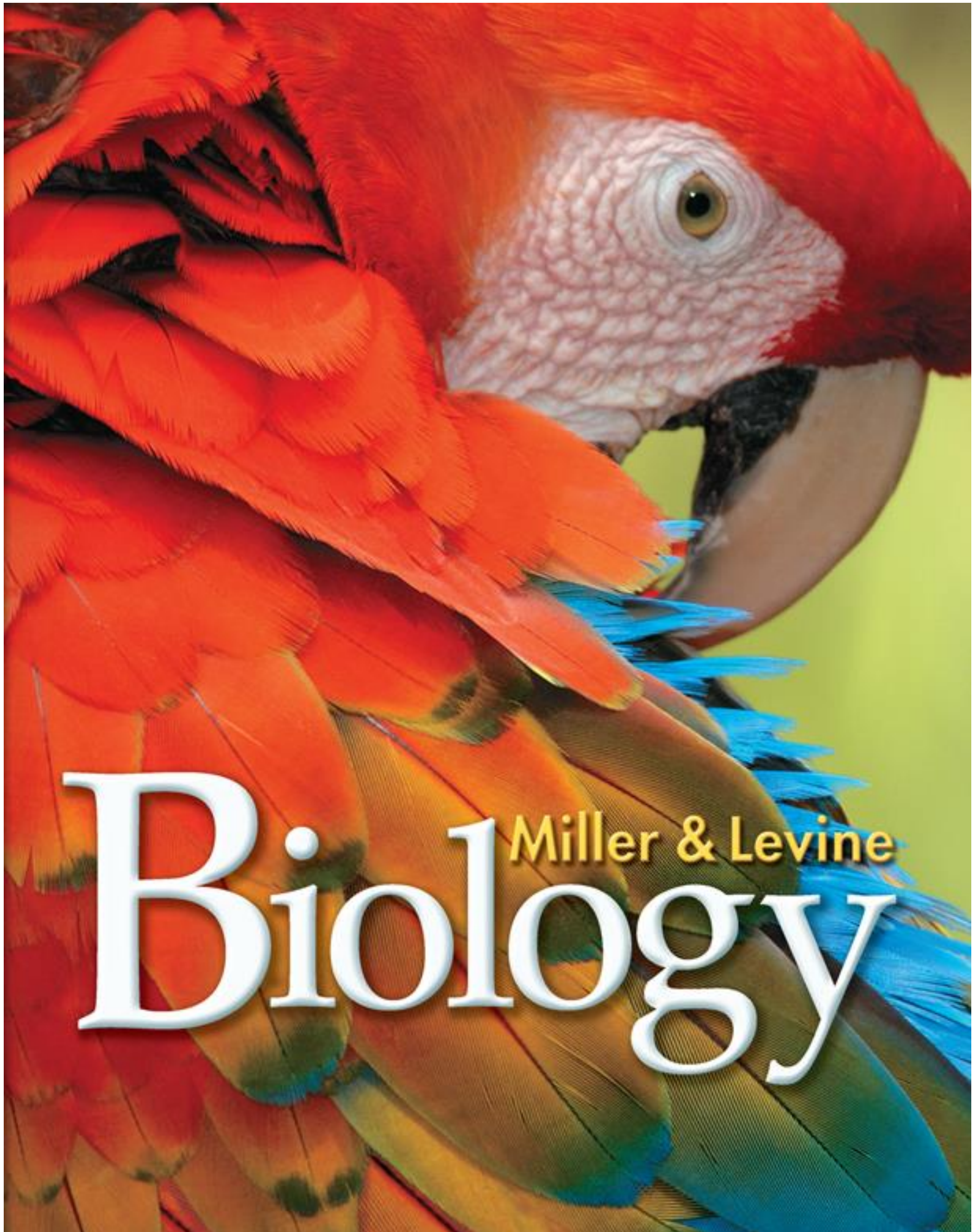


Lesson Overview

9.1 Cellular Respiration: An Overview

Chemical Energy and Food

Food provides living things with the **chemical building blocks** they need to grow and reproduce.

Food molecules contain **chemical energy** that is released when its chemical **bonds are broken**.

Chemical Energy and Food

- Cells use all sorts of molecules for food, including **fats, proteins, and carbohydrates:** energy stored in each molecule varies because their energy-storing bonds differ

- Cells break down food molecules gradually, and use the energy stored in the chemical bonds to produce compounds such as **ATP** that power the activities of the cell

Overview of Cellular Respiration

If oxygen is available, organisms can obtain energy from food by a process called **cellular respiration.**

Summary of cellular respiration:

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

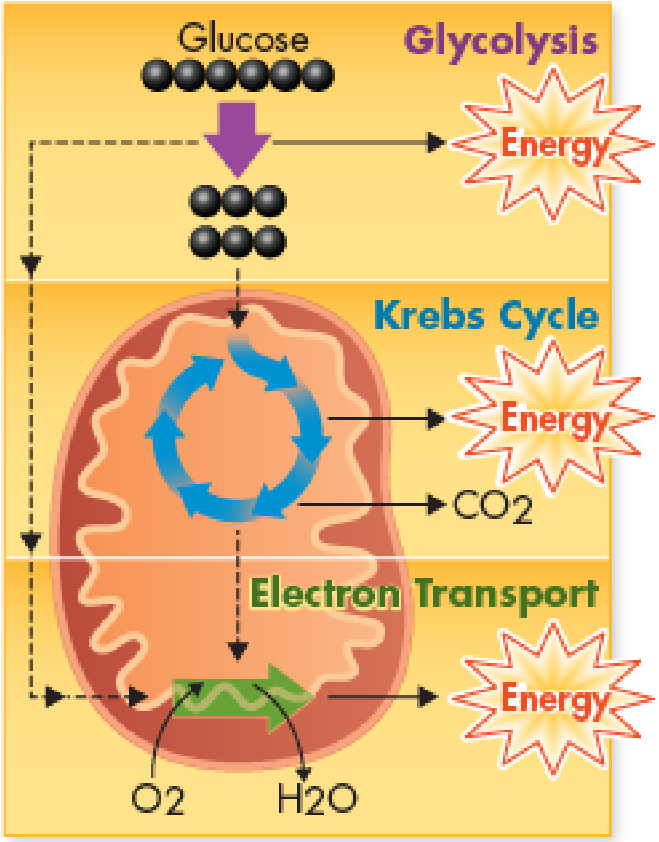
Oxygen + Glucose → Carbon dioxide + Water + Energy

Chemical energy in food molecules (like glucose) has to be released gradually, otherwise most of the energy would be lost as **heat and light.**

Stages of Cellular Respiration

Three main stages:

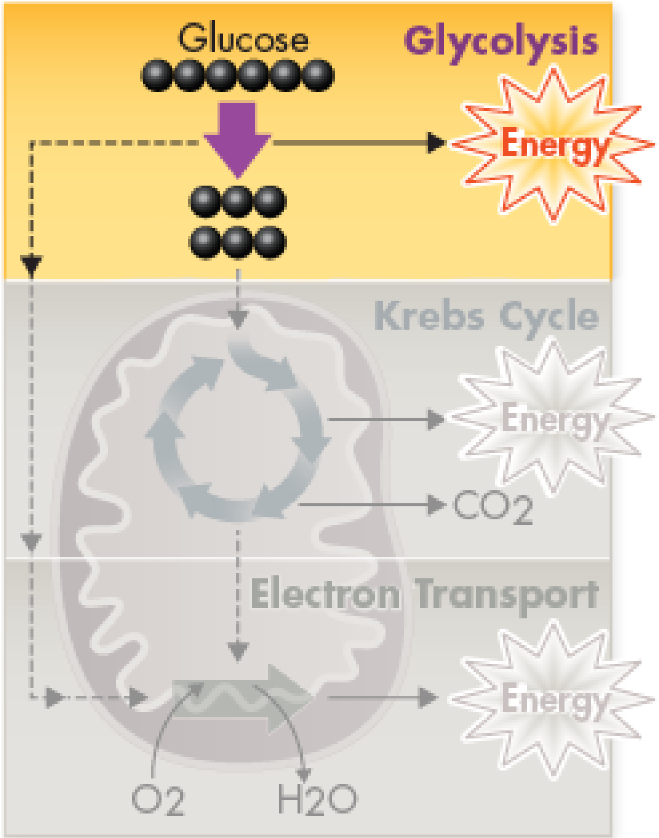
- **Glycolysis**
  - Small amount of energy
- **Krebs cycle**
  - Small amount of energy
- **Electron transport chain**
  - Majority of energy



Oxygen and Energy

Glycolysis is **“anaerobic”**: does not require oxygen.

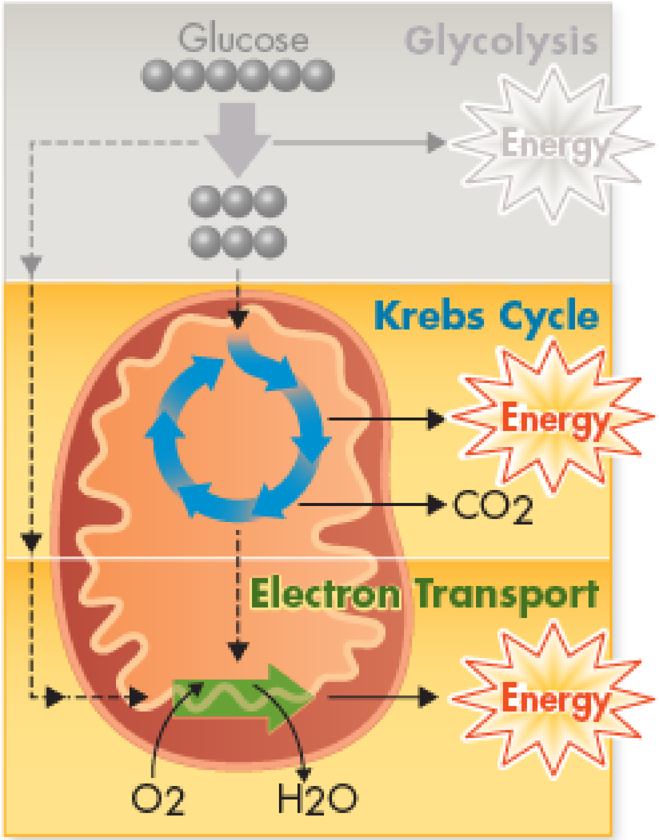
- Some single-celled organisms only use glycolysis as energy source…lower efficiency (less energy per glucose)



Oxygen and Energy

Pathways that require oxygen are **"aerobic"**

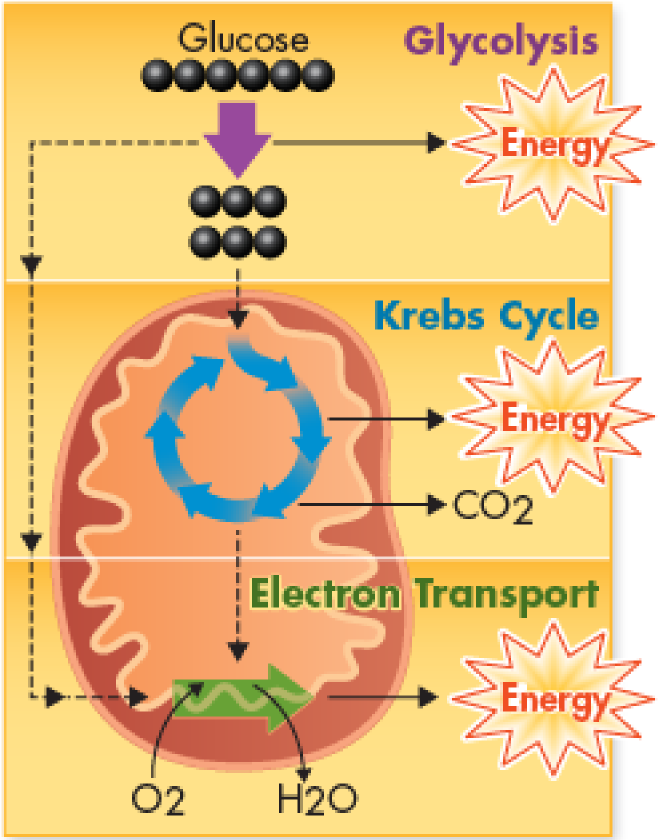
- Krebs cycle
- Electron transport chain



Stages of Cellular Respiration

Three main stages:

- **Glycolysis**
  - Small amount of energy
  - No oxygen (anaerobic)
  - In cytoplasm
- **Krebs cycle**
  - Small amount of energy
  - Oxygen required (aerobic)
  - In mitochondria
- **Electron transport chain**
  - Majority of energy
  - Oxygen required (aerobic)
  - In mitochondria

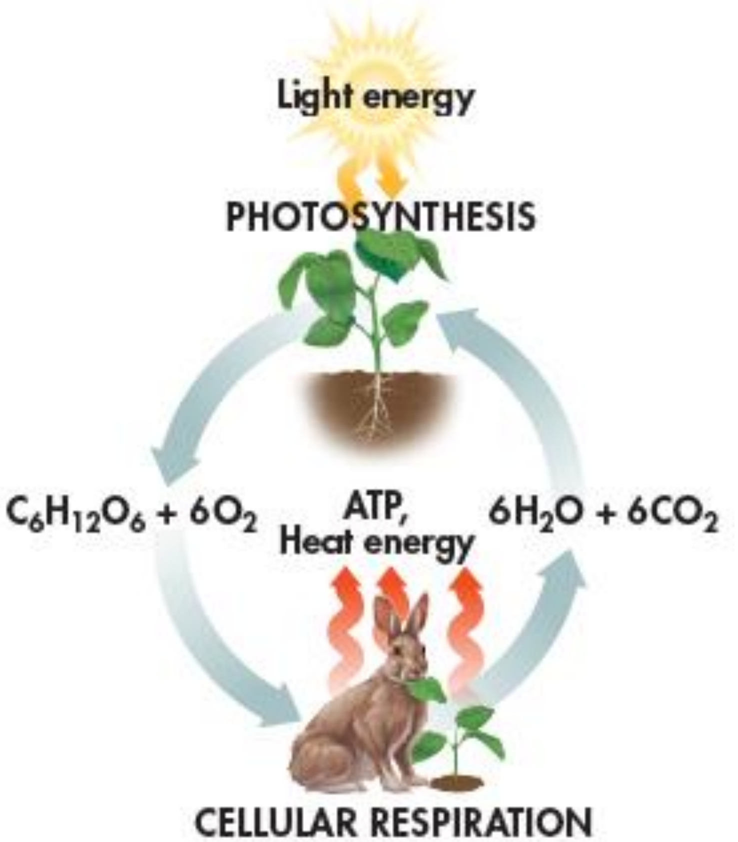


Comparing Photosynthesis and Cellular Respiration

Photosynthesis and cellular respiration are **opposite processes**.

- Photosynthesis "deposits" energy, and cellular respiration "withdraws" energy.

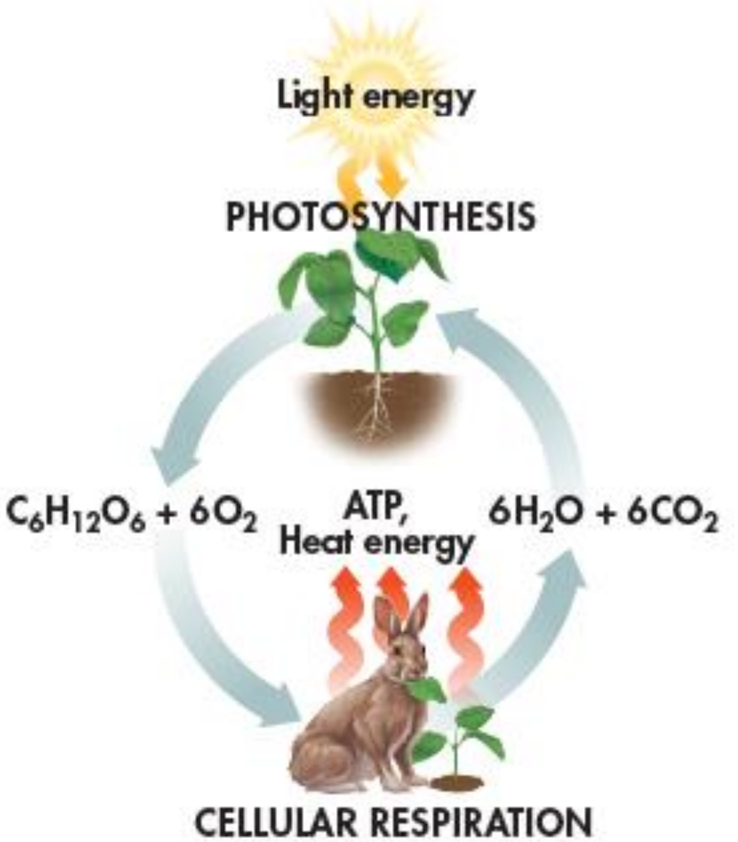
- **Inputs of one are the products of the other.**

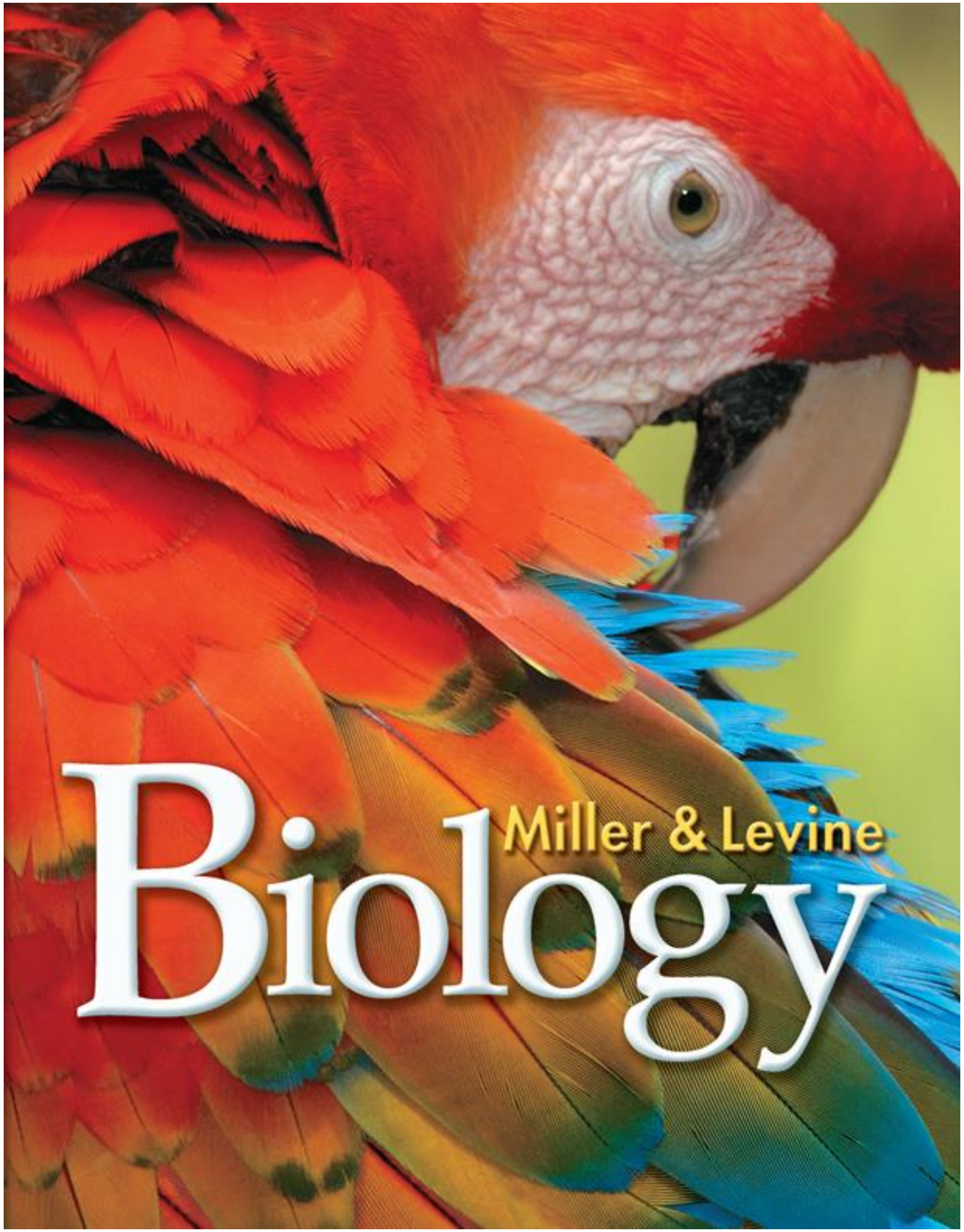


Comparing Photosynthesis and Cellular Respiration

Photosynthesis occurs only in **plants, algae, and some bacteria.**

Cellular respiration is performed by most living things: **plants, animals, fungi, protists, and most bacteria.**





Lesson Overview

9.2 The Process of Cellular Respiration

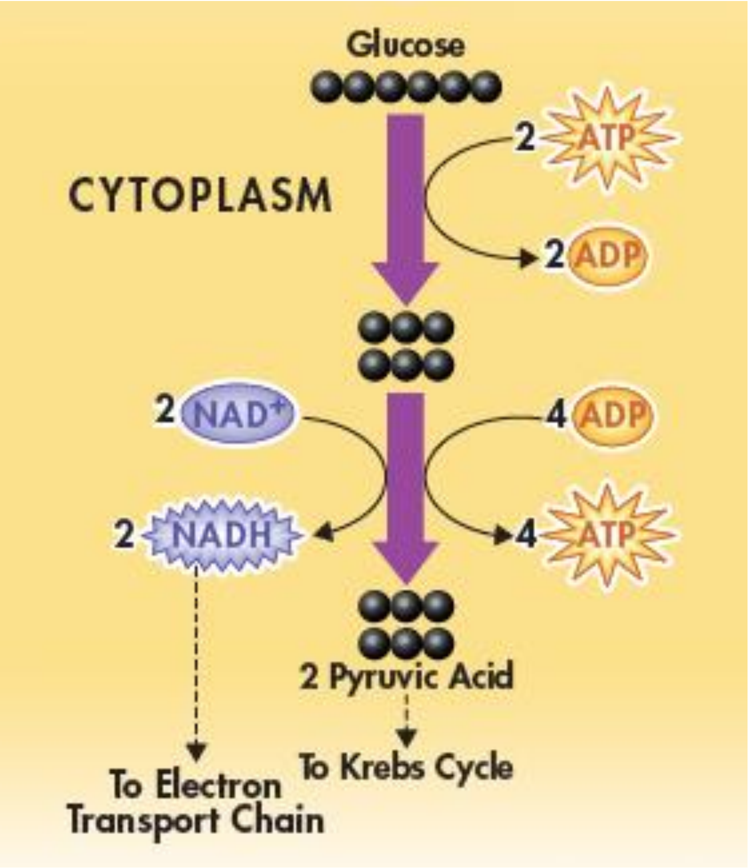
(6-3 Equivalent)

Glycolysis Overview

Glycolysis is the first stage of cellular respiration.

During glycolysis, **glucose is broken down into** 2 molecules of the 3-carbon molecule **pyruvic acid** (used in Krebs cycle).

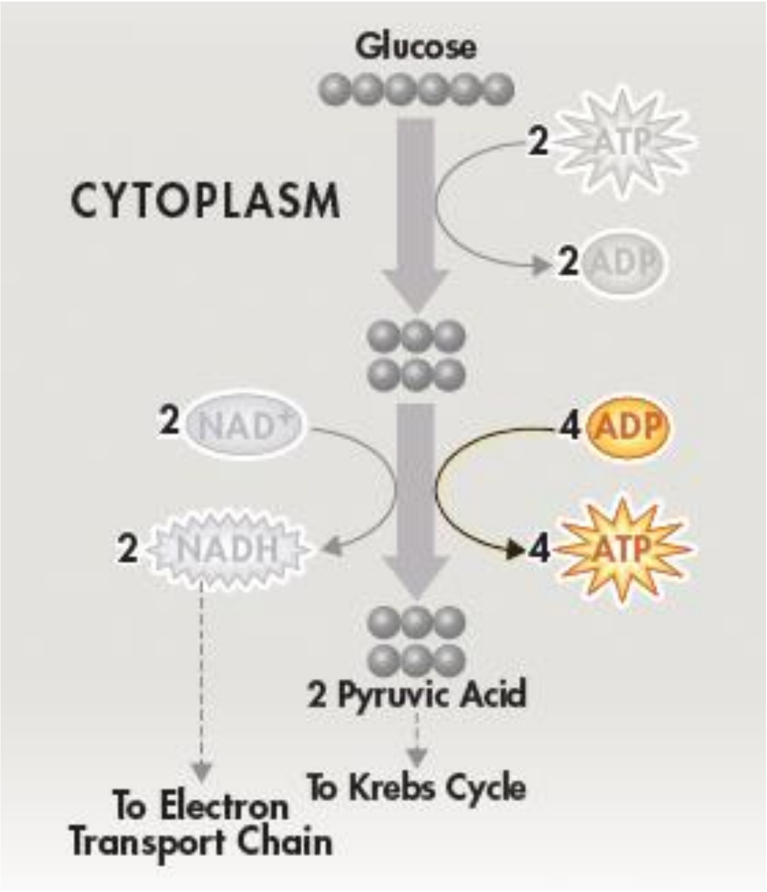
ATP and NADH are produced as part of the process.



ATP Production

The cell **uses 2 ATP** to start glycolysis

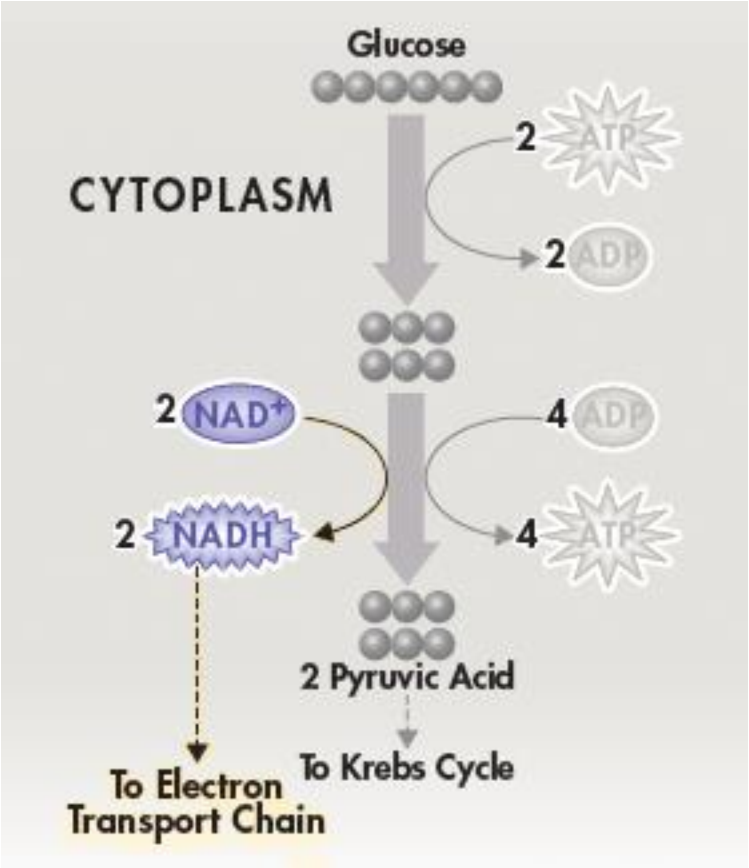
Glycolysis then produces **4 ATP**: **net gain of 2 ATP** for each glucose



NADH Production

During glycolysis:

- Electron carrier **NAD^+** accepts a pair of high-energy electrons and **becomes NADH**
- NADH **carries high-energy electrons to electron transport chain** to make more ATP
- **2 NADH molecules produced for every glucose**



The Advantages of Glycolysis

Glycolysis produces ATP very quickly

- Cell can adapt to increased energy needs

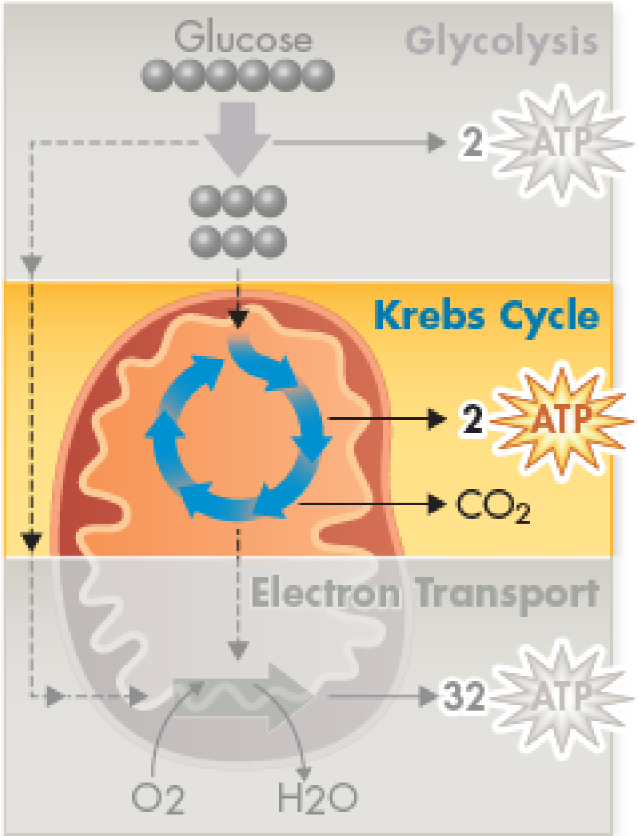
Glycolysis does not require oxygen

- Cell can still obtain energy when oxygen is unavailable

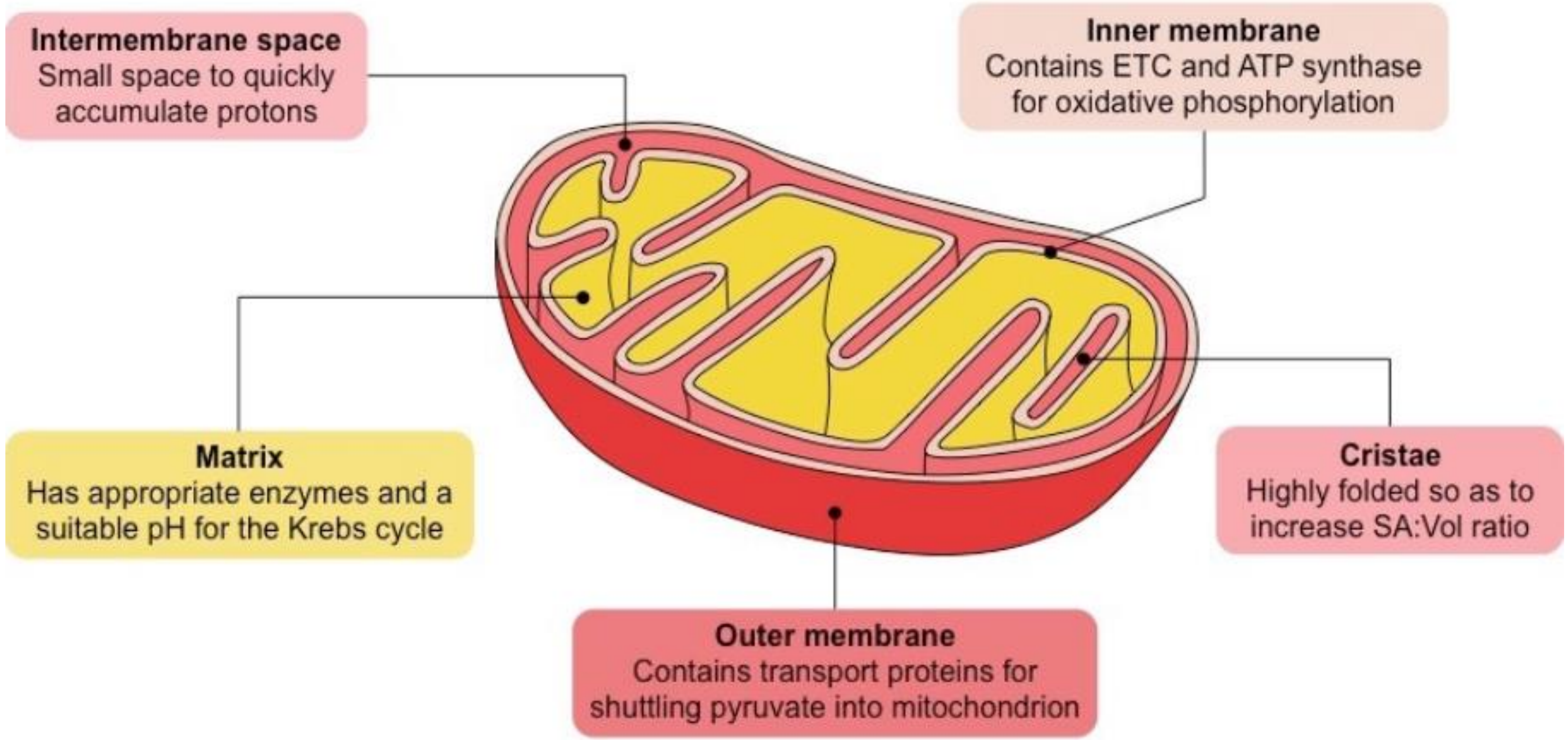
The Krebs Cycle Overview

The **Krebs cycle** (also known as citric acid cycle) is the second stage of cellular respiration.

Pyruvic acid (from glycolysis) is broken down into carbon dioxide in a series of energy-extracting reactions.



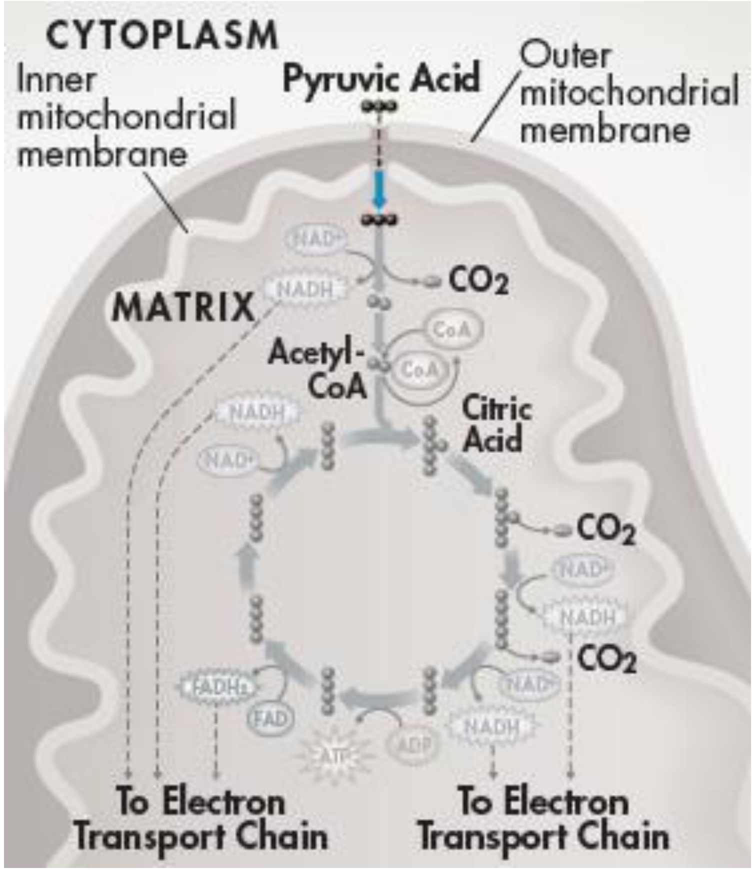
Structure of a Mitochondrion



How is the structure of a chloroplast similar? What are the 'equivalent' structures called?

Citric Acid Production

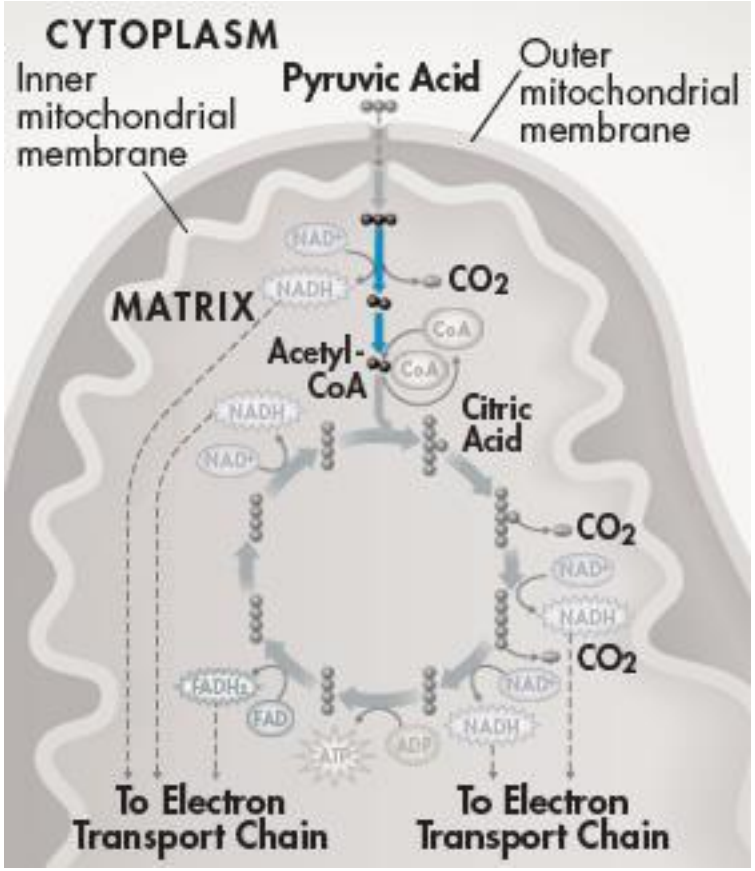
Pyruvic acid from glycolysis enters the **matrix**, the innermost compartment of the mitochondrion.



Citric Acid Production

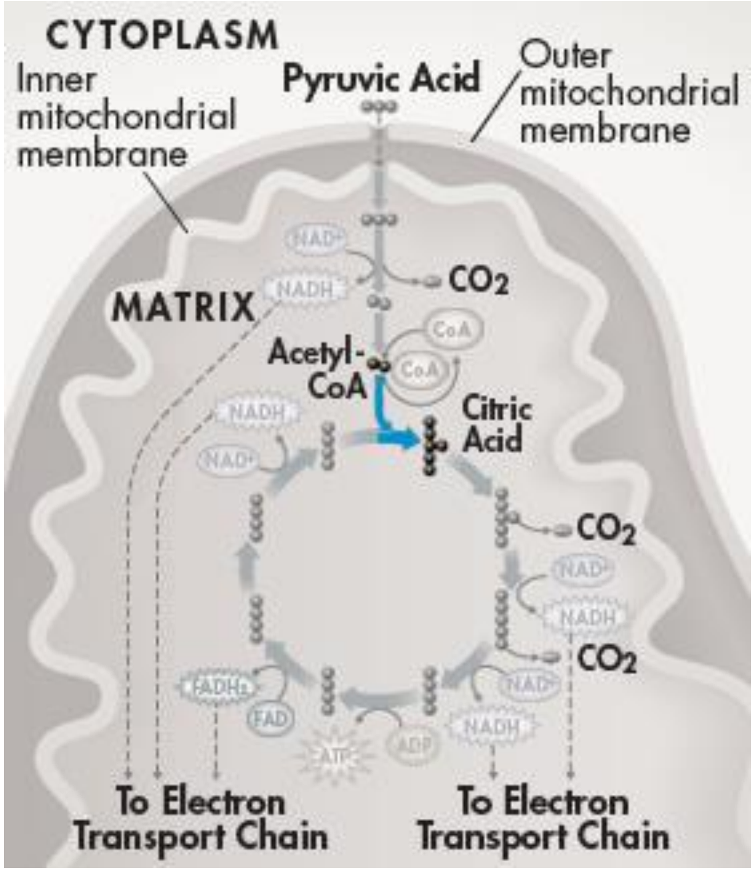
Pyruvic acid in the matrix:

- **NAD^+** accepts 2 high-energy electrons to **form NADH**
- One molecule of **CO_2** is produced
- Remaining **2 carbon atoms** react to **form acetyl-CoA**



Citric Acid Production

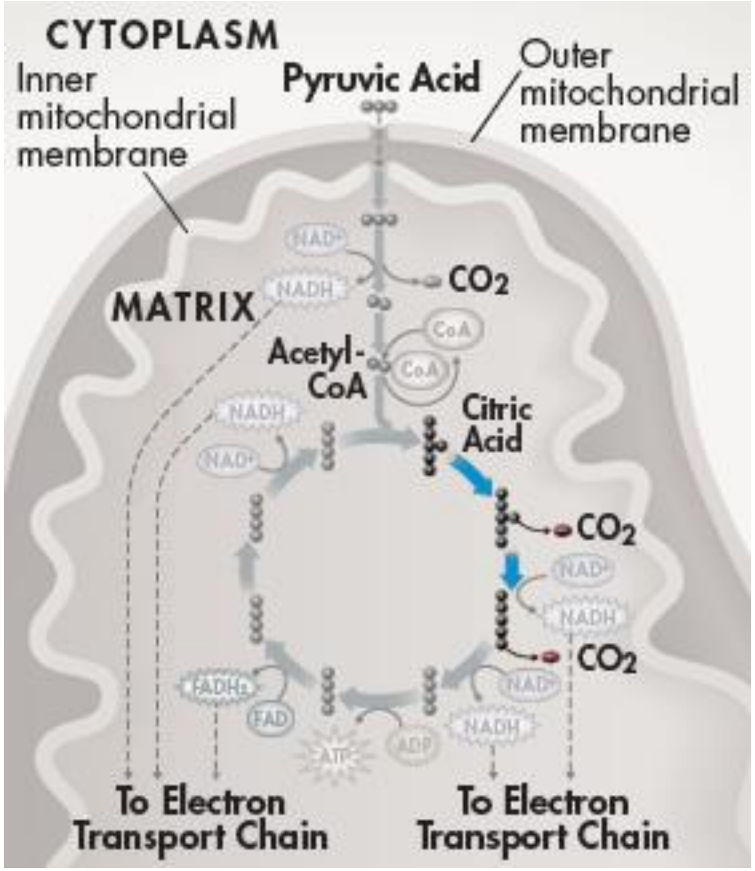
Acetyl-CoA combines with a 4-carbon molecule to produce citric acid (6-carbon molecule)



Energy Extraction

Citric acid is broken down to a 4-carbon compound, releasing **two molecules of CO_2.**

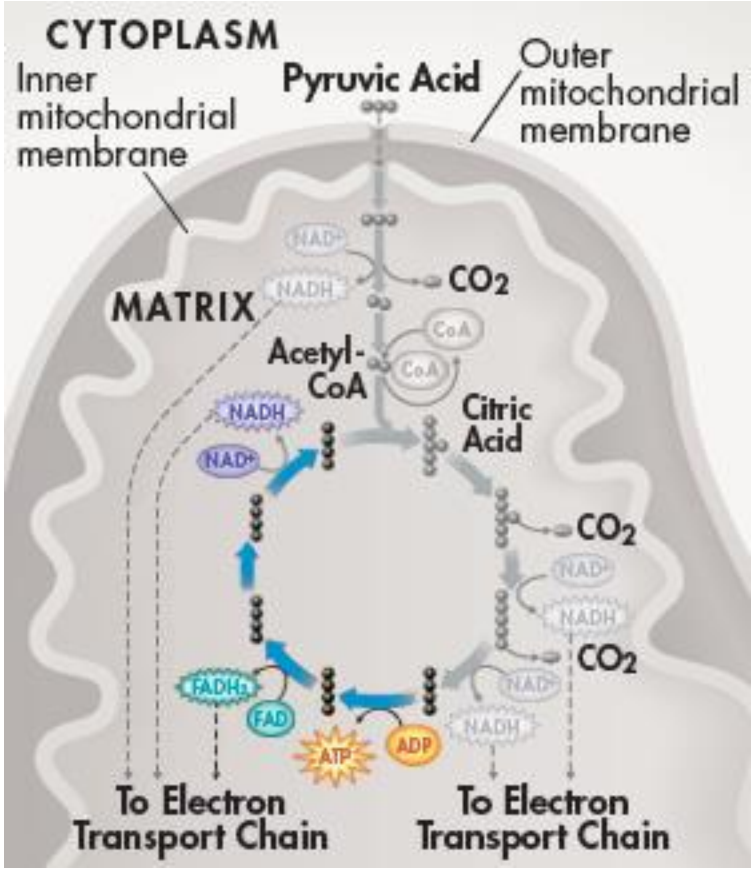
4-carbon compound reused in cycle.



What similar process happens in the Calvin cycle (during photosynthesis)?

Energy Extraction

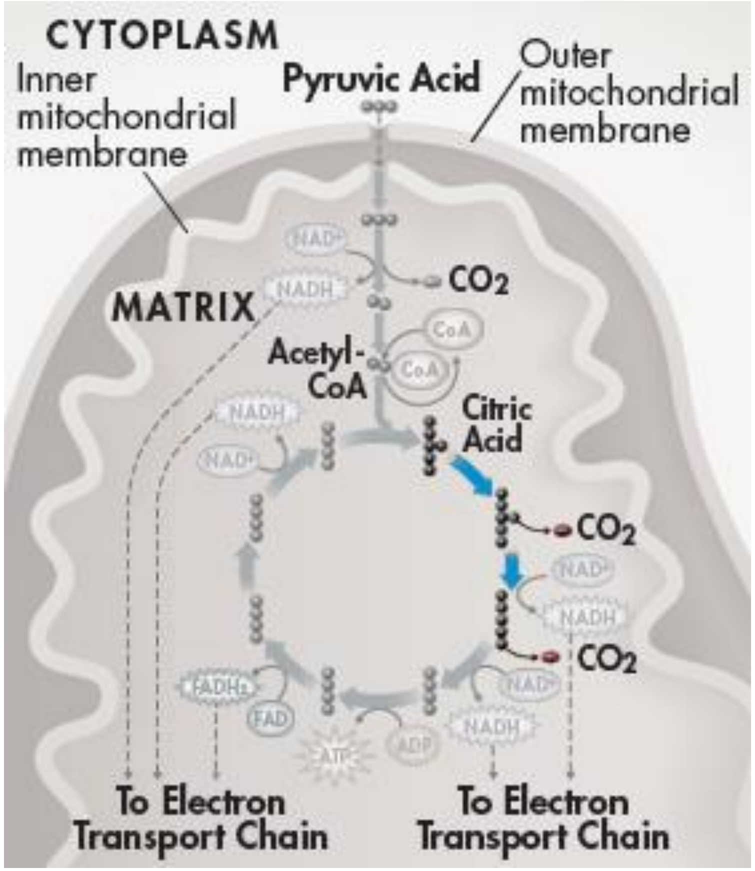
Energy released by the breaking and rearranging of carbon bonds **is captured as ATP, NADH, and FADH$_2$** (see following slides)



Energy Extraction

- **For each turn of the cycle, one ADP molecule is converted into ATP**

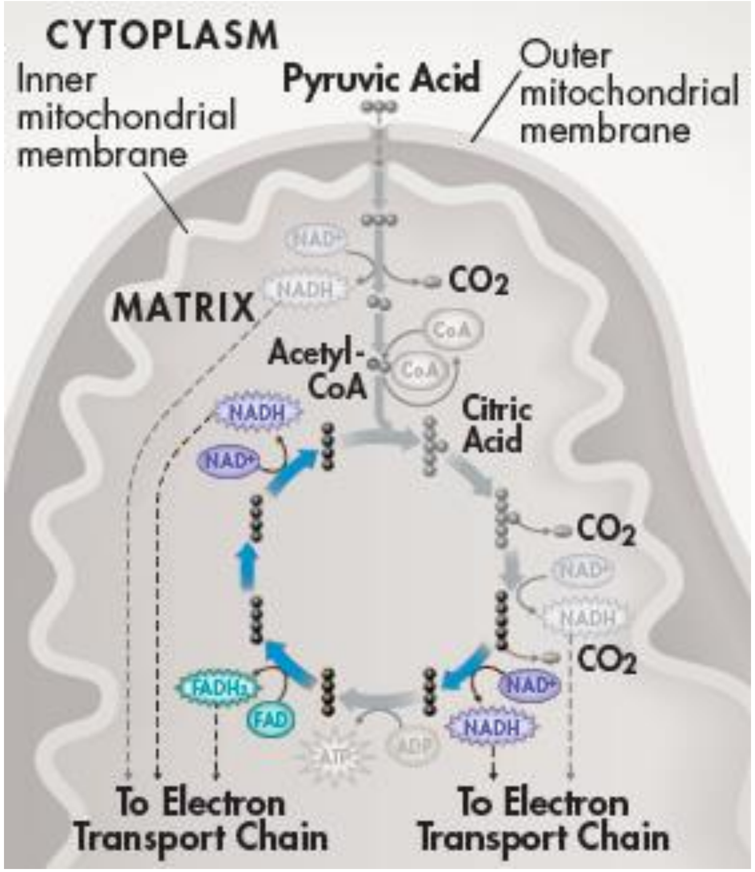
- ATP can directly power the cell’s activities



Energy Extraction

- The **electron carriers NAD$^+$ and FAD** each accept pairs of high-energy electrons **to form NADH and FADH$_2$**

- NADH and FADH$_2$ **used in the electron transport chain** (to generate ATP)

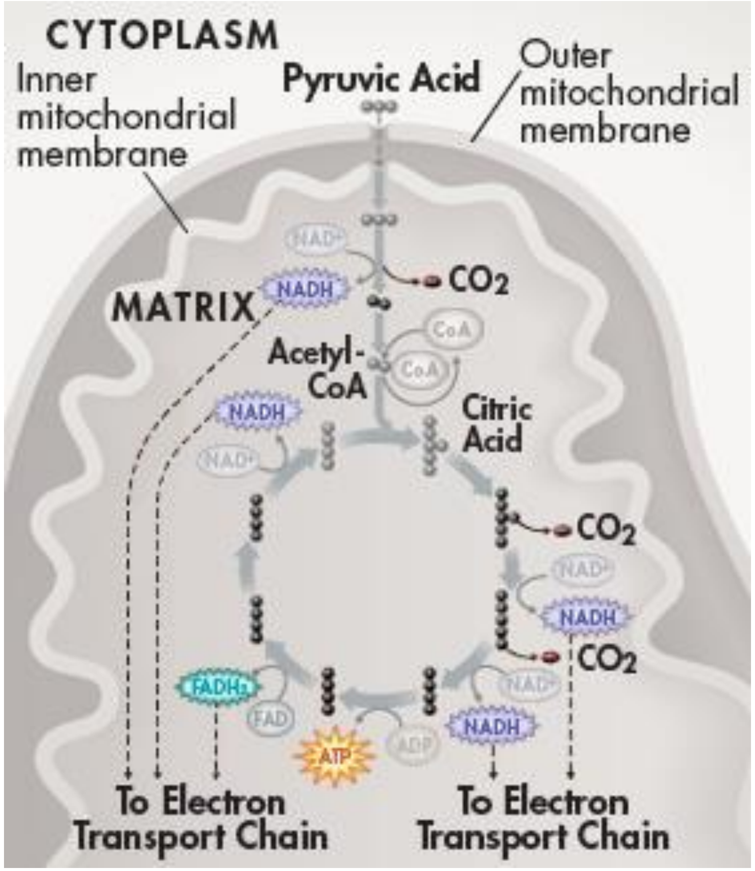


Energy Extraction

Book-keeping note:

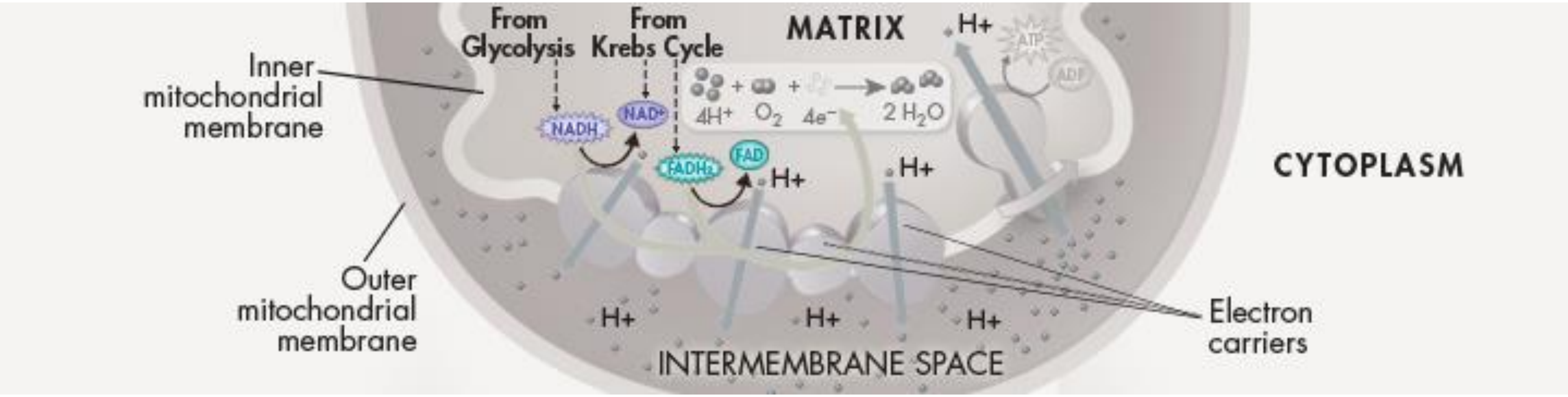
Recall that each molecule of glucose results in 2 molecules of pyruvic acid. **Each molecule of glucose results in two complete “turns” of the Krebs cycle.**

For each glucose molecule, **6 CO_2** molecules, **2 ATP** molecules, **8 NADH** molecules, and **2 $FADH_2$** molecules are produced.



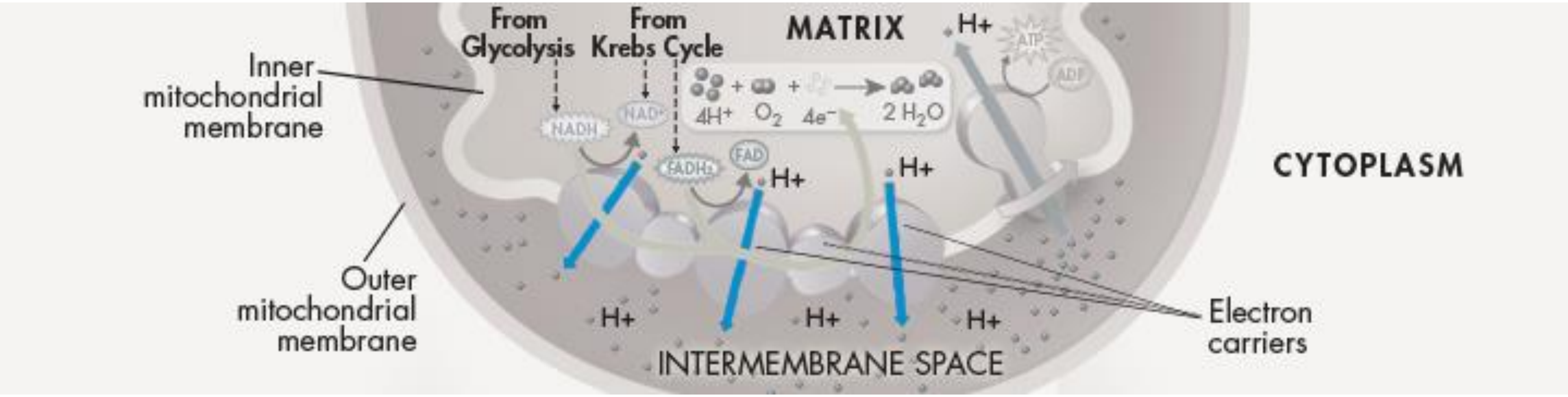
Electron Transport

NADH and FADH$_2$ pass their high-energy electrons to electron carrier proteins in the electron transport chain.



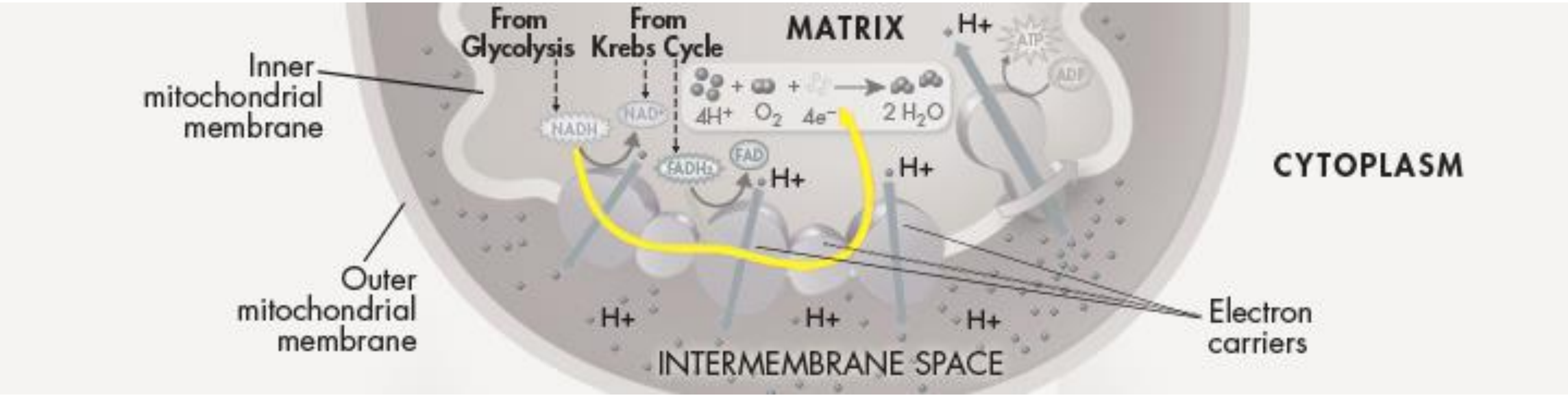
Electron Transport

Energy generated by the electron transport chain is used to move H+ ions against a concentration gradient across the inner mitochondrial membrane and into the intermembrane space.



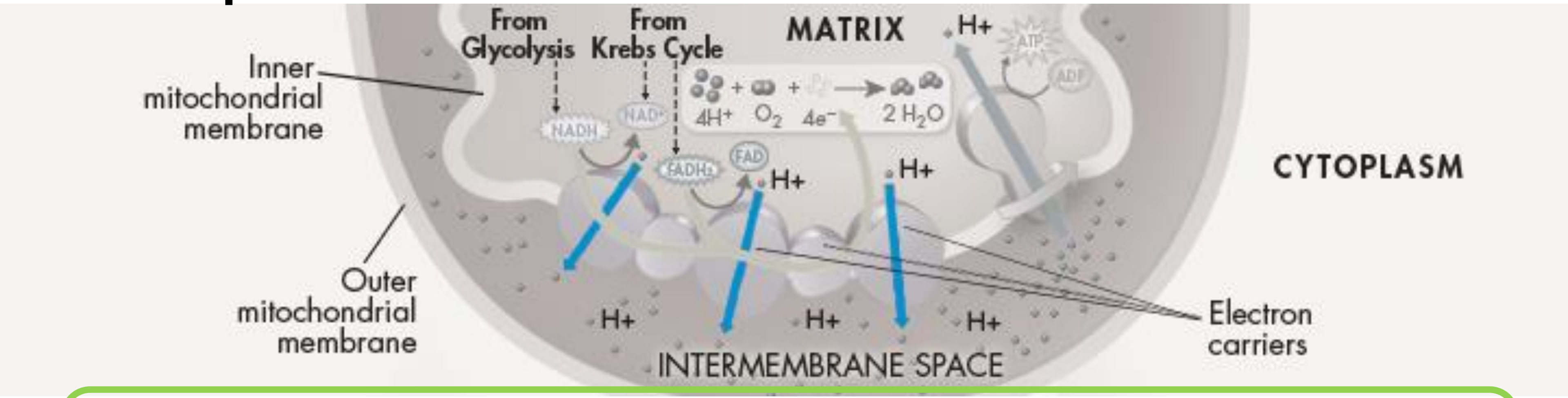
Electron Transport

At the end of the electron transport chain, the **electrons combine with H^+ ions and oxygen to form water.**



ATP Production

H+ ions pass back across the mitochondrial membrane through the ATP synthase, causing the ATP synthase molecule to spin. With each rotation, the ATP synthase **attaches a phosphate to ADP to produce ATP**.

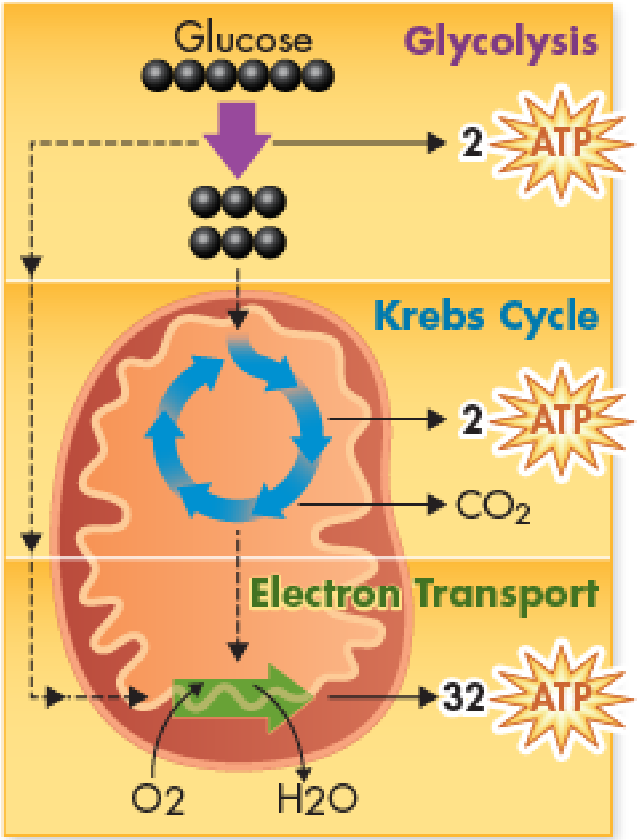


Compare and contrast the cellular respiration electron transport chain (ETC) with the photosynthesis ETCs.

Energy Totals

Aerobic cellular respiration produces **36 ATP molecules** from a single glucose molecule.

This is only 36% efficient: 64% of total energy stored in glucose is released as **heat.**

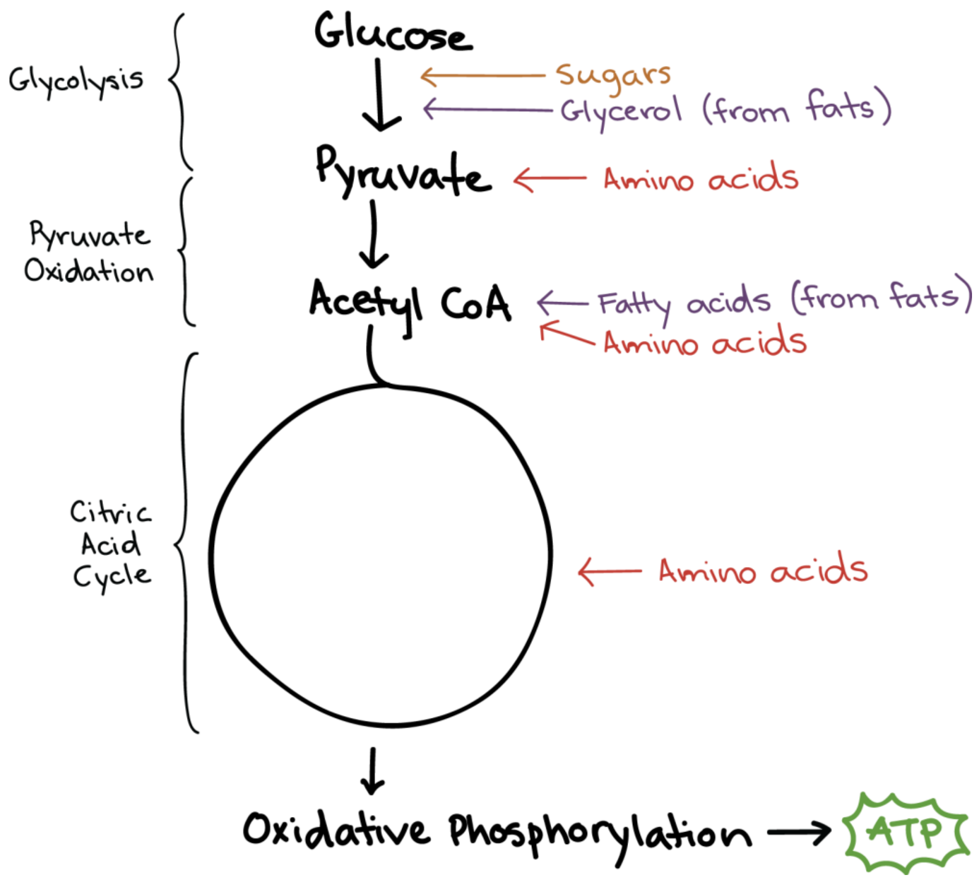


Energy Totals

Other molecules can be used for energy:

- Complex **carbohydrates** broken down into simple sugars that undergo glycolysis, etc.

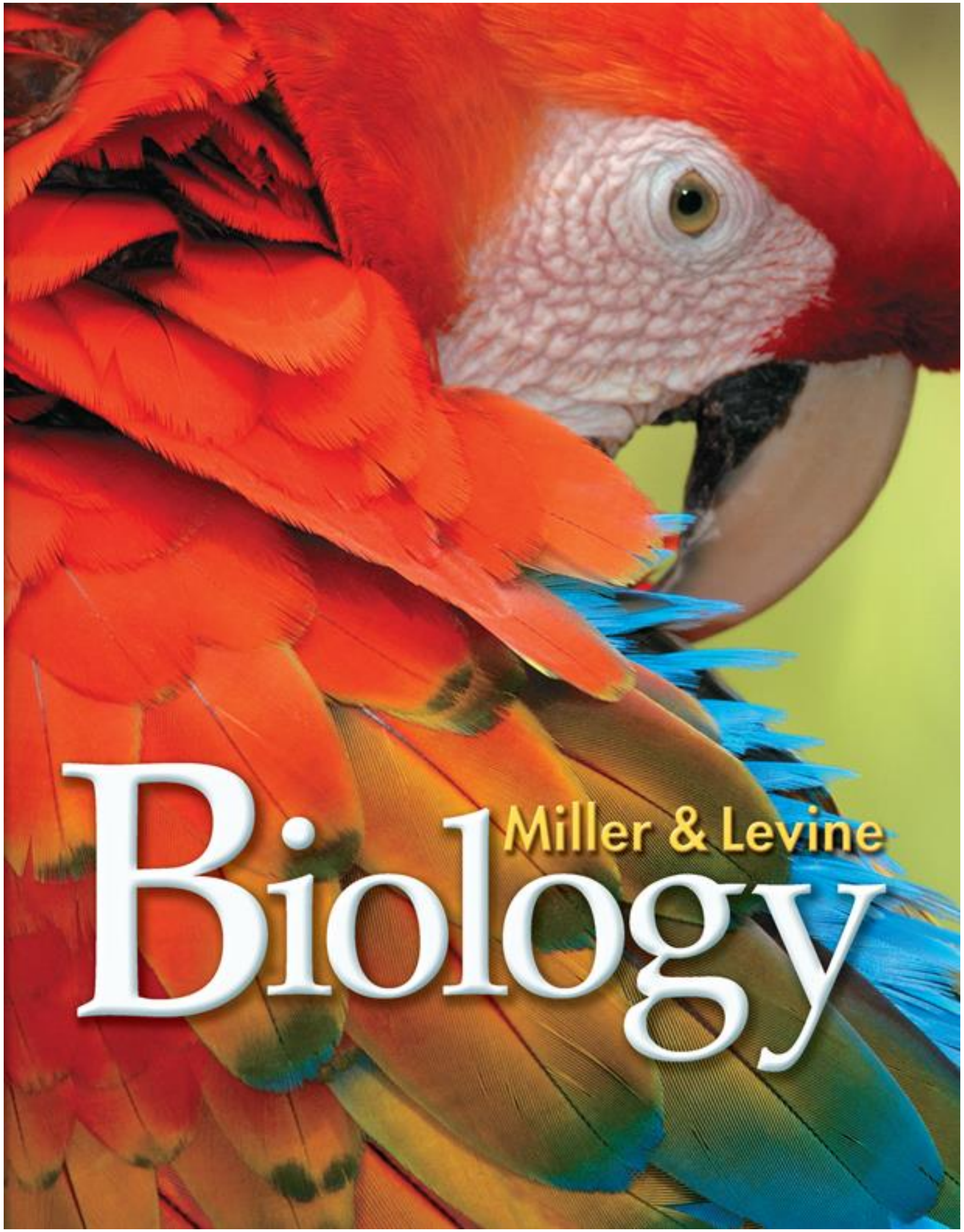
- **Lipids** and **proteins** broken down into molecules that enter cellular respiration at certain points



Practice =)

Find supporting documents on my website.

- Worksheet questions #13-27
- Construct an inputs and outputs chart/diagram for each of the 3 stages in cellular respiration
- Compare and contrast photosynthesis and cellular respiration, using the guiding questions.



Lesson Overview

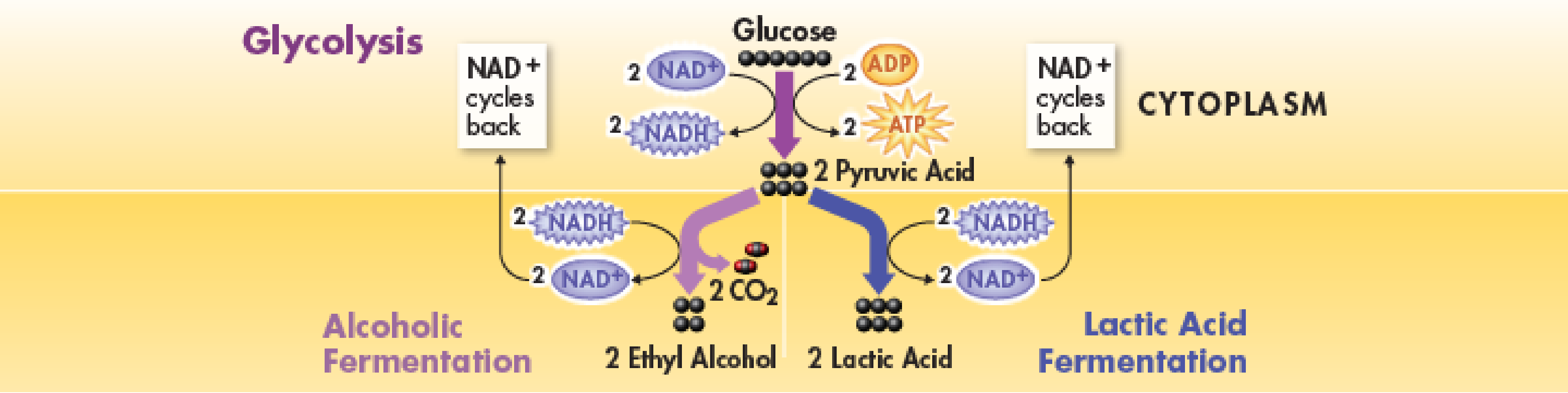
9.3 Fermentation

(6-4 Equivalent)

Fermentation

Fermentation is a process by which energy can be released from food molecules in the **absence of oxygen**.

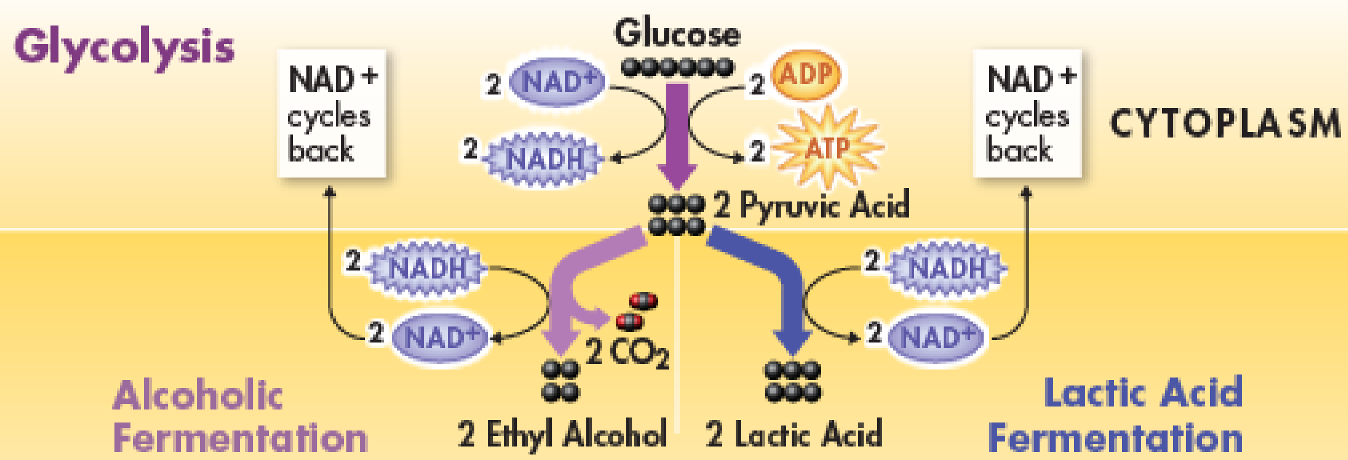
Fermentation occurs in the **cytoplasm** of cells.



Fermentation

Under **anaerobic conditions, fermentation follows glycolysis**.

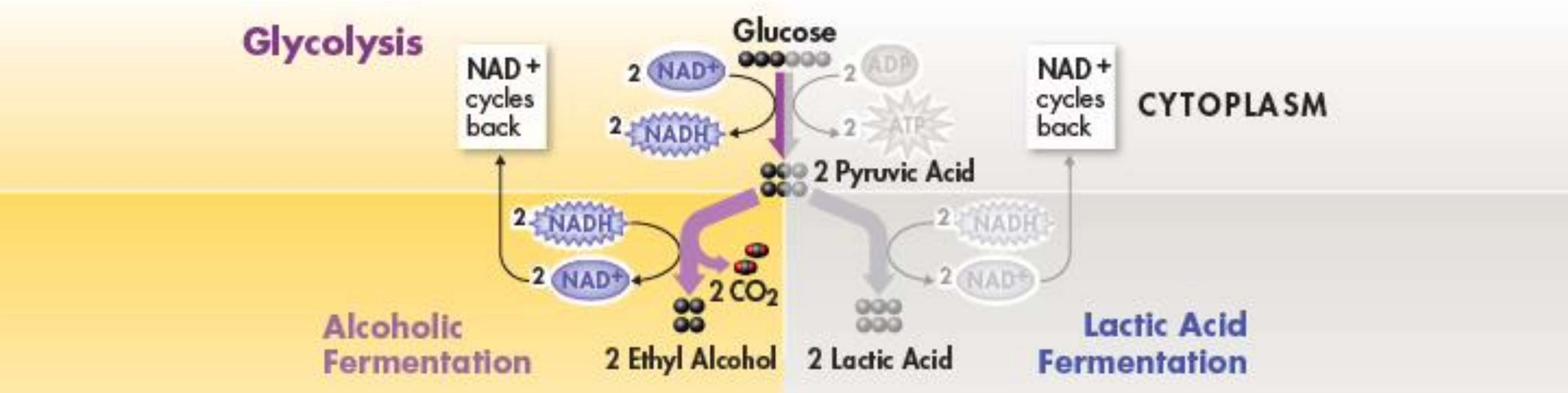
During fermentation, cells **convert NADH produced by glycolysis back into the electron carrier NAD$^+$**, which allows glycolysis to continue producing ATP.



Alcoholic Fermentation

Yeast and a few other microorganisms use **alcoholic fermentation** that **produces ethyl alcohol and carbon dioxide**.

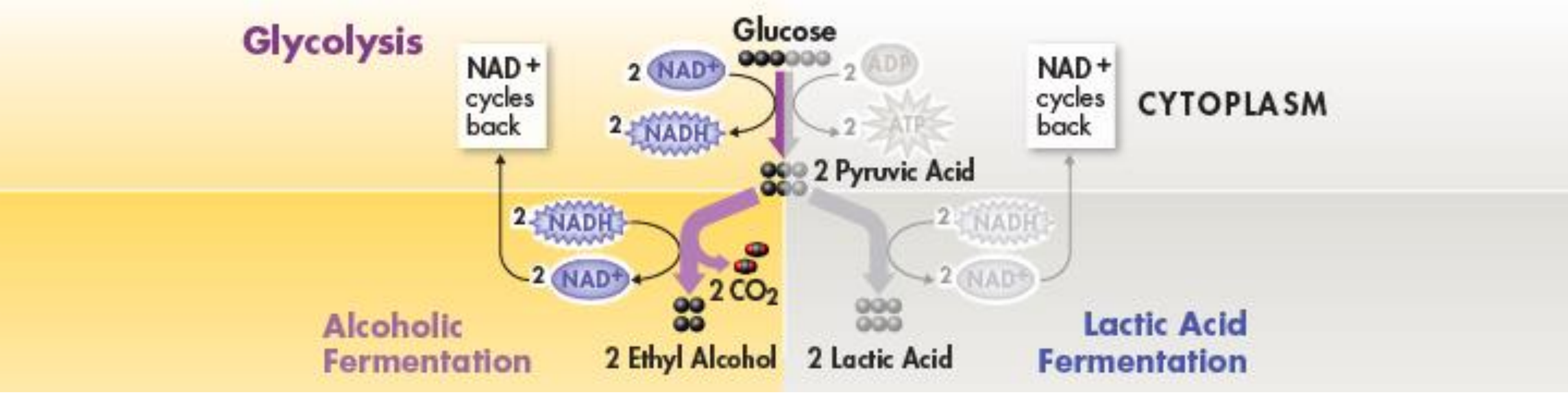
This process is used to produce alcoholic beverages and causes bread dough to rise.



Alcoholic Fermentation

Chemical equation:

Pyruvic acid + NADH → Alcohol + CO_2 + NAD^+

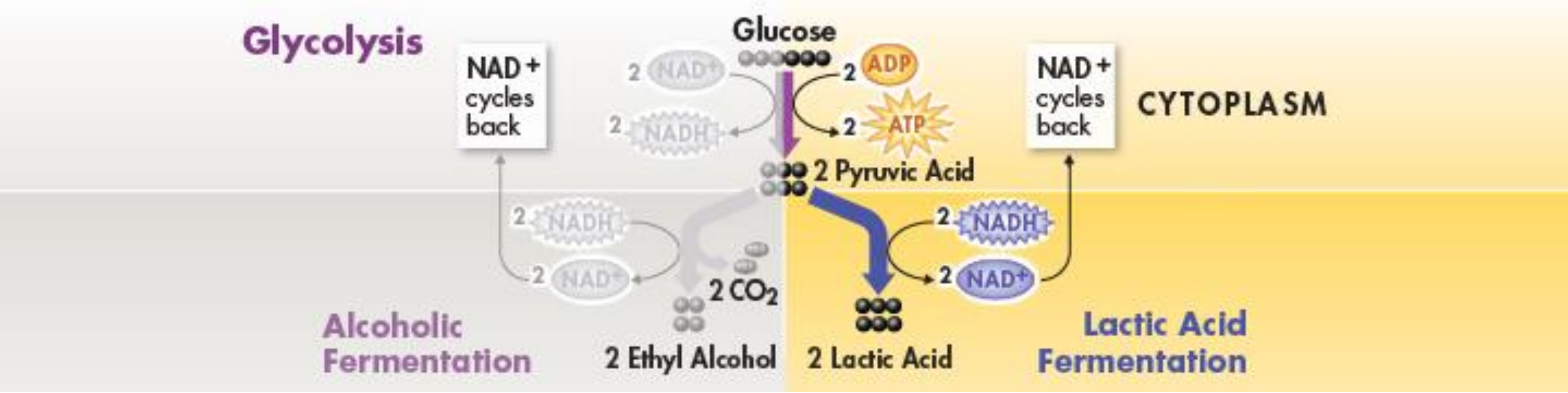


Lactic Acid Fermentation

Most organisms, including humans, carry out fermentation using a chemical reaction that converts **pyruvic acid to lactic acid**.

Chemical equation:

Pyruvic acid + NADH → Lactic acid + NAD^+



Energy and Exercise

- How does the body produce ATP during different stages of exercise?
- For short, quick bursts of energy, the body uses ATP already in muscles as well as ATP made by lactic acid fermentation.
- For exercise longer than about 90 seconds, cellular respiration is the only way to continue generating a supply of ATP.

Quick Energy

Cells normally contain small amounts of ATP produced during cellular respiration, enough for **a few seconds** of intense activity.

Lactic acid fermentation can supply enough ATP to last about 90 seconds.

However, **extra oxygen is required to get rid of the lactic acid produced.**

Following **intense exercise**, a person will huff and puff for several minutes in order to pay back the built-up “**oxygen debt**” and clear the lactic acid from the body.

Long-Term Energy

For intense exercise lasting longer than 90 seconds, cellular respiration is required to continue production of ATP.

Cellular respiration releases energy more slowly than fermentation does.

The **body stores energy** in the form of the carbohydrate **glycogen**.

These glycogen stores are enough to last for **15 to 20 minutes of activity**.

After that, the body begins to break down other stored molecules, including fats, for energy.

Long-Term Energy

Hibernating animals, such as a brown bear, **rely on stored fat** for energy when they sleep through the winter.