Review: How Cells Obtain Energy From Food

Our blood glucose levels are kept in tight regulation, if too high (e.g., in diabetes) we can experience poor circulation and organ failure, if too low we can experience headaches, dizziness and fainting.

- What do you expect to happen after you consume a lot of sugary treats?

- If you fast and consume no sugar for an extended period of time, what options does our body have to avoid hypoglycemia (low blood sugar)?

Review: How Cells Obtain Energy From Food

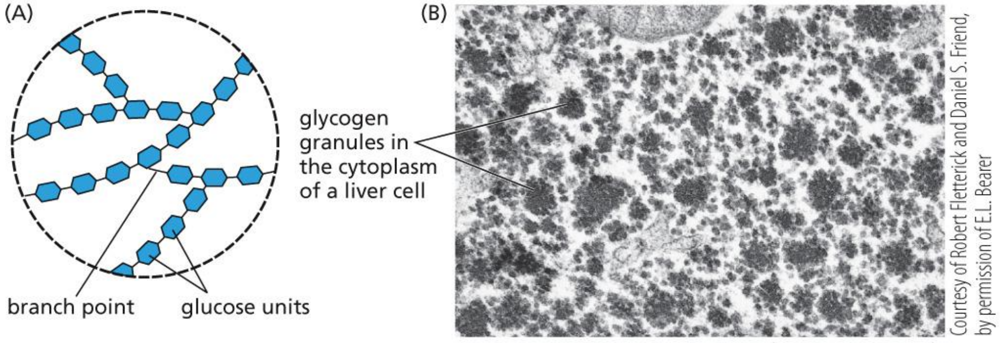
Our blood glucose levels are kept in tight regulation, if too high (e.g., in diabetes) we can experience poor circulation and organ failure, if too low we can experience headaches, dizziness and fainting.

- What do you expect to happen after you consume a lot of sugary treats?
  - Blood sugar levels will rise, GLUT1 transporters throughout the body will facilitate the entry of glucose into our cells to partake in glycolysis to breakdown glucose and produce energy.
  - If ATP levels are sufficiently high, excess glucose will be stored as *glycogen* to be used later when energy is needed.

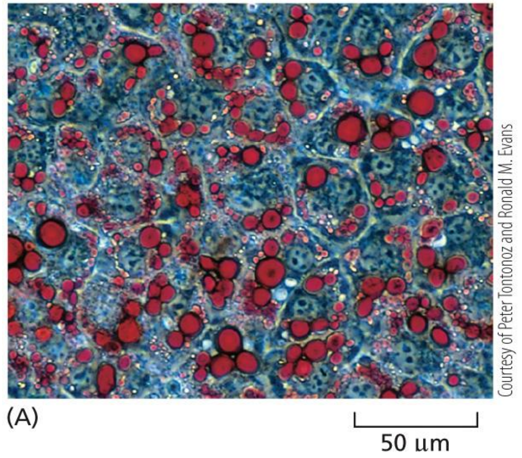
- If you fast and consume no sugar for an extended period of time, what options does our body have to generate energy?
  - Our body could break down stored fat via β-oxidation to produce acetyl-CoA to enter the citric acid cycle or metabolize protein into byproducts needed for cellular respiration.
  - To avoid hypoglycemia (low blood sugar), our body can also engage in *gluconeogenesis*, which is the reverse process to glycolysis whereby glucose is generated from alternative metabolite sources.

Cells store food molecules in special reservoirs to provide energy in times of need

- Glucose is stored as glycogen, a branched polymer of glucose, in mostly liver and muscle cells
- Mobilized at times of fasting

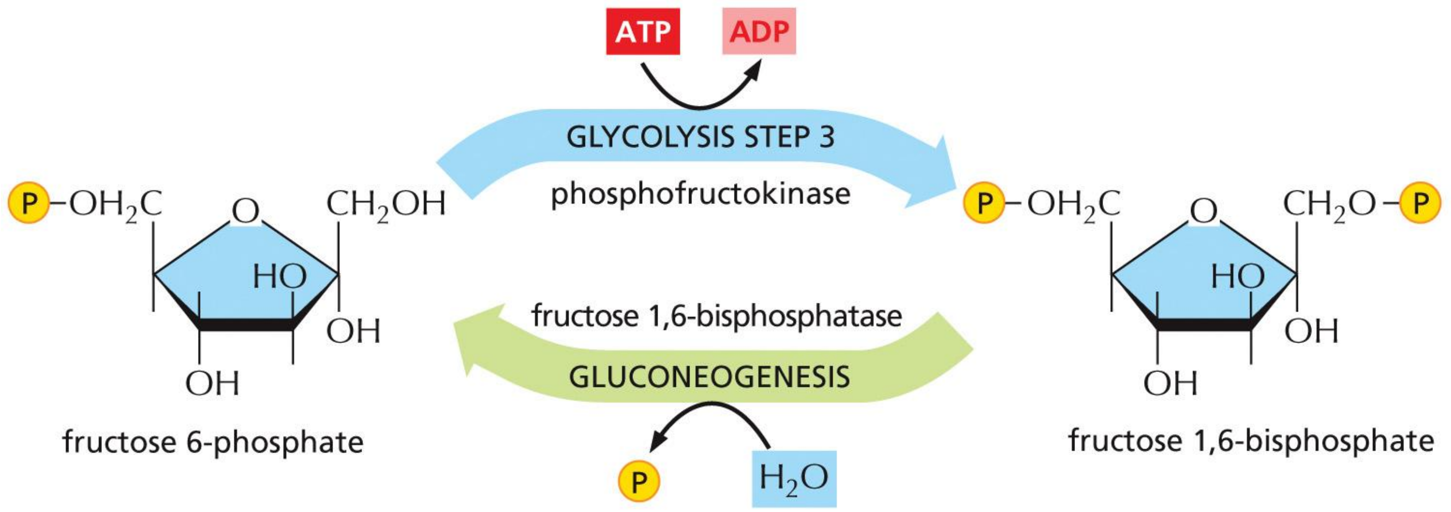


- Fats are stored as lipid droplets in adipocytes
- Fatty acids released into bloodstream at times of fasting



Gluconeogenesis

- Process of reforming glucose from pyruvate, lactate, amino acids (*in effect, a reverse of glycolysis*)
- Uses an alternative set of enzymes that catalyze a bypass reaction during the irreversible steps of glycolysis (1, 3, 10)
- Energetically costly so only occurs when glycogen stores are depleted and is carefully regulated:
  - Phosphofructokinase is inhibited by ATP
  - Fructose 1,6-bisphophatase is activated when phosphofructokinase is inhibited



Chapter 14: Energy Generation in Mitochondria and Chloroplasts

Cellular Respiration (Part II)

SDSU BIOL366

Matthew Ellis, PhD

March 20, 2025

Learning Objectives for Today's Lecture:

Upon completing this module, **you should be able to**:

- Describe the key components of mitochondrial **oxidative phosphorylation**
- Establish what **redox potentials** are and connect them to powering the **electron transport chain**
- Understand the generation of the **chemiosmotic potential** and how this drives ATP production
- Compare animal cell energy production with energy production in plant cells via **photosynthesis** in chloroplasts

Key Terms

- **Aerobic:** "with O_2"
- **Anaerobic:** "without O_2"
- **Oxidation:** molecule loses electrons, releases energy
- **Reduction:** molecule gains electrons, stores energy
- **Redox potential:** a measure of how easily electrons are transferred between species
- **Chemiosmosis:** the movement of hydrogen ions (protons) down their electrochemical gradient
- **Proton-motive force:** the potential energy stored across the mitochondrial membrane that is leveraged to produce ATP
- **Photosynthesis:** the process by which plants leverage light energy into chemical energy

Learning Objectives for Today's Lecture:

Upon completing this module, **you should be able to**:

- Describe the key components of mitochondrial **oxidative phosphorylation**
- Establish what **redox potentials** are and connect them to powering the **electron transport chain**
- Understand the generation of the **chemiosmotic potential** and how this drives ATP production
- Compare animal cell energy production with energy production in plant cells via **photosynthesis** in chloroplasts

Cellular Respiration

The degradation of biomolecules to generate energy that cells can utilize

a.k.a

Aerobic Respiration

GLYCOLYSIS .... **TCA CYCLE** .... **OXIDATIVE PHOSPHORYLATION**

Glycolysis ⬇ ATP ATP + 2 NADH

Pyruvate (2)

TCA cycle ⬇ GTP + 3 NADH + 1 $FADH_2$

Glucose (From FOOD) + O_2 $\longrightarrow$ CO_2 + H_2O + Energy

Cellular Respiration

The degradation of biomolecules to generate energy that cells can utilize

a.k.a

Aerobic Respiration

GLYCOLYSIS ⇩ ATP ATP + 2 NADH

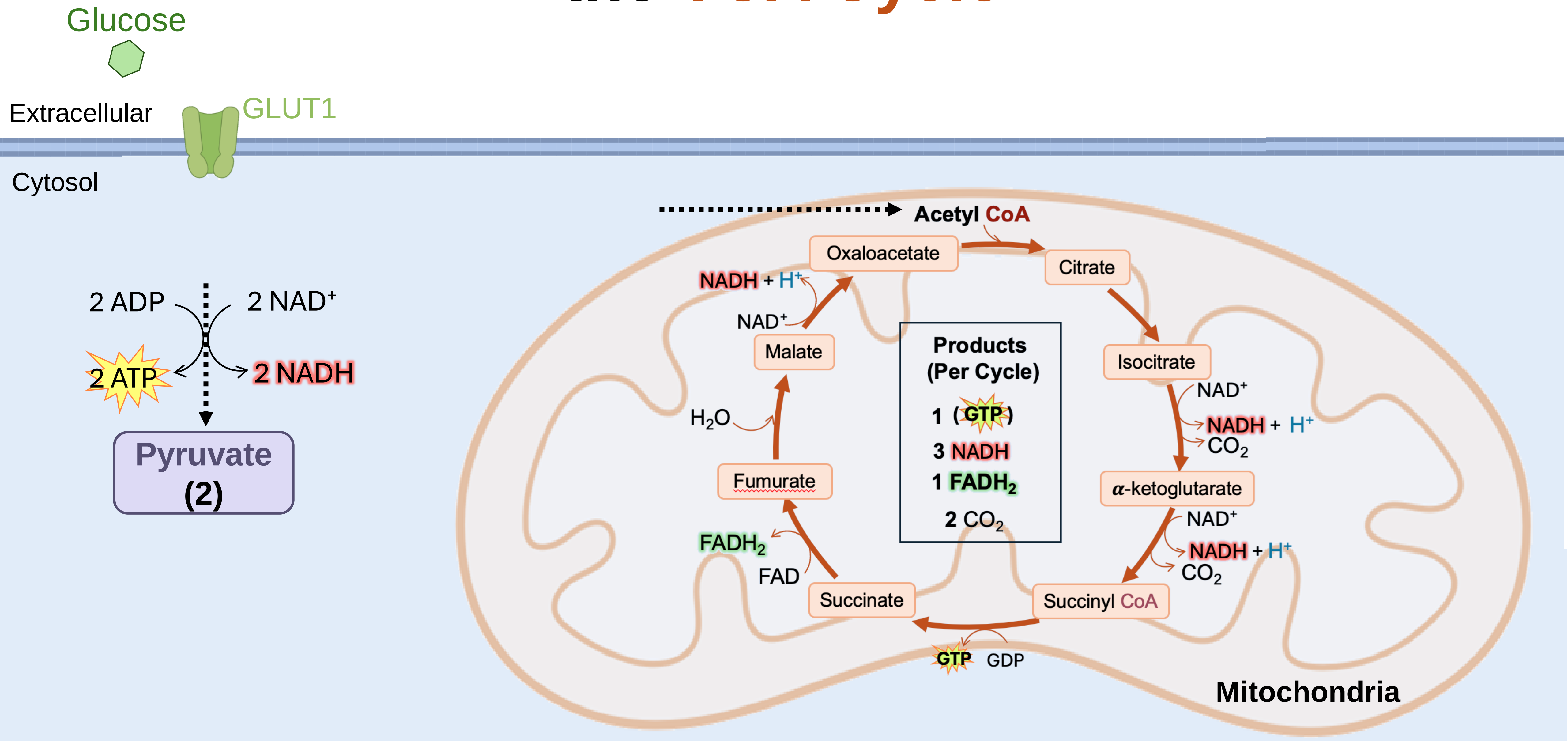
Pyruvate (2)

TCA CYCLE ⬇ GTP + 3 NADH + 1 $FADH_2$

OXIDATIVE PHOSPHORYLATION

Glucose (From FOOD) + O_2 ⟶ CO_2 + H_2O + Energy

Recap: Glycolysis, pyruvate oxidation and the TCA Cycle



Oxidative Phosphorylation

Loss of e^-

Addition of P_i + ADP to make ATP

Key Steps in **Oxidative Phosphorylation**

e^- TRANSPORT CHAIN

↓ **Helps to establish**

H^+ ELECTROCHEMICAL GRADIENT

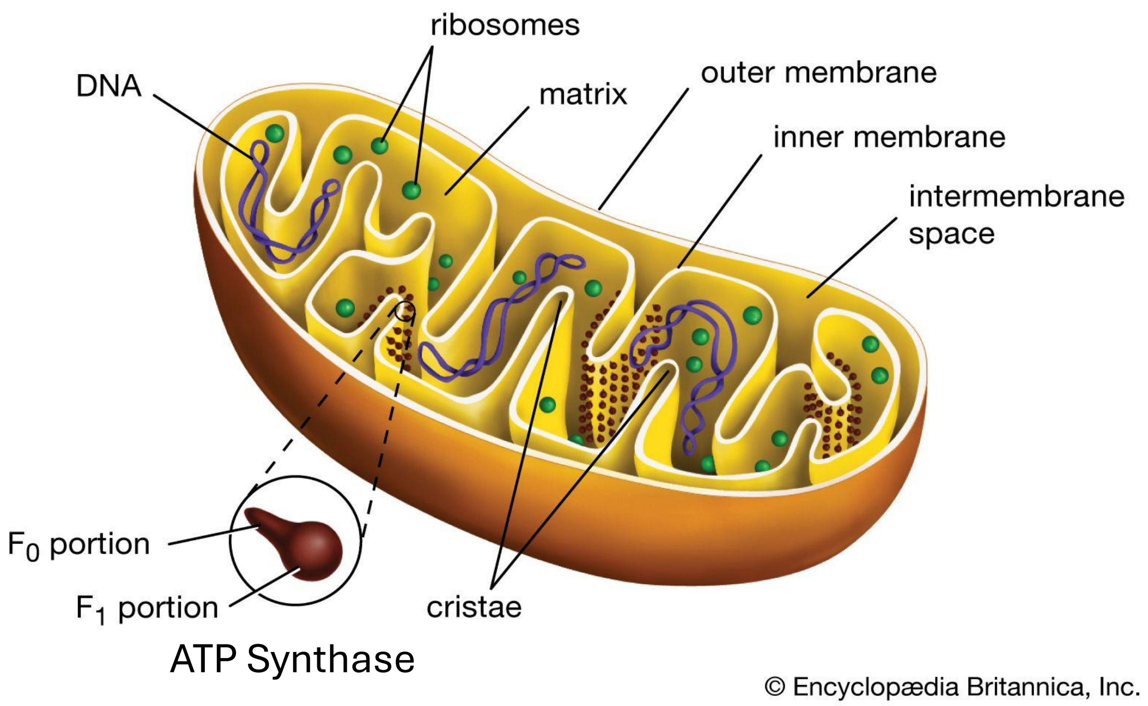
↓ **Used for**

ATP SYNTHESIS

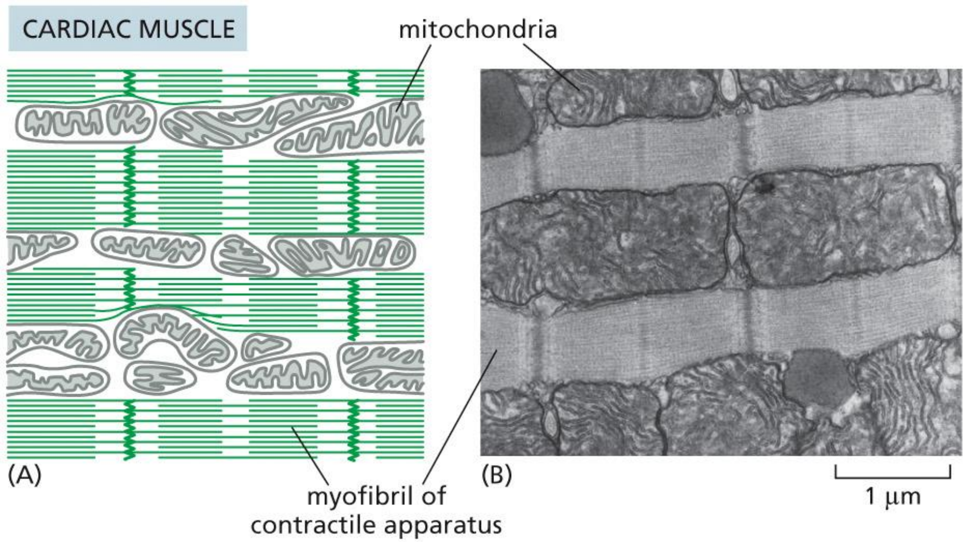
Chemiosmotic coupling

Oxidative Phosphorylation occurs in the Mitochondria

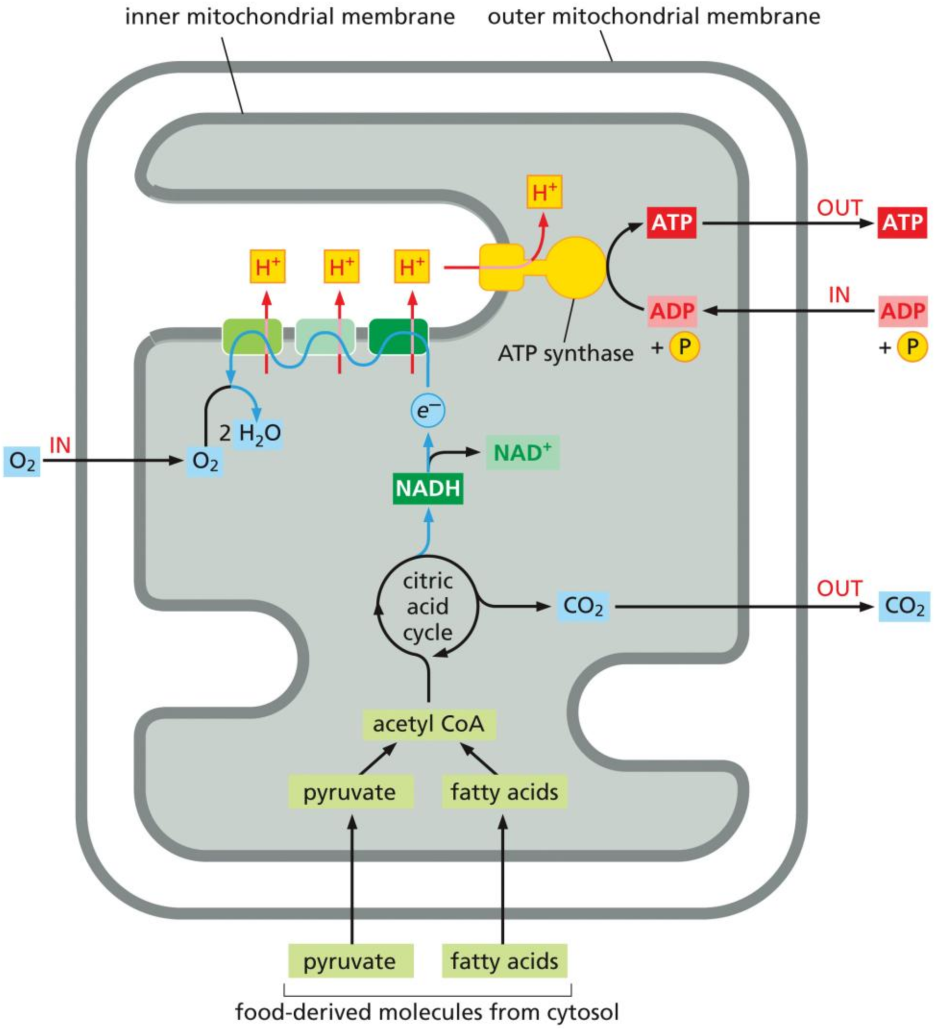
- Has clear roots to bacterial ancestry in the cell
    - Membrane-based chemiosmotic coupling occur in bacteria and archaea
    - Participate in fusion and fission
    - Contain own DNA and ribosomes (endosymbiont theory)

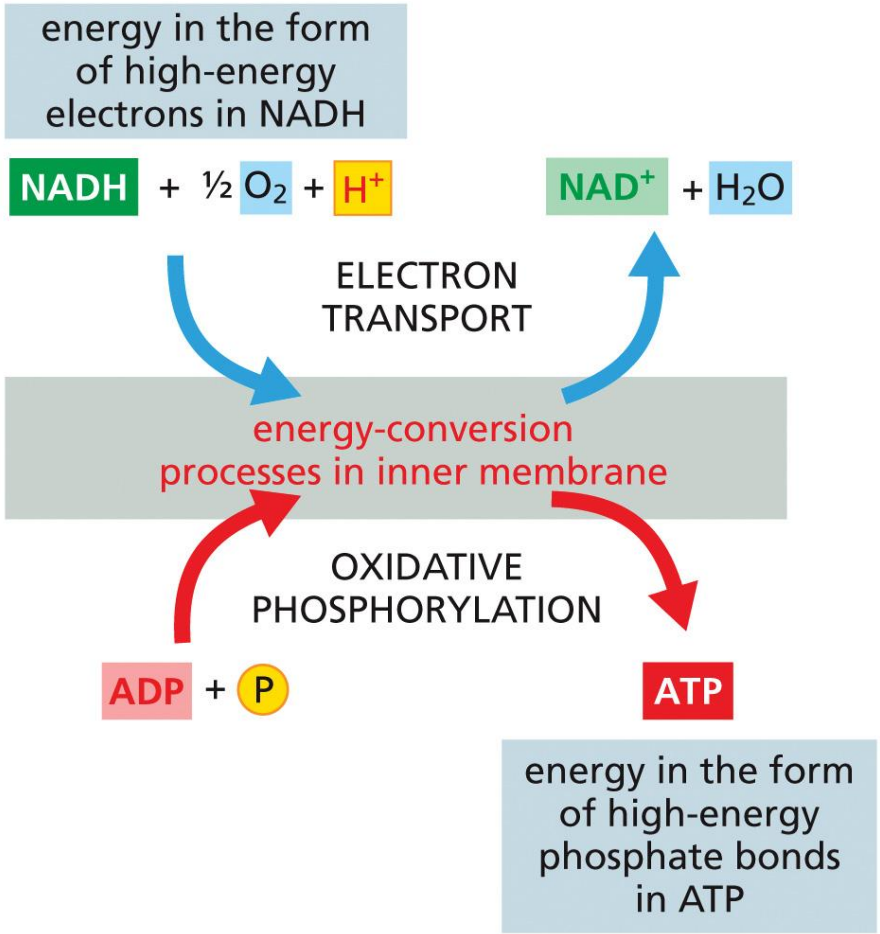


- Elevated expression in high ATP usage body regions (e.g., heart muscle)

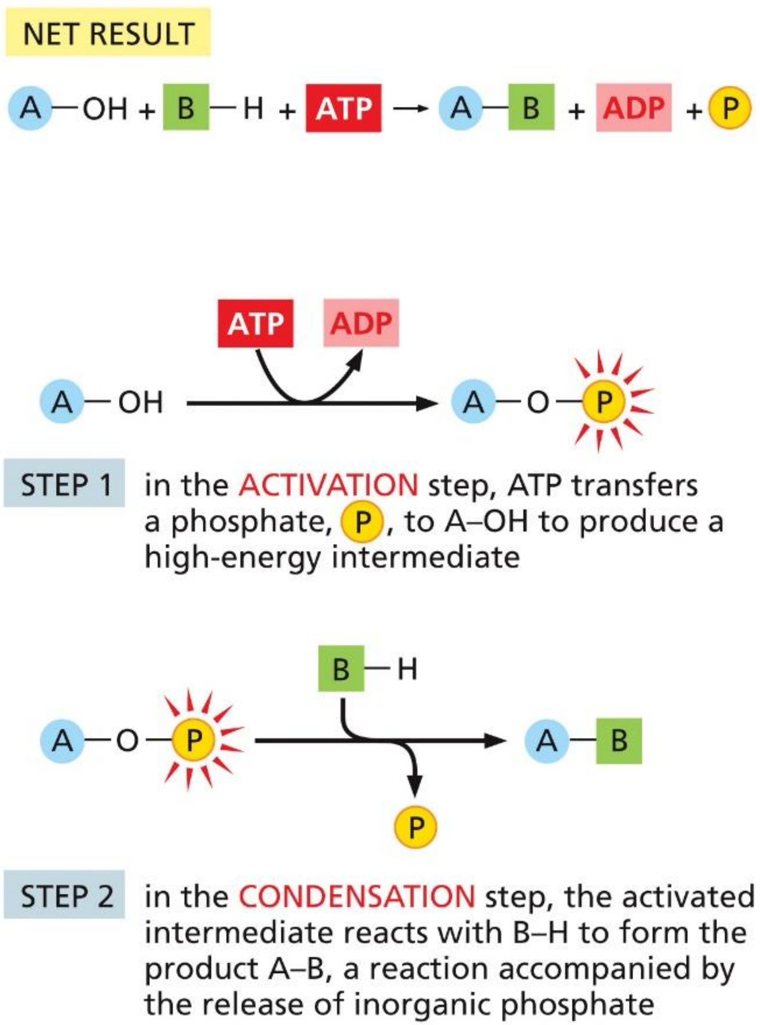


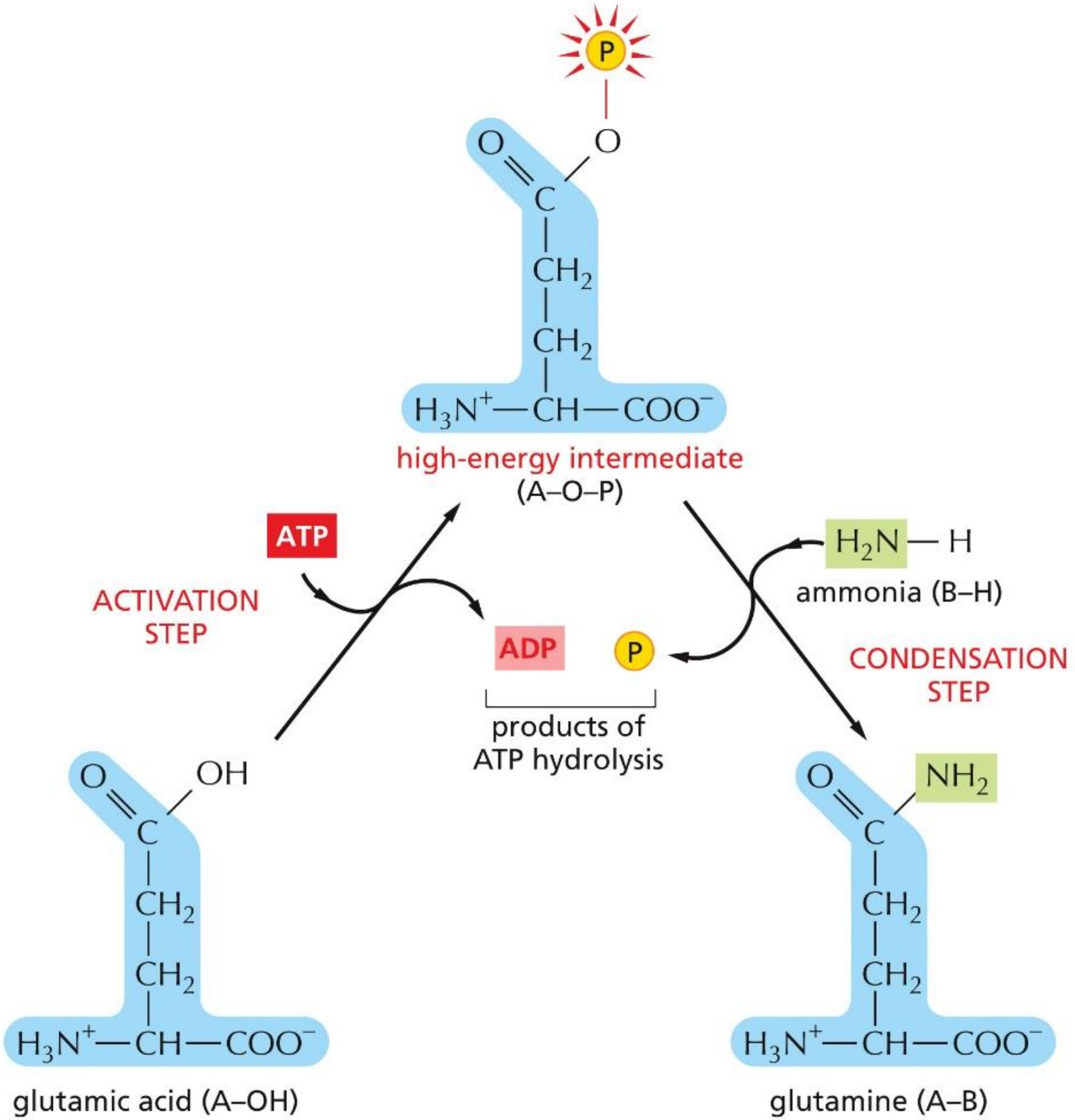
Energy is converted from electrons to phosphate bonds





ATP is a more versatile energy source for our cells, coupling energetically unfavorable reactions to drive them forward



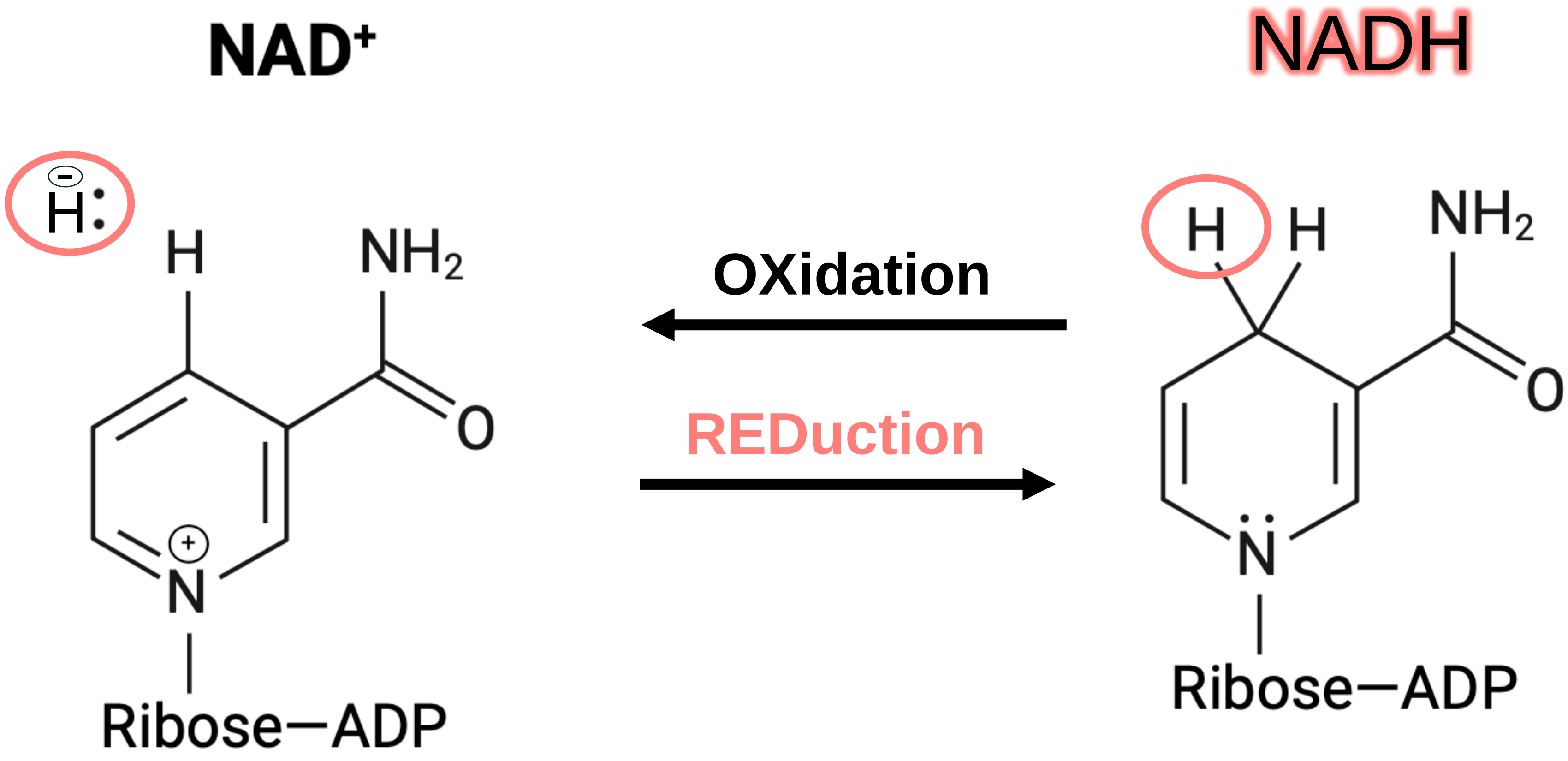


Learning Objectives for Today's Lecture:

Upon completing this module, **you should be able to**:

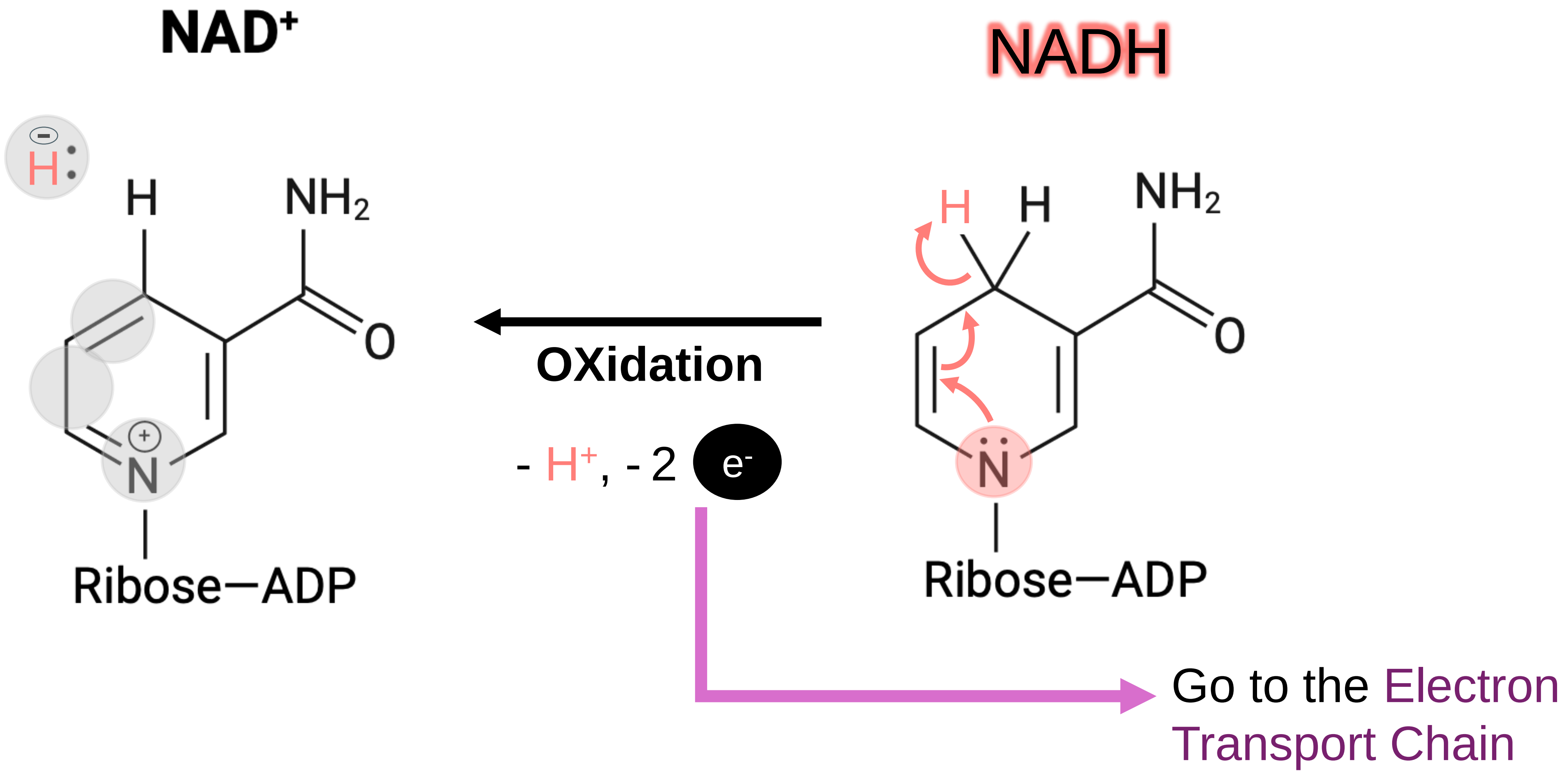
- Describe the key components of mitochondrial **oxidative phosphorylation**
- Establish what **redox potentials** are and connect them to powering the **electron transport chain**
- Understand the generation of the **chemiosmotic potential** and how this drives ATP production
- Compare animal cell energy production with energy production in plant cells via **photosynthesis** in chloroplasts

Activated carrier molecules undergo REDOX reactions



Recall: Oxidation is loss of electrons; Reduction is gain of electrons

Activated carrier molecules undergo REDOX reactions



Redox potentials (electron affinities) are a measure of how easily electrons are transferred

direct measure of the standard free energy change (ΔG)

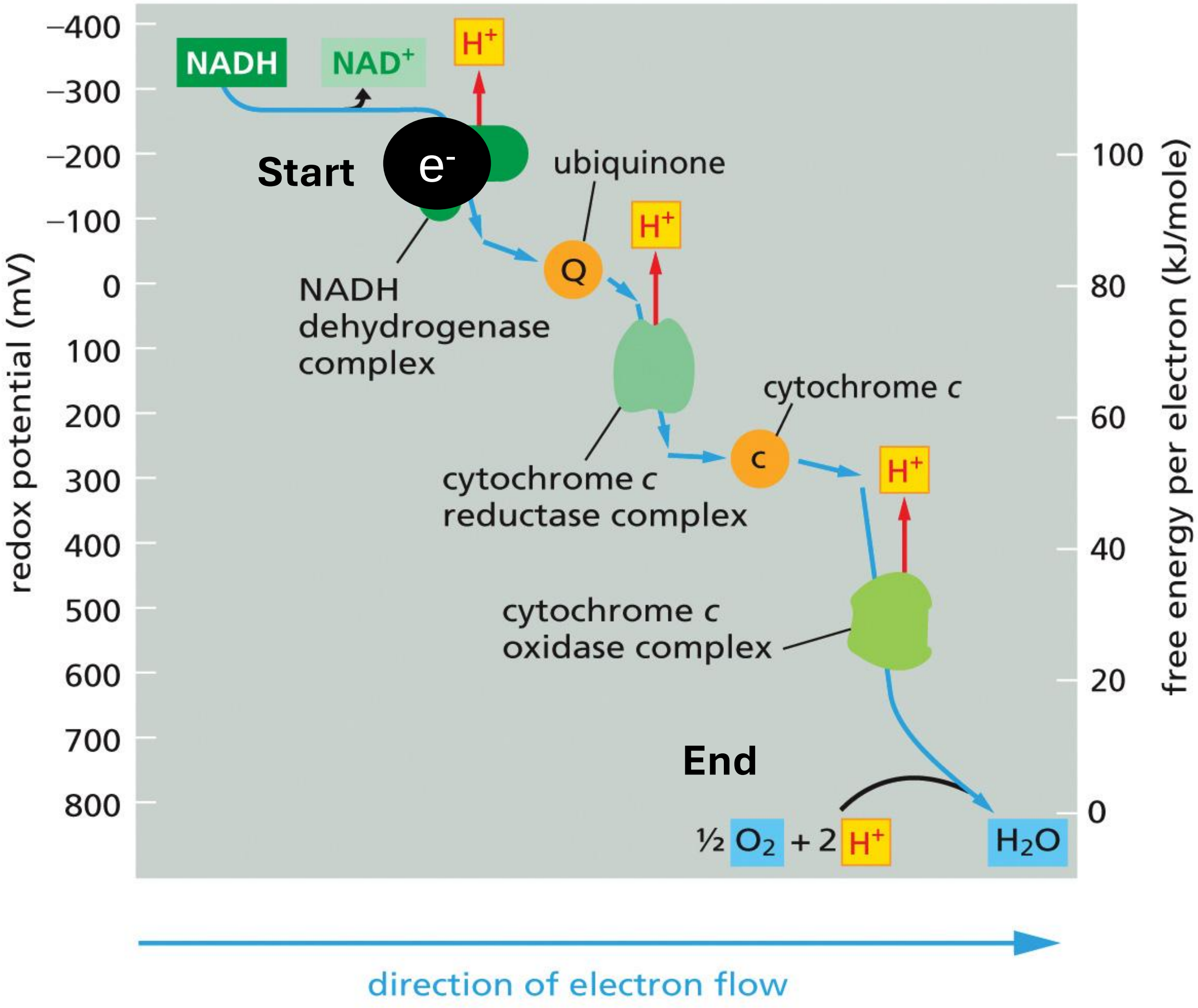
NADH: Strong donor

O_2: Strong affinity for electrons

examples of redox reactions	standard redox potential E'_0
$NADH \rightleftharpoons NAD^+ + H^+ + 2e^-$	–320 mV
reduced ubiquinone $\rightleftharpoons$ oxidized ubiquinone $+ 2H^+ + 2e^-$	+30 mV
reduced cytochrome c $\rightleftharpoons$ oxidized cytochrome c $+ e^-$	+230 mV
$H_2O \rightleftharpoons \frac{1}{2}O_2 + 2H^+ + 2e^-$	+820 mV

Electrons will ***move spontaneously from*** a redox pair with **low redox potential** (NADH/NAD+) **to** a pair with **high redox potential** (O_2/H_2O)

Redox potential **increases** along the mitochondrial electron-transport chain

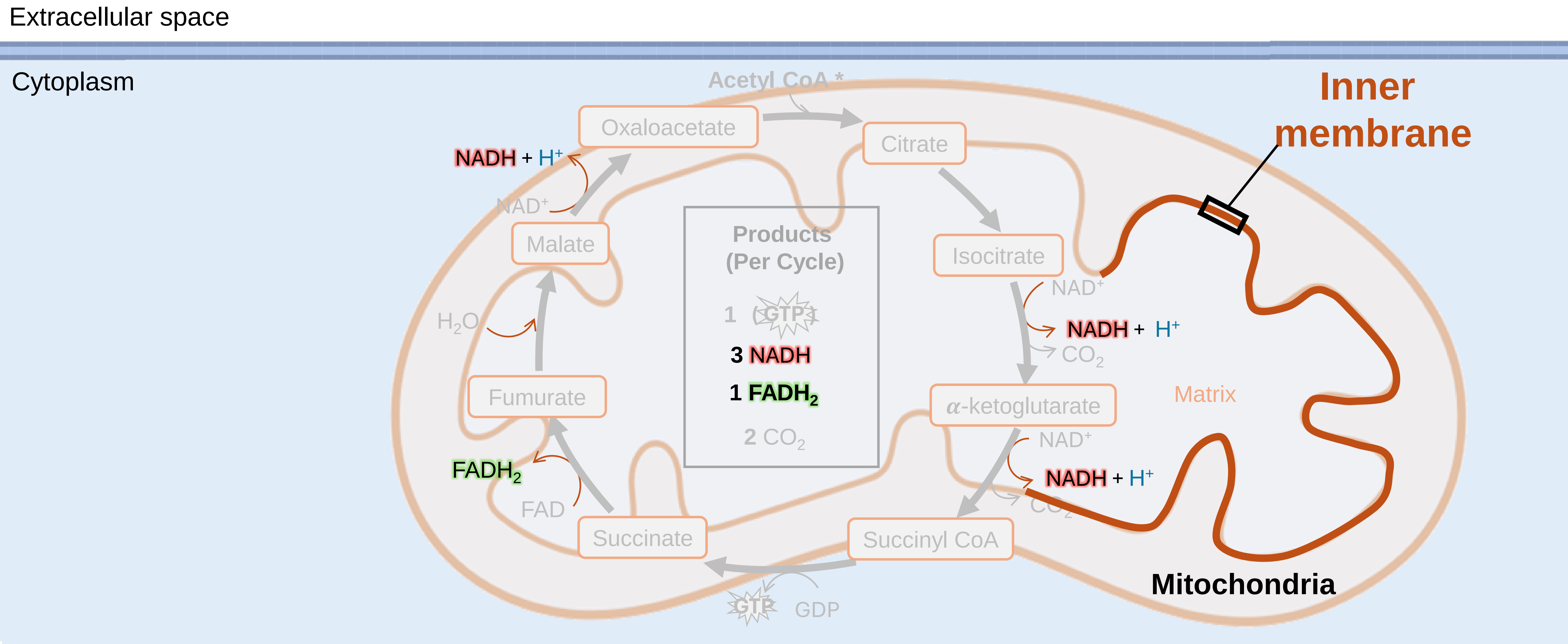


This means electrons spontaneously move through the chain from NADH all the way to oxygen (O_2)

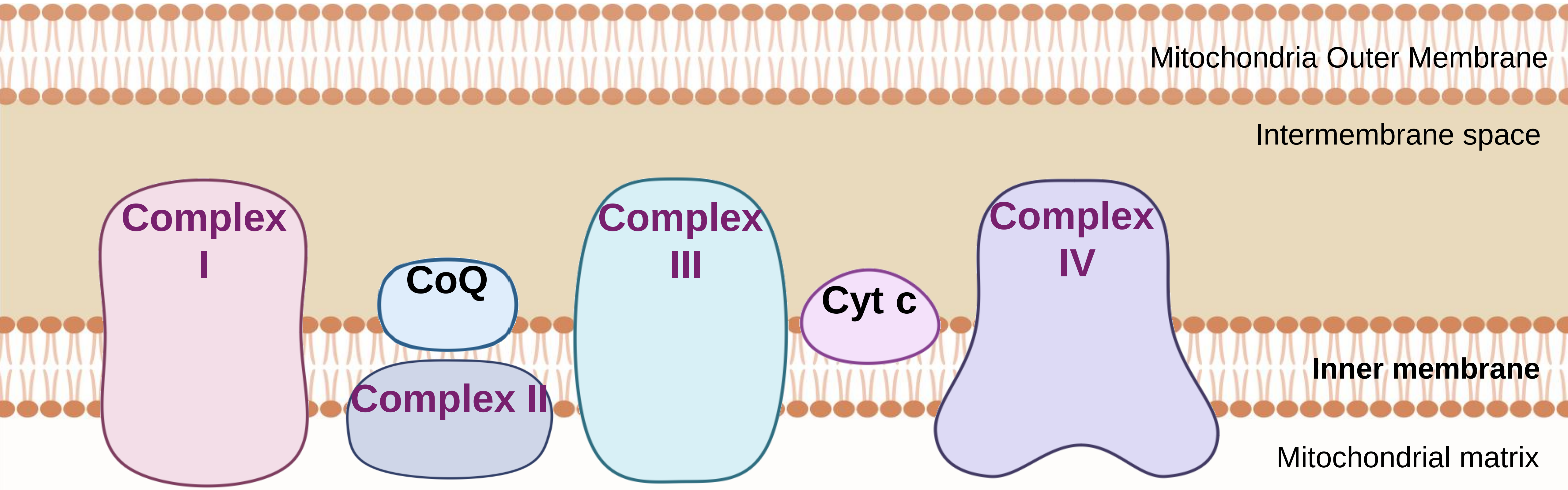
e^- TRANSFER

Electron Transport Chain

The **Electron Transport Chain** resides in the mitochondrial inner membrane



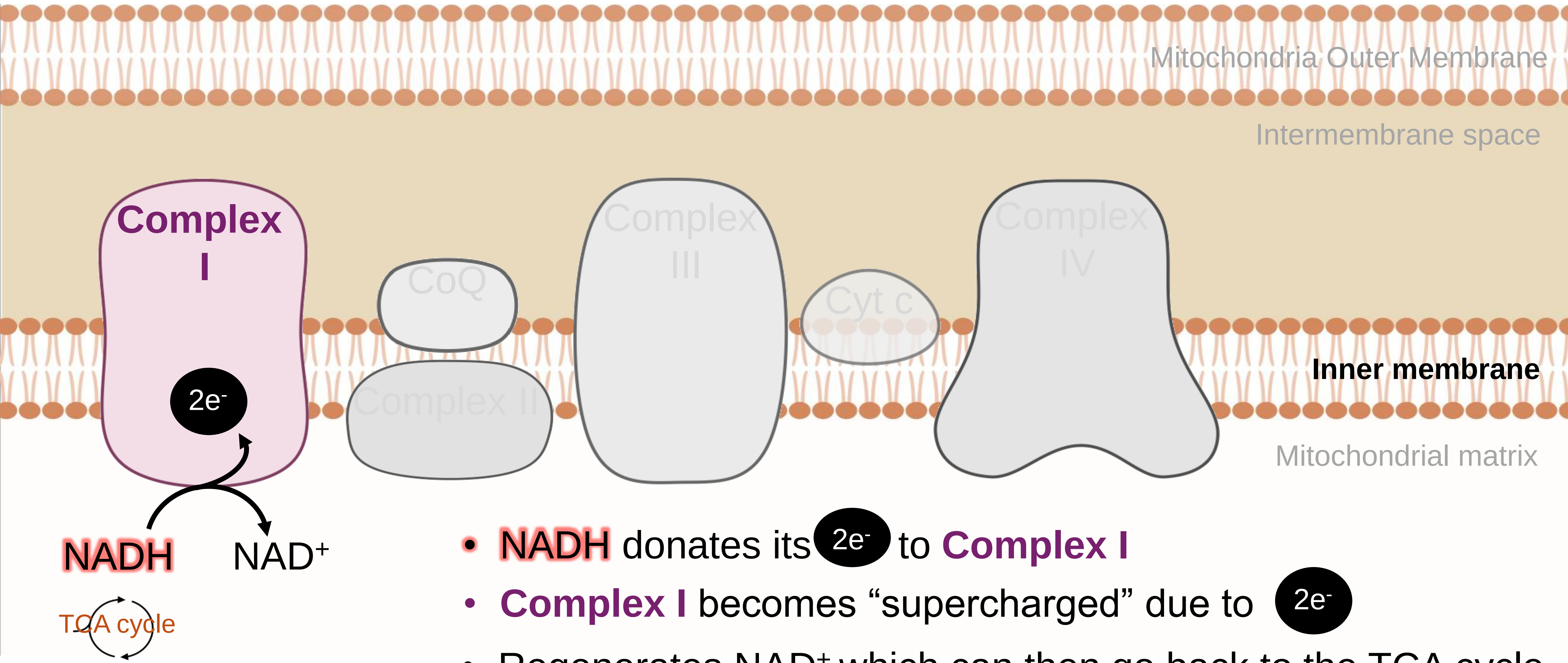
The **Electron Transport Chain** comprises **4 protein complexes** and 2 e⁻ **carrier molecules**



4 protein complexes: **Complex I, II, III,** and **IV**

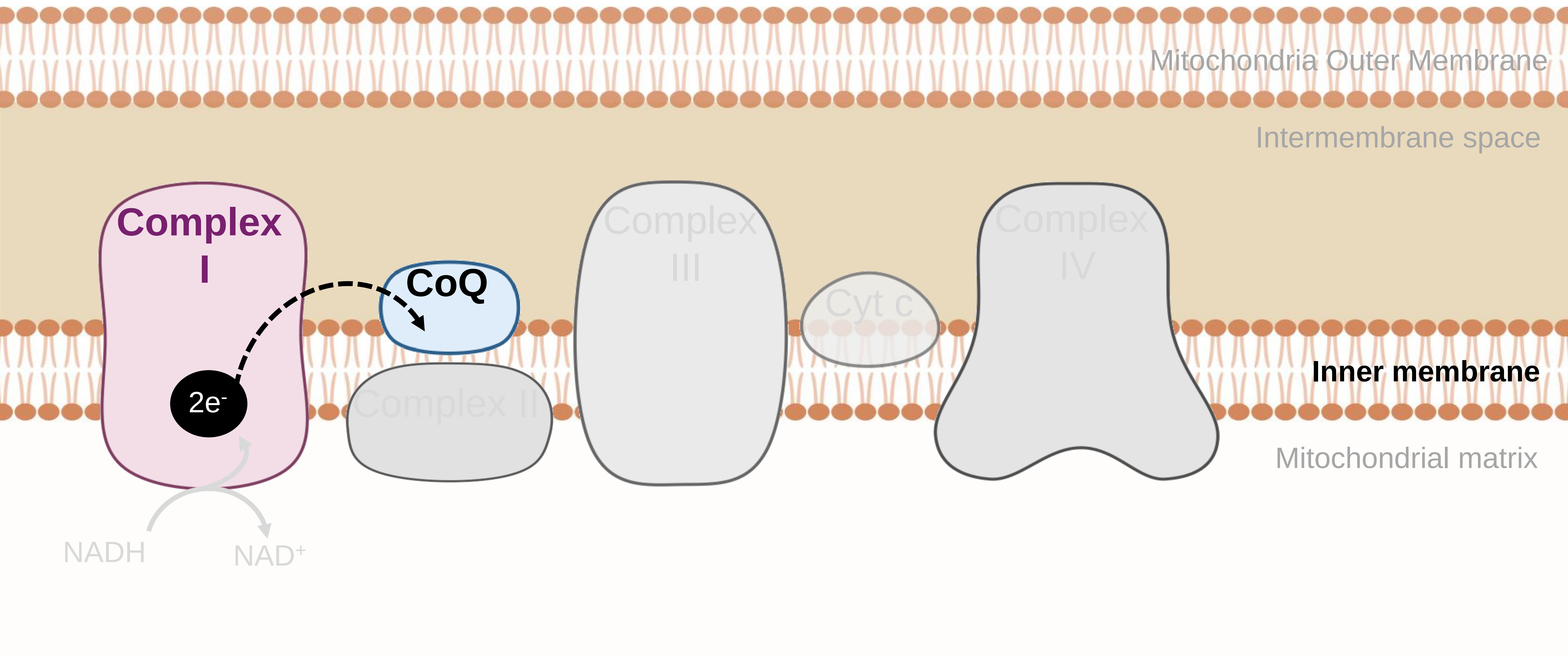
2 e^- carrier molecules: CoenzymeQ (**CoQ**) and cytochrome C (**Cyt c**)

NADH from TCA cycle kicks off the Electron Transport Chain at Complex I

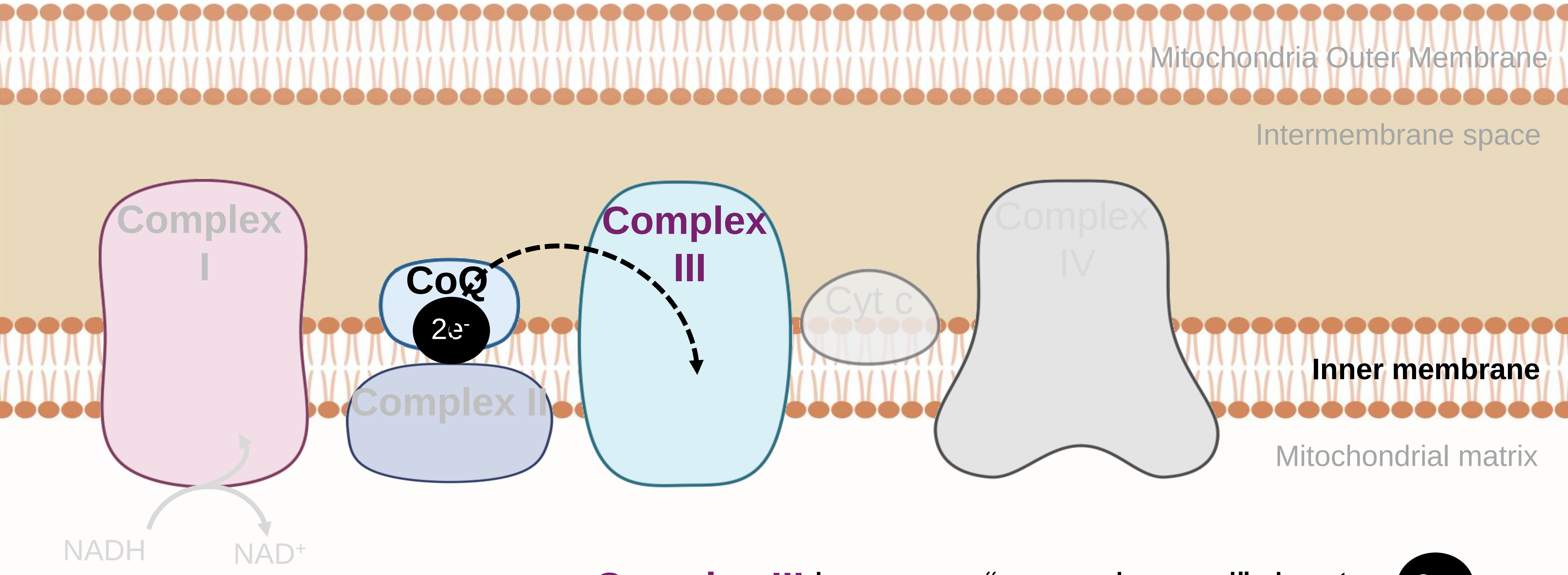


- NADH donates its 2e- to Complex I
- Complex I becomes “supercharged” due to 2e-
- Regenerates NAD^+ which can then go back to the TCA cycle

These 2e⁻ are transferred from **Complex I** to **CoQ** which shuttles them to **Complex III**

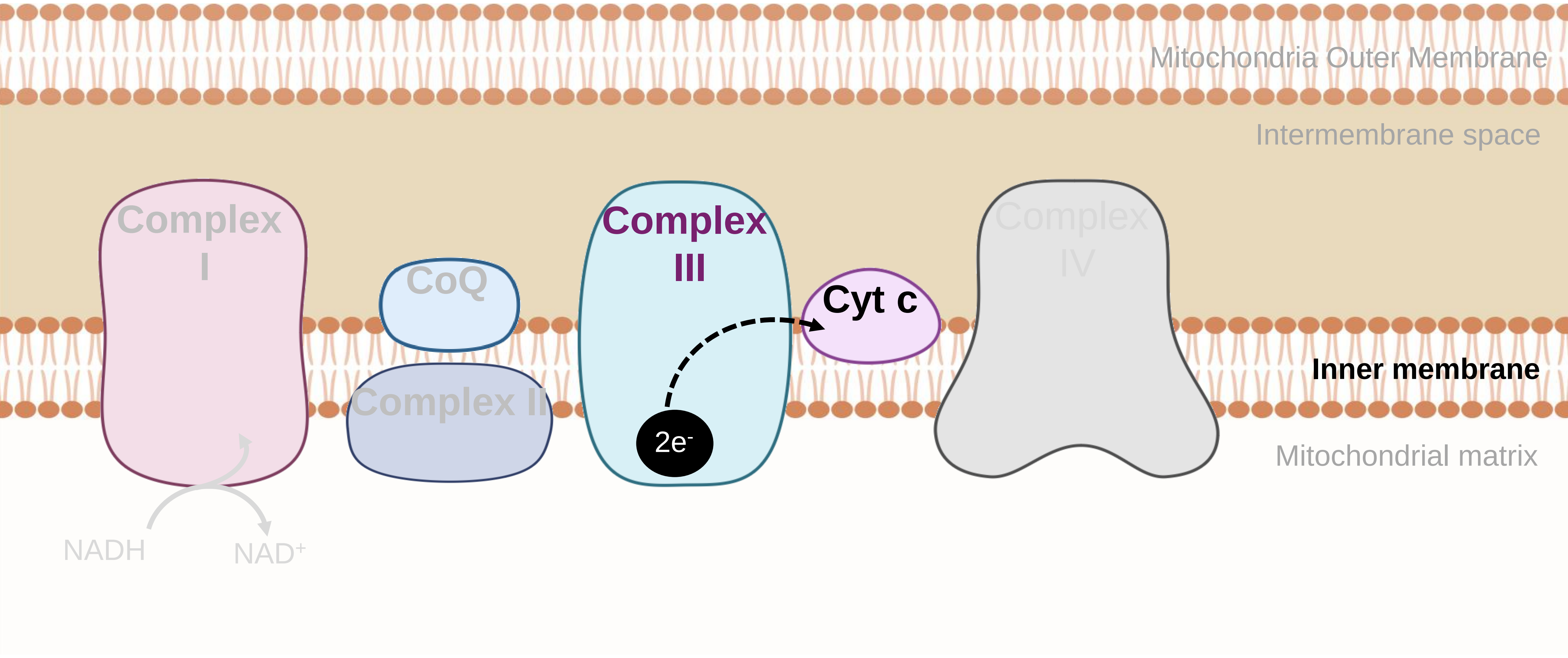


These 2e⁻ are transferred from **Complex I** to **CoQ** which shuttles them to **Complex III**

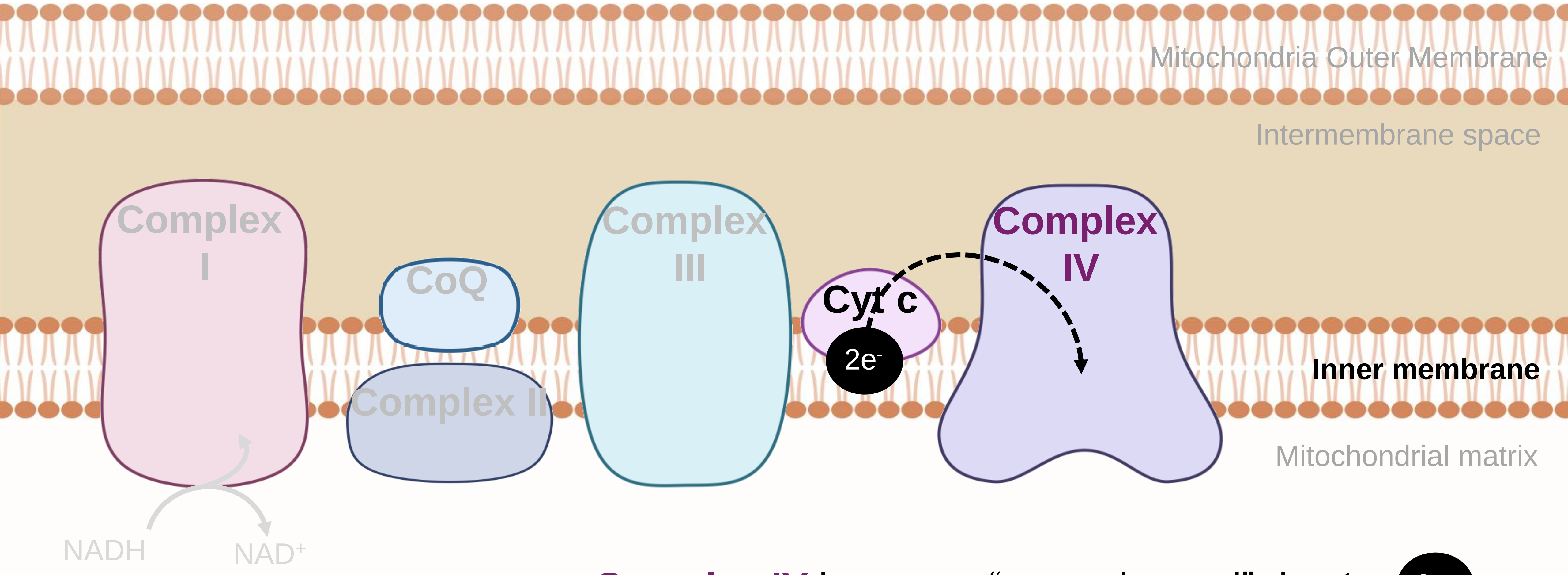


- **Complex III** becomes "supercharged" due to 2e⁻

This process is then continued as **Complex III** transfers its 2e⁻ to **Cyt c** which shuttles them to **Complex IV**

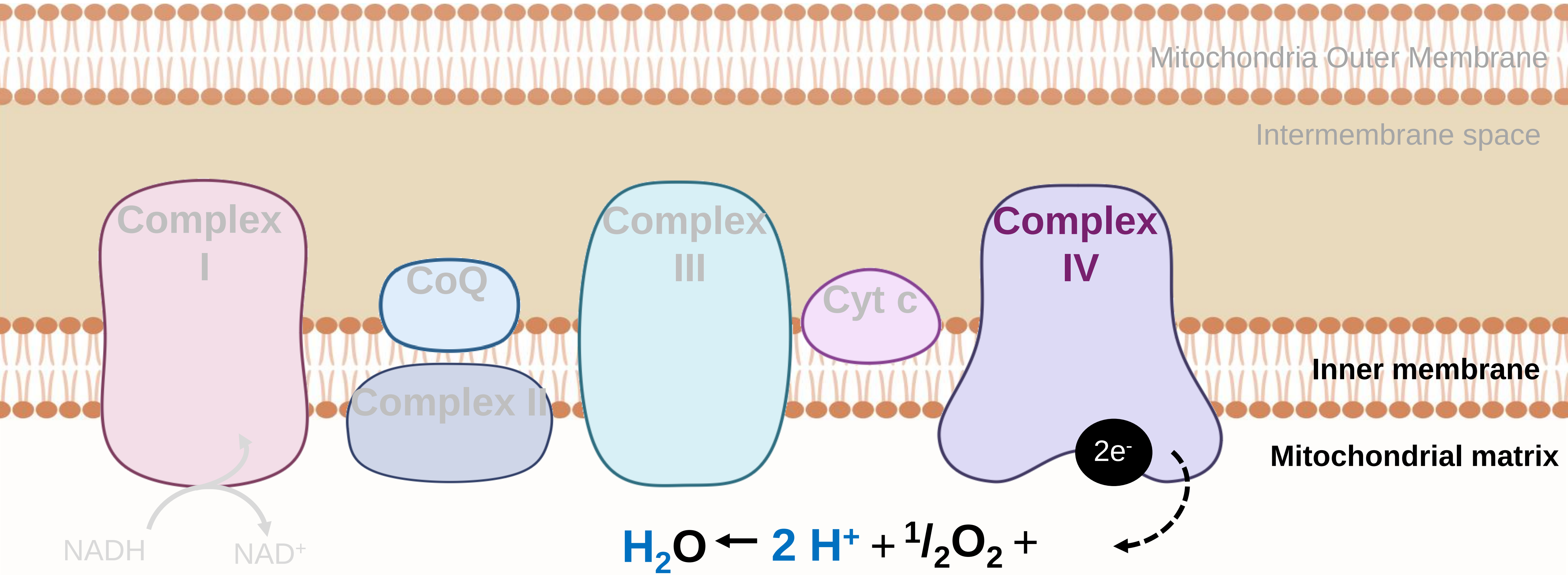


This process is then continued as **Complex III** transfers its 2e⁻ to **Cyt c** which shuttles them to **Complex IV**



- **Complex IV** becomes "supercharged" due to 2e-

Finally, Complex IV transfers its 2e⁻ to O_2, the final e⁻ acceptor



$$H_2O \leftarrow 2\,H^+ + {}^1/_2O_2 +$$

- **O_2** gets reduced to **H_2O** by accepting 2e- and **$2\,H^+$** in the mitochondrial matrix

What's the point of all this? Oh yeah, ATP

e^- TRANSPORT CHAIN

↓ Helps to establish

H^+ ELECTROCHEMICAL GRADIENT

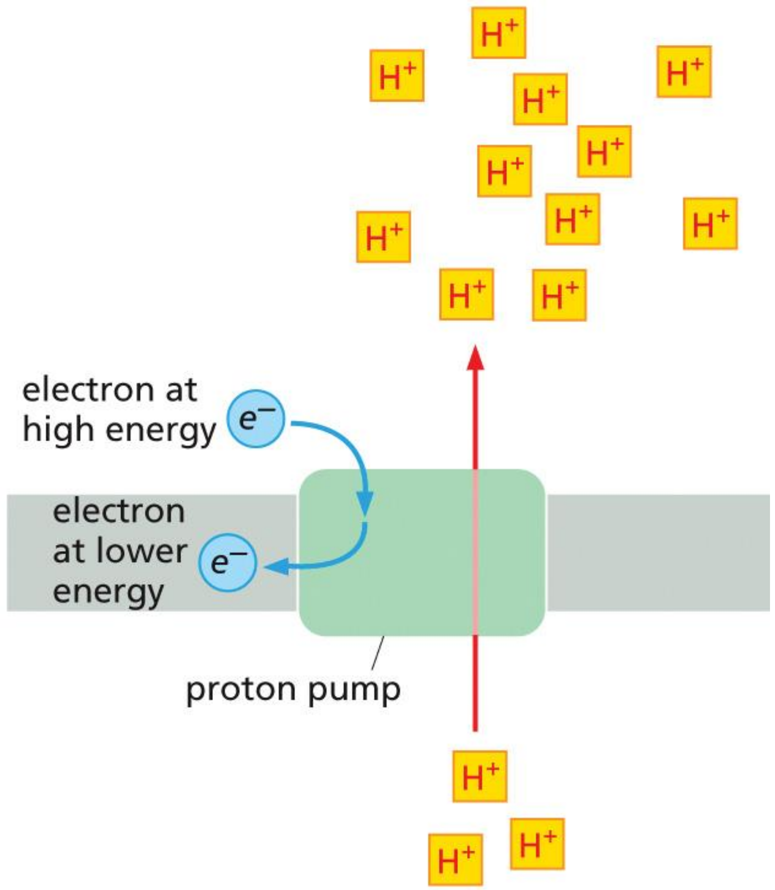
↓ Used for

ATP SYNTHESIS

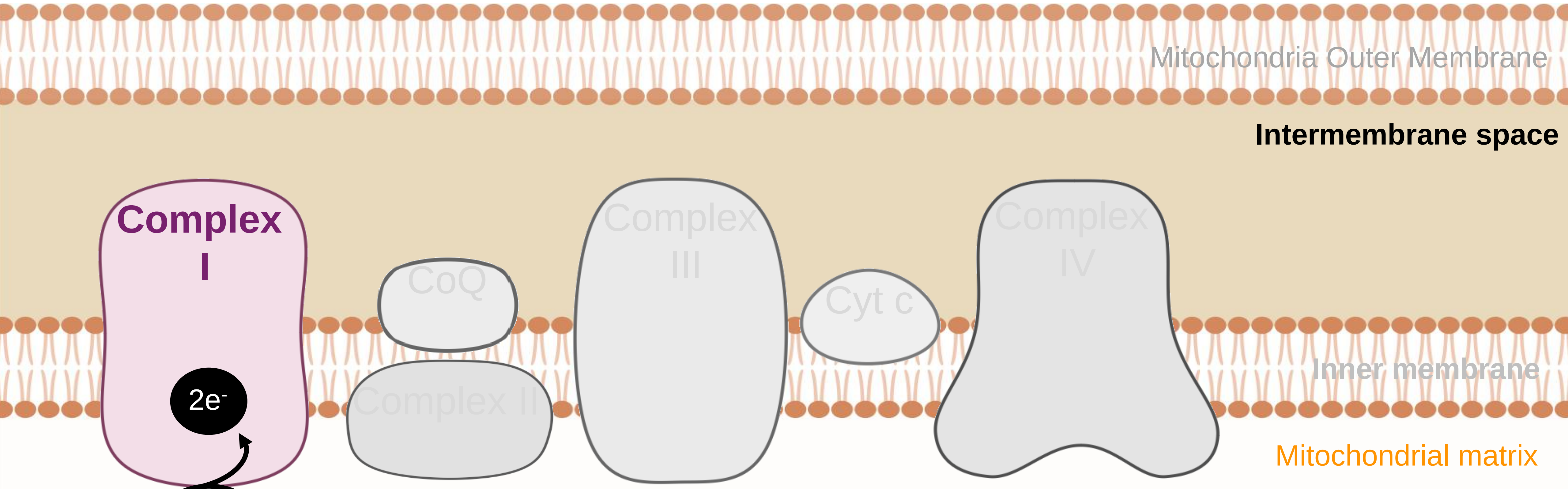
Chemiosmotic coupling

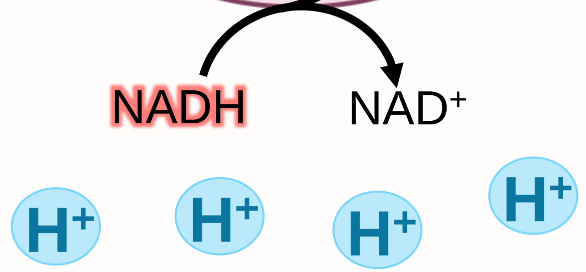
Electron Transfer establishes a Proton Gradient

- Electrons are transferred from carriers with a weak affinity to those with a stronger affinity: *energetically favorable*
- Electrons travel from a high energy state to a low energy state, ***releasing energy to pump protons***
- H+ (protons) are derived from water – ubiquitous in cells



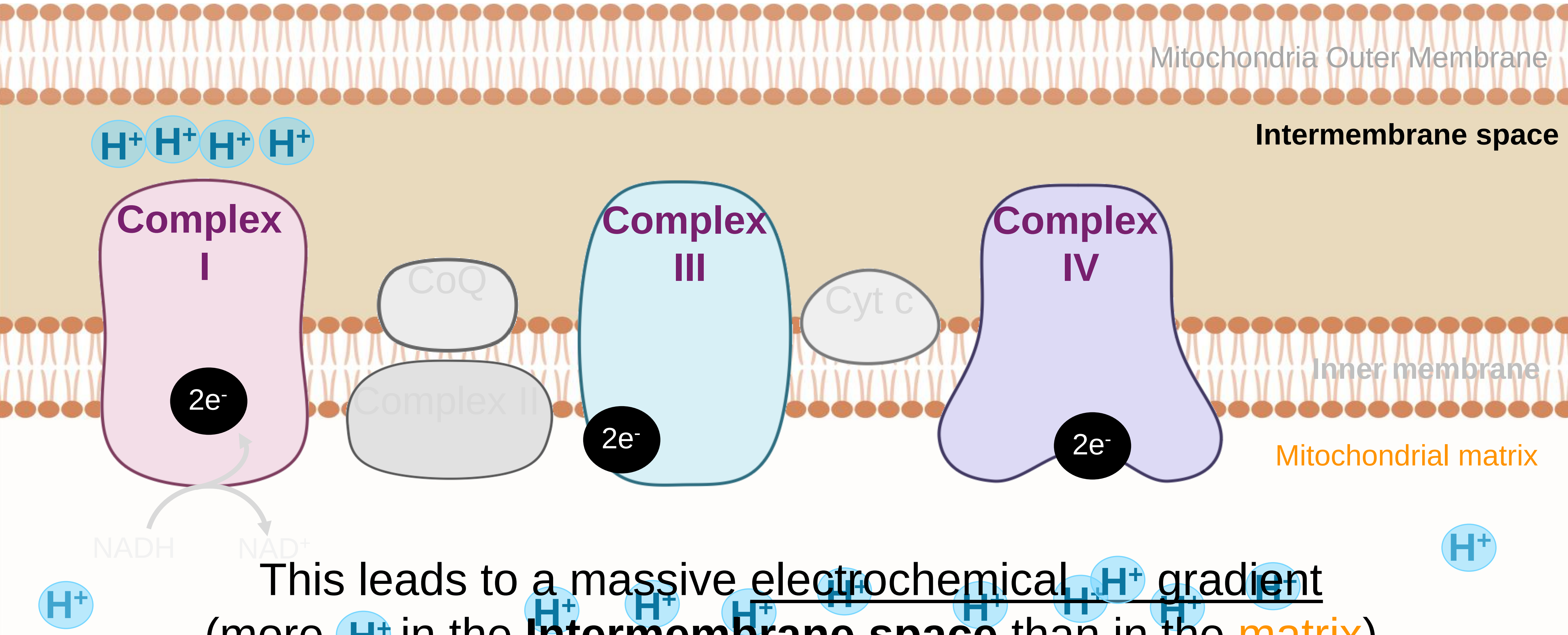
H+ from the mitochondrial matrix are pumped into the Intermembrane space via Complex I





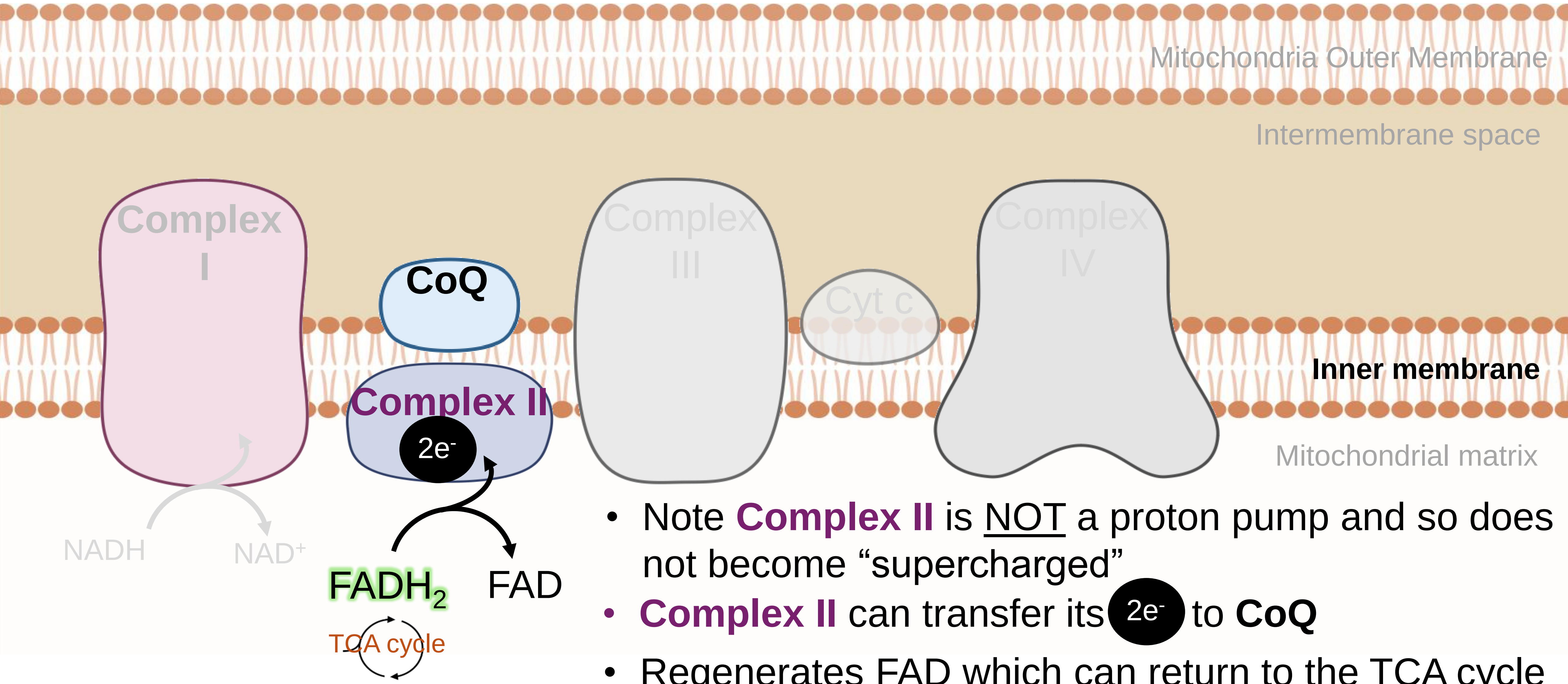
- **Complex I** becomes "supercharged" due to 2e-
- "Supercharged" **Complex I** now has the energy potential to pump H+ into the **Intermembrane Space**

H^+ from the mitochondrial matrix are pumped into the **Intermembrane space** via **Complex I, III** and **IV**



This leads to a massive electrochemical H^+ gradient
(more H^+ in the **Intermembrane space** than in the matrix)

$FADH_2$ from the TCA cycle transfers its 2e⁻ to Complex II



- Note **Complex II** is NOT a proton pump and so does not become "supercharged"
- **Complex II** can transfer its 2e⁻ to **CoQ**
- Regenerates FAD which can return to the TCA cycle

Squarecap Q#1-2

Learning Objectives for Today's Lecture:

Upon completing this module, **you should be able to**:

- Describe the key components of mitochondrial **oxidative phosphorylation**
- Establish what **redox potentials** are and connect them to powering the **electron transport chain**
- Understand the generation of the **chemiosmotic potential** and how this drives ATP production
- Compare animal cell energy production with energy production in plant cells via **photosynthesis** in chloroplasts

Key Steps in Oxidative Phosphorylation

e^- TRANSPORT CHAIN

Helps to establish

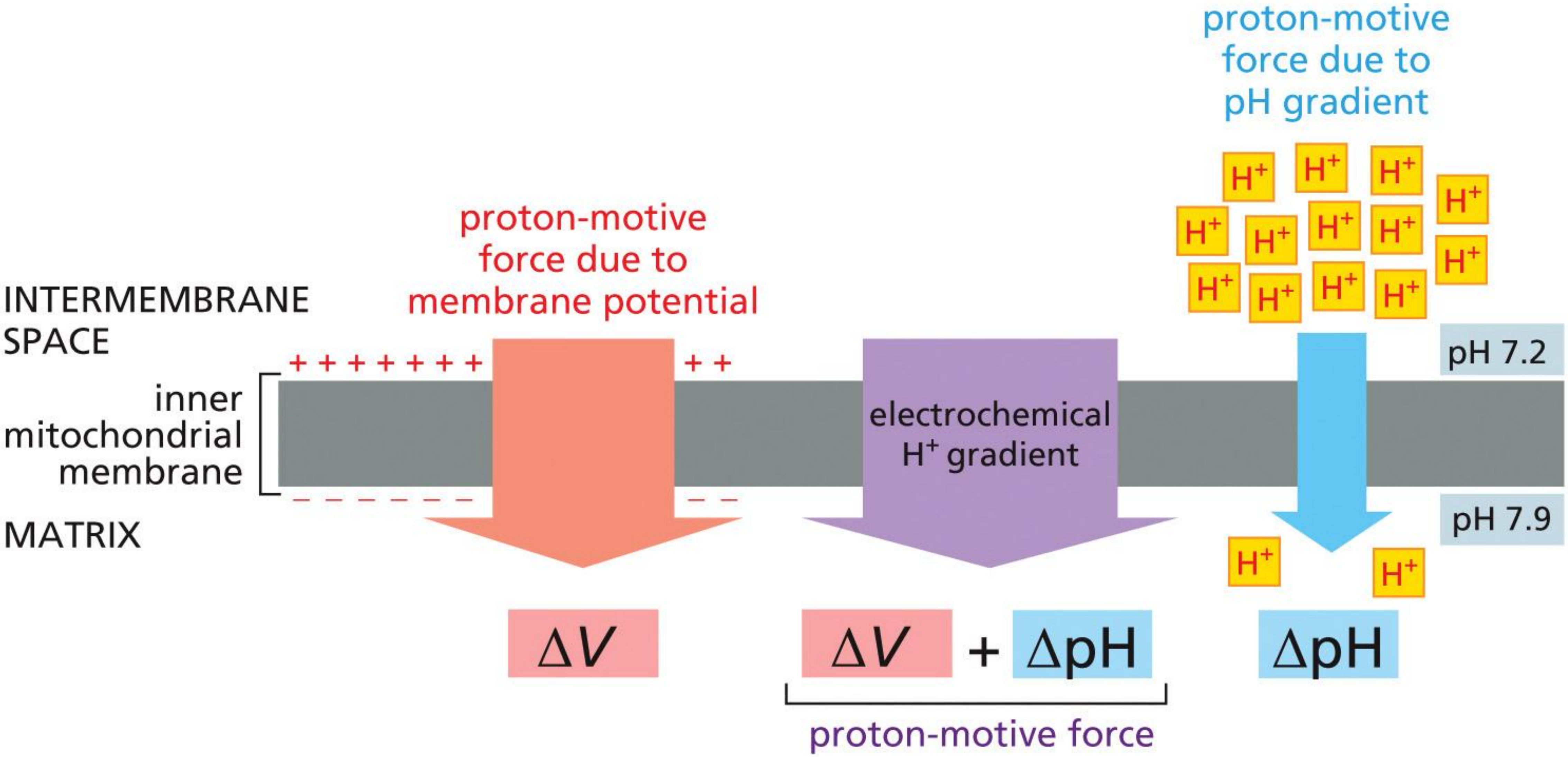
H^+ ELECTROCHEMICAL GRADIENT

Used for

ATP SYNTHESIS

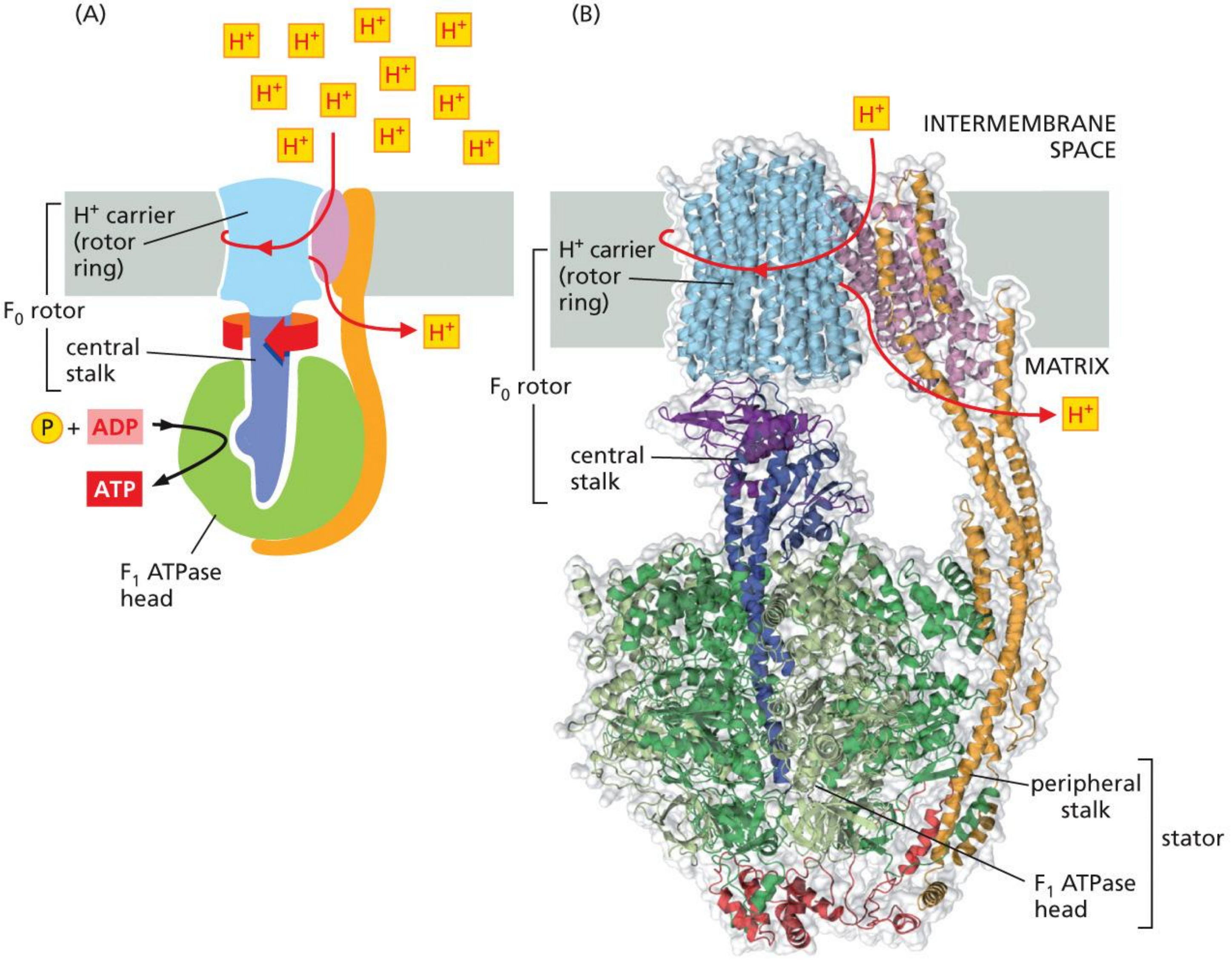
Chemiosmotic coupling

Both a *membrane potential* (ΔV) and *concentration gradient* (ΔpH) drive H^+ movement: the ***proton-motive force***

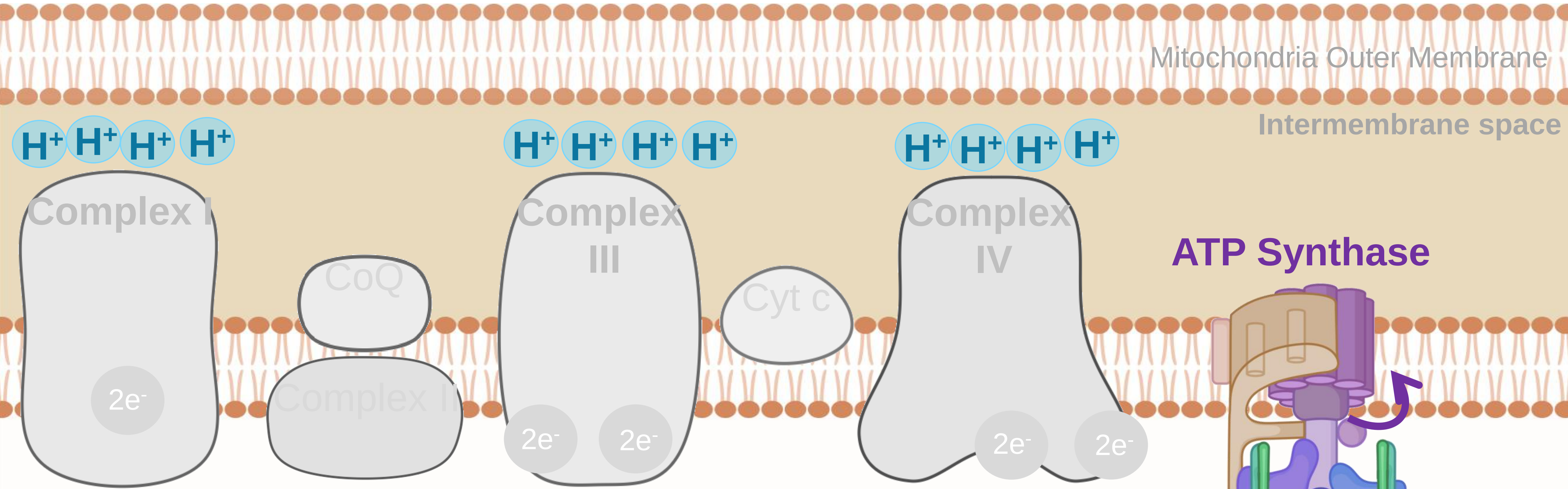


The proton-motive force drives the enzyme **ATP Synthase** to produce ATP

- ATP synthase acts like a rotor to convert energy of proton flow into the mitochondrial matrix to ATP
- Very efficient process (100 ATPs per second)



Energy stored in the electrochemical H+ gradient is also **used to synthesize ATP in the mitochondria**



- This process is known as **"Chemiosmotic Coupling"**
  Coupling the movement of H+ across the **Inner membrane** in order to generate **ATP**

H+

- ~ **32-38 ATP molecules produced per 1 molecule of glucose!**

https://www.youtube.com/watch?v=CN2XOe_c0iM

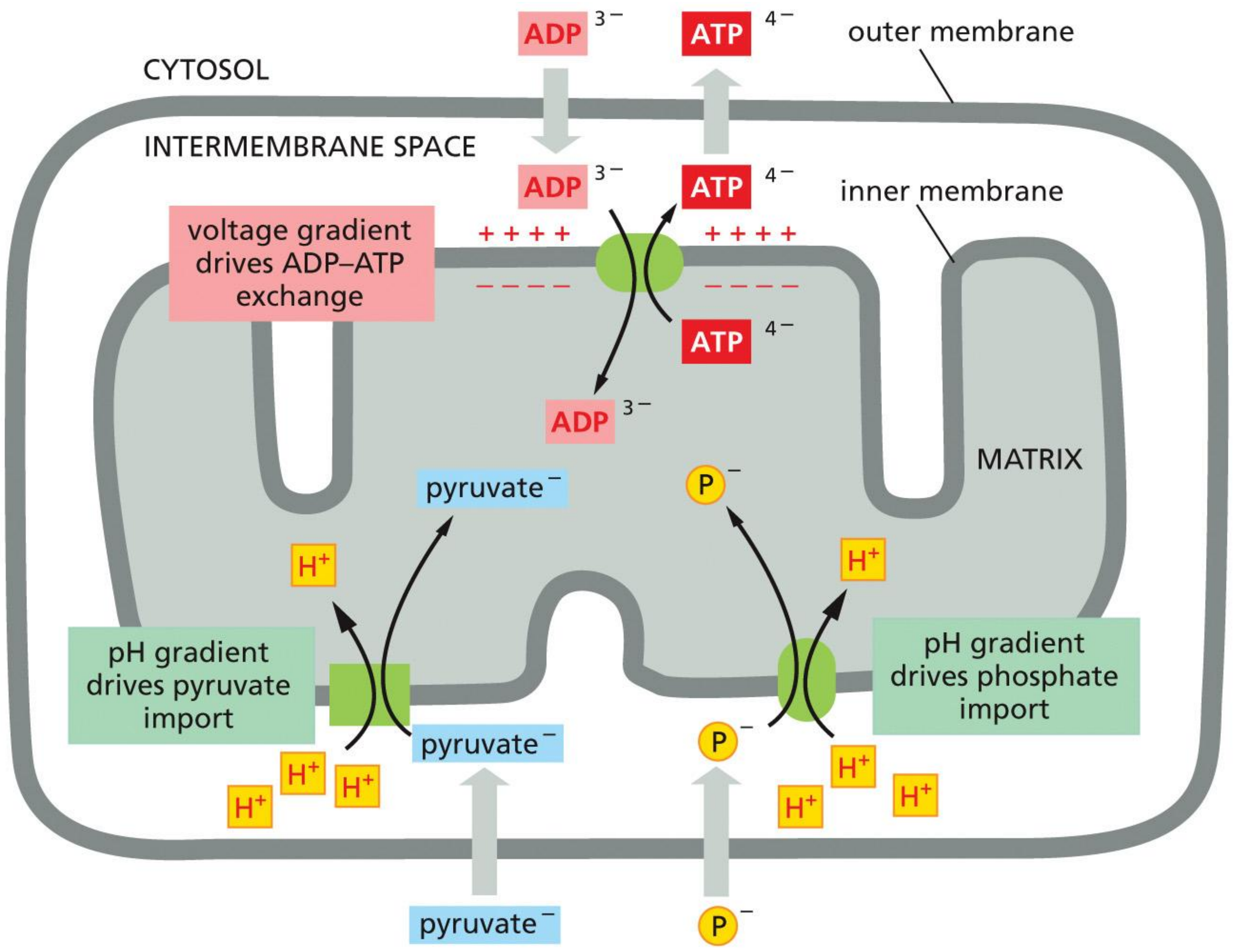
Estimated values of ATP produced at various stages of cellular respiration

TABLE 14–1 PRODUCT YIELDS FROM GLUCOSE OXIDATION		
Process	**Direct Product**	**Final ATP Yield per Glucose**
Glycolysis	2 NADH (cytosolic)	3*
	2 ATP	2
Pyruvate oxidation to acetyl CoA (two per glucose)	2 NADH (mitochondrial matrix)	5
Complete oxidation of the acetyl group of acetyl CoA (two per glucose)	6 NADH (mitochondrial matrix)	15
	2 $FADH_2$	3
	2 GTP	2
	TOTAL	30

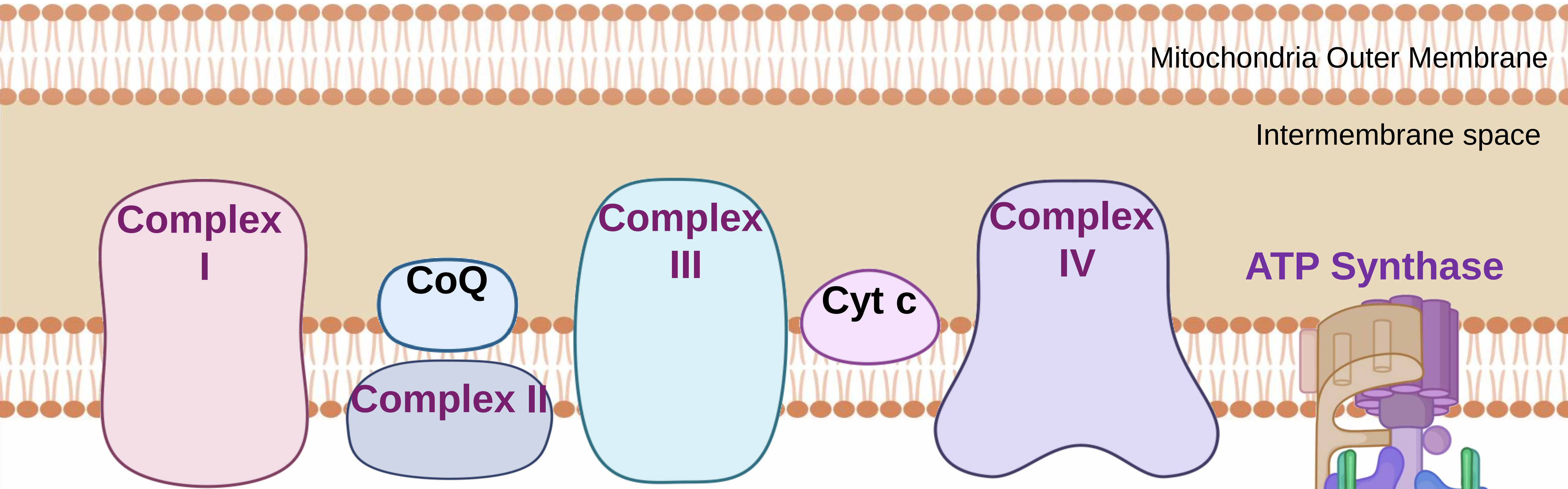
*NADH produced in the cytosol yields fewer ATP molecules thanNADH produced in the mitochondrial matrix because the mitochondrial inner membrane is impermeable to NADH. Transporting NADH into the mitochondrial matrix—where it can pass electrons to NADH dehydrogenase—thus requires energy.

These values are assuming 2.5 ATP per NADH and 1.5 ATP per $FADH_2$ instead of 3 and 2, respectively

Electrochemical proton gradient drives transport of other molecules across membrane as well



Mitochondria are crucial for cellular energy and survival



- Disruption of **Oxidative Phosphorylation** can lead to mitochondrial dysfunction
- Examples include: **Uncoupling agents**, **Electron Transport Chain** inhibitors and **Complex** inhibitors

2,4-Dinitrophenol (DNP)

- One of the first weight loss drugs of the 1900s

- Acts to uncouple oxidative phosphorylation by dissipating the proton gradient across the mitochondrial membrane

- Causes rapid loss of ATP as heat and uncontrolled hyperthermia

Men'sHealth HEALTH ENTERTAINMENT FITNESS STYLE GROOMING Search SUBSCRIBE

Weight Loss > Bodybuilding

A Bodybuilder Died After Taking DNP, a Weight Loss Drug That's Slowly Killing Fit Young Men

DNP has been illegal for years— but that didn't stop 24-year-old bodybuilder Liam Willis from buying it online

BY REEGAN VON WILDENRADT PUBLISHED: DEC 8, 2017

DNP: the return of a deadly weight-loss drug

How could a chemical used a century ago in explosives come to be used by bodybuilders to lose weight? The story of dinitrophenol illustrates the fatal allure of slimming drugs

DNP: the dangerous diet pill pharmacists should know about

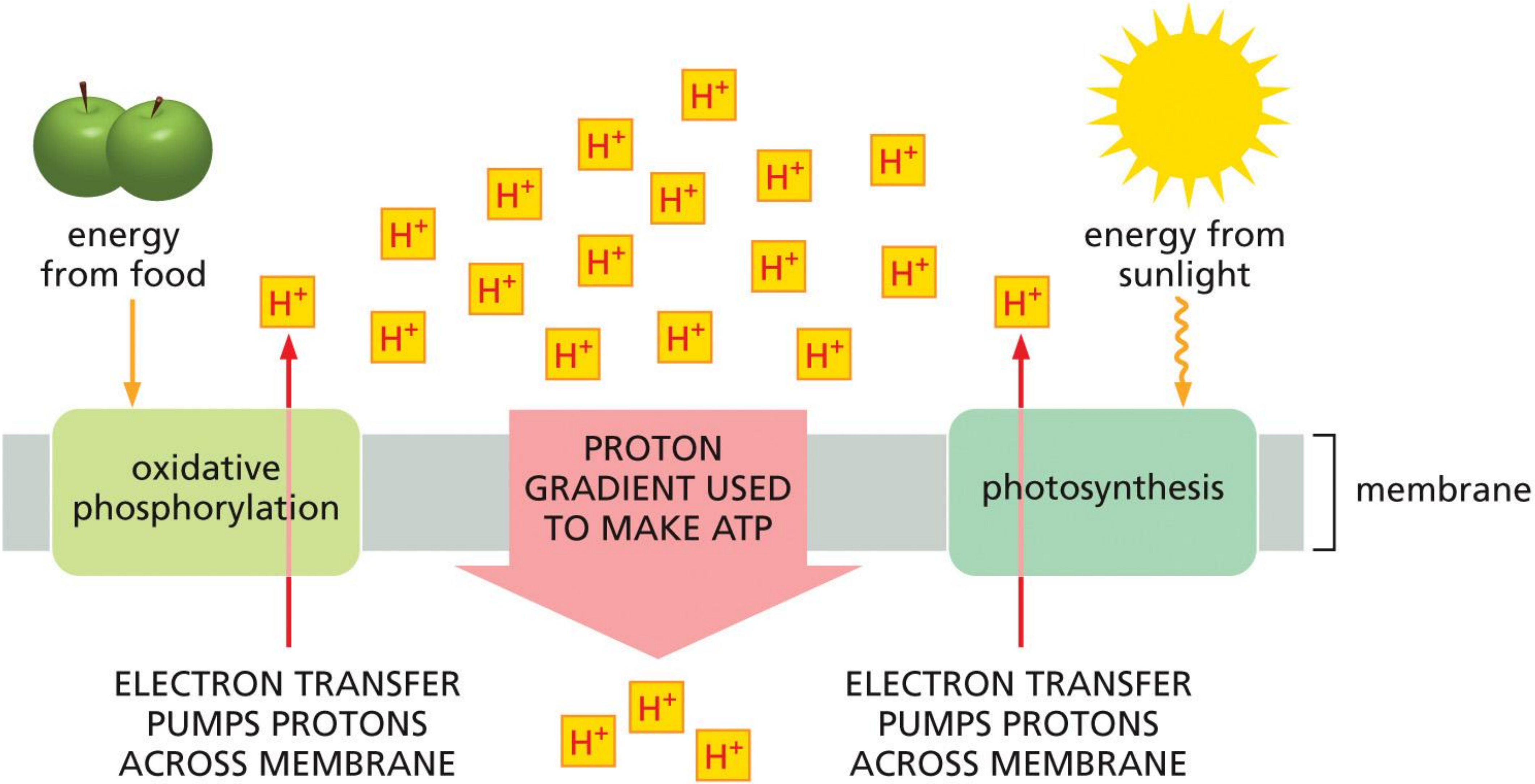
As concerns over deaths related to the diet pill 2,4-dinitrophenol (DNP) increase, healthcare professionals — including pharmacists — are being called on to play their part in raising awareness and preventing DNP-related harm.

Learning Objectives for Today's Lecture:

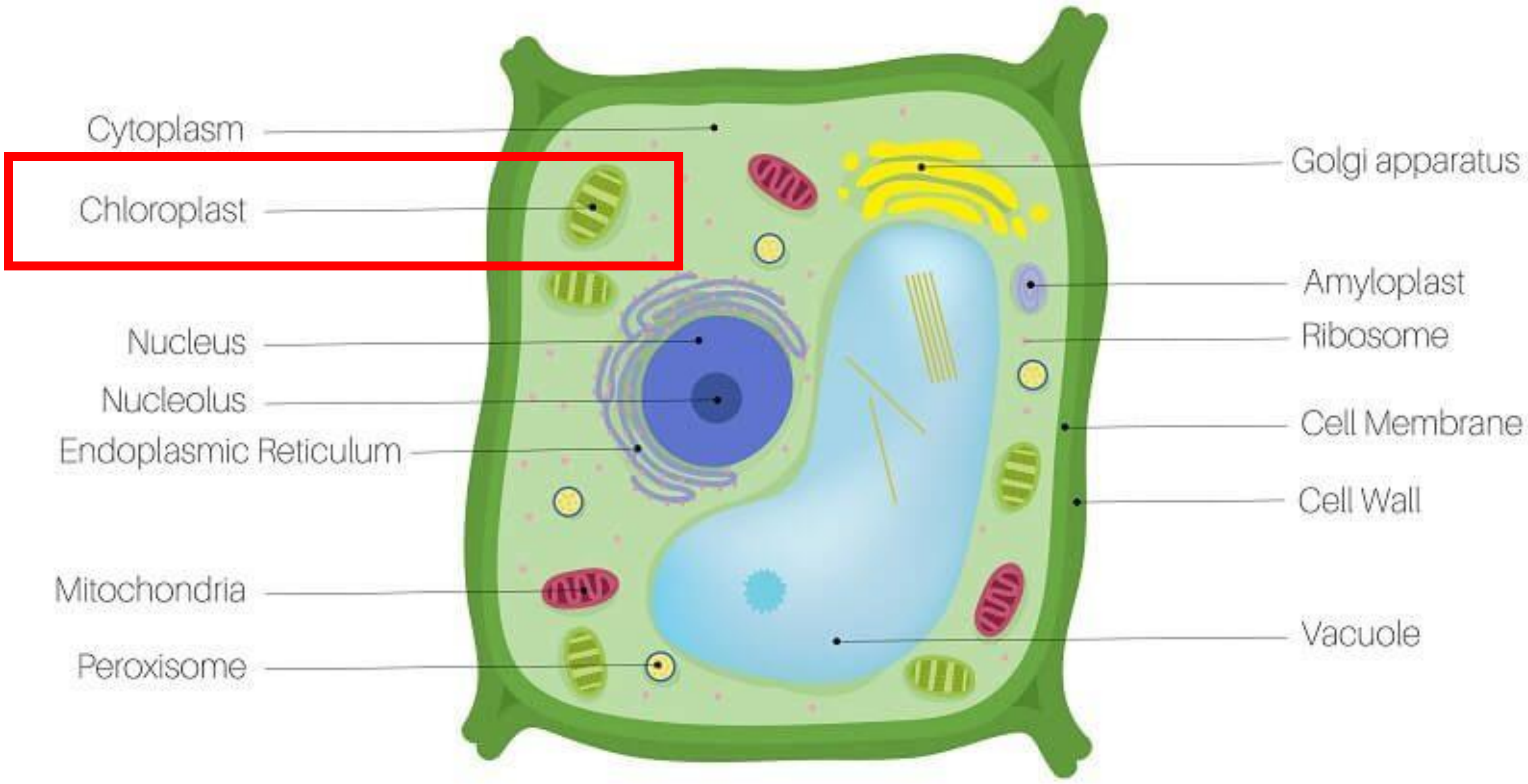
Upon completing this module, **you should be able to**:

- Describe the key components of mitochondrial **oxidative phosphorylation**
- Establish what **redox potentials** are and connect them to powering the **electron transport chain**
- Understand the generation of the **chemiosmotic potential** and how this drives ATP production
- Compare animal cell energy production with energy production in plant cells via **photosynthesis** in chloroplasts

Energy production in photosynthetic organisms uses energy from sunlight



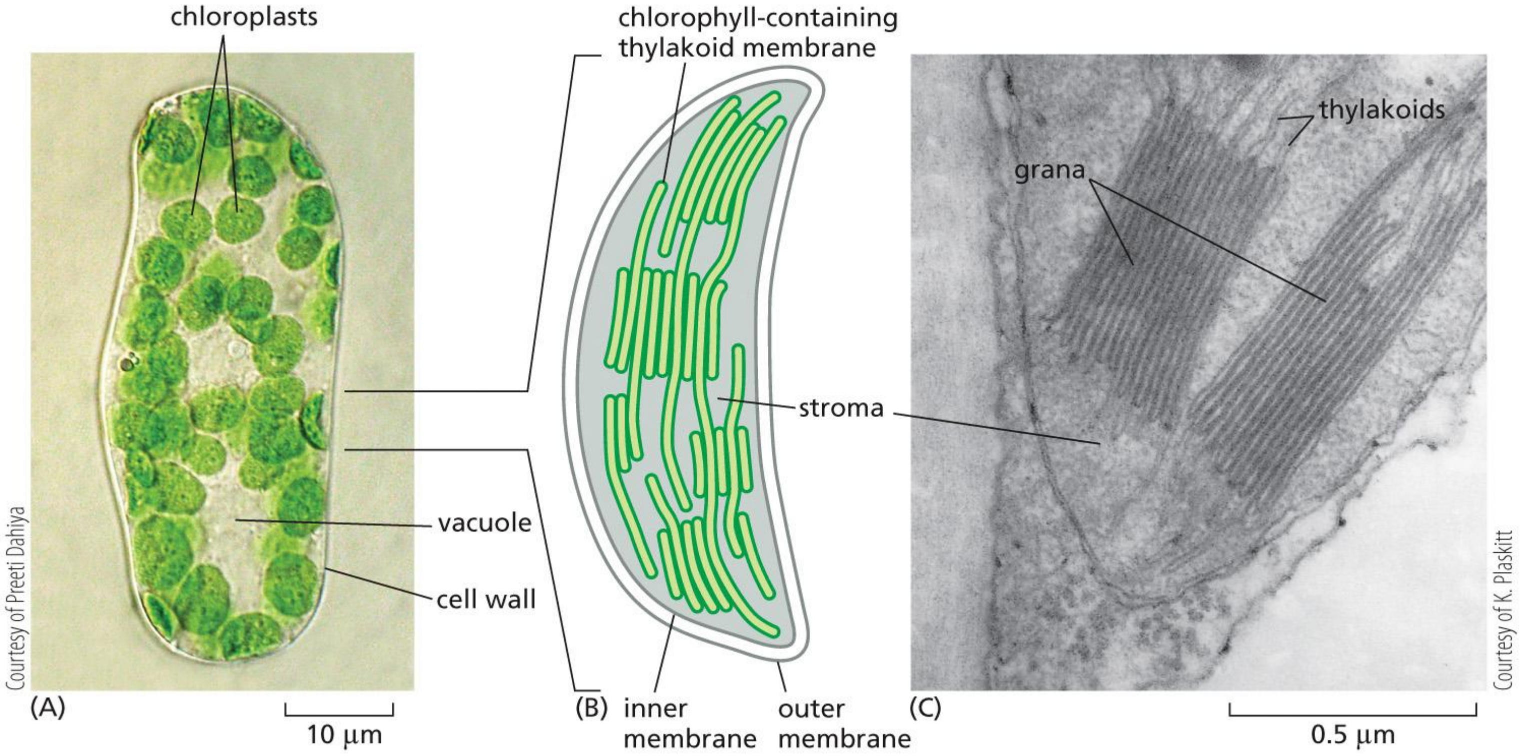
Energy generation in plant cells: the chloroplast



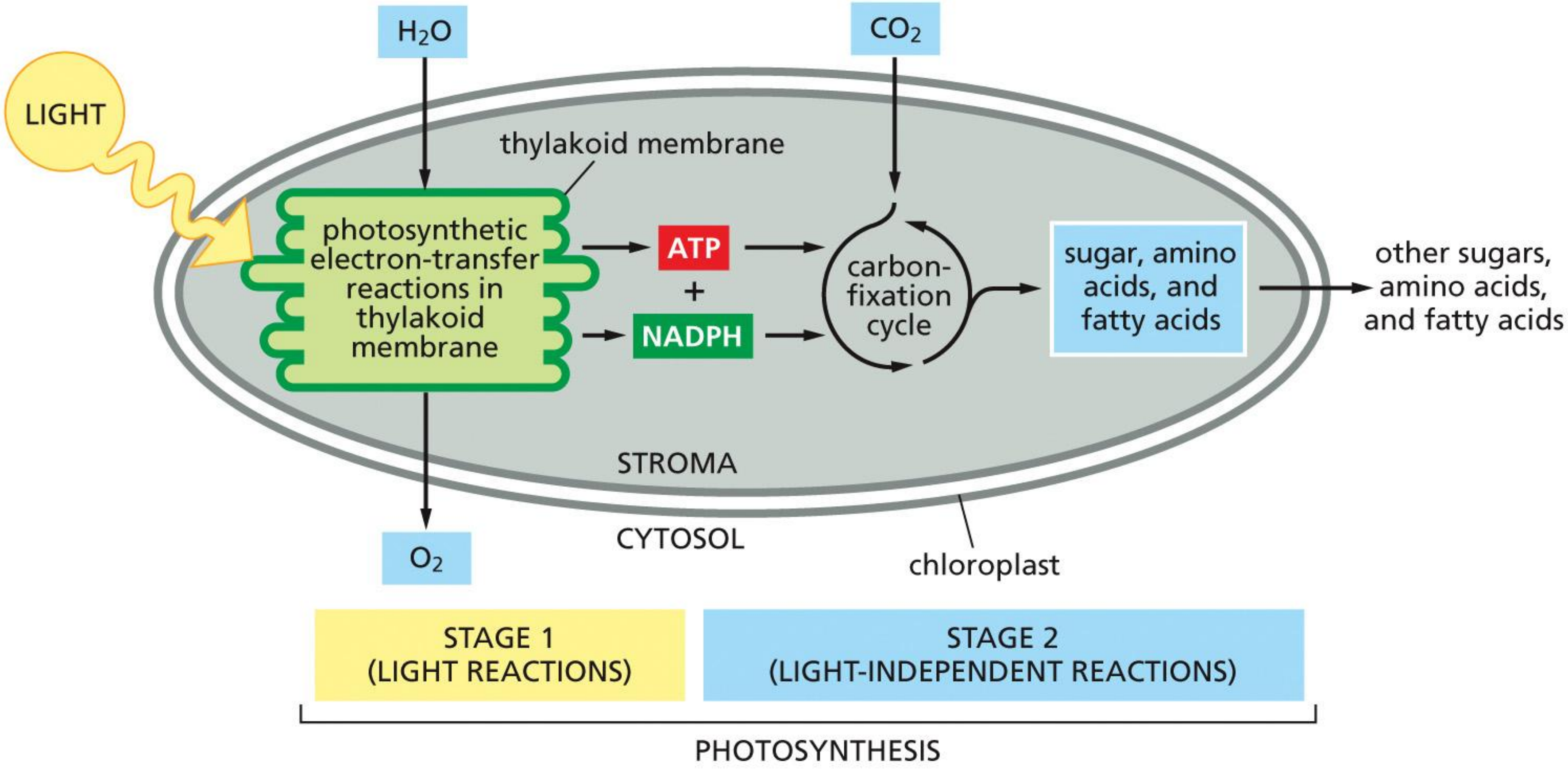
Chloroplast structure

- Chloroplasts resemble mitochondria but have an extra compartment—the *thylakoid*

- Light-capturing systems, the electron transport chain and ATP synthase are all contained within the thylakoid membranes (a third membrane system)

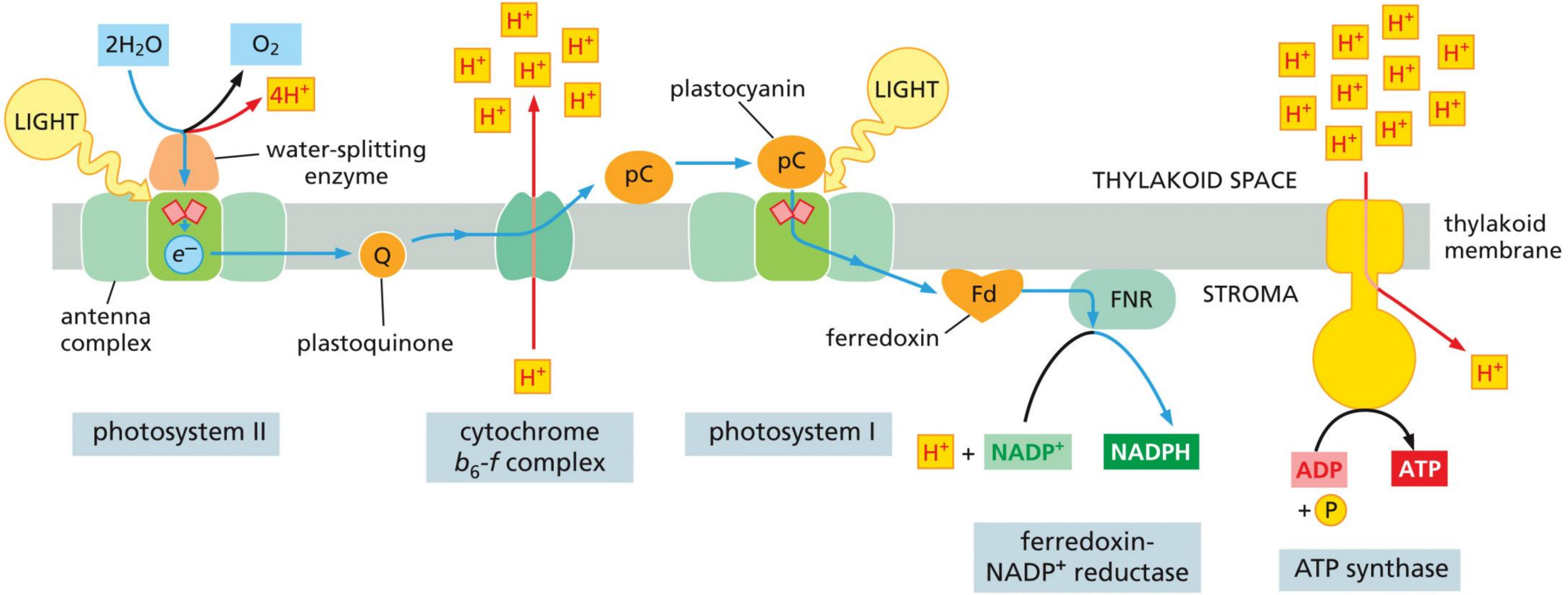


Photosynthesis is essentially the *opposite of cellular respiration*, leveraging the energy of light to produce sugars and oxygen from carbon dioxide and water



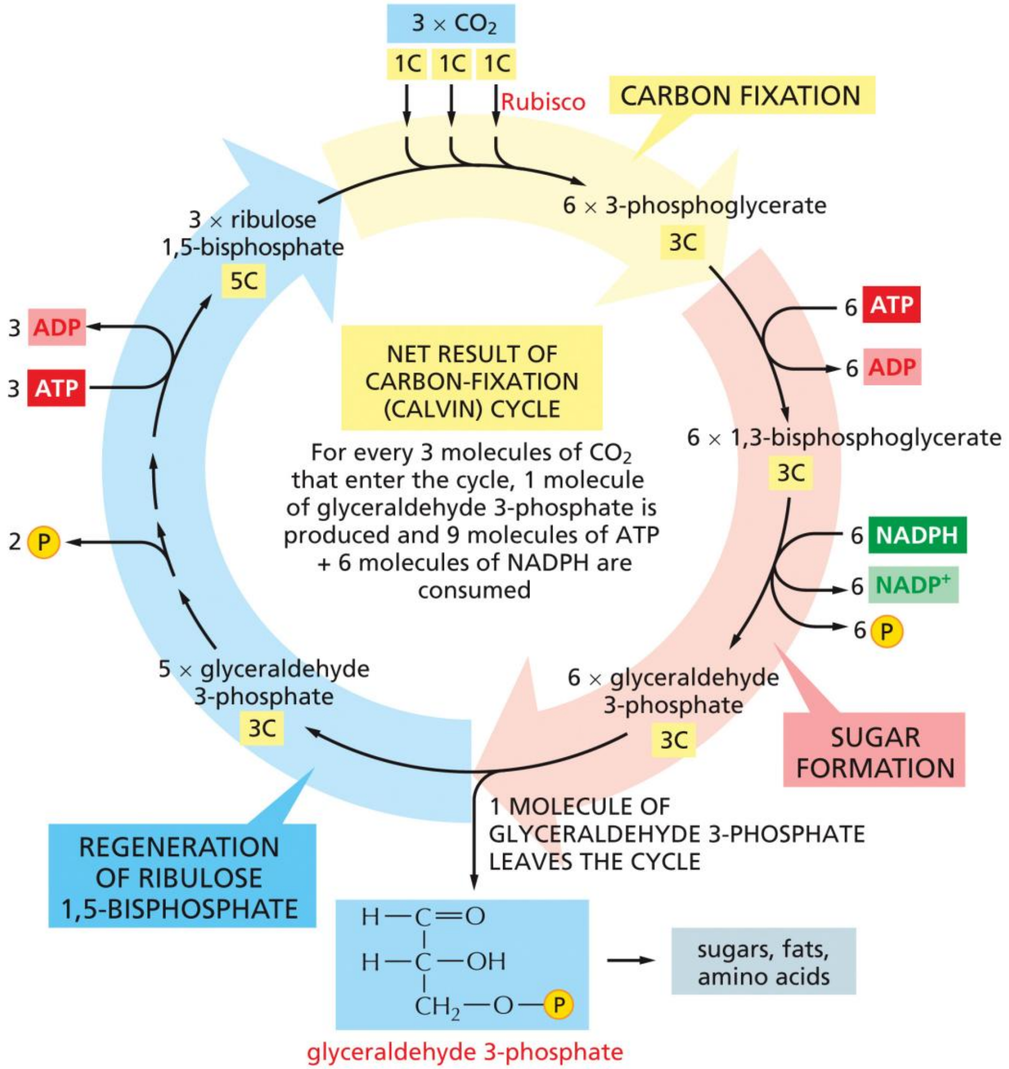
Chloroplasts & Photosynthesis

- Photosynthesis ***generates, and then consumes***, ATP and NADPH to make sugars
  - Chlorophyll molecules within chloroplast absorb light energy
  - Electron transport chains generate a proton gradient for ATP synthesis while creating NADPH

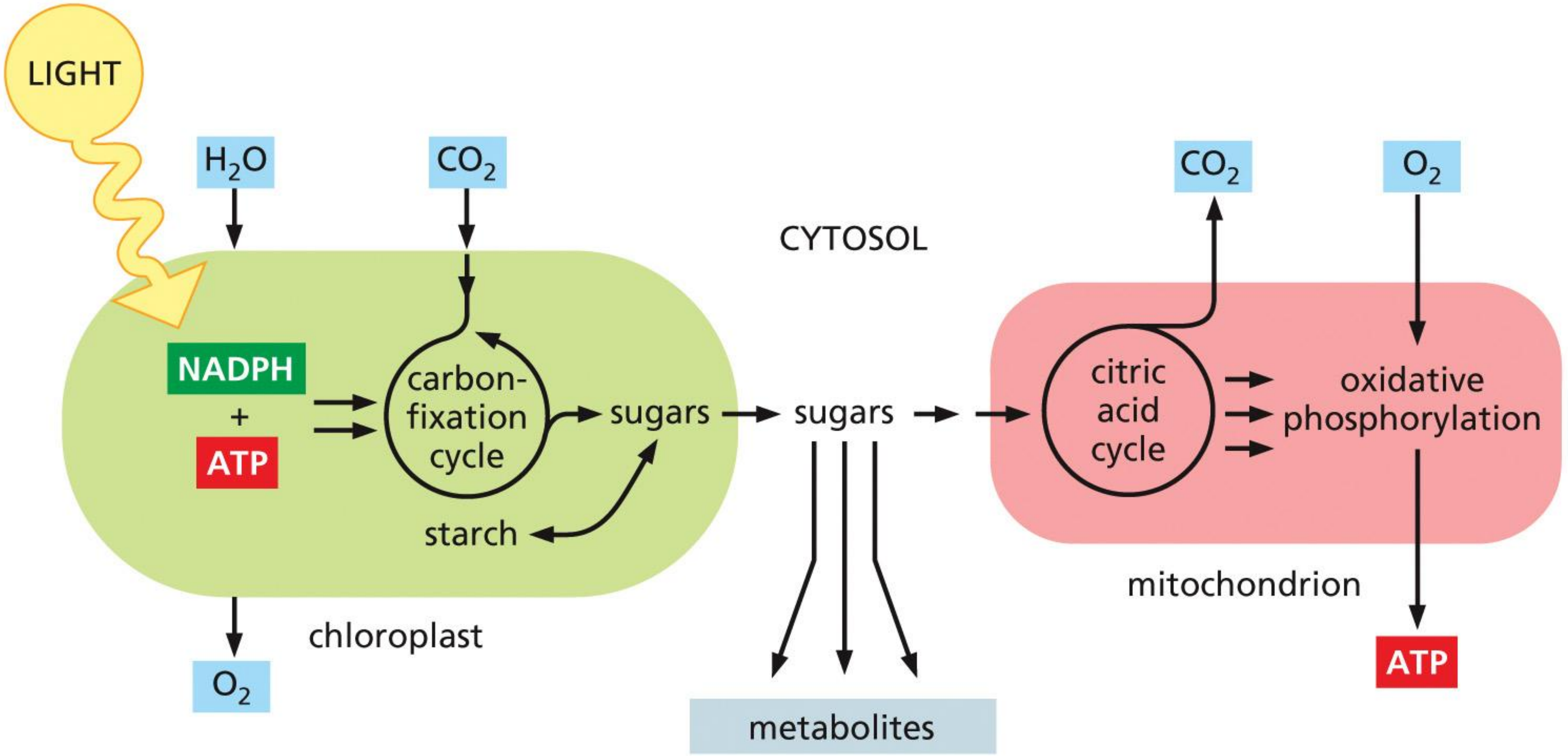


Chloroplasts & Photosynthesis

- Photosynthesis ***generates, and then consumes***, ATP and NADPH to make sugars
  - *Carbon fixation* uses ATP+NADPH to covert CO_2 to sugar which can be stored as *starch* or consumed to make ATP
  - Extremely costly energetically to produce sugar, and so plants rely on mitochondria for majority of energy production

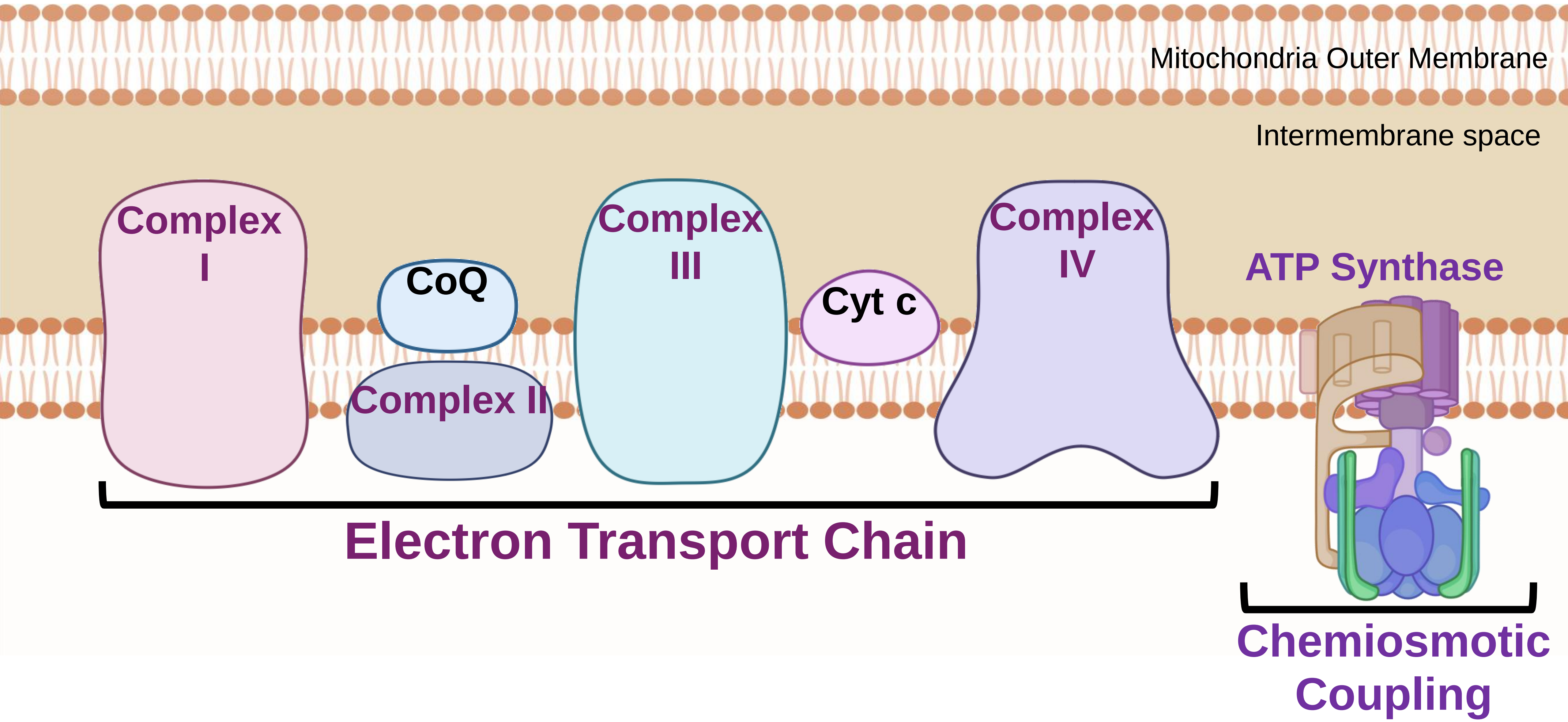


Stored sugars in plant cells can then go through oxidative phosphorylation to produce ATP



Squarecap Q#3-4

Oxidative Phosphorylation



Cellular Respiration

The degradation of biomolecules to generate energy that cells can utilize

a.k.a

Aerobic Respiration

GLYCOLYSIS → ATP ATP + 2 NADH

Pyruvate (2)

TCA CYCLE → GTP + $\boxed{\text{3 NADH + 1 FADH}_2}$

OXIDATIVE PHOSPHORYLATION → **~32-38 ATP!**

$$\boxed{\textbf{Glucose}} + O_2 \longrightarrow CO_2 + H_2O + \text{Energy}$$

(From FOOD)

Learning Objectives for Today's Lecture:

Upon completing this module, **you should be able to**:

- Describe the key components of mitochondrial **oxidative phosphorylation**
- Establish what **redox potentials** are and connect them to powering the **electron transport chain**
- Understand the generation of the **chemiosmotic potential** and how this drives ATP production
- Compare animal cell energy production with energy production in plant cells via **photosynthesis** in chloroplasts

Metacognitive Reflection Form