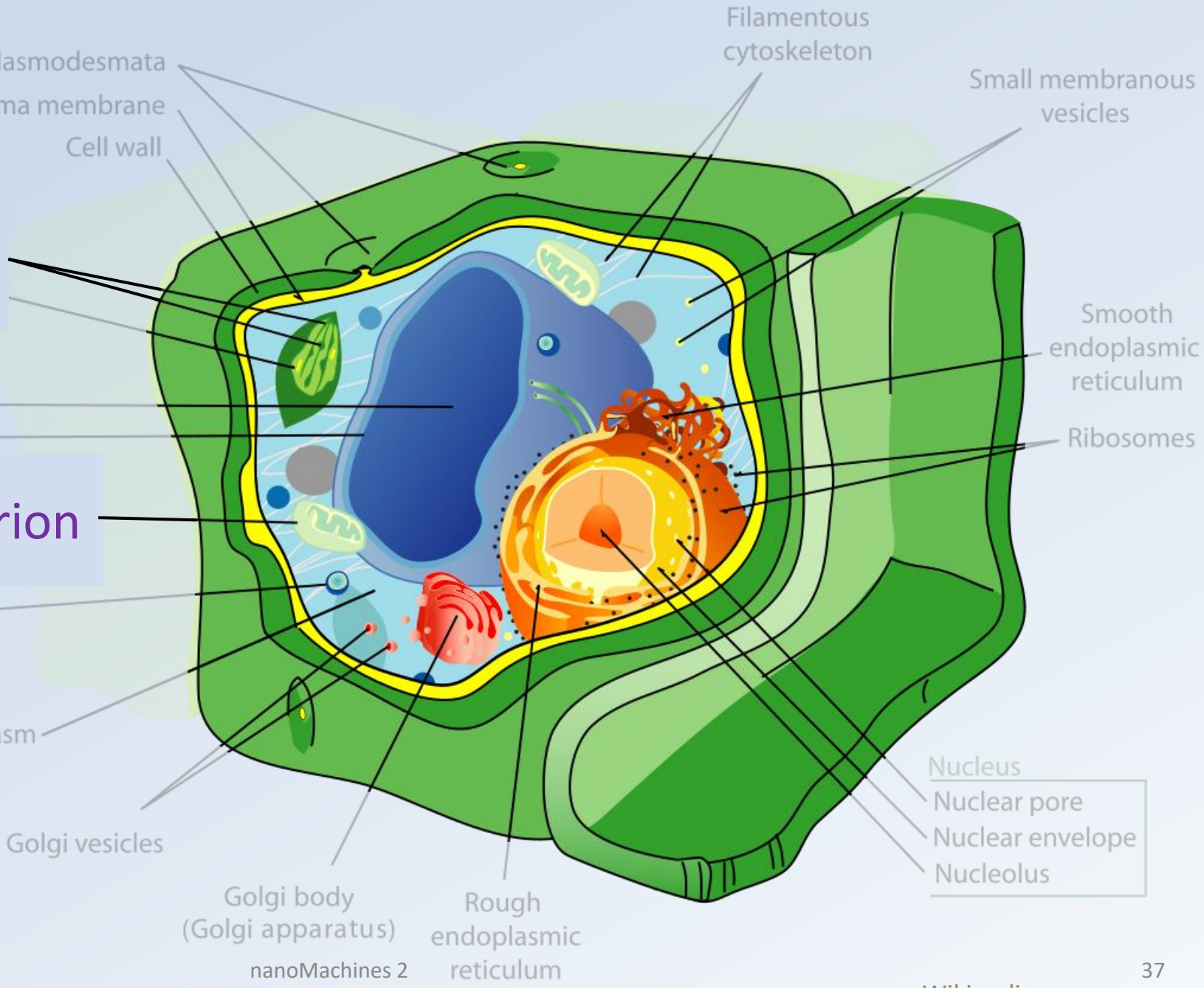


Photosynthesis



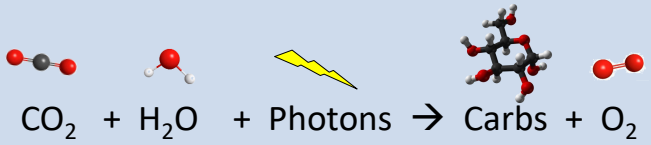
Typical Plant Cell

with Organelles



Wikipedia

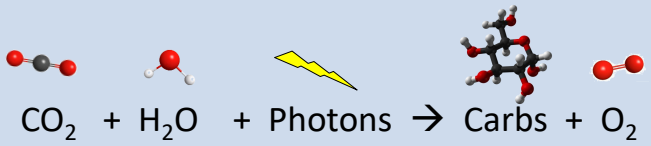
Photosynthesis



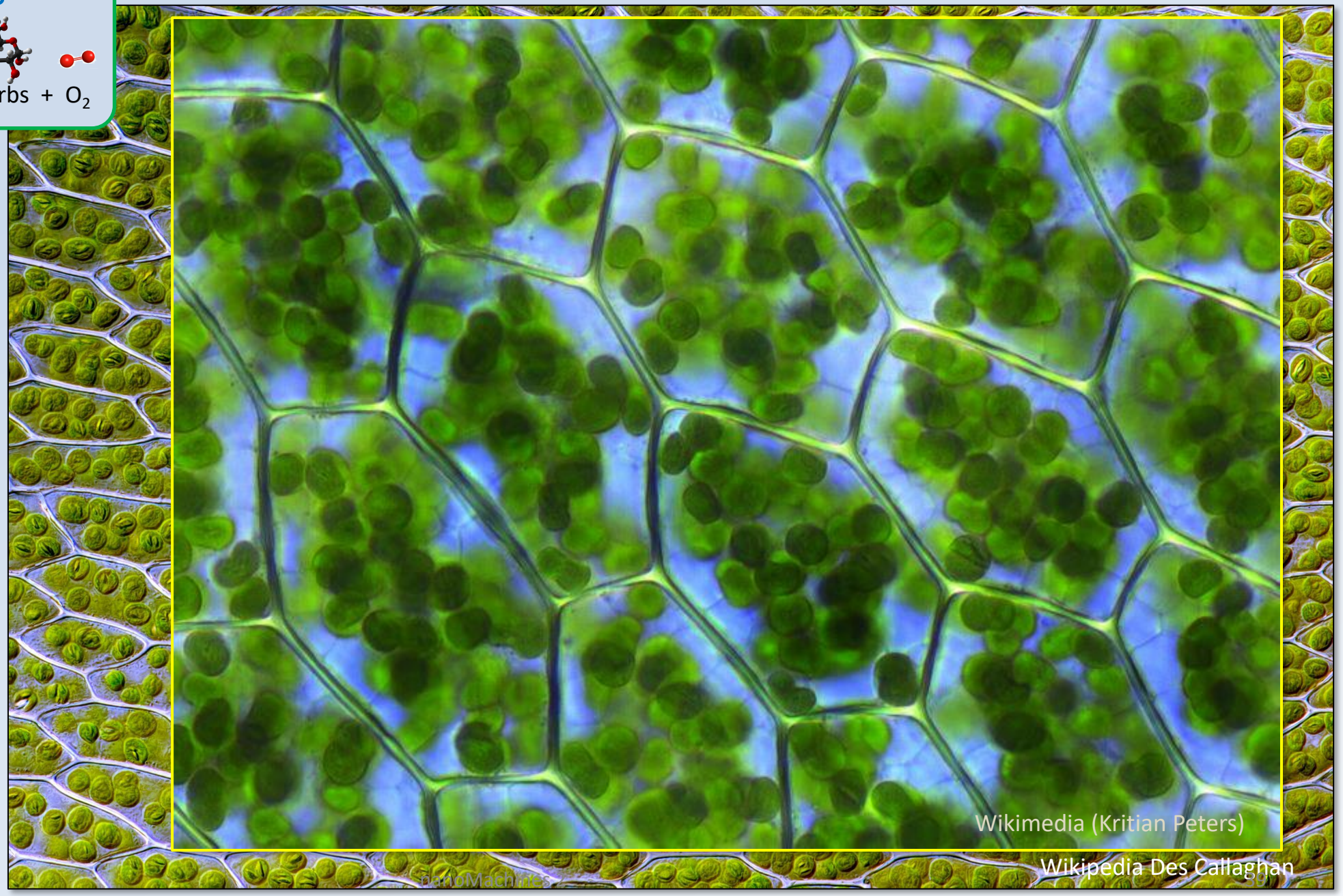
Moss Cells with Chloroplasts

Wikipedia Des Callaghan

Photosynthesis

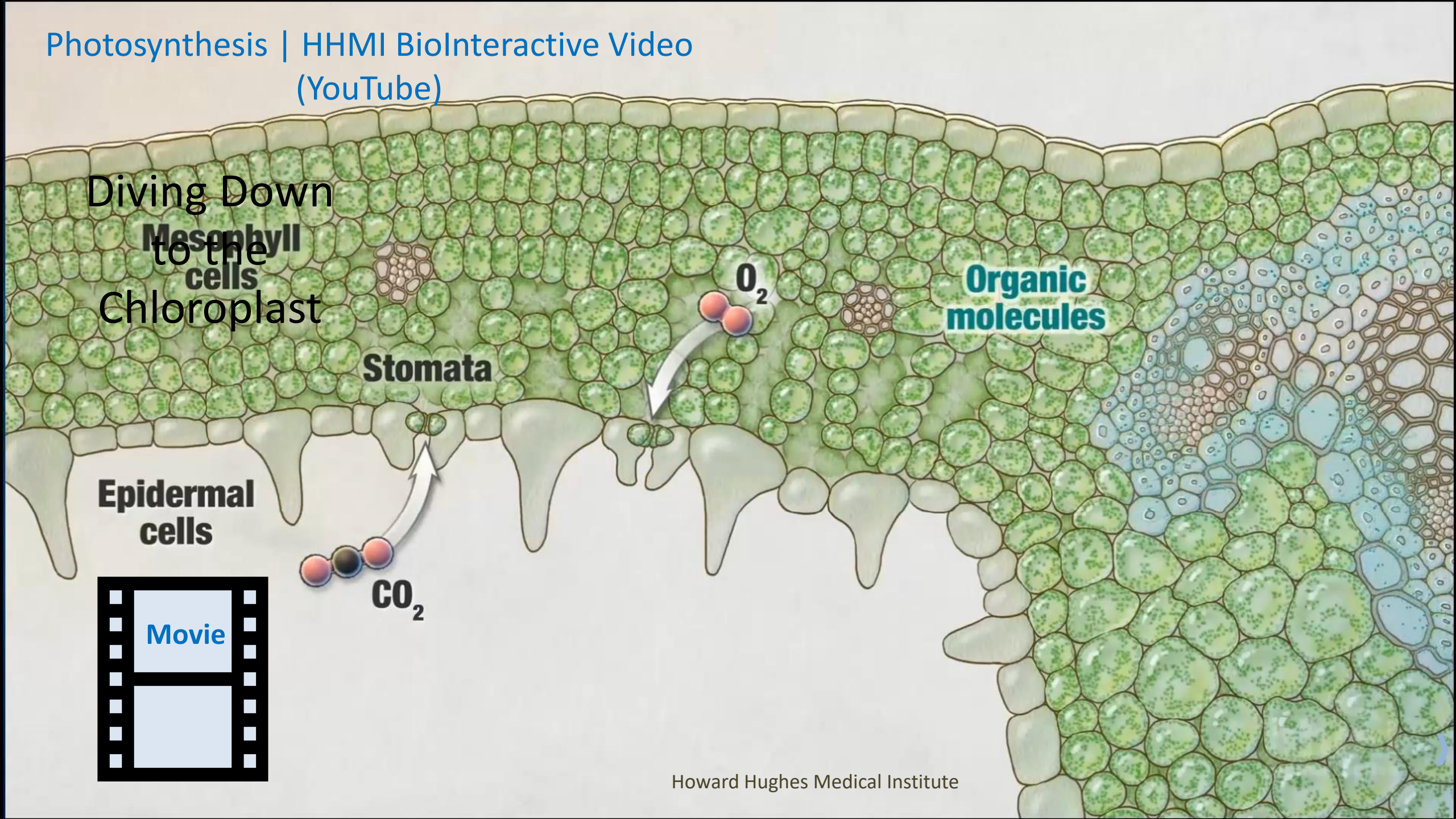


Moss Cells with Chloroplasts



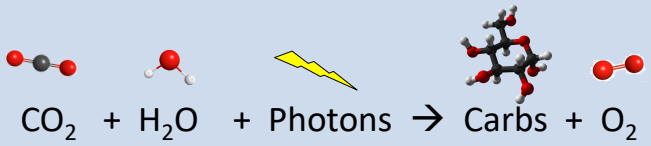
Photosynthesis | HHMI BioInteractive Video (YouTube)

Diving Down to the Chloroplast

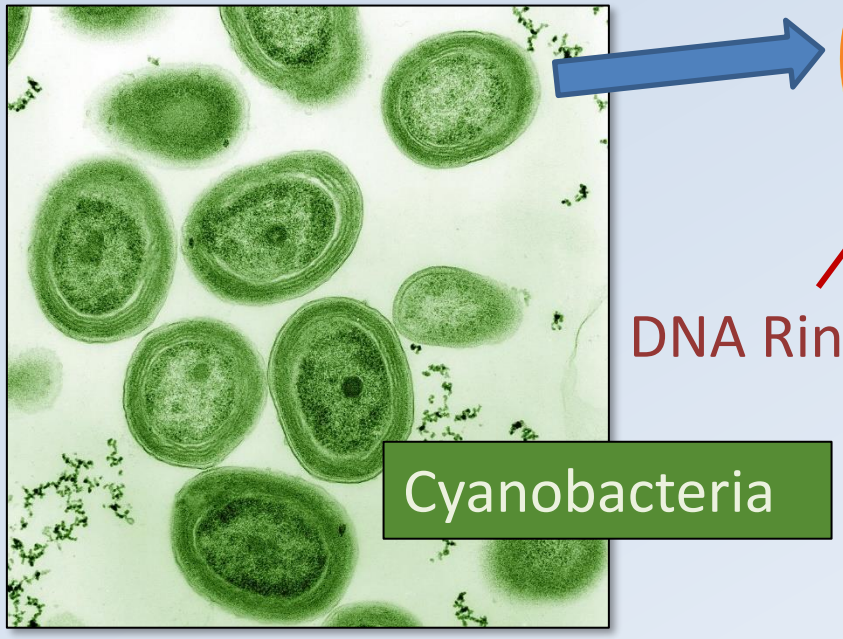


Howard Hughes Medical Institute

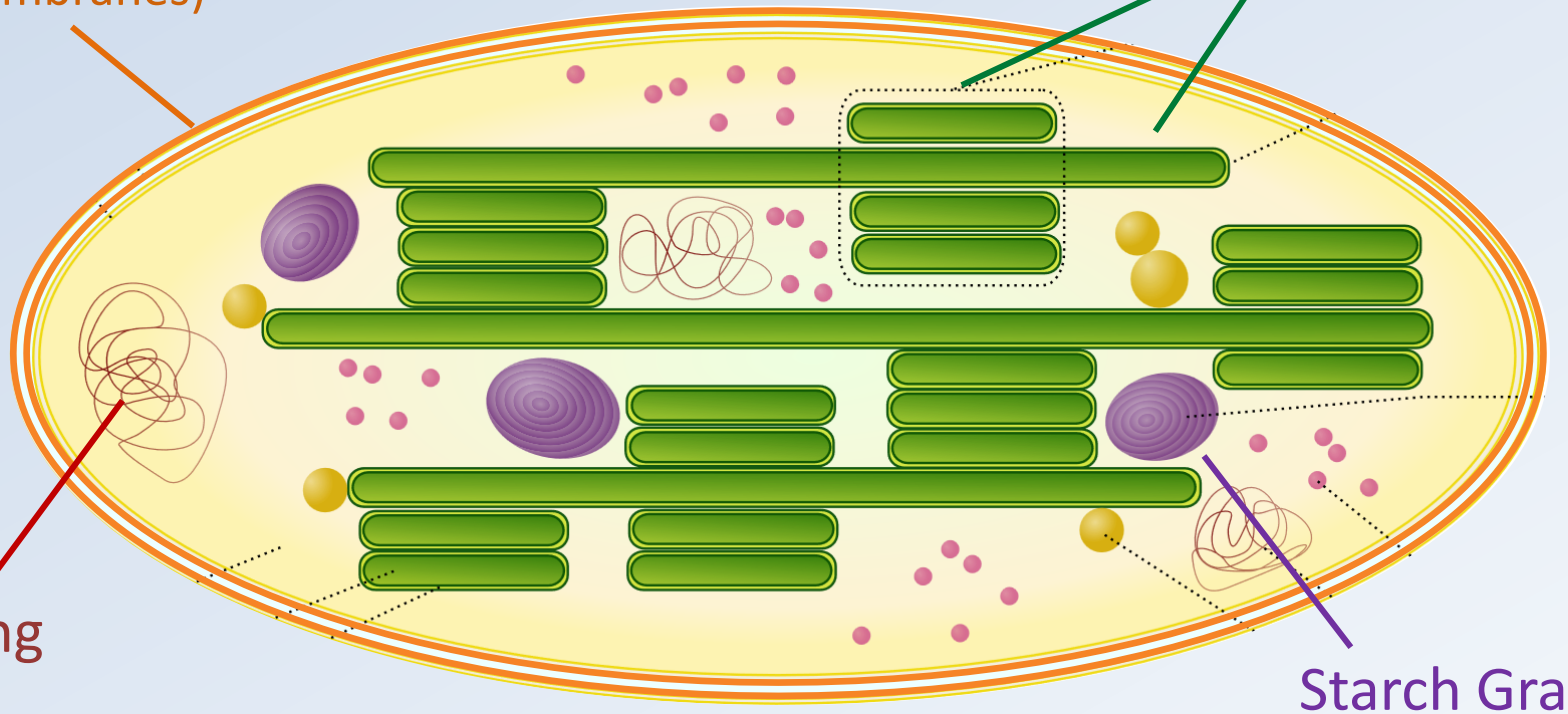
Photosynthesis



Inner Structure of Chloroplast



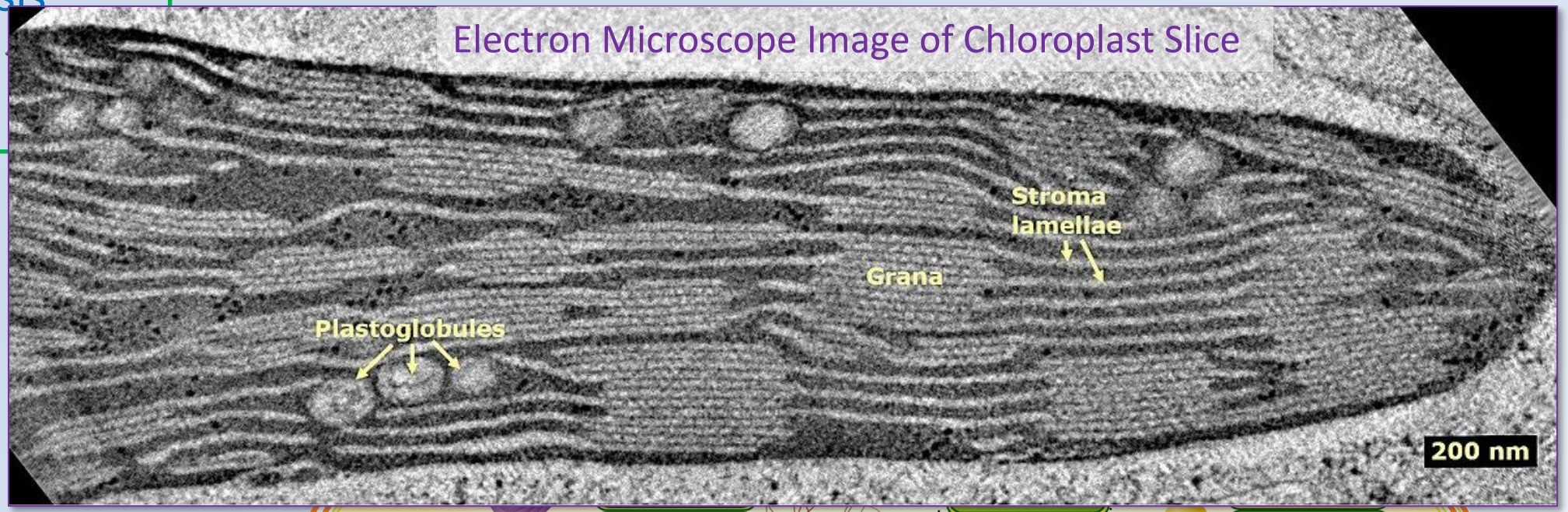
Cyanobacteria

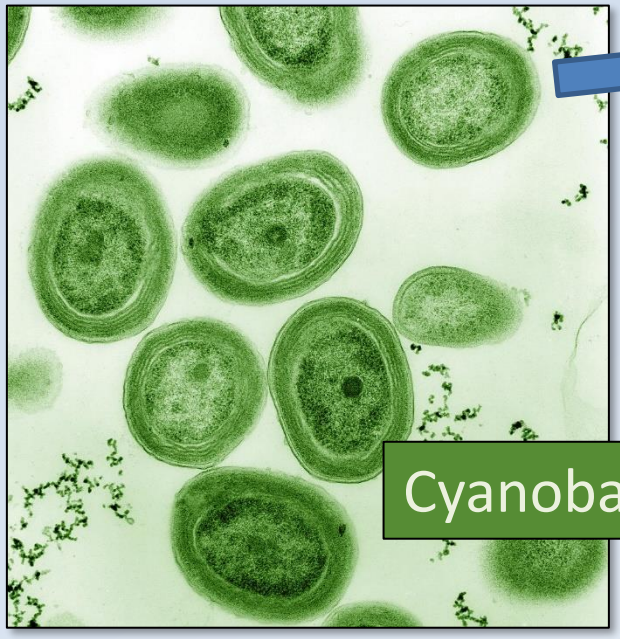


Photosynthesis

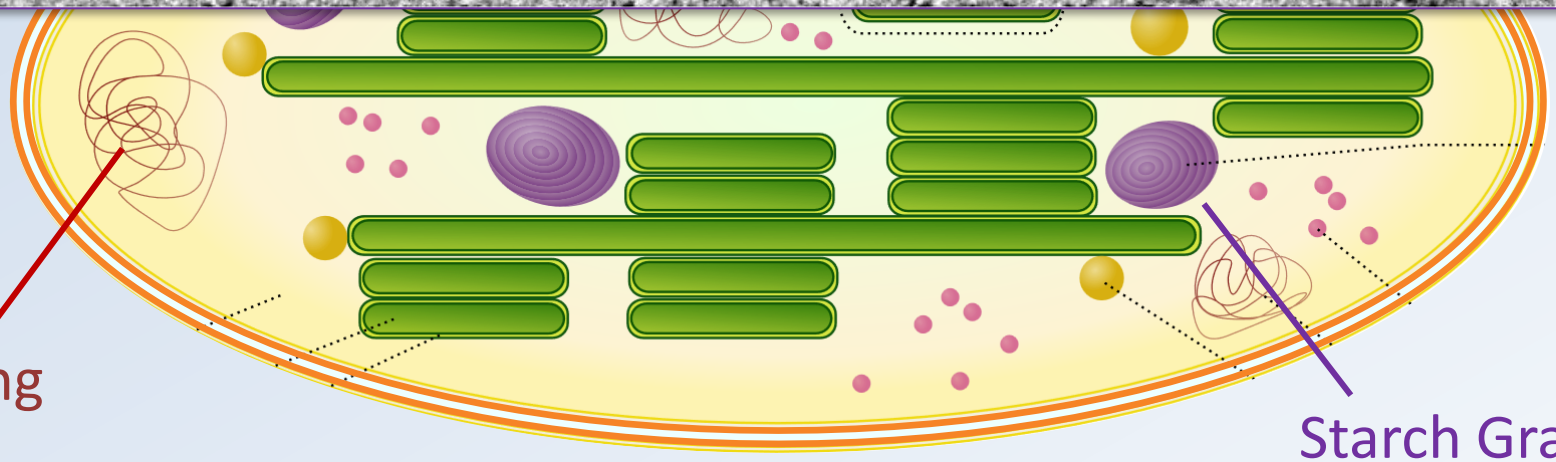
CO_2 + H_2O + Photons →

Inner Structure of Chloroplast



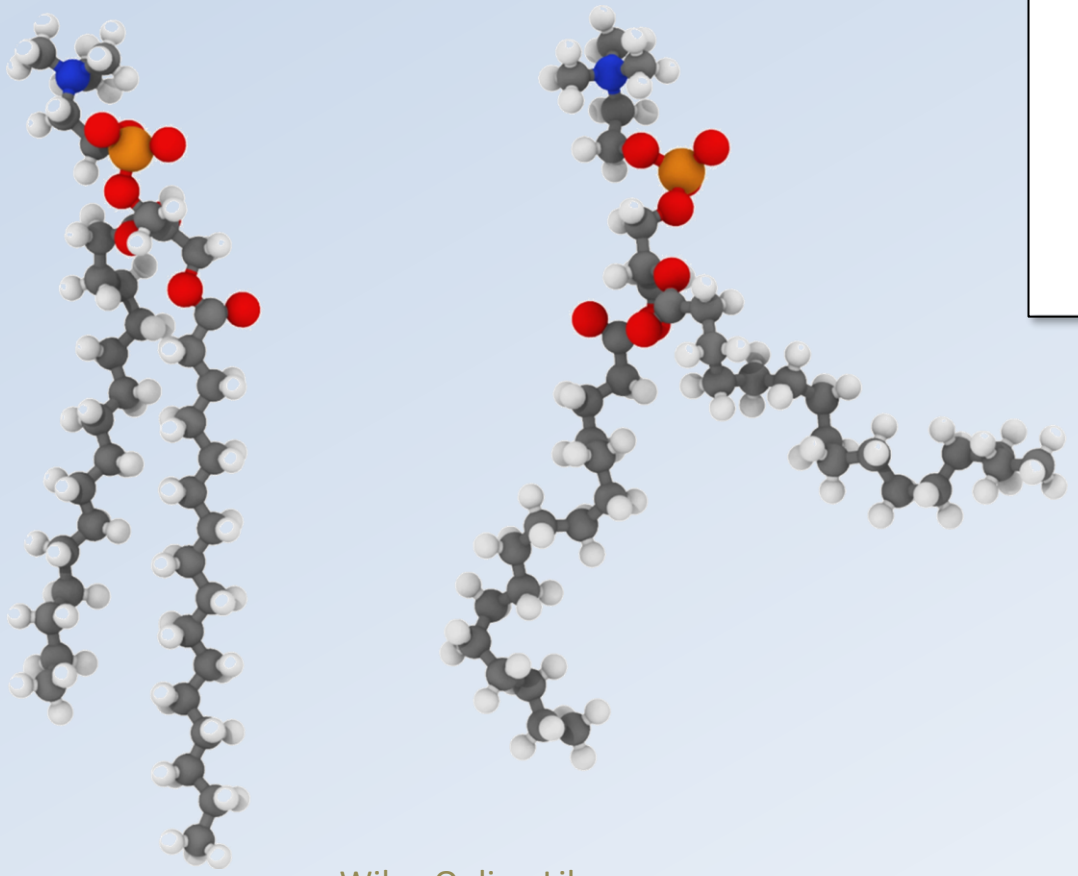


Cyanobacteria

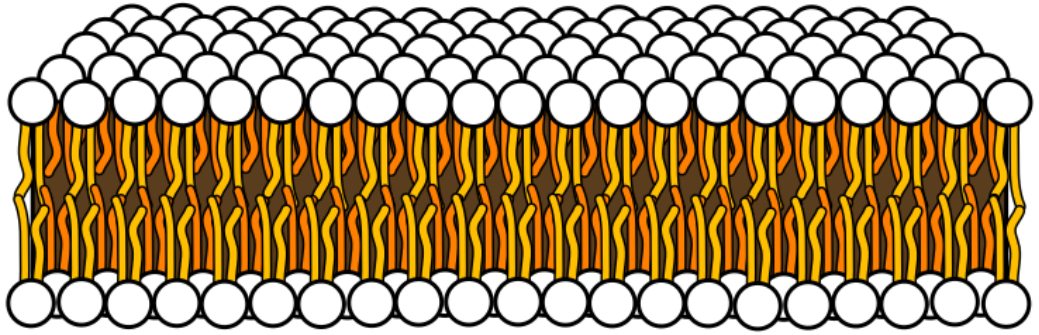


A Short Aside: Bilayer Membranes

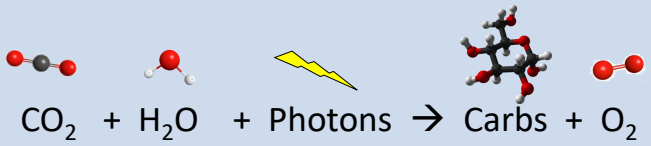
Phospholipids



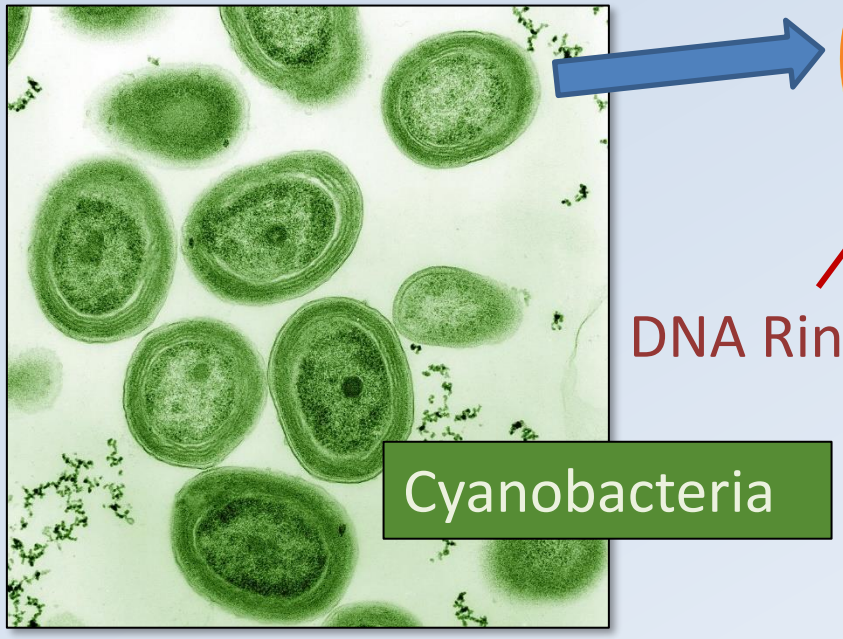
These Lipids Self-Assemble into Bilayer Membranes



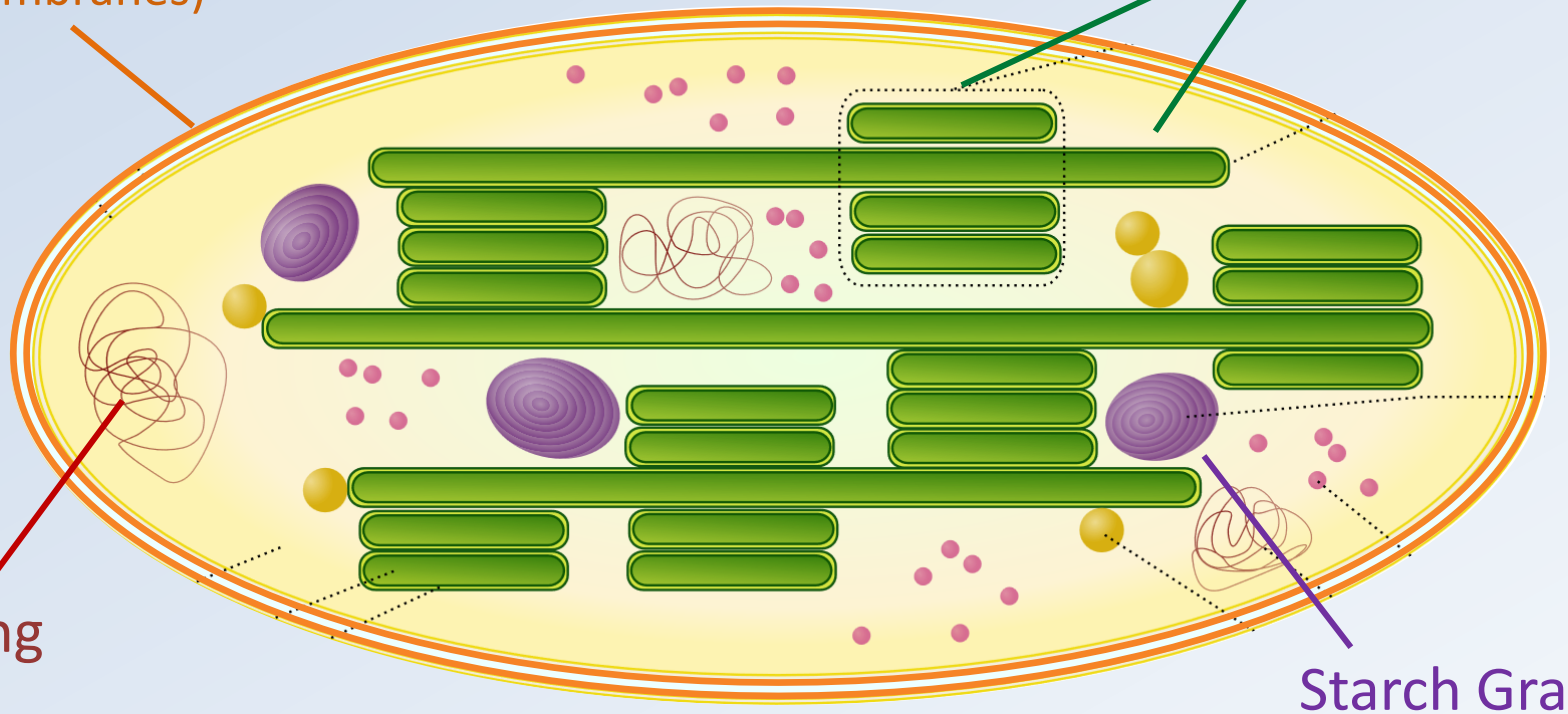
Photosynthesis



Inner Structure of Chloroplast

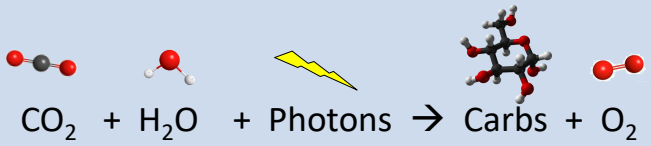


Cyanobacteria



Questions?

Photosynthesis

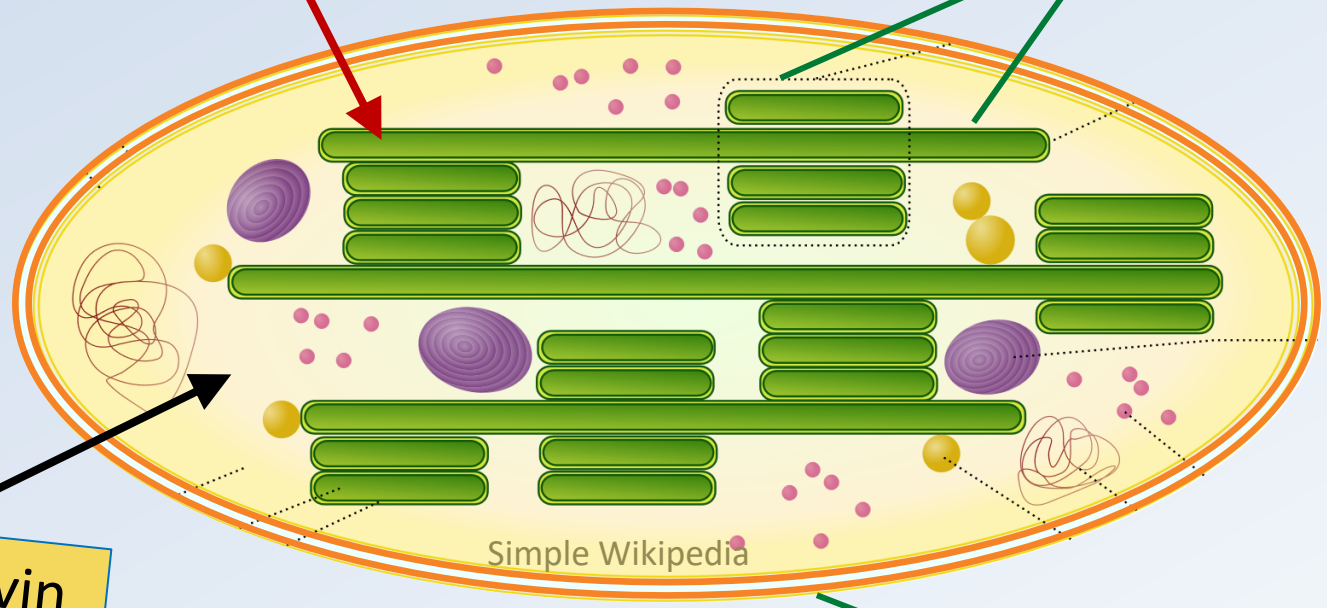


Two Main Steps of Photosynthesis

① "Light Reactions"

- Harvest sunlight photons
- Store energy in NADPH & ATP
- Located *In* Thylakoid Membranes

Temporarily



② "Dark Reactions"

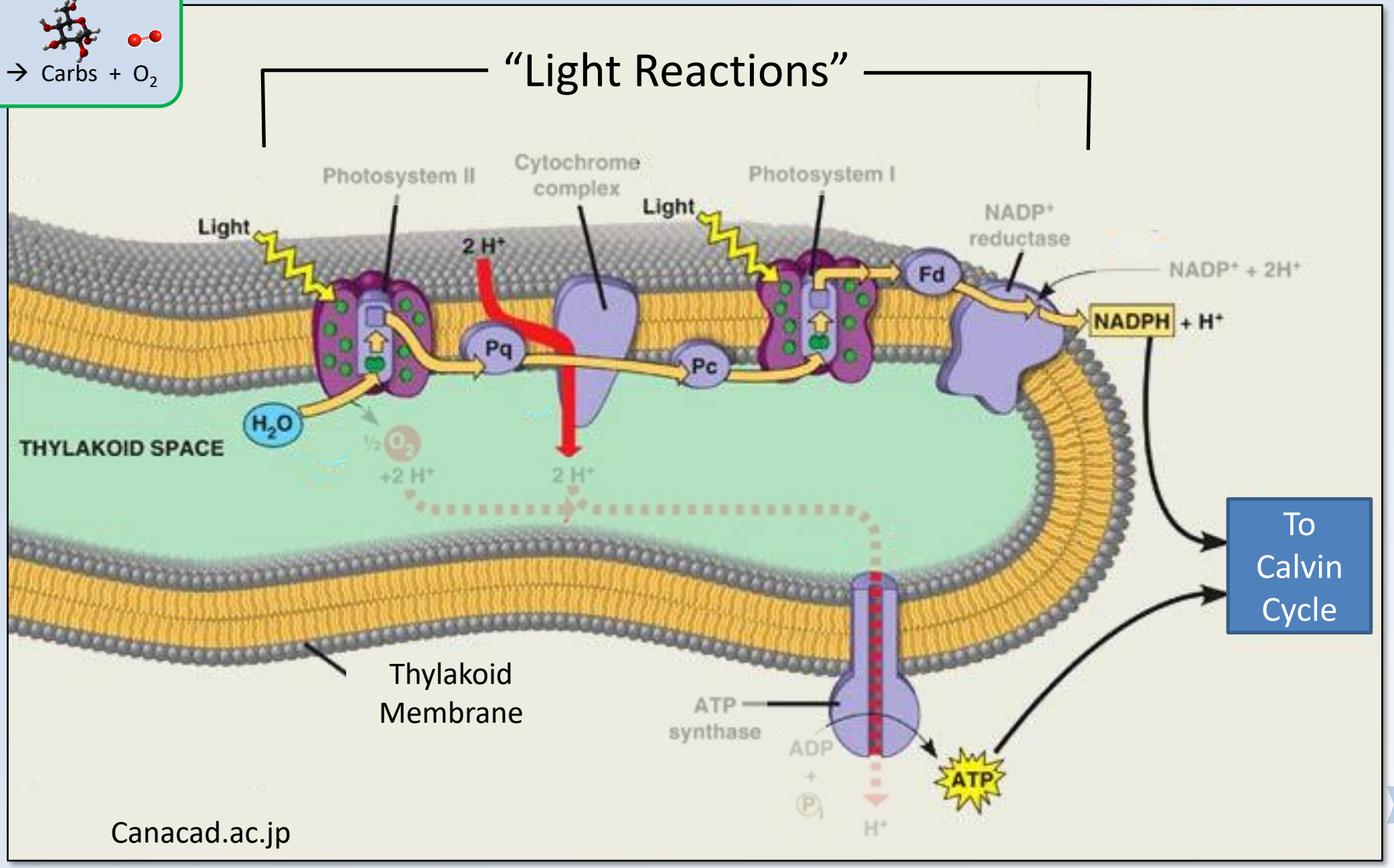
- Use energy and electrons from NADPH & ATP
- Combine CO_2 + H_2O to make sugars
- *Outside* of Thylakoids

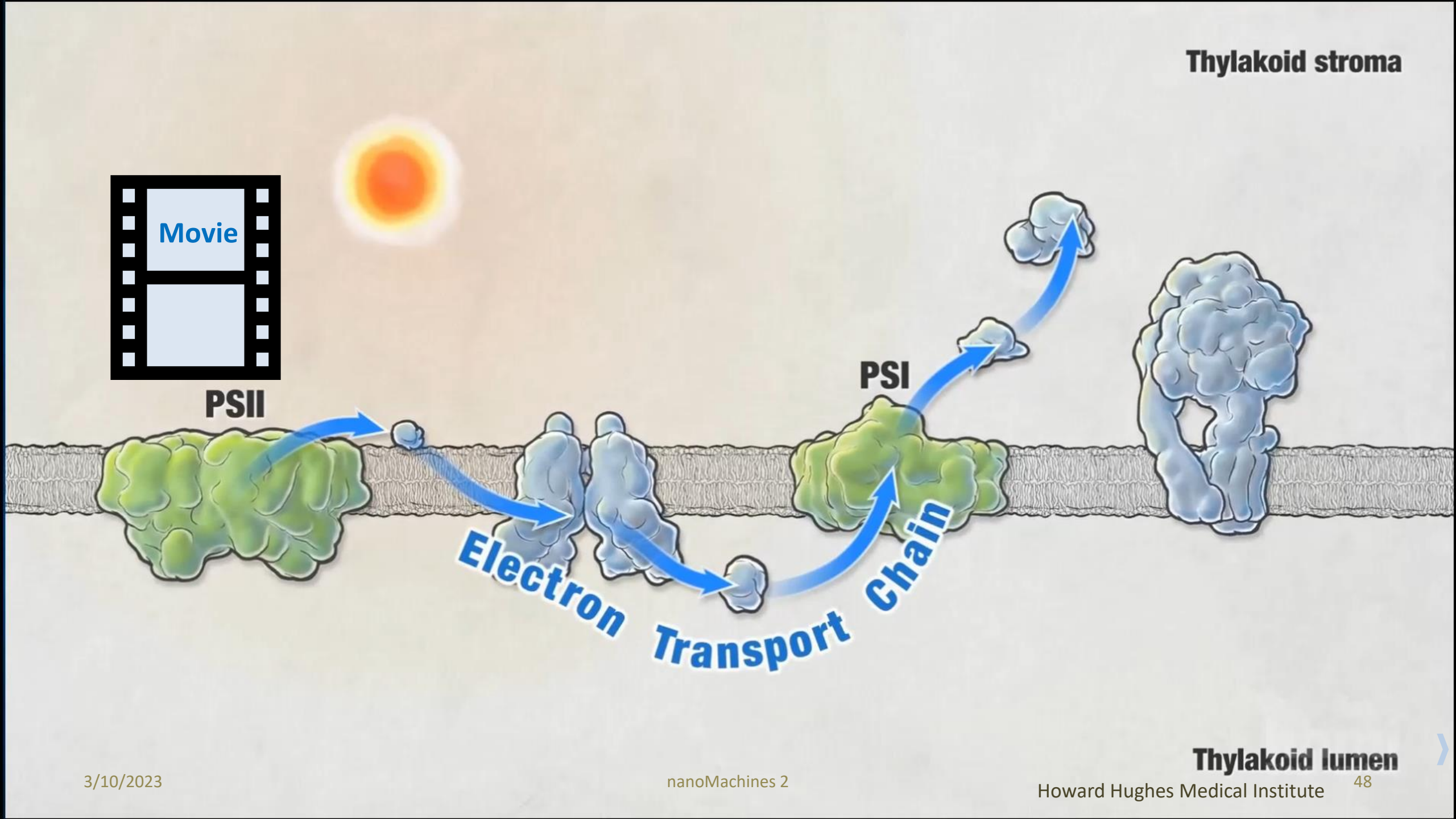
Calvin Cycle

Photosynthesis

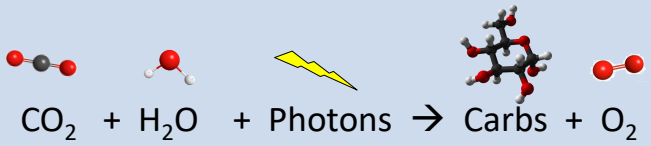
CO_2 + H_2O + Photons → Carbs + O_2

Inner Structure of a Thylakoid

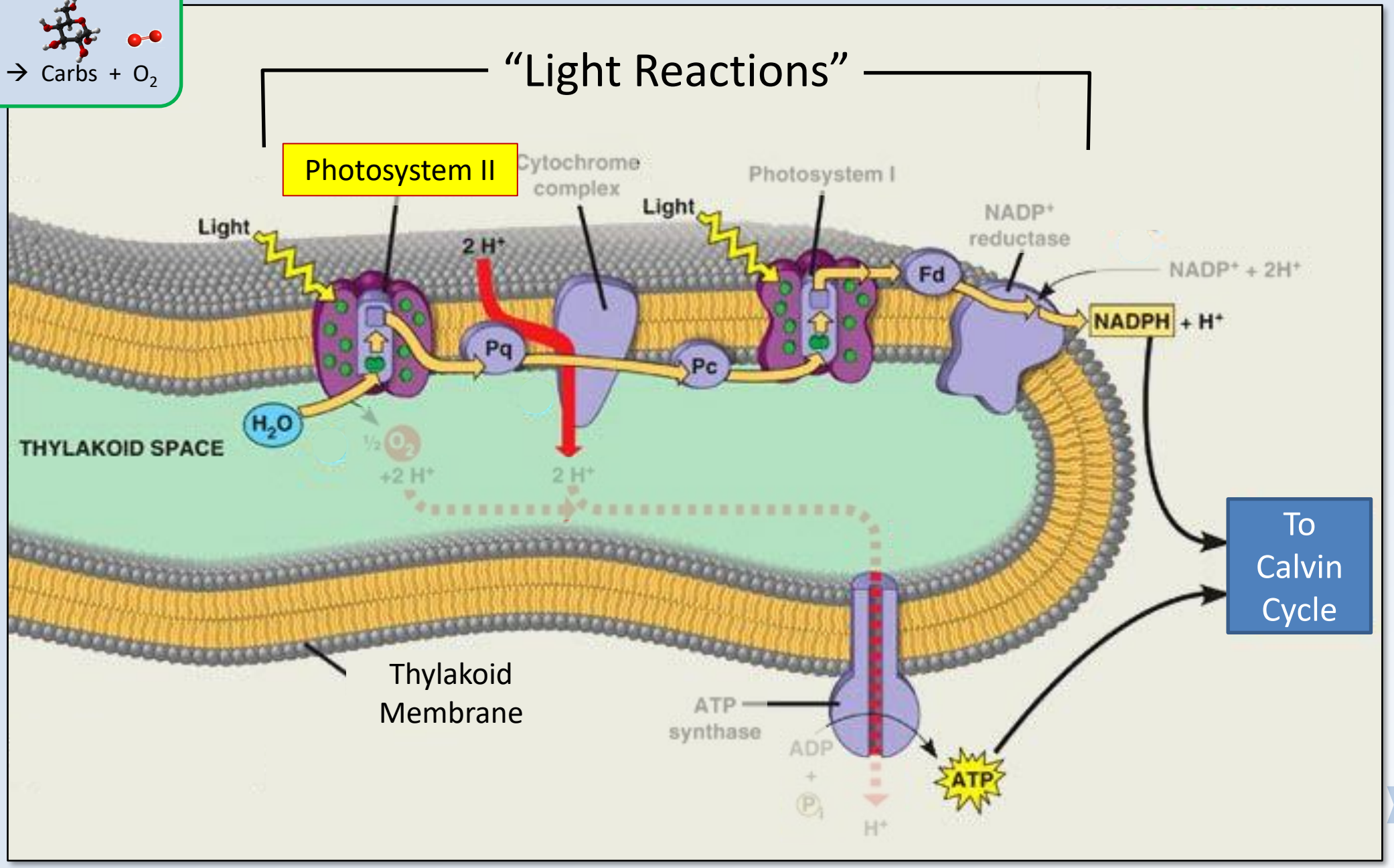


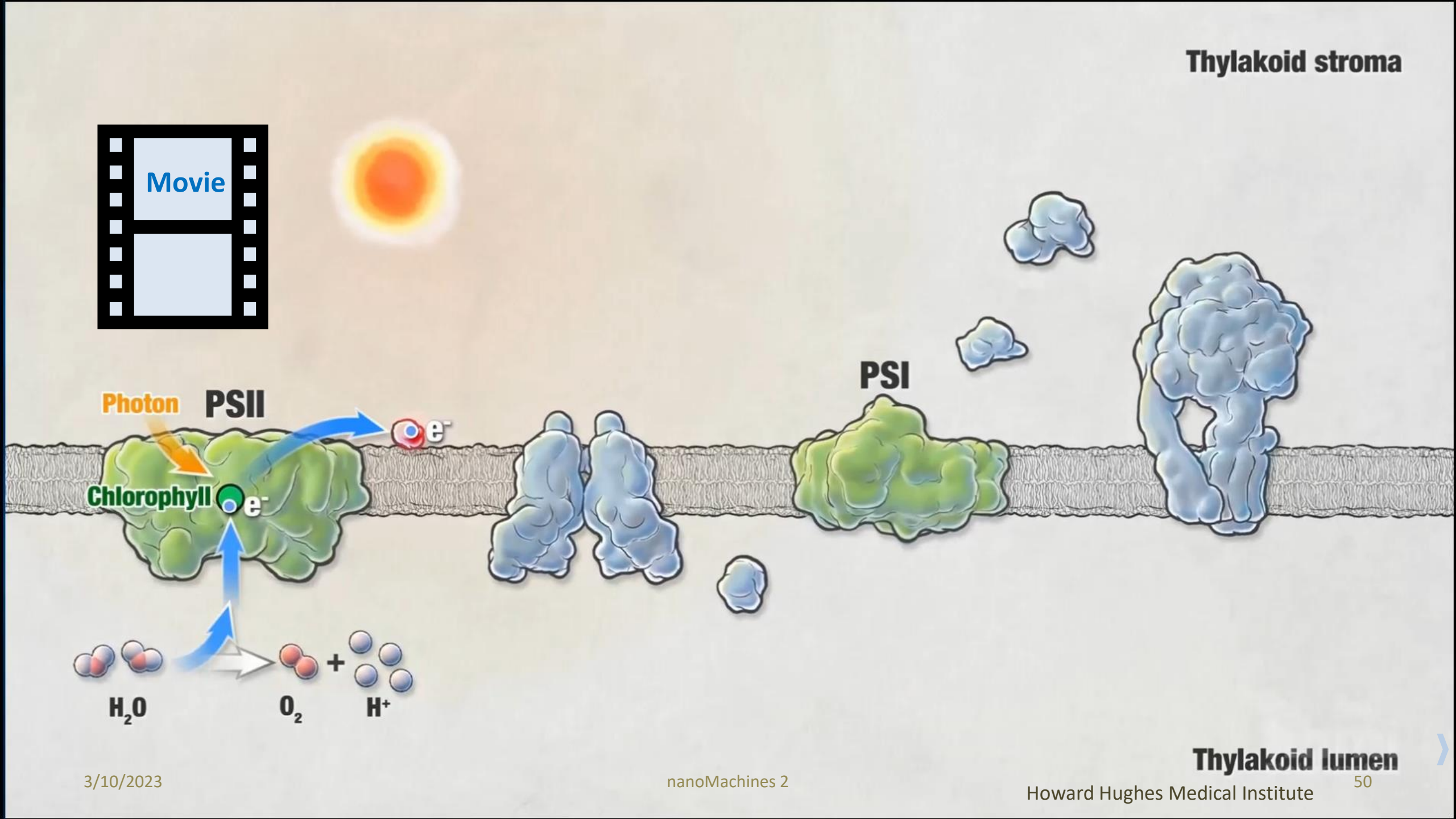

Thylakoid stroma
Movie
PSII
PSI
Electron Transport Chain
Thylakoid lumen

Photosynthesis

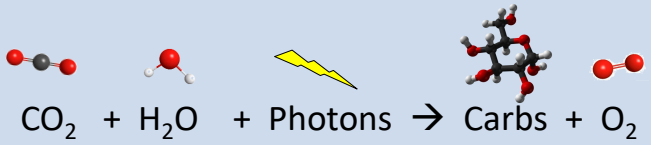


Inner Structure of a Thylakoid



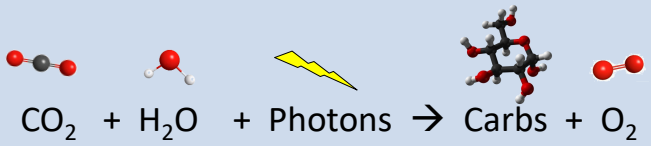

Thylakoid stroma
Movie
Photon
PSII
PSI
e⁻
Chlorophyll
e⁻
H₂O
O₂
+
H⁺
Thylakoid lumen

Photosynthesis



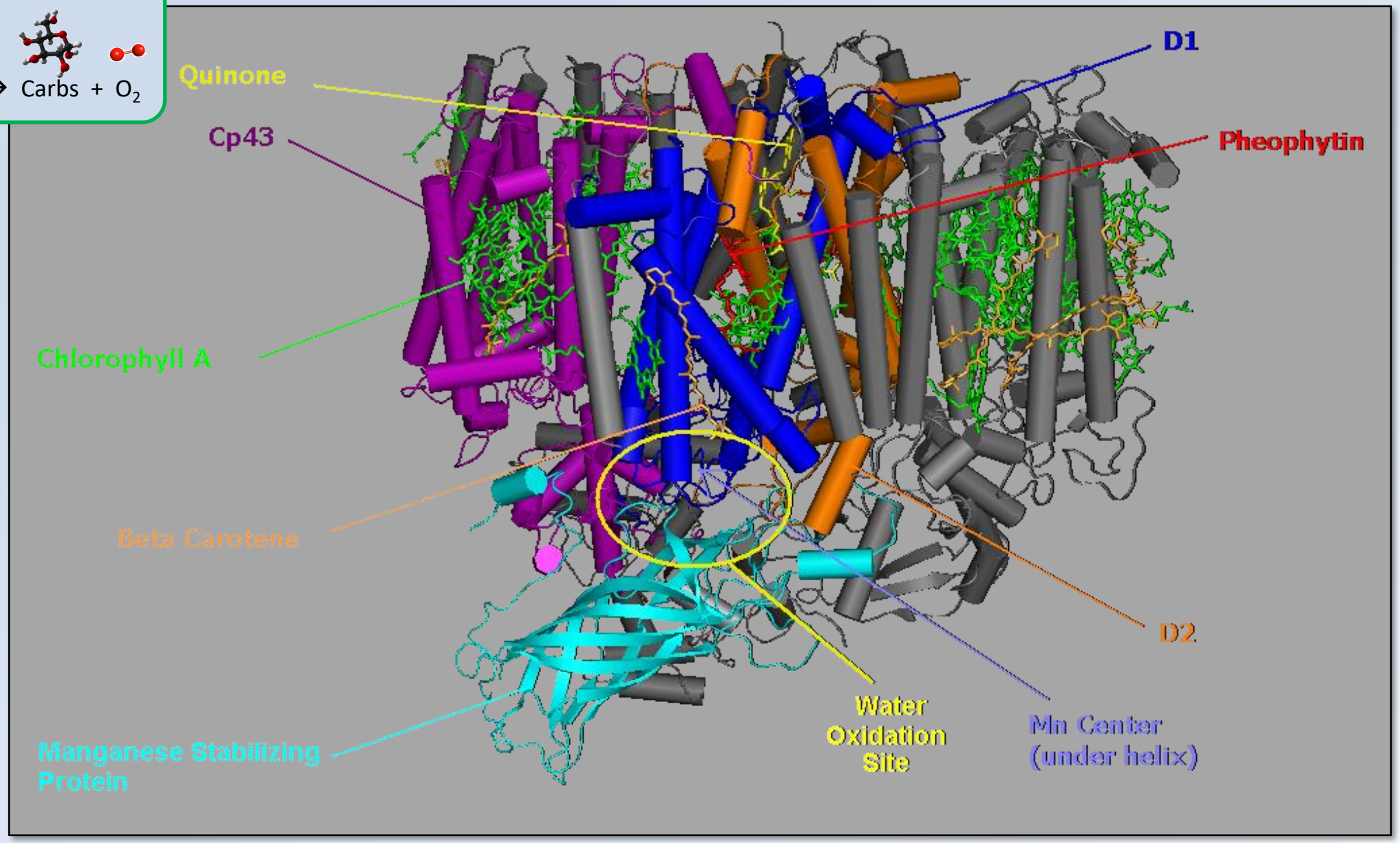
PS II Dimer

Photosynthesis



PS II Monomer

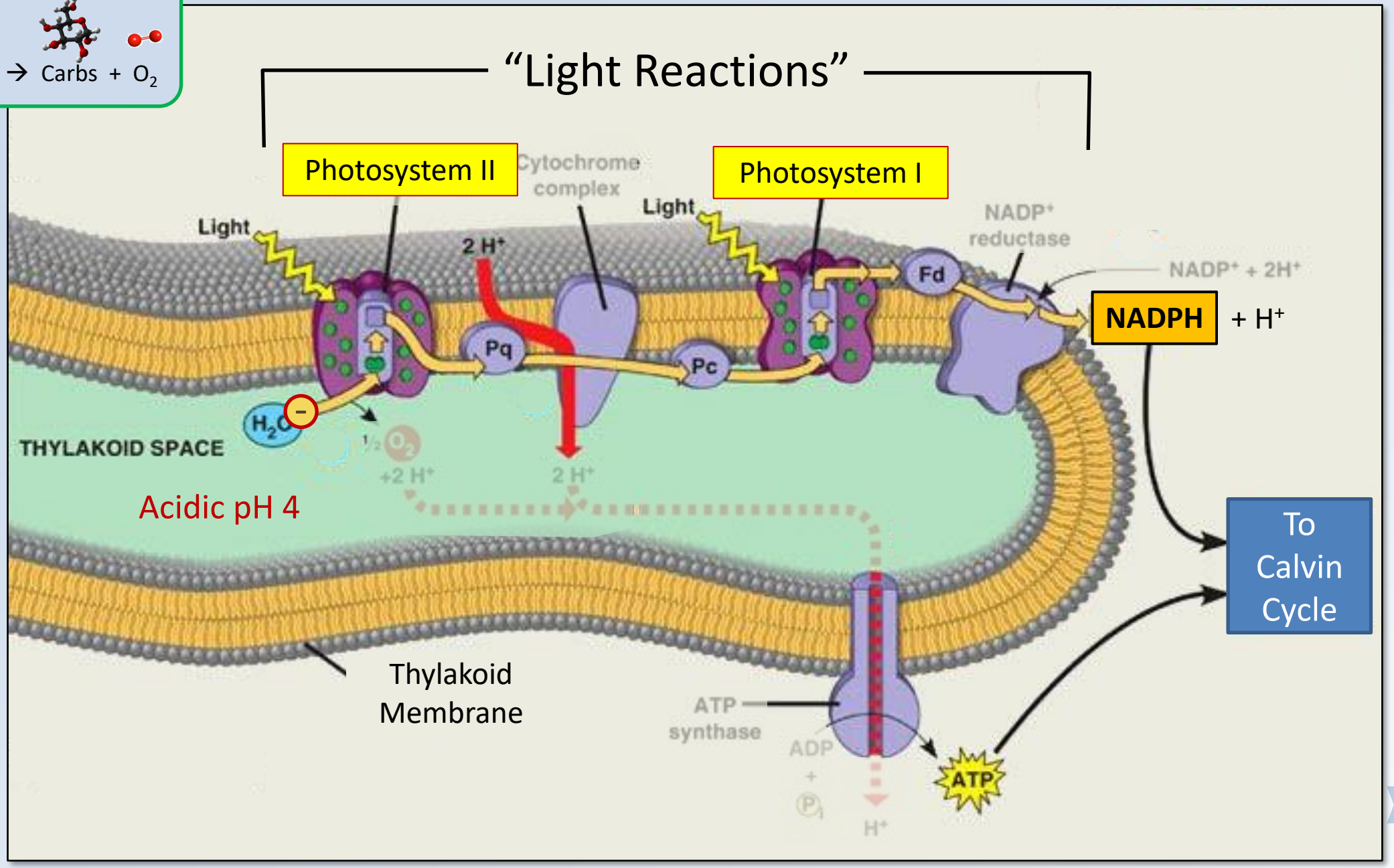
- 20 Protein Subunits
- 35 Chlorophyll *a*
- 12 Beta-Carotene
- 20 Lipids
- 1 Manganese Center (Mn_4CaO)
- Lots of other stuff

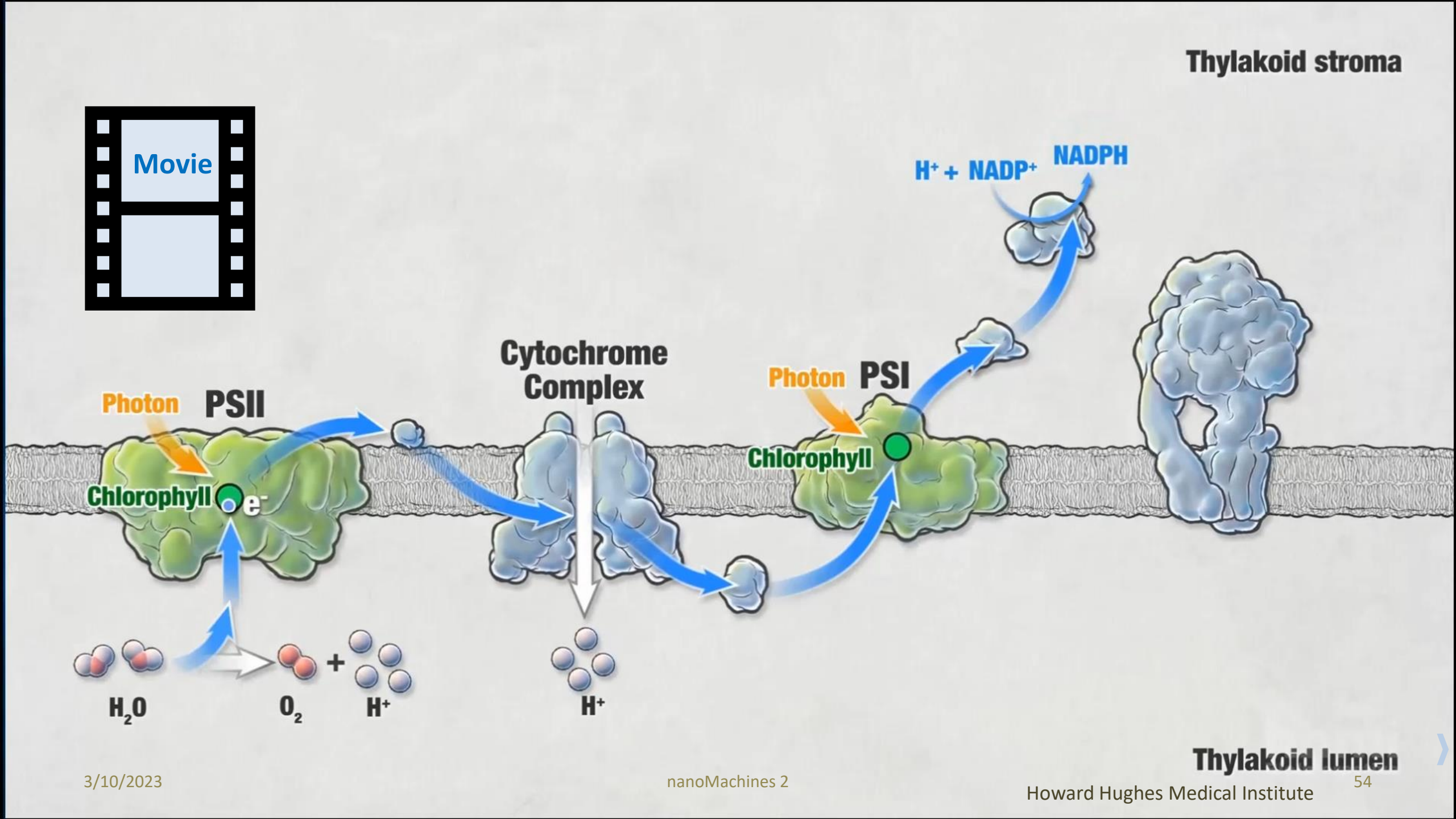


Photosynthesis

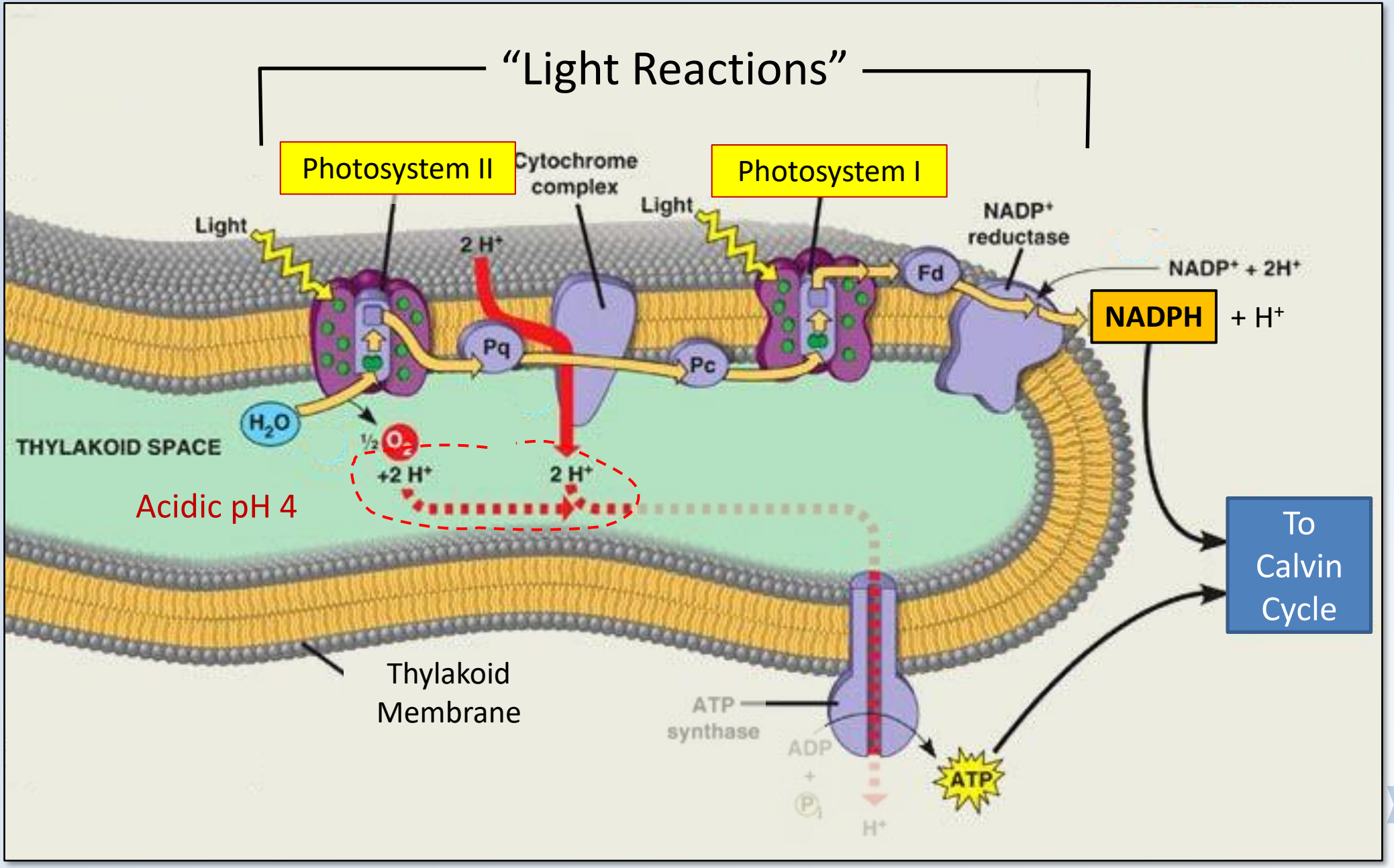
CO_2 + H_2O + Photons → Carbs + O_2

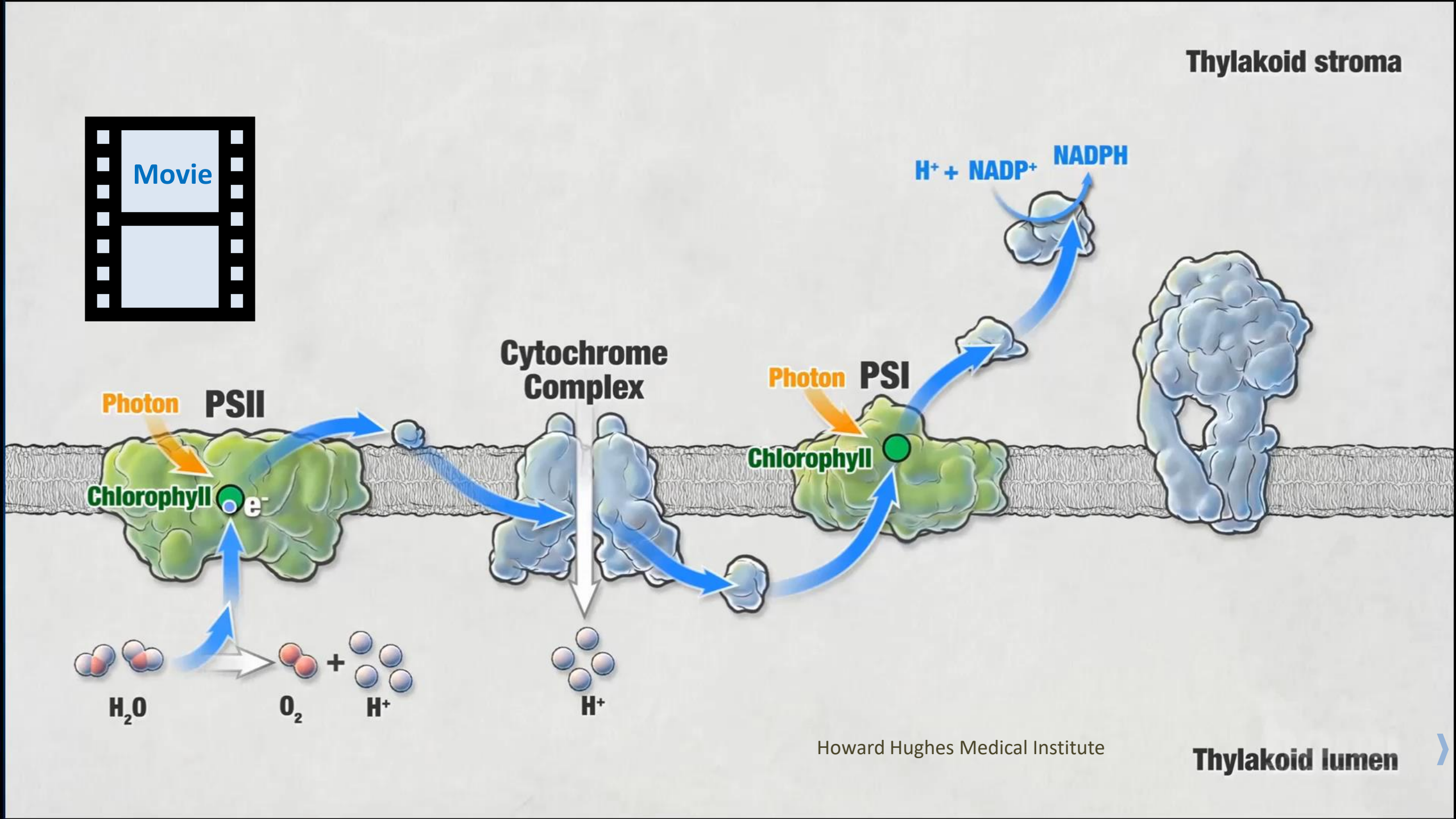
Inner Structure of a Thylakoid




Thylakoid stroma
Movie
H+ + NADP+
NADPH
Cytochrome Complex
Photon
PSII
Photon
PSI
Chlorophyll
e-
Chlorophyll
H2O
O2
+
H+
H+
Thylakoid lumen

Inner Structure of a Thylakoid





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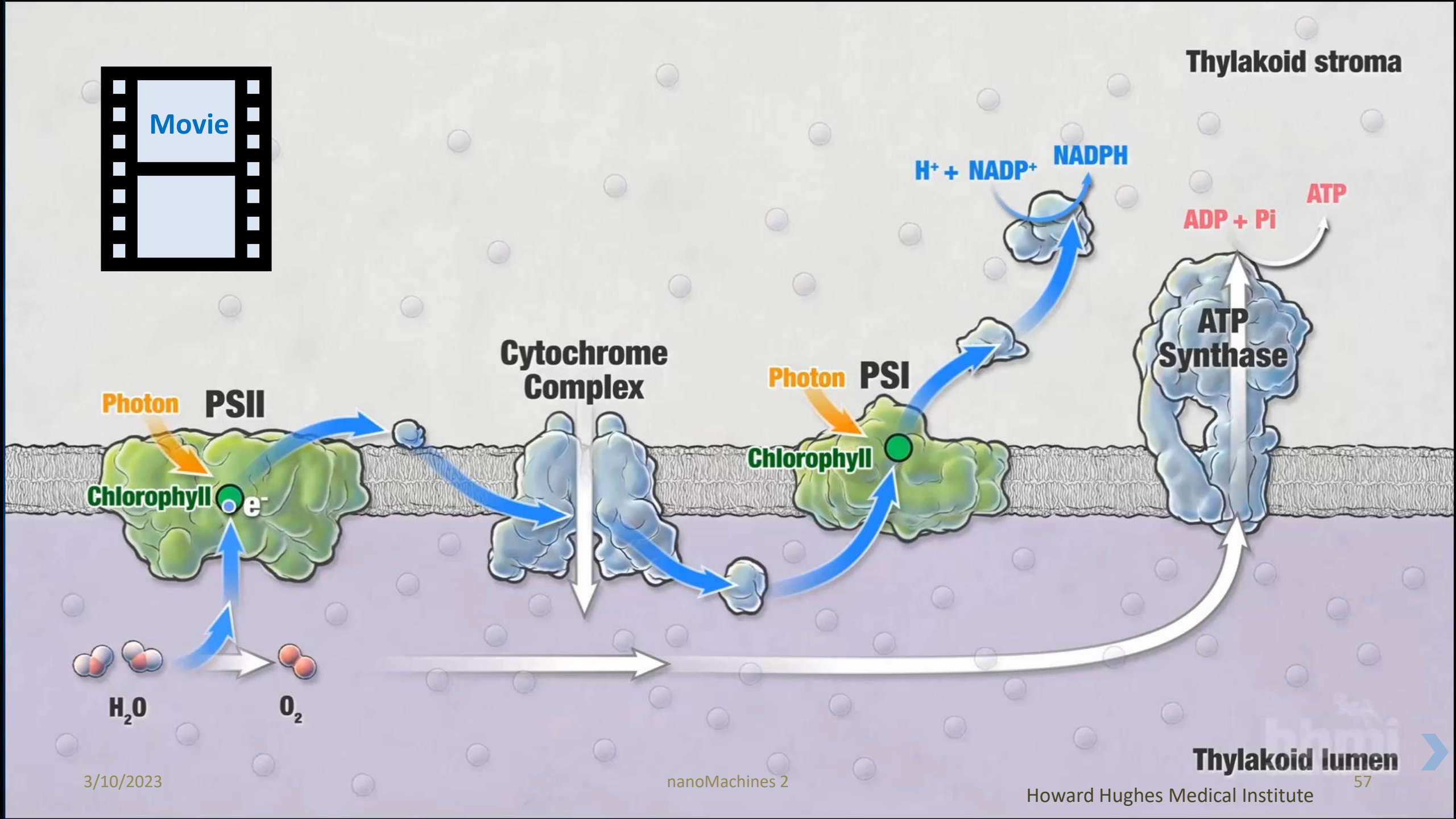
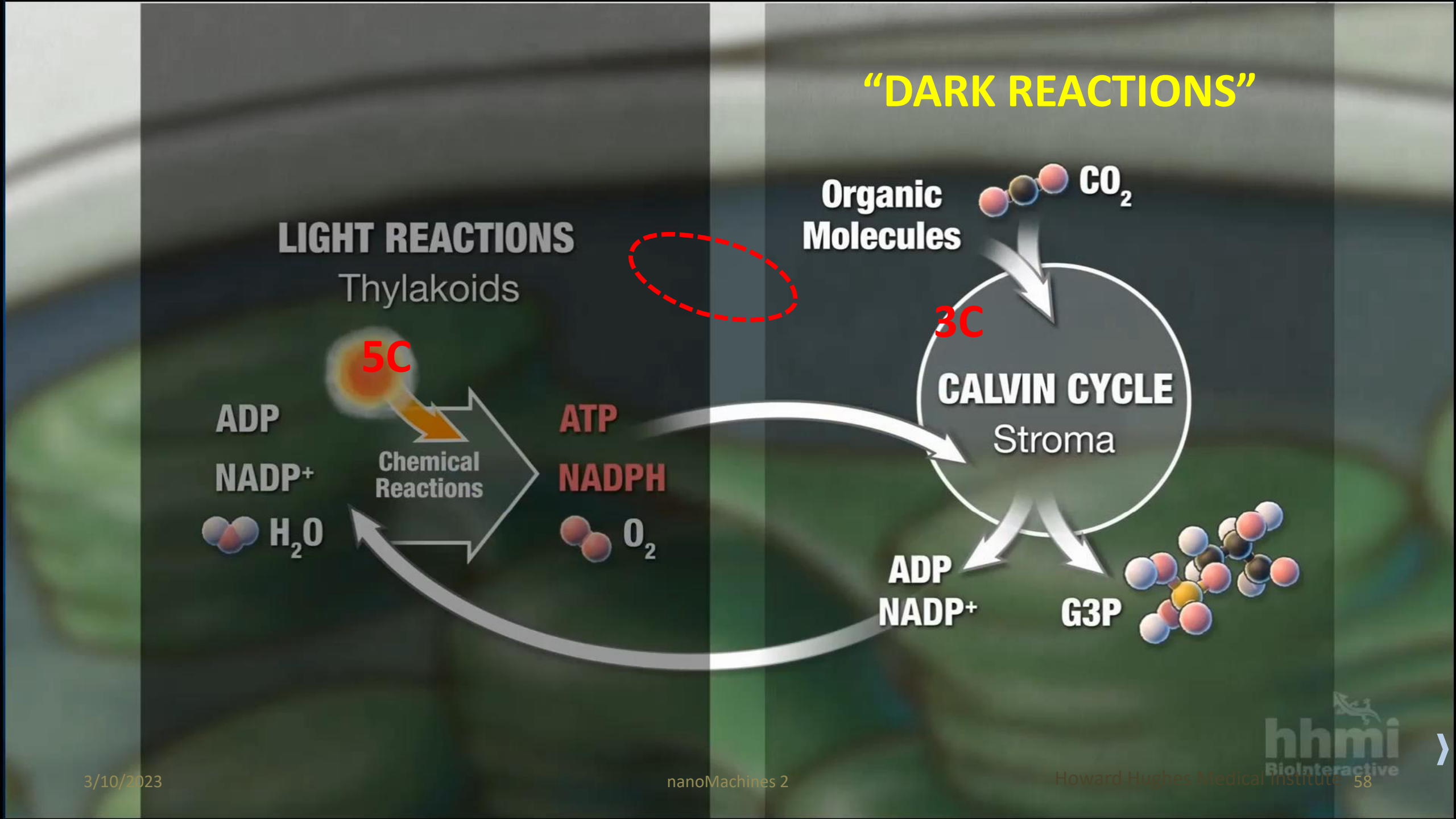
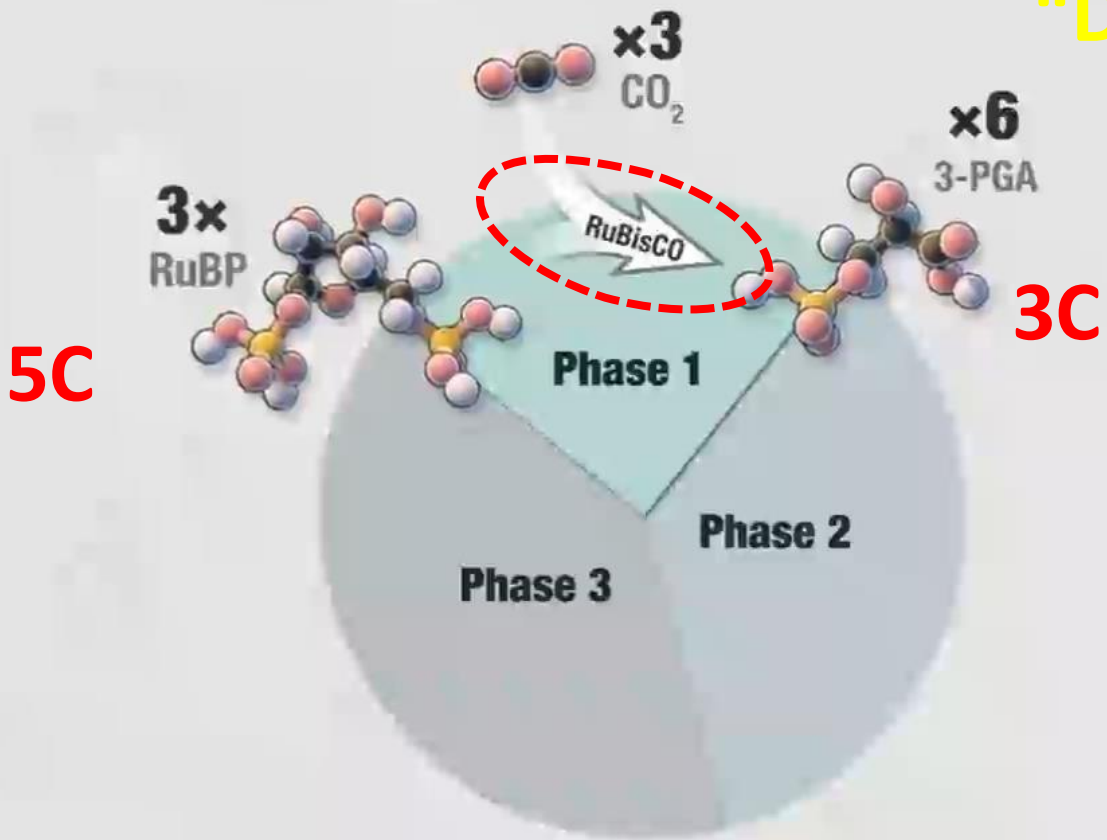



"DARK REACTIONS"
Organic Molecules
CO_2
LIGHT REACTIONS
Thylakoids
3C
5C
CALVIN CYCLE
Stroma
ADP
NADP+
Chemical Reactions
ATP
NADPH
H_2O
O_2
ADP
NADP+
G3P

CALVIN CYCLE: Phase 1 — Carbon Fixation

"DARK REACTIONS"

Movie

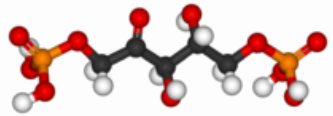


Spinach Rubisco

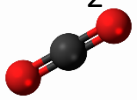
- 8 Identical Units
- Each has
  2 Protein Subunits
- One Unit
- 2 Proteins:
  - 467 Amino Acids
  - 123 Amino Acids

Magnesium Ion

RuBP (5 C) Molecule



CO_2

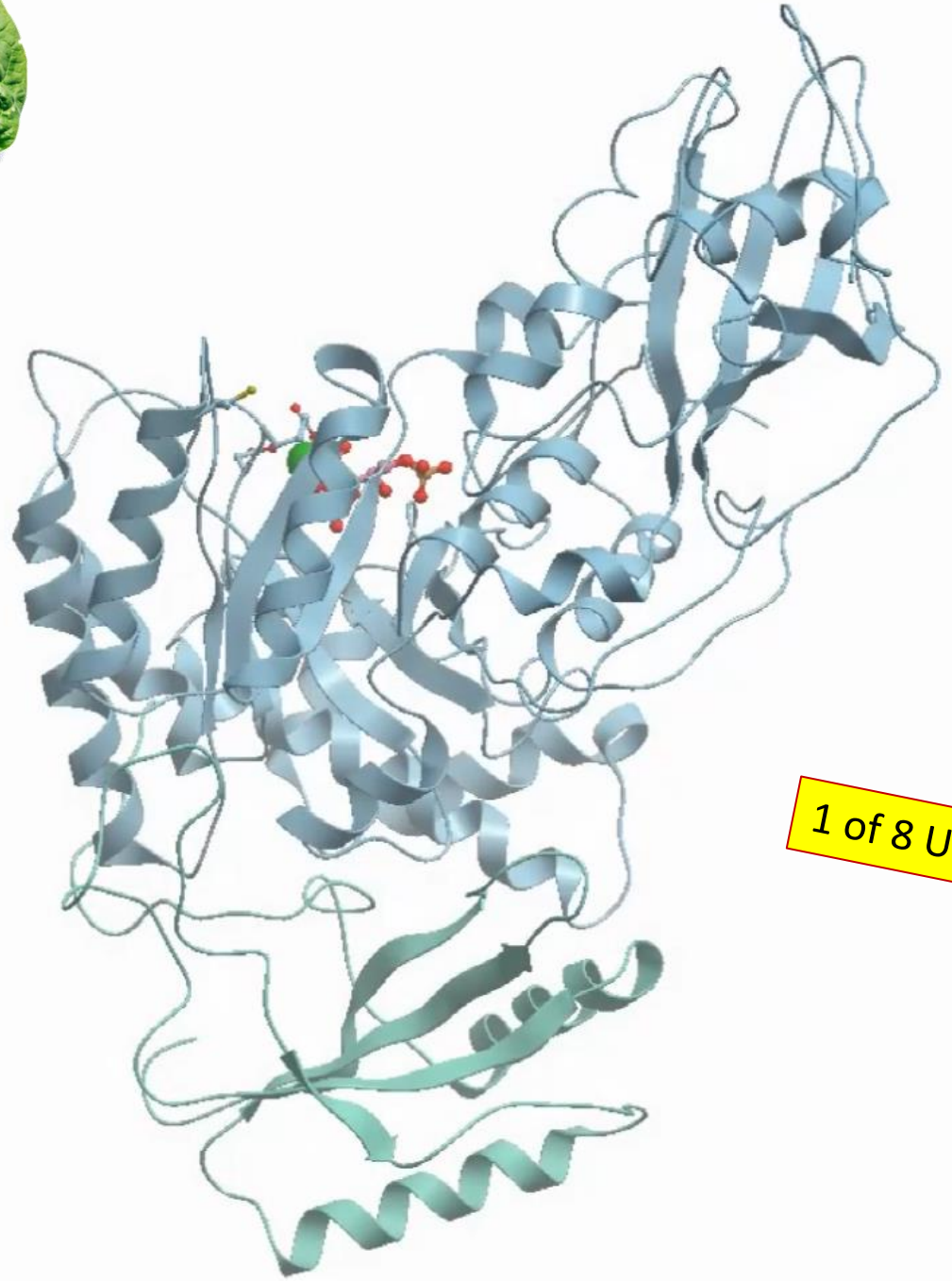


(not visible)

Spinach Rubisco

- 8 Identical Units
- Each has
  2 Protein Subunits
- One Unit
- 2 Proteins:
  - 467 Amino Acids
  - 123 Amino Acids

Movie

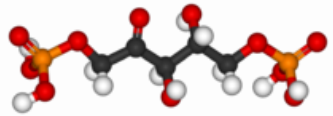


1 of 8 Units

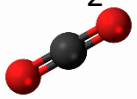
Magnesium Ion

Mg ++

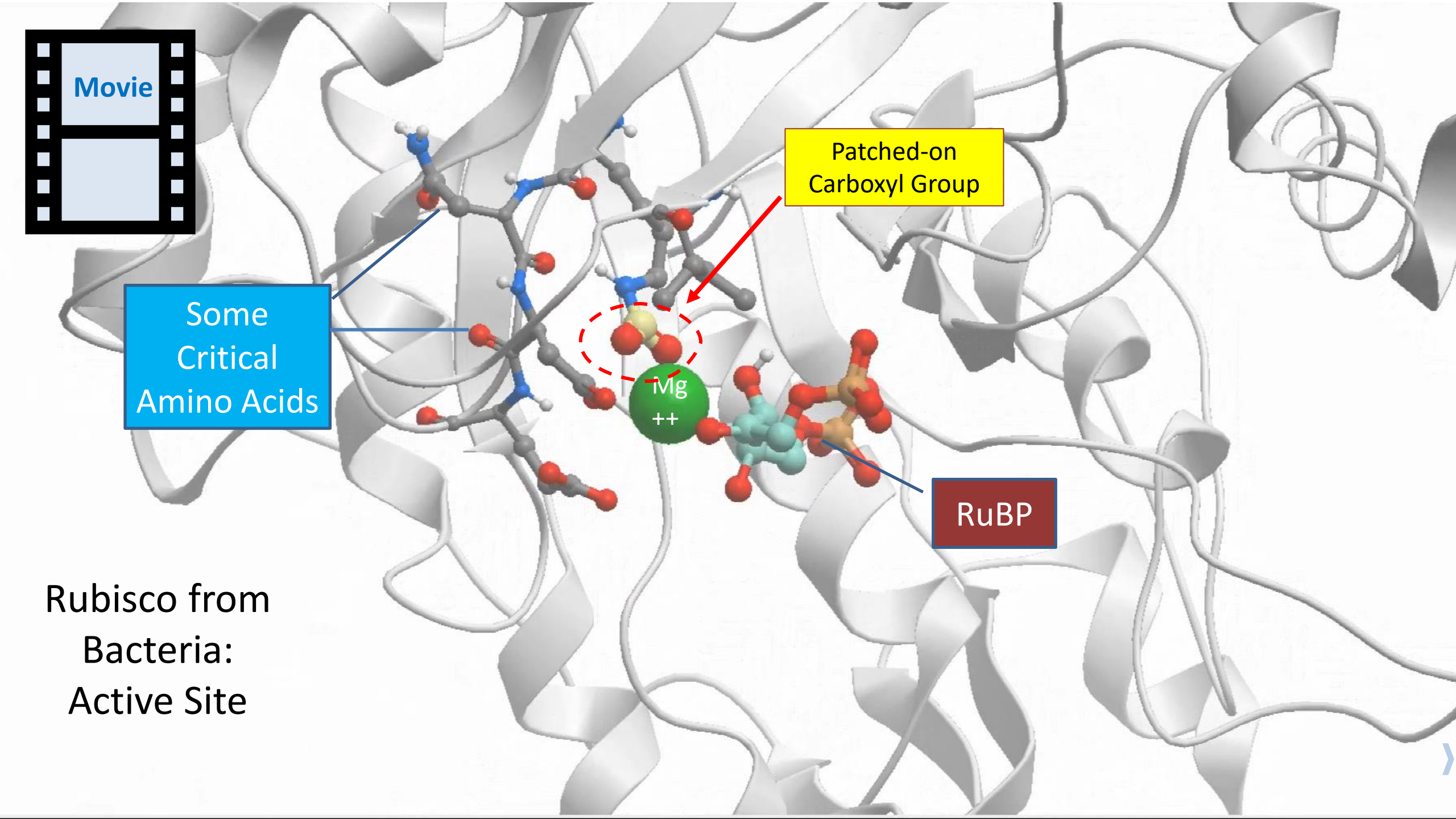
RuBP (5 C) Molecule



CO_2

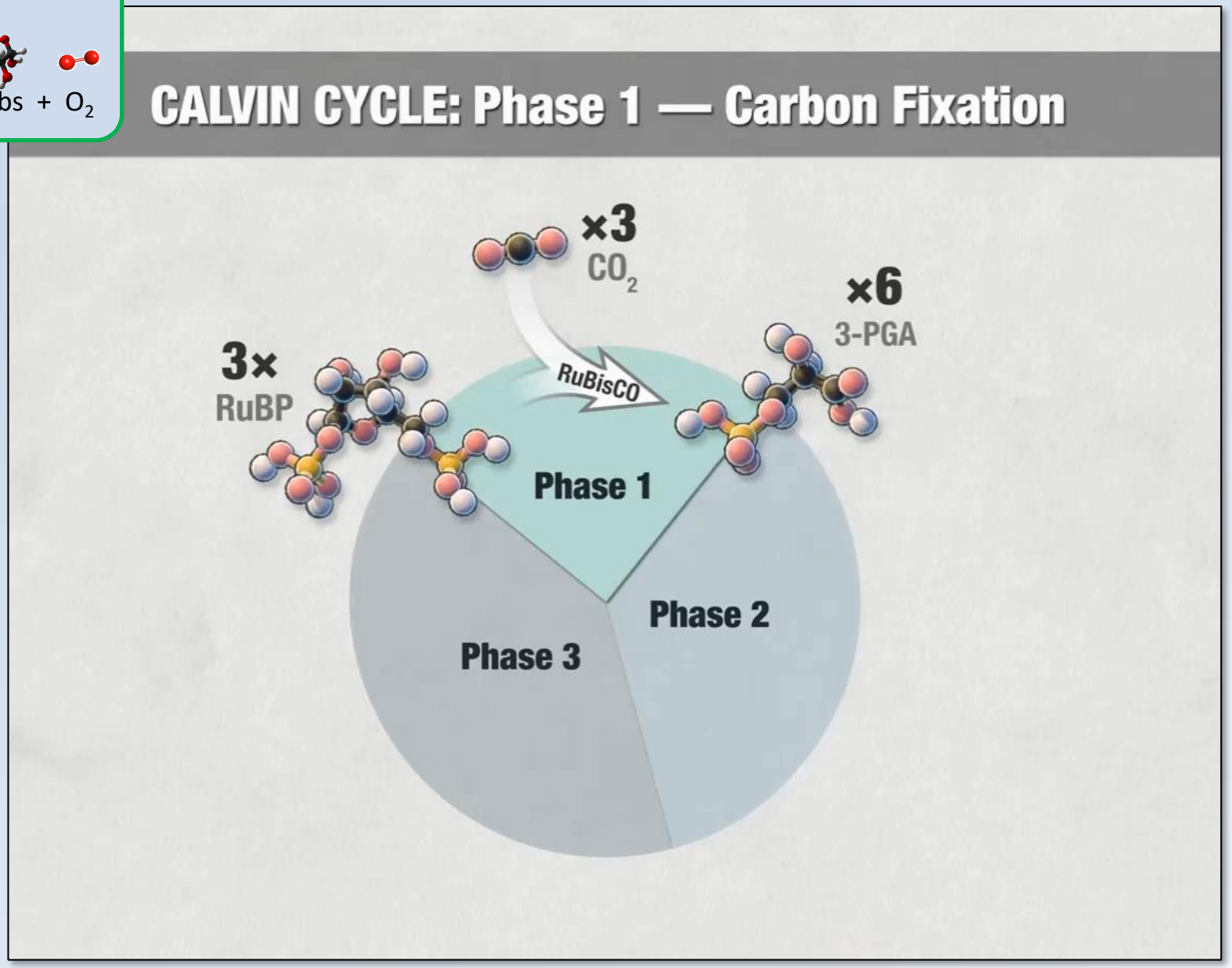


(not visible)

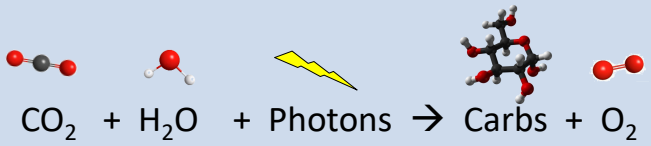


Rubisco from Bacteria: Active Site

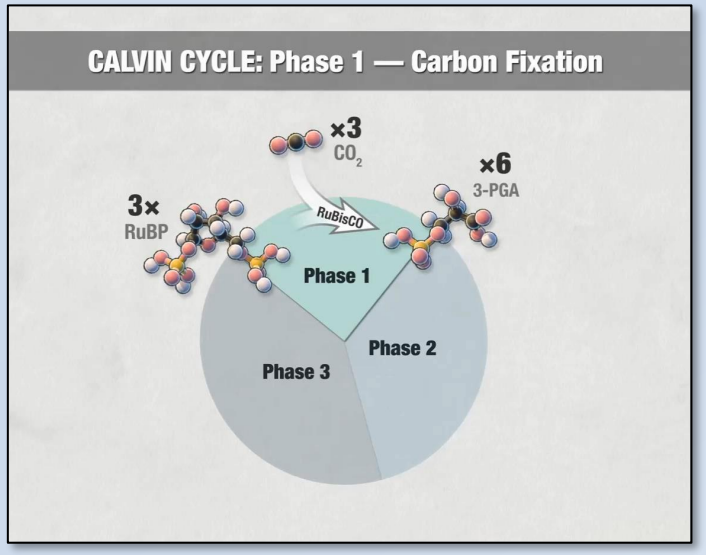
Photosynthesis



Photosynthesis



CO_2 + H_2O + Photons → Carbs + O_2



So How Does Rubisco Stack Up as a Molecular Machine?

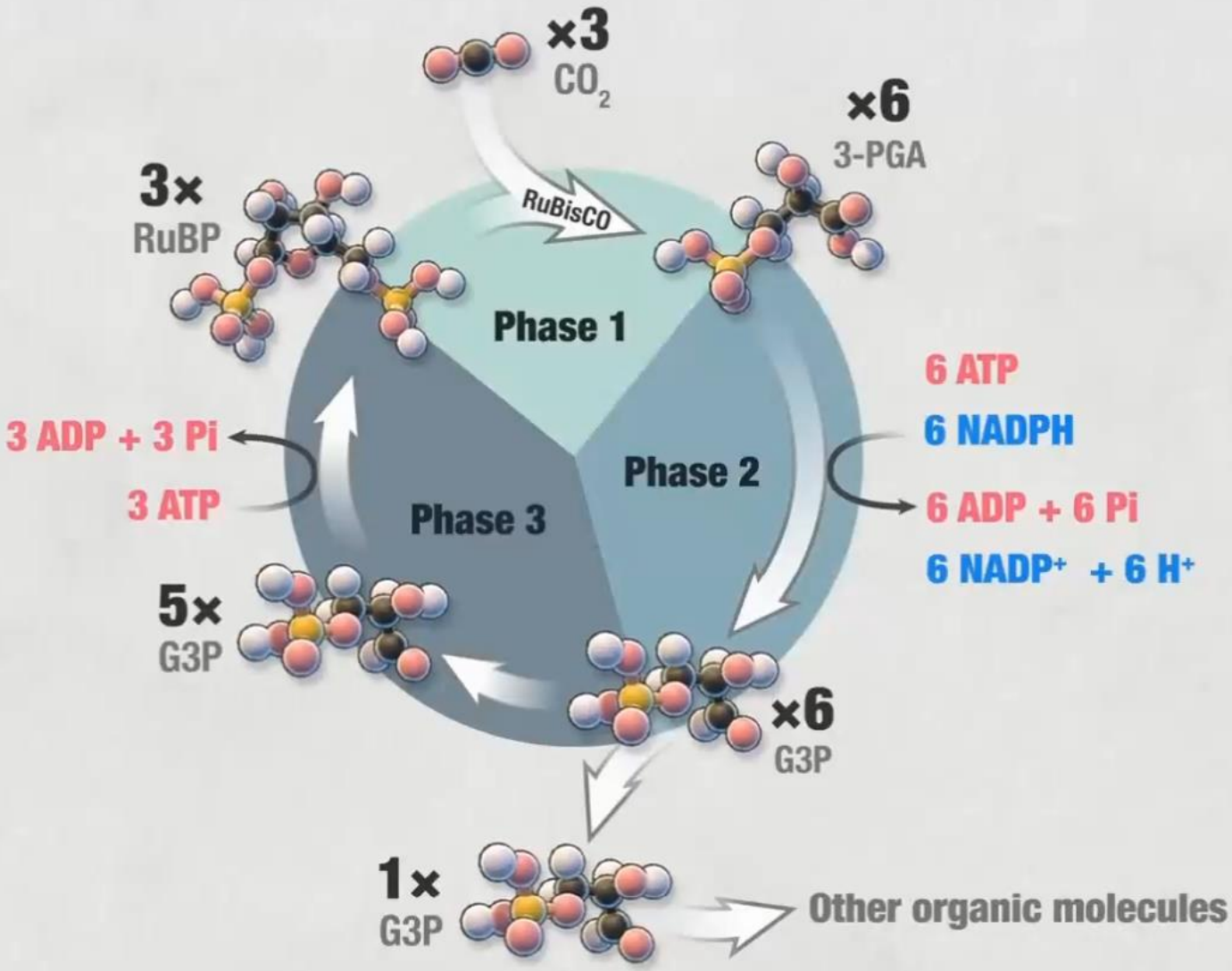
- All land life (and most sea life) depends on it
- But …. it **barely** works
  - Excruciatingly slow - only a couple of **CO_2**'s per second are fixed.
    - As a result, huge numbers of these machines needed: Possibly the *most abundant* Protein in nature!
  - It makes a *lot* of mistakes
    - 25% of the time it tries to process **O_2** instead of **CO_2**
    - Often it misfires and generates the wrong product
      - Frequently gets gummed up and stuck, requiring special repair machines to reset it and get it going again

Garbage Out

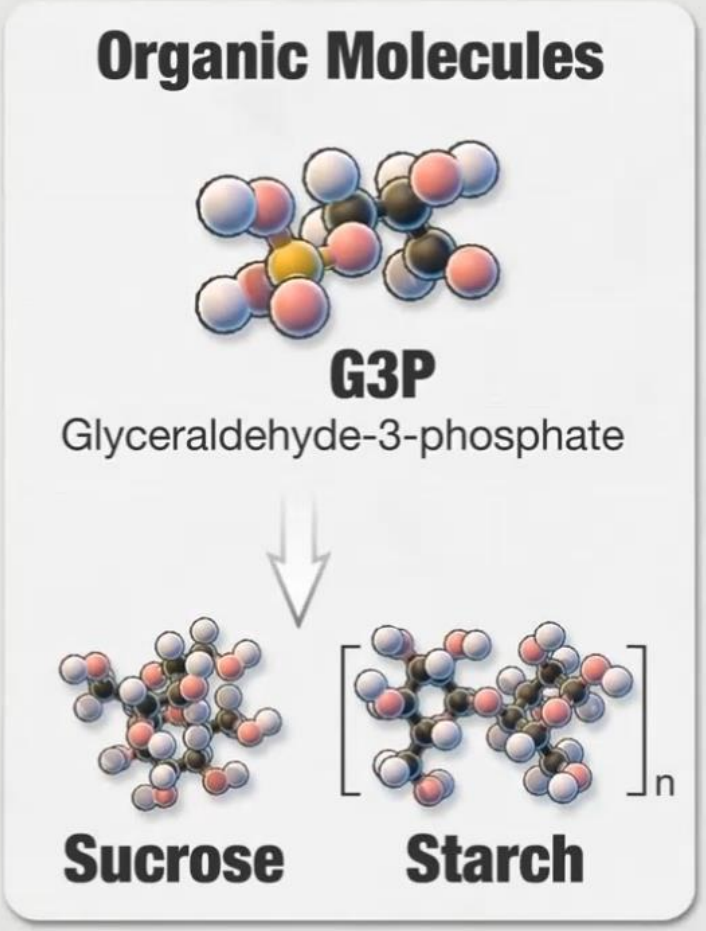
- So why does nature stick with it?

CALVIN CYCLE

Movie

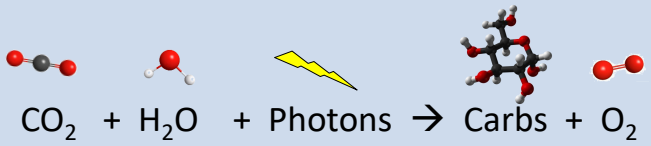


Movie


Organic Molecules
G3P
Glyceraldehyde-3-phosphate
n
Sucrose
Starch

What is Sucrose?

Photosynthesis

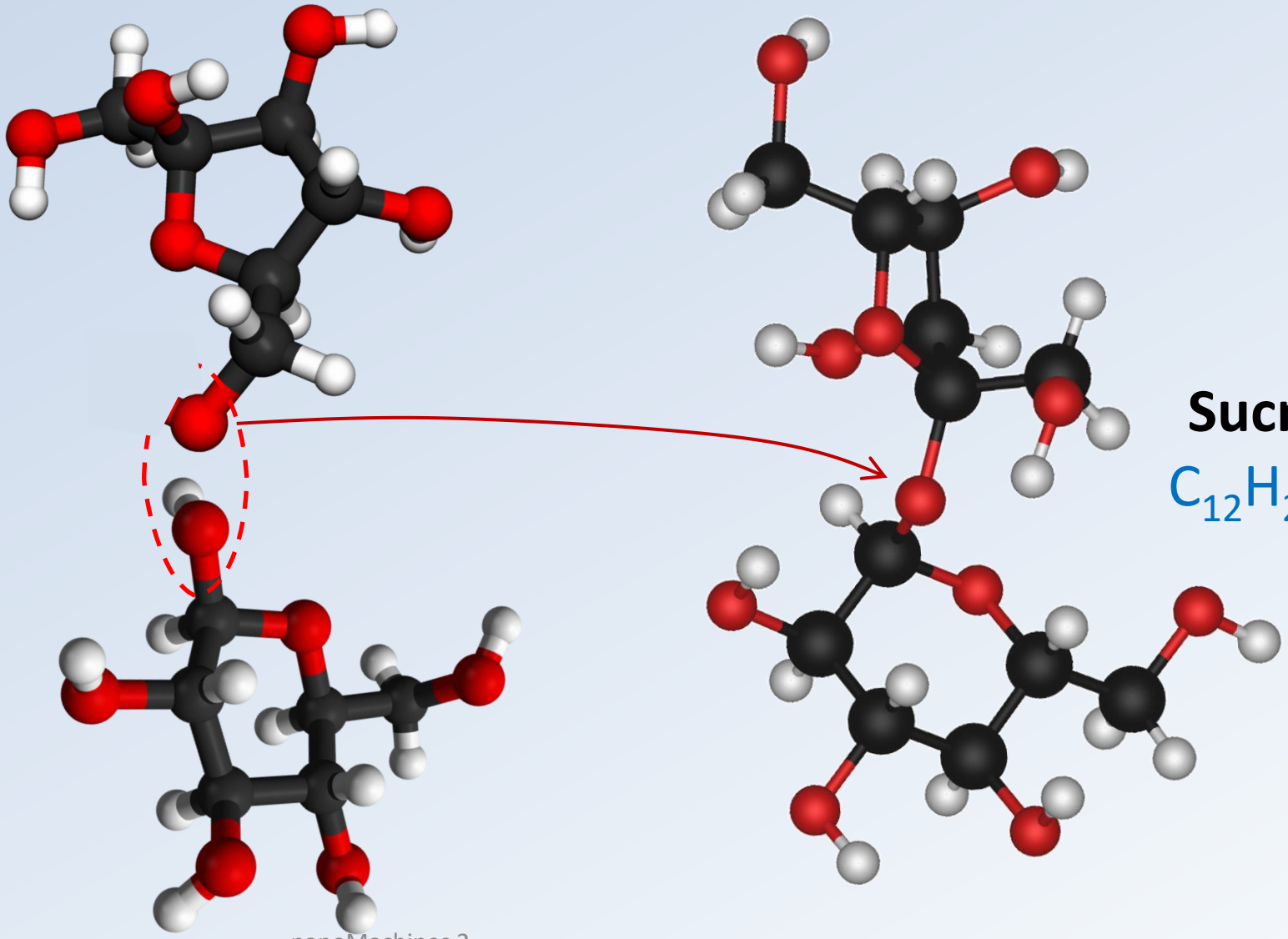


Fructose

$C_6H_{12}O_6$

2 G3P → Glucose

$C_6H_{12}O_6$

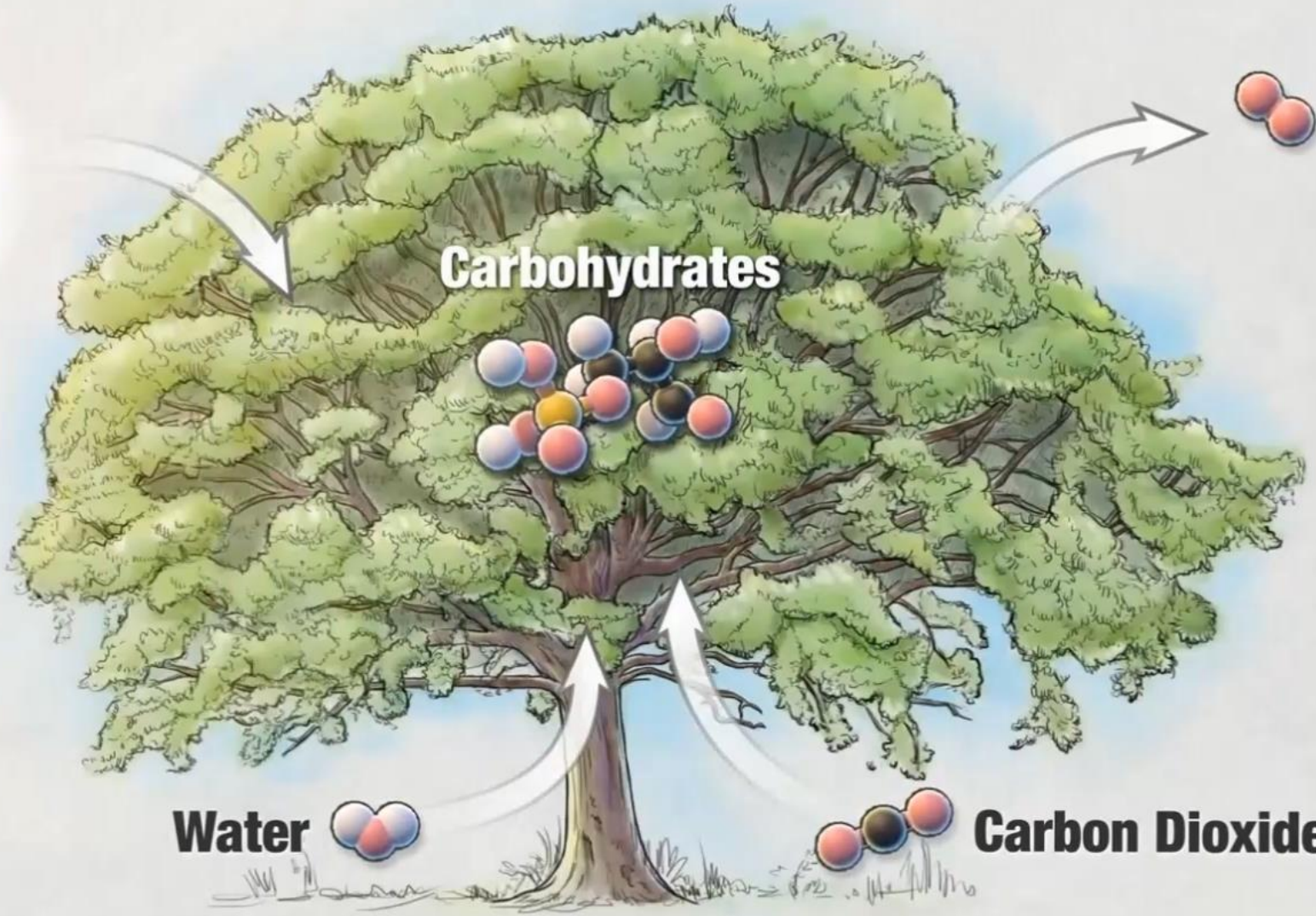


Sucrose

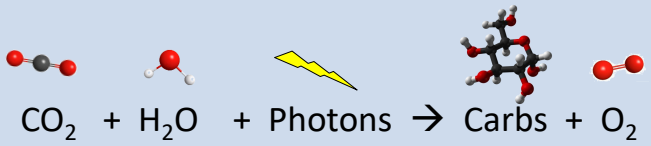
$C_{12}H_{22}O_{11}$

Sun

Movie

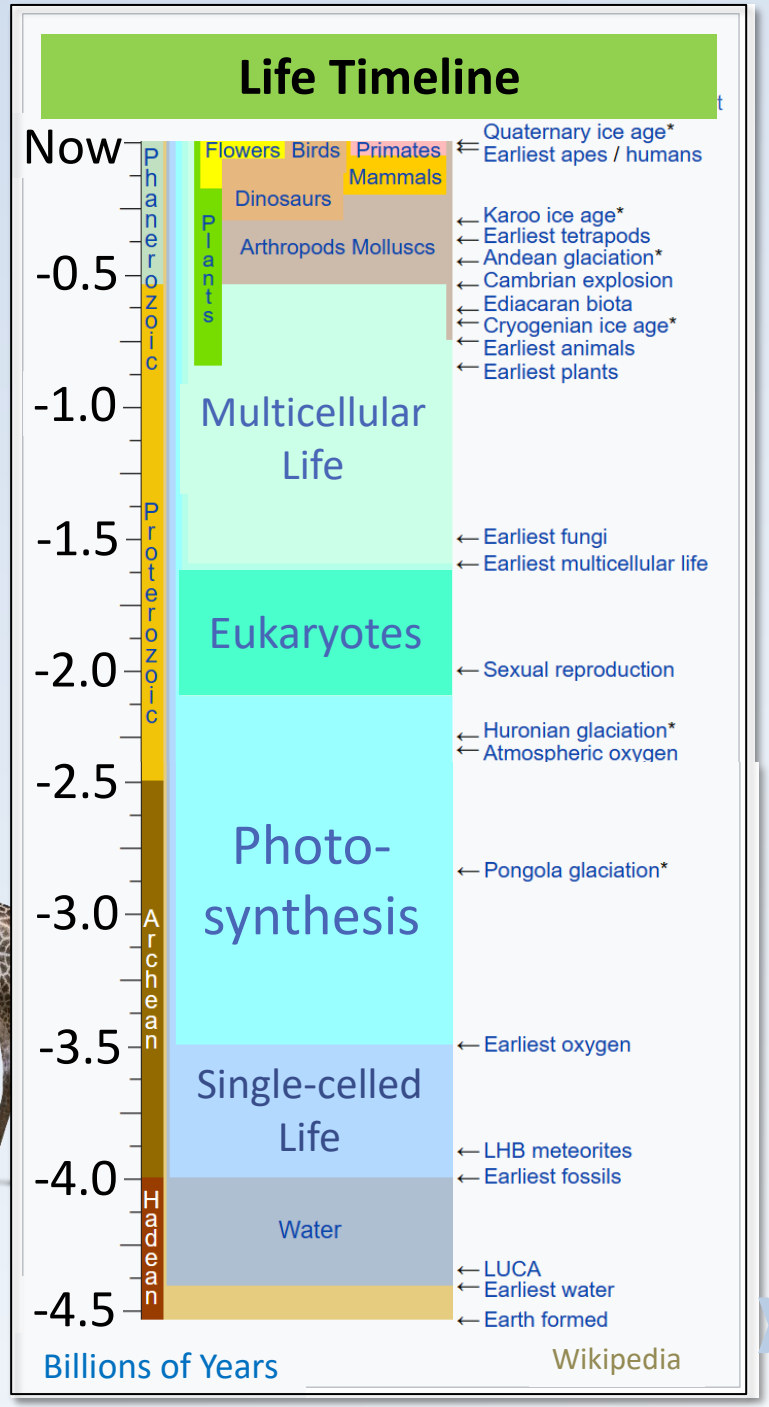


Photosynthesis



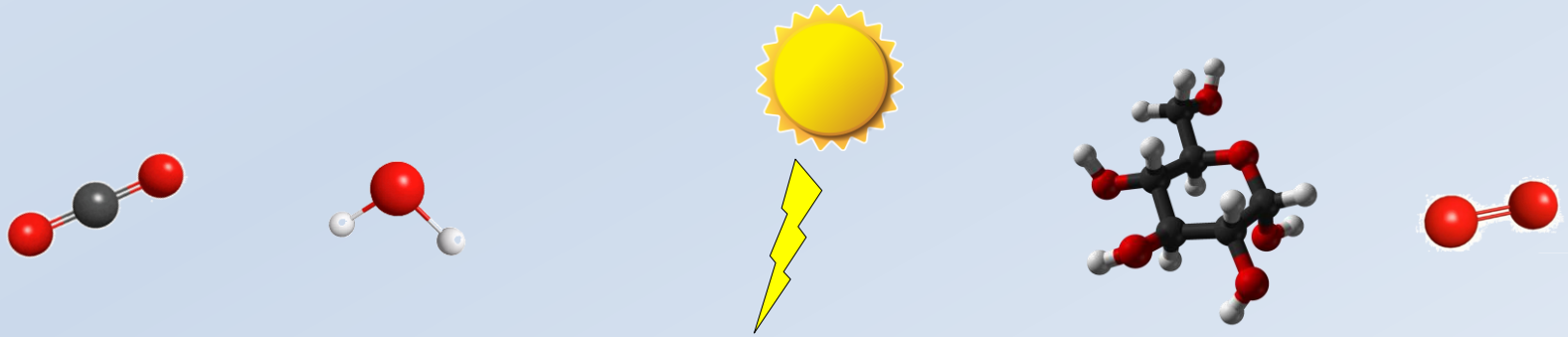
Photosynthetic Oxygen Changed the World

- Created Ozone layer
  - UV Protection of Oceans
- Reduced Temperatures
  - by removing CO_2
- Enabled Multi-cellular Life



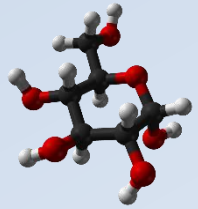
Questions?

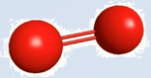
For the last few billion years, the main source of Energy for living things has been Sunlight

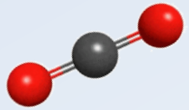


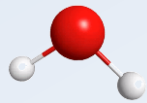
$CO_2 + H_2O + Energy \rightarrow Carbs + O_2$

Photosynthesis



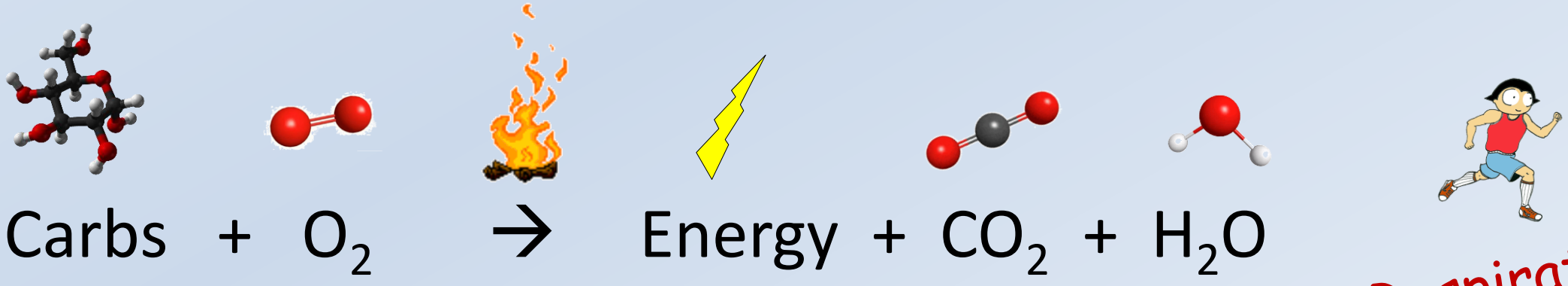




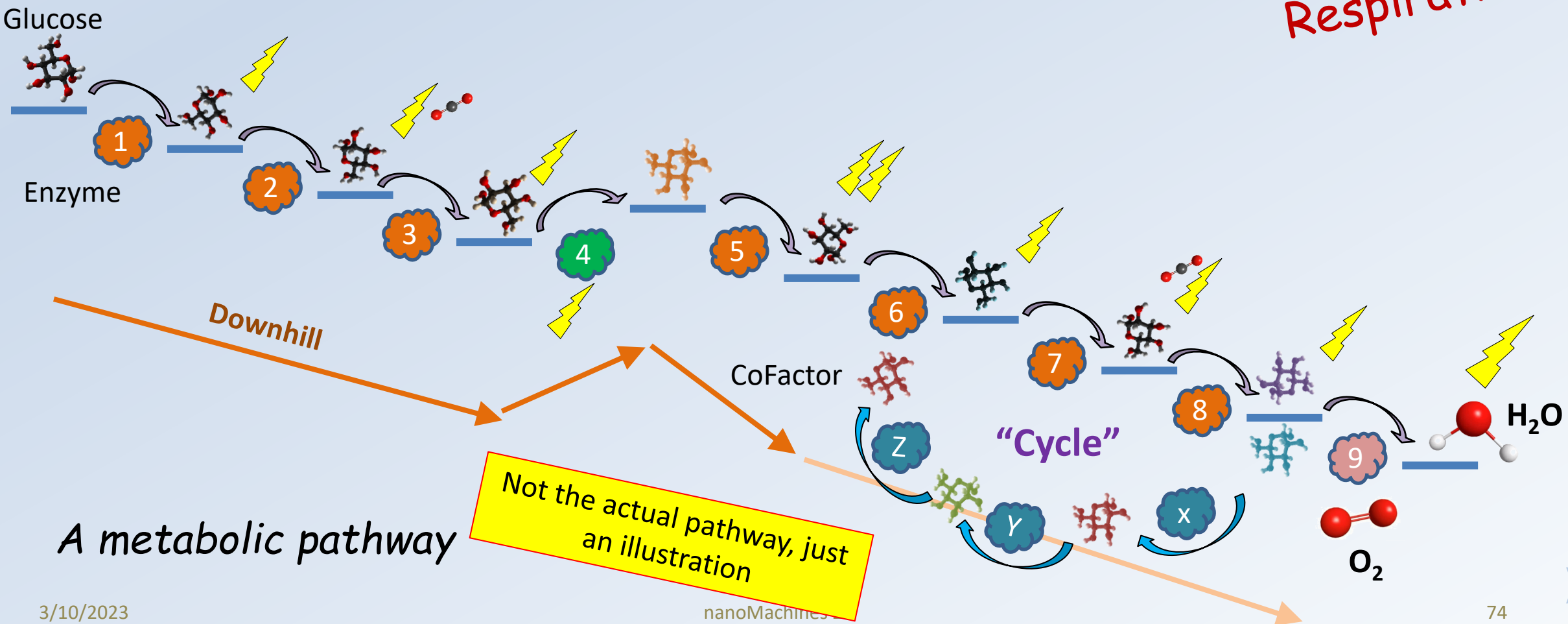


$Carbs + O_2 \rightarrow Energy + CO_2 + H_2O$

Respiration

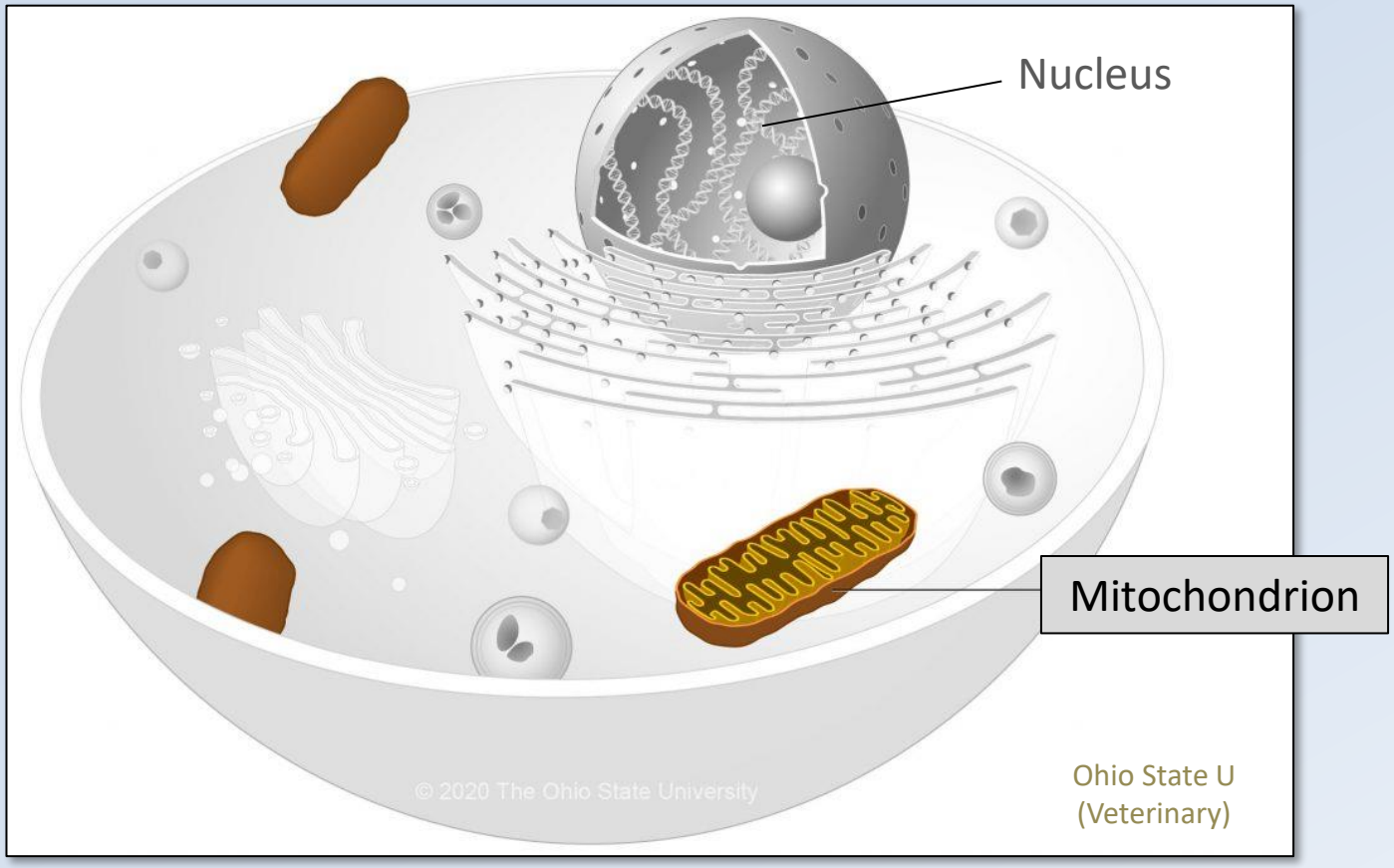


Respiration

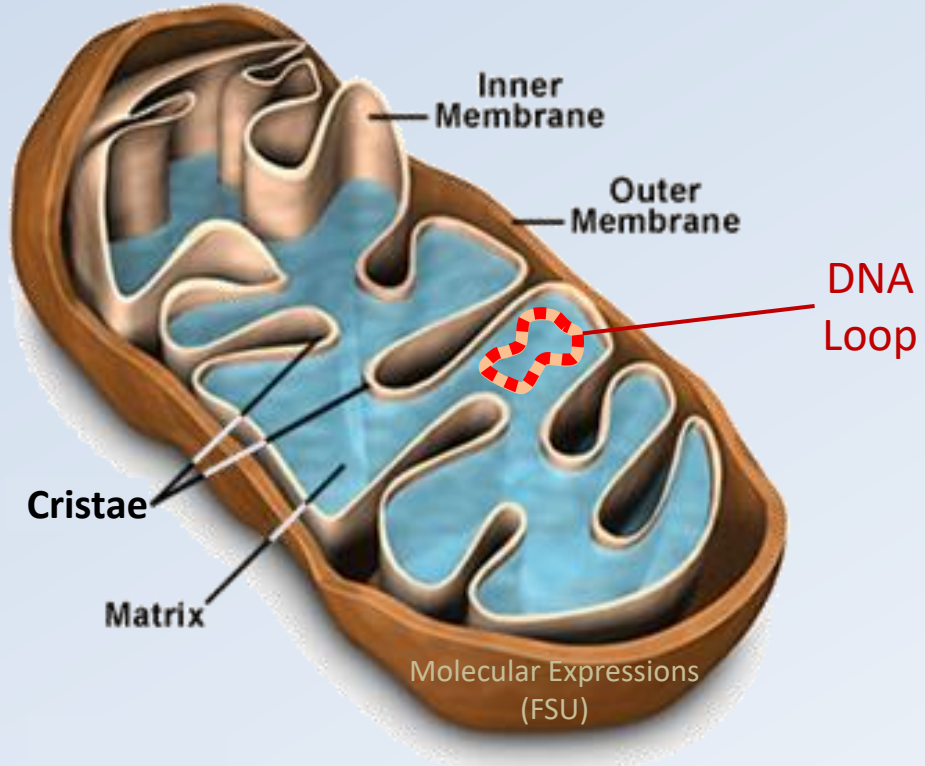


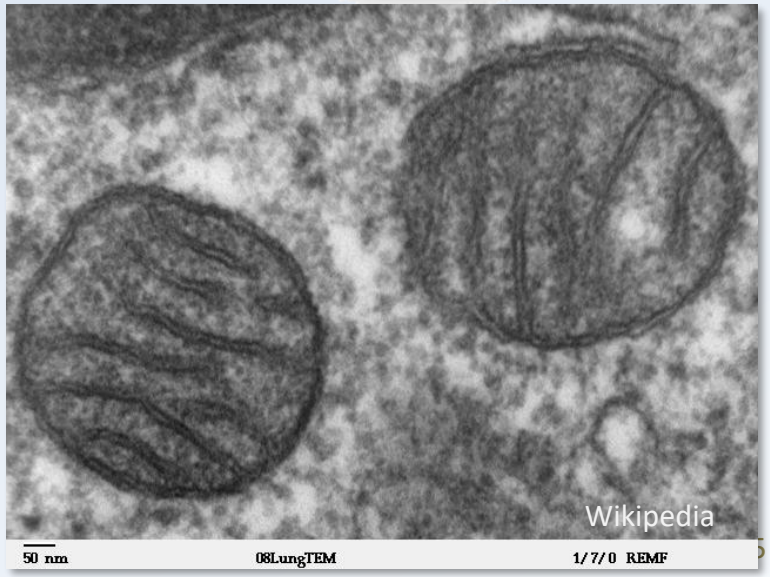
Mitochondria:

The Eukaryotic Cell's Powerhouses



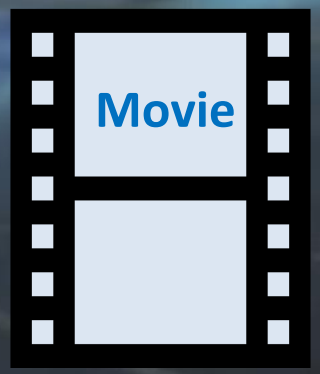
Simplified Animal Cell





Mitochondria: The Cell's Powerhouse

Harvard BioVisions



Nanomachine Proteins are transported into the Mitochondrial Matrix as long *unfolded* Amino Acid Chains!

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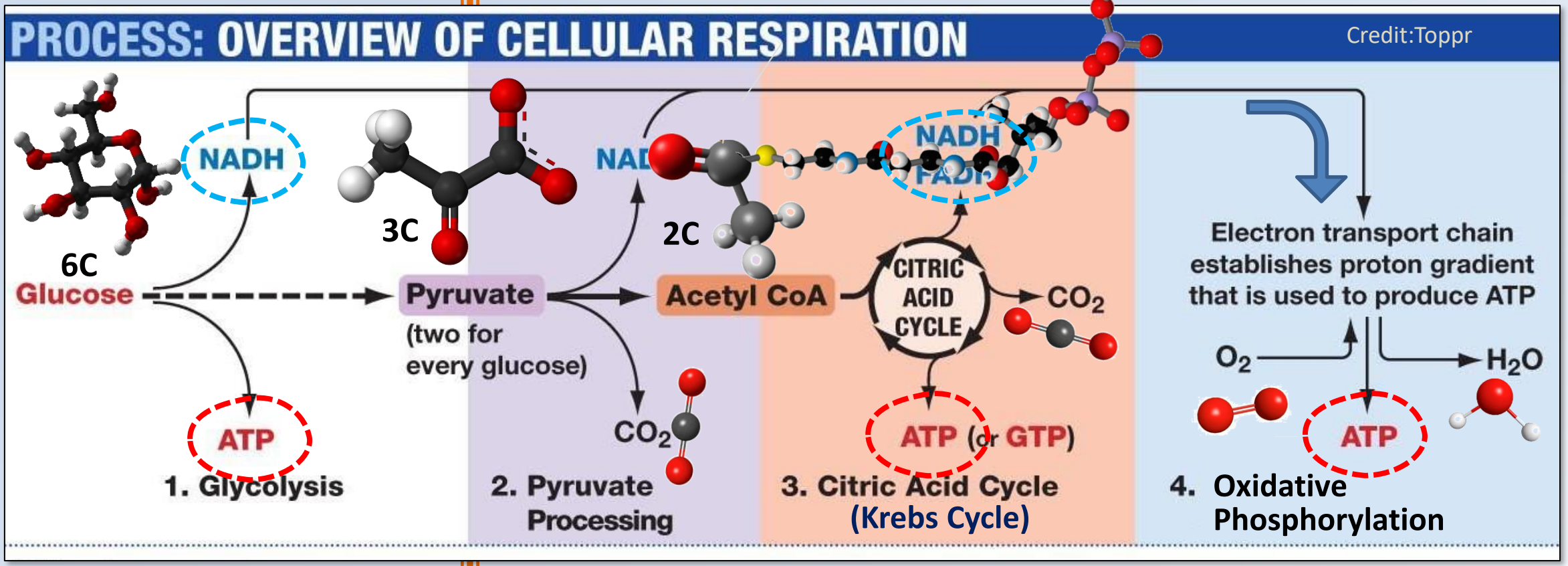
Respiration

Co-Enzyme A

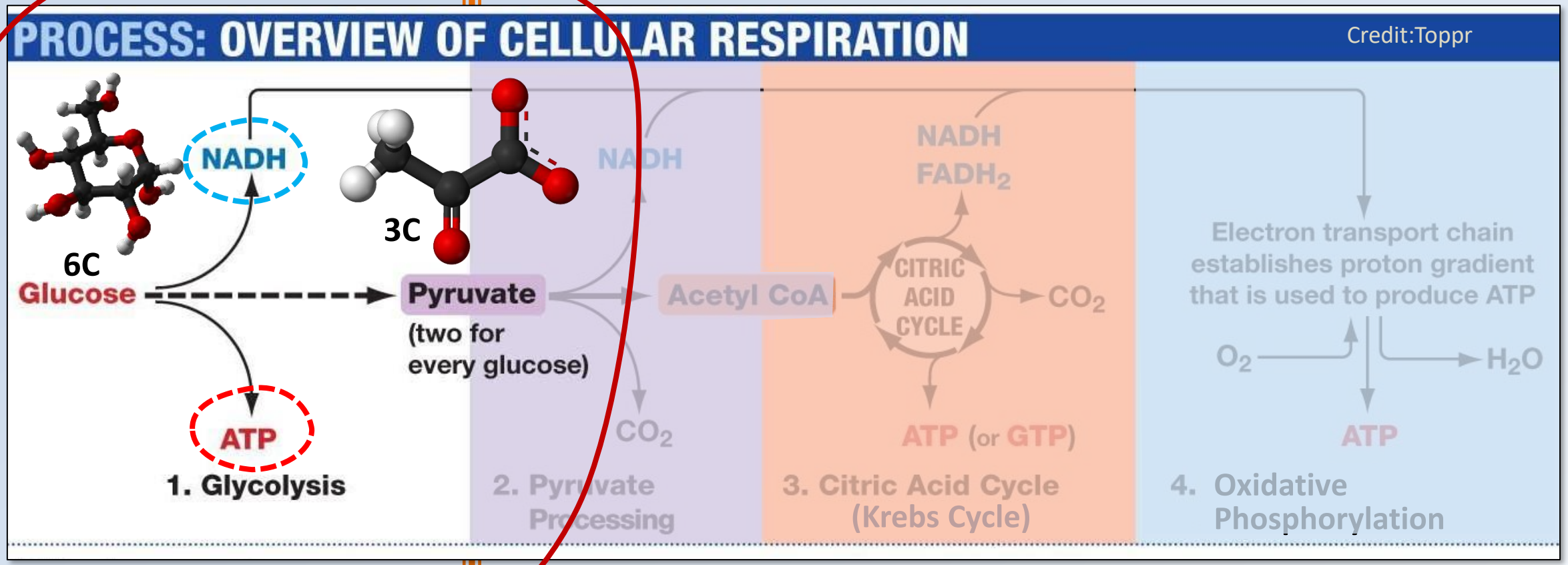


Outside of Mitochrondria

Inside Inner Membrane of Mitochrondria

Respiration

Carbs + O_2 → + CO_2 + H_2O

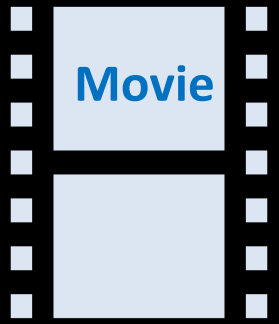


Outside of Mitochrondria

Inside Inner Membrane of Mitochrondria

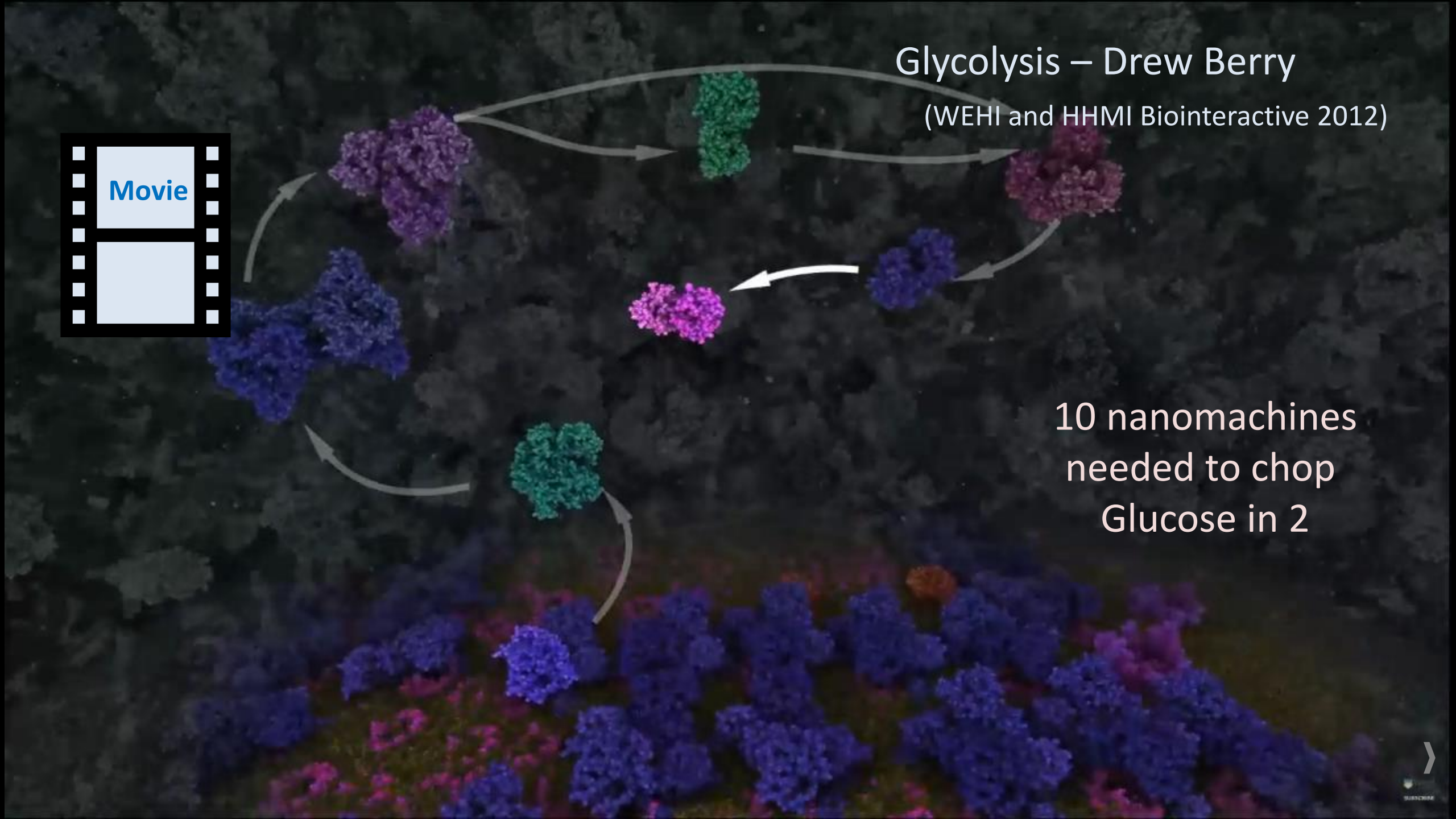
Glycolysis – Drew Berry

(WEHI and HHMI Biointeractive 2012)



Glucose

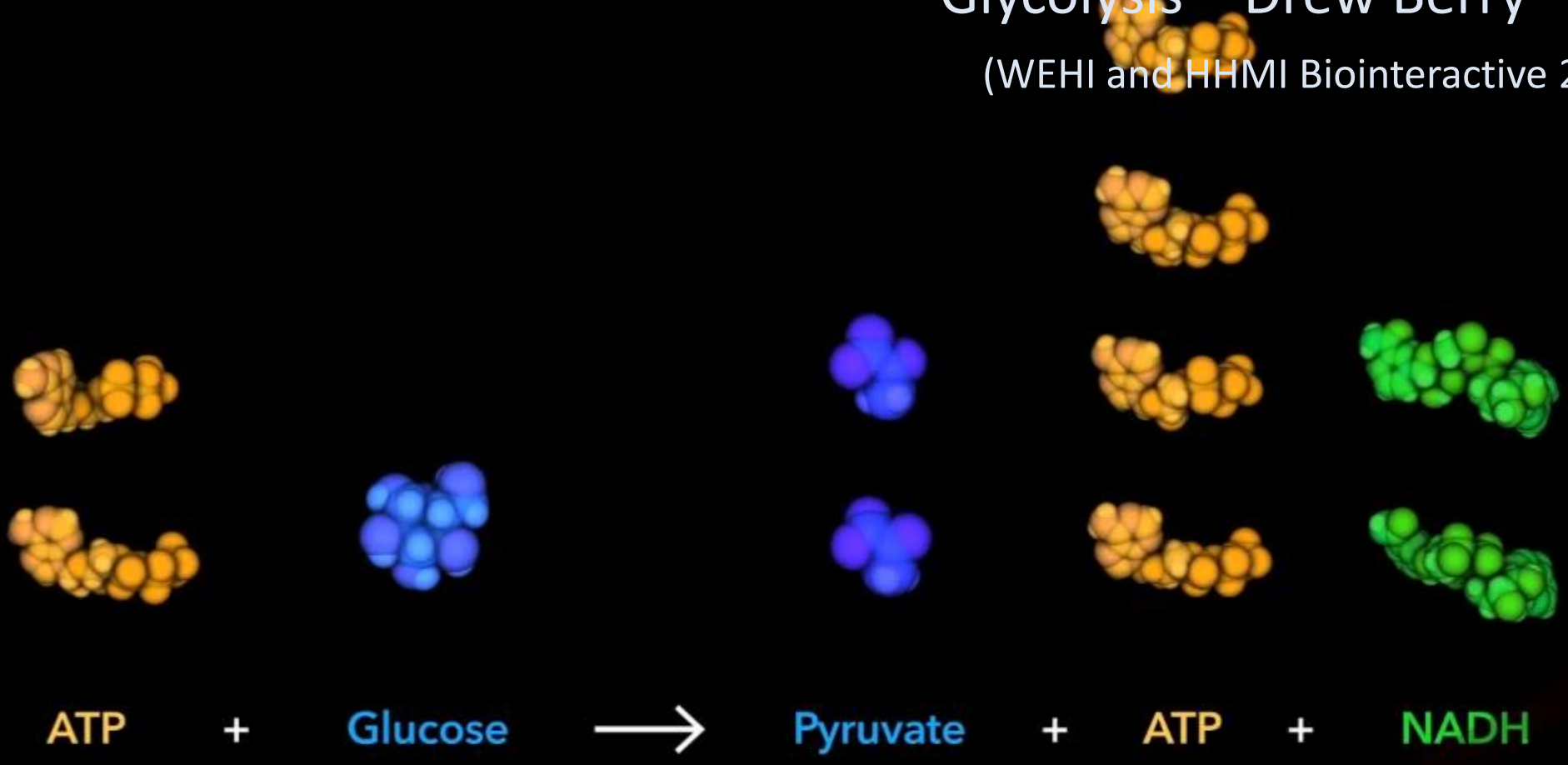
Pyruvate


Glycolysis – Drew Berry
(WEHI and HHMI Biointeractive 2012)
Movie
10 nanomachines
needed to chop
Glucose in 2

Glycolysis – Drew Berry

(WEHI and HHMI Biointeractive 2012)

Movie



Glycolysis

10 nanomachines needed to chop Glucose in 2!

Pause here until next week……