HOW CELLS OBTAIN ENERGY FROM FOOD

Cellular Respiration (Part I)

SDSU BIOL366
Matthew Ellis, PhD

Vision for the Course

- I aim to teach **critical thinking** in a biological context

- While the specifics are important, the purpose is *not memorization*
  - Assessment questions do not test your ability to remember things, and you will not be punished for not remembering something (i.e., open book exam policy)

- Being able to apply information that you know to novel contexts is an invaluable and transferable skill which you will develop and carry through to other courses and into your future careers and lives

How to Succeed in this Course

- Come to class and engage with the material and your peers, particularly during Squarecap questions and Group Activities
  - Active learning helps enforce newly learned information more effectively
  - These are your “dry run” opportunities to make mistakes and course correct before the exam

- Look through the slides before coming to lecture
  - You don’t have to understand anything, but seeing it beforehand allows your brain to focus on understanding when you see it the second time instead of becoming overwhelmed

- Find a note-taking strategy that works well for you
  - Simply marking slides that were less clear or taking brief notes on the critical points can often streamline studying later on
  - Allows you to focus during lecture rather than frantically writing down as many words as possible and falling behind

How to Succeed in this Course

- Fill out the metacognitive reflection at the end of each lecture
  - Rather than moving on and immediately forgetting everything we talked about, taking a moment to reflect on what points of the lecture you found straightforward and which complex helps facilitate long-term memory and comprehension
  - Also provides an opportunity to provide me feedback on how to improve the course to benefit yourself and your peers

- Come to “Office Hours” to supplement your learning, or approach me after class or email me with questions
  - I am here as a resource and my goal is for you to succeed

- Use the learning objectives to guide your review and form study groups with your colleagues
  - Frame the learning objectives as questions and write down what you know about the topic, and practice explaining concepts out loud to your classmates

Learning Objectives

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

- Describe how cells breakdown food to create energy to be used by the body (**cellular respiration**)
- Explain key steps and enzymes of **glycolysis**
- Assess how and why fermentation occurs in animal cells
- Understand the metabolism of acetyl-CoA via the **TCA cycle** to produce high energy activated carriers
- Understand how the breakdown of fat and protein incorporates into cellular energy production

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Cellular Respiration

The degradation of biomolecules to generate energy that cells can utilize

a.k.a

Aerobic Respiration

(in the presence of oxygen)

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

Glucose (From FOOD) + O_2 → CO_2 + H_2O + Energy (In the form of ATP)

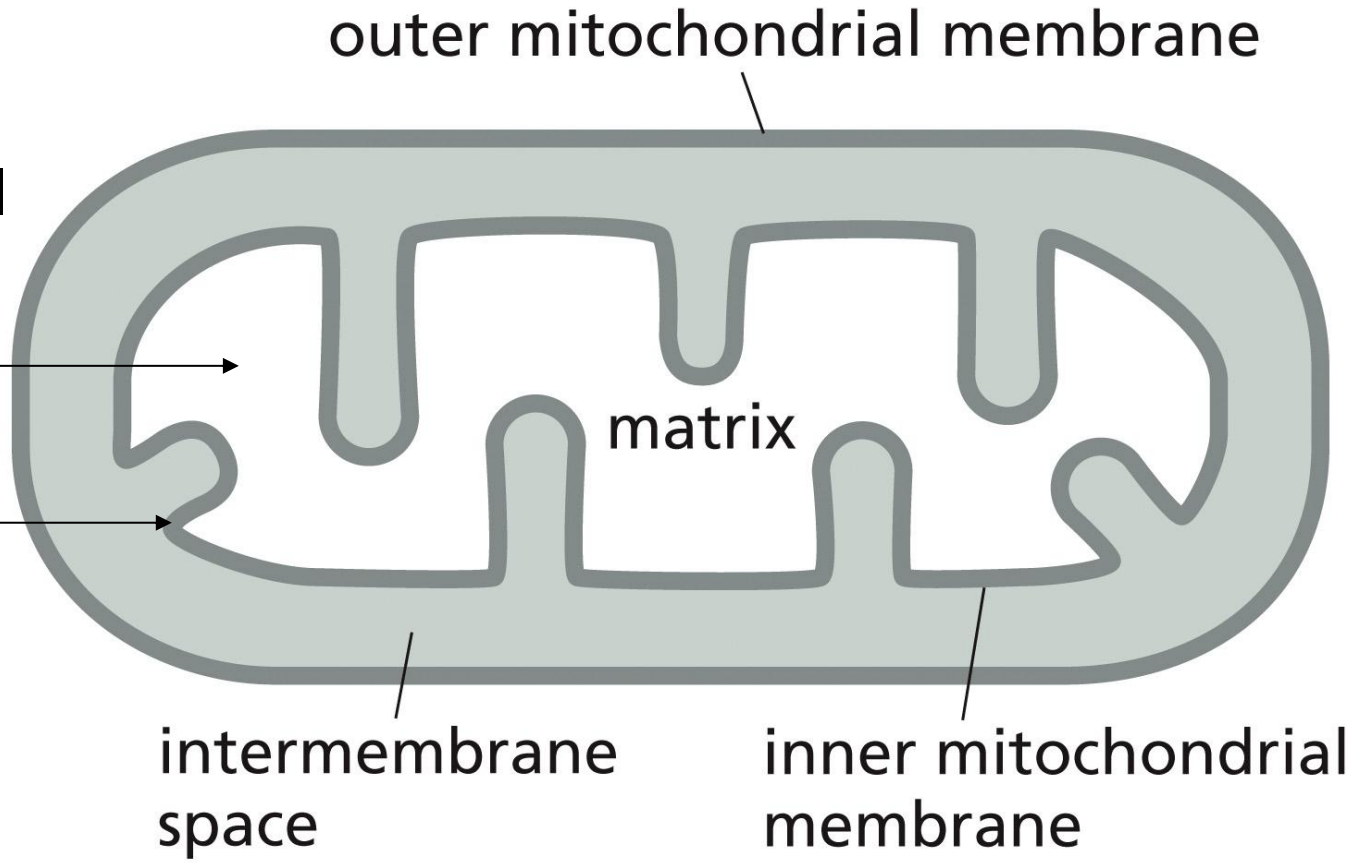
Location, Location, Location

Mitochondria

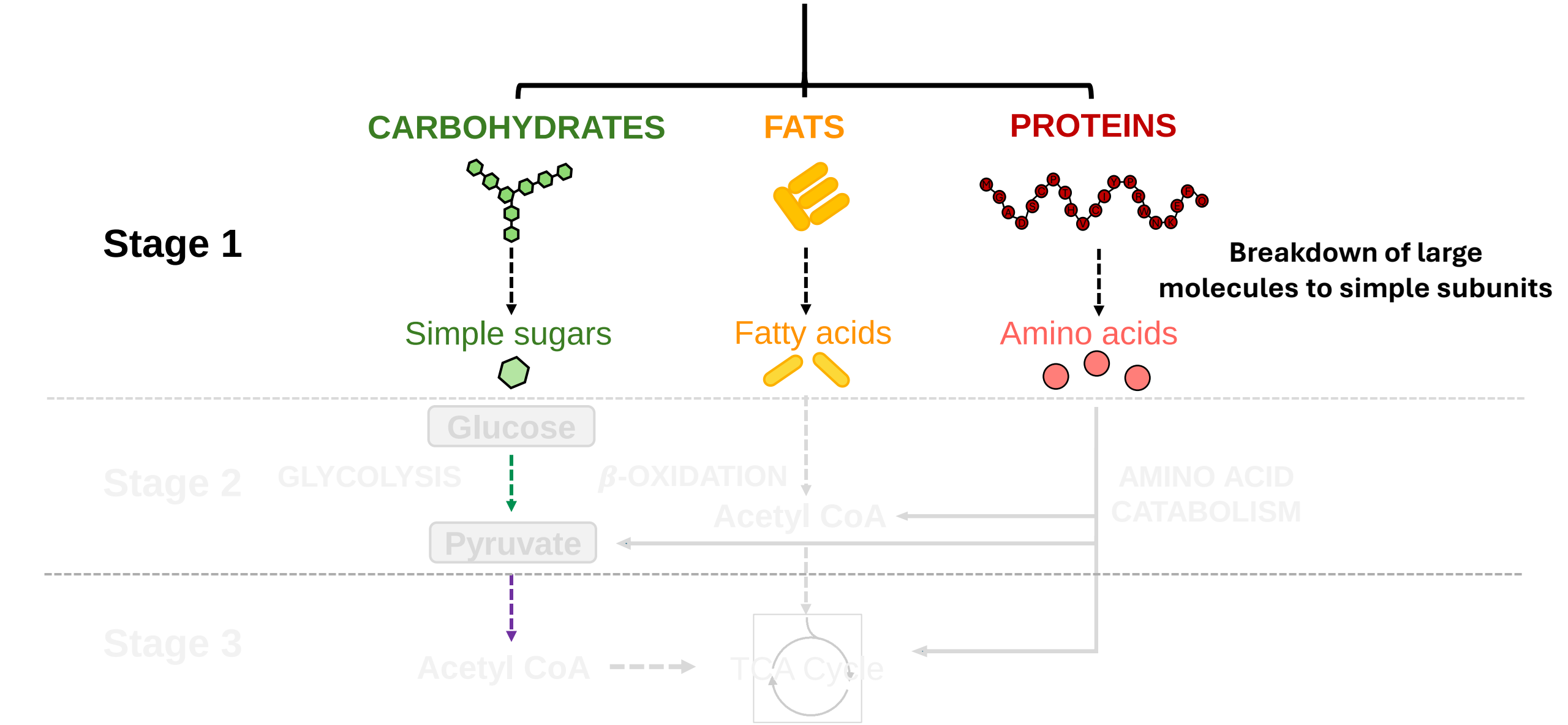
Glycolysis → cytosol

Citric Acid Cycle →

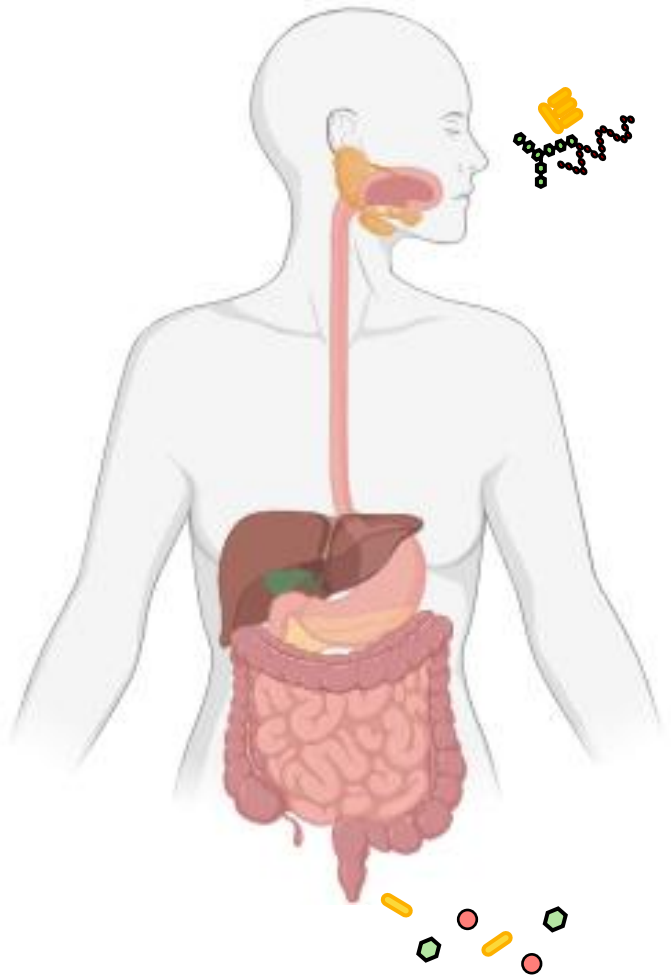
Oxidative Phosphorylation →



The breakdown of FOOD occurs in 3 stages

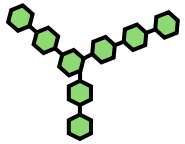


Digestion: The start of food breakdown



- Proper digestion requires mechanical and chemical digestion
- Occurs in the mouth, stomach, and small intestine

CARBOHYDRATES



i.e., Sucrase

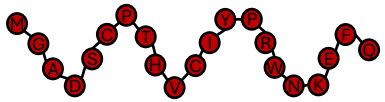
Simple sugars

FATS

i.e., Lipase

Fatty acids

PROTEINS



i.e., Protease

Amino acids

Food breakdown occurs in 3 stages

CARBOHYDRATES FATS PROTEINS

Stage 1

Simple sugars Fatty acids Amino acids

Formation of Acetyl-CoA and Pyruvate

Glucose

Stage 2

GLYCOLYSIS

β-OXIDATION

AMINO ACID CATABOLISM

Acetyl CoA

Pyruvate

Stage 3

Acetyl CoA ----> TCA Cycle

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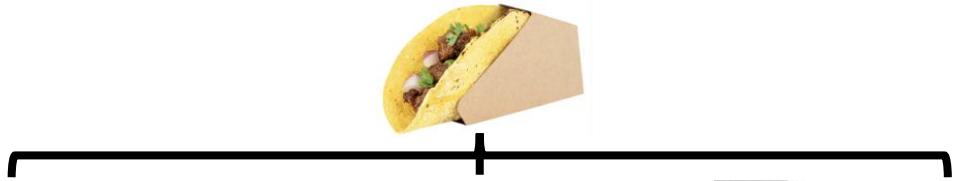
Glycolysis

“sugar” “breakdown”

Food breakdown occurs in 3 stages



CARBOHYDRATES FATS PROTEINS

Stage 1

Simple sugars Fatty acids Amino acids

Glucose

Stage 2 **GLYCOLYSIS**

Pyruvate

β-OXIDATION

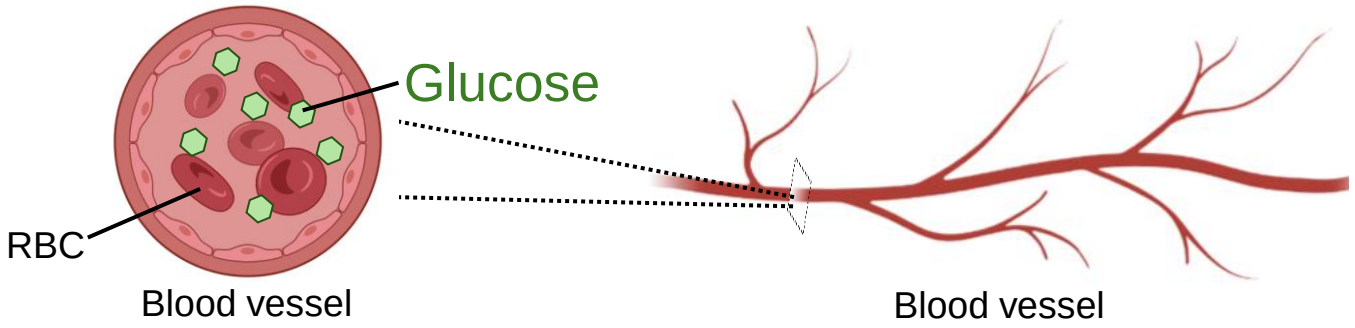
AMINO ACID CATABOLISM

Acetyl CoA

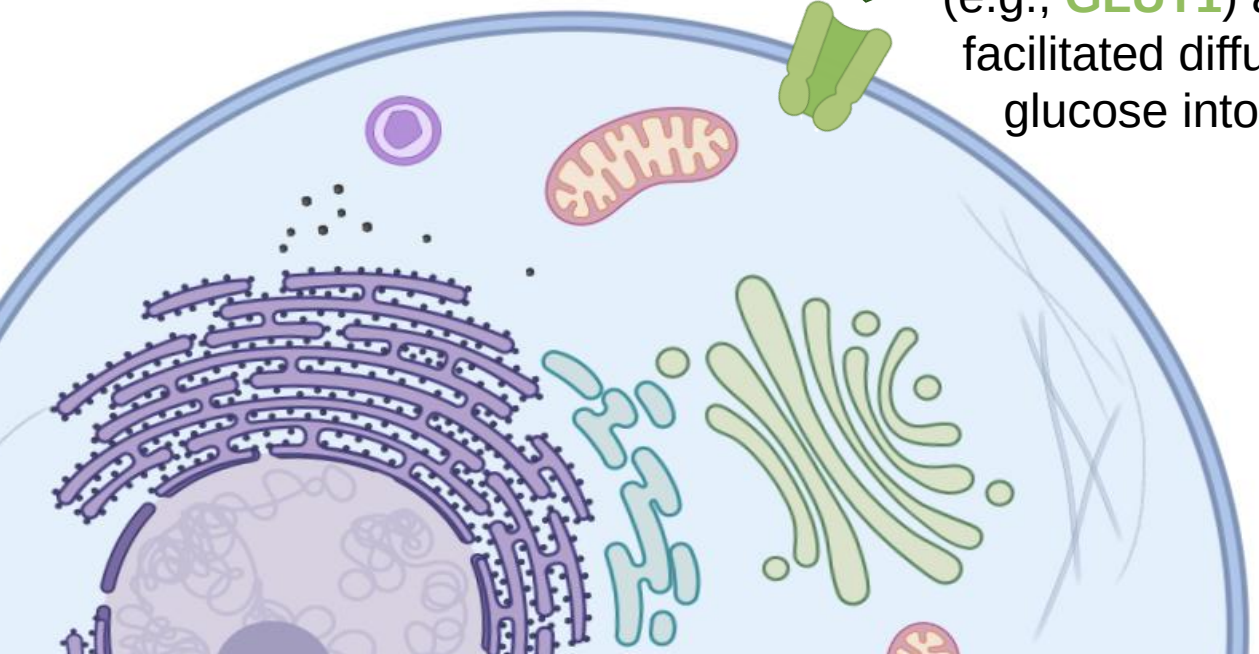
Stage 3

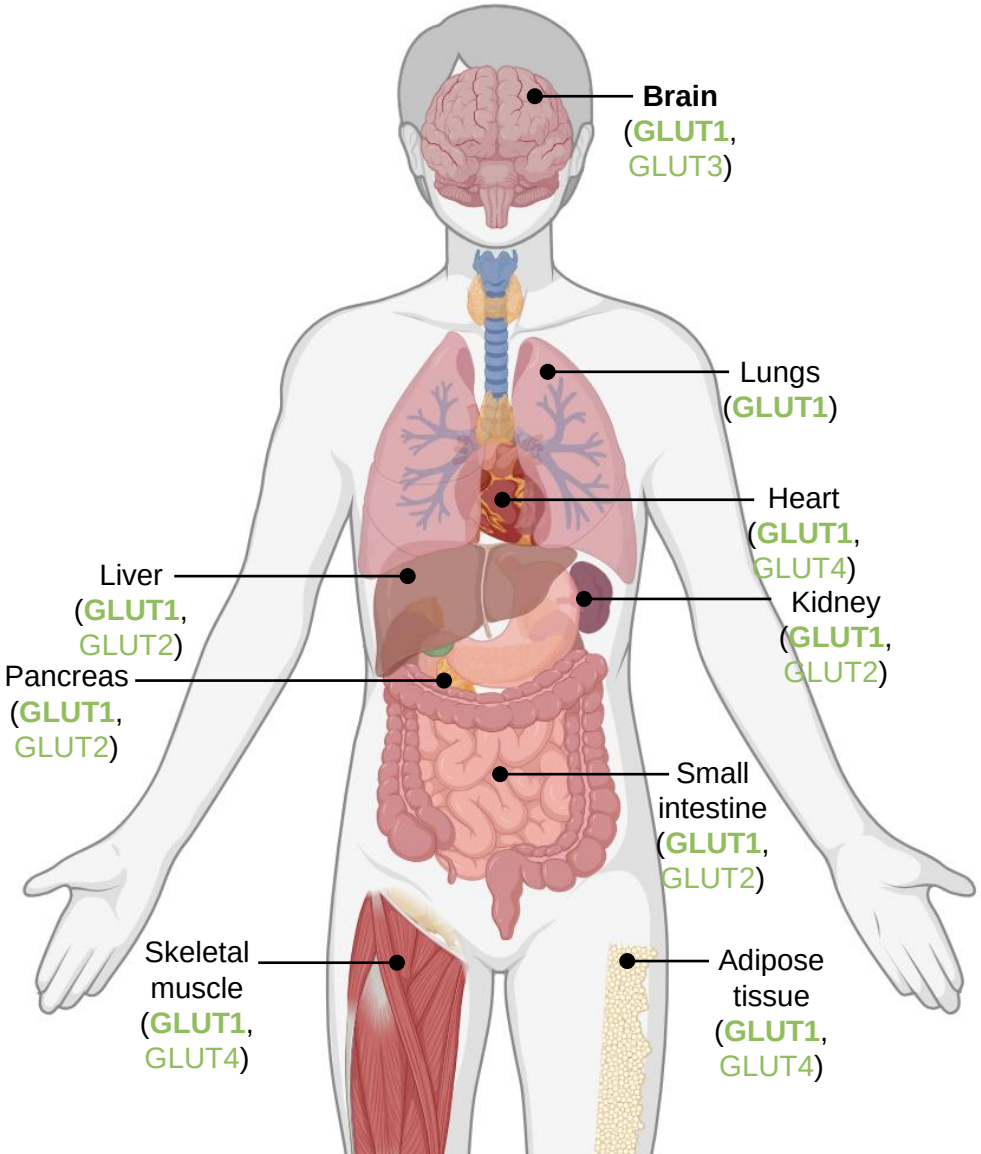
Acetyl CoA ----> TCA Cycle

Glucose is transported throughout the body via the bloodstream



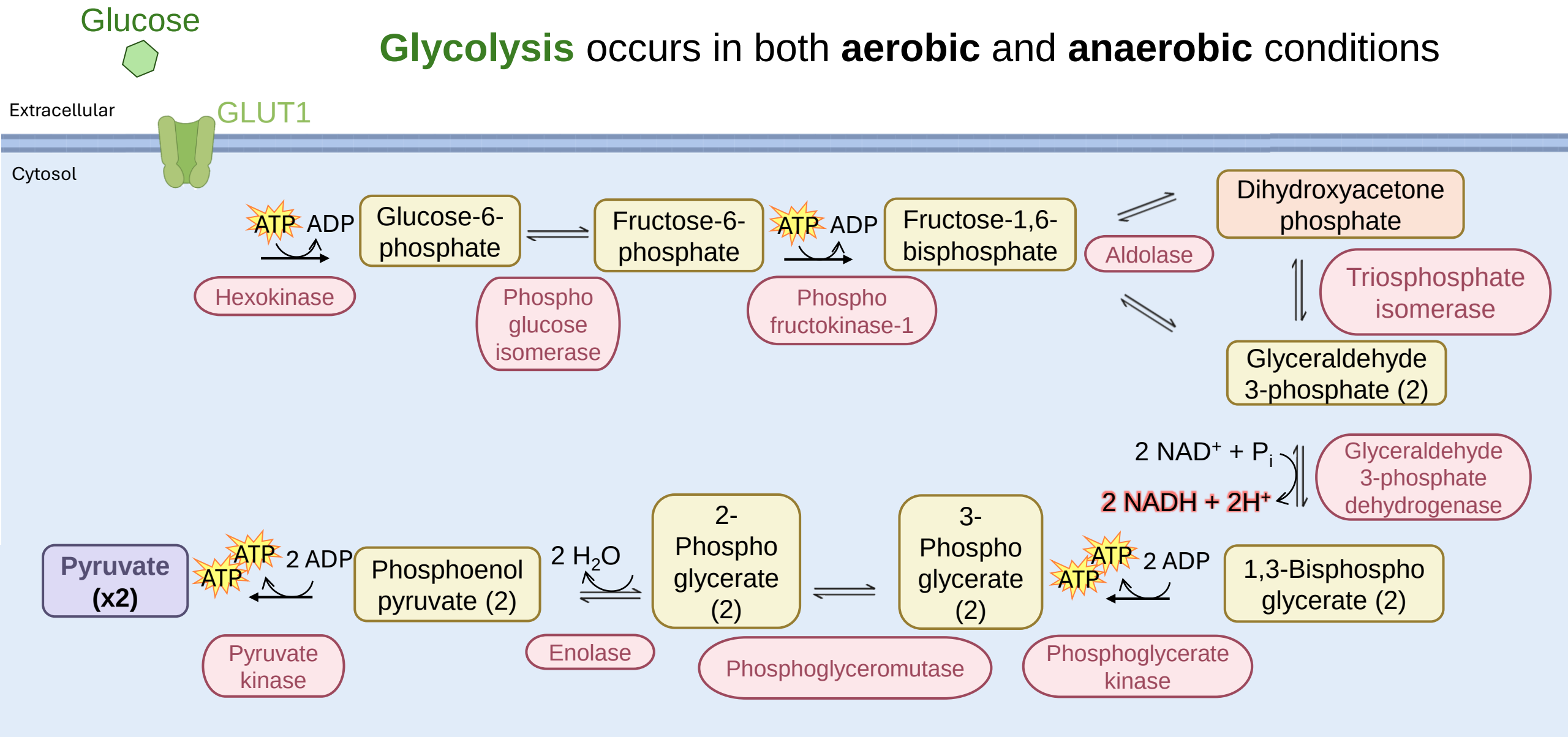
Glucose transporters (e.g., **GLUT1**) allow for facilitated diffusion of glucose into cells



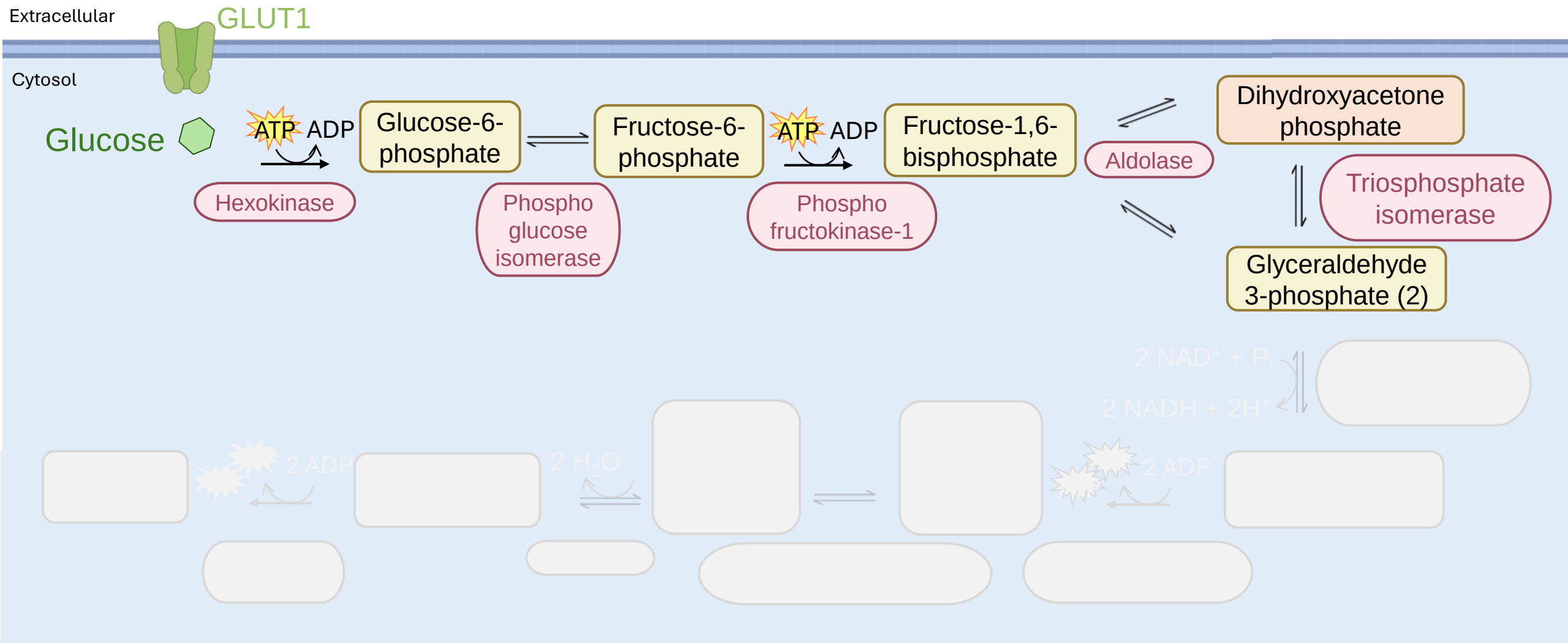


The 10-step program for Glycolysis

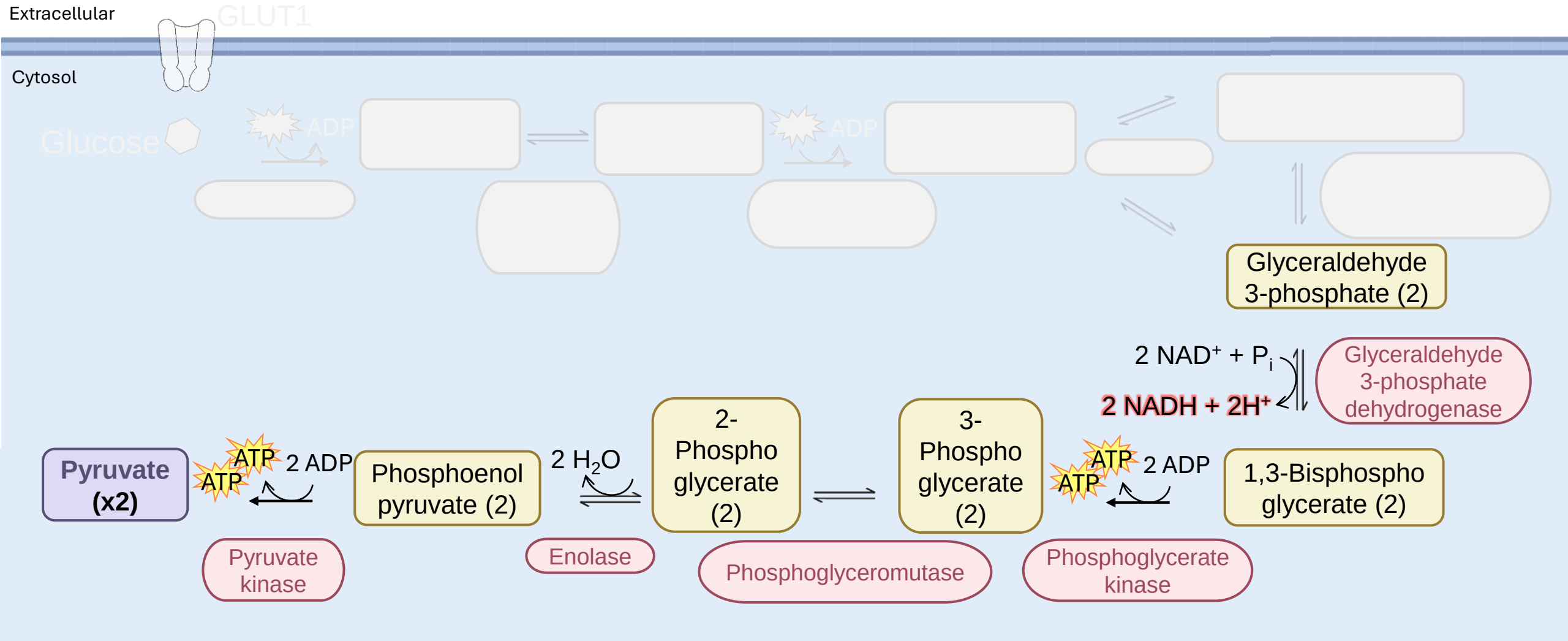
Glycolysis occurs in both **aerobic** and **anaerobic** conditions



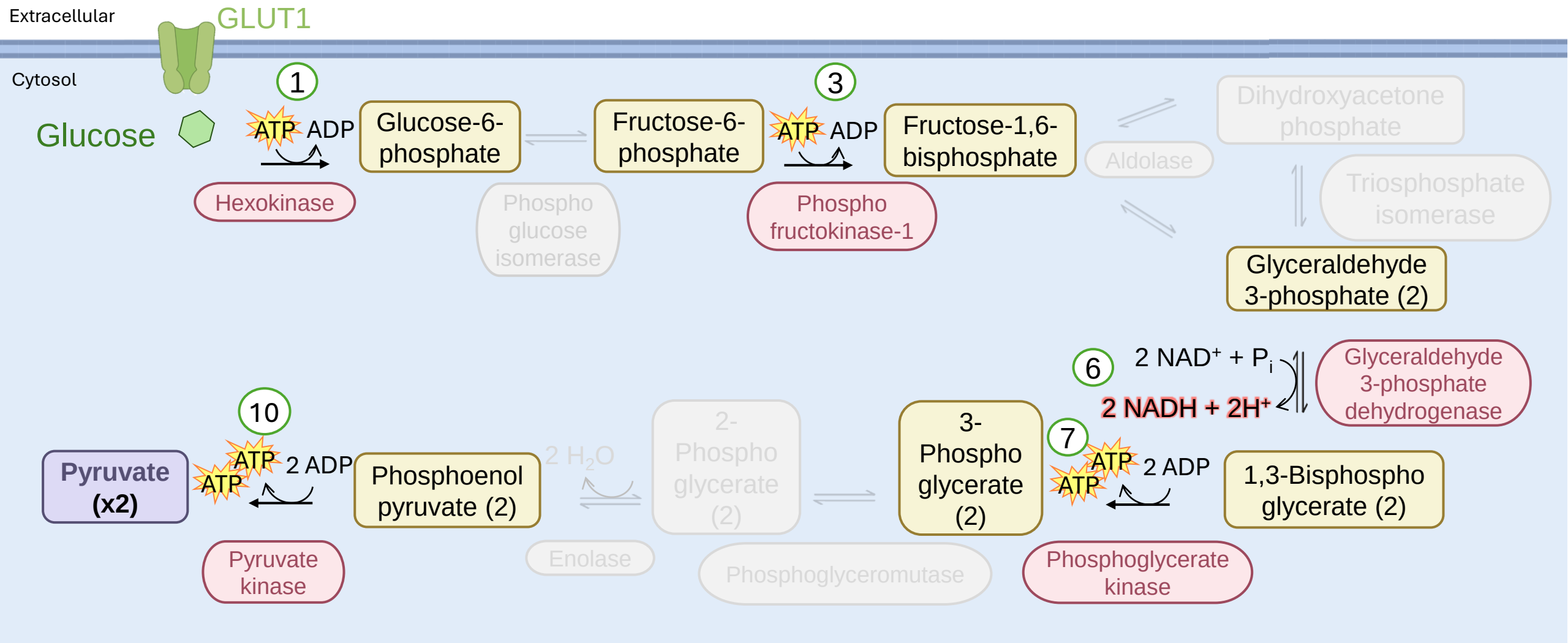
Glycolysis: Preparatory (or Investment) Phase



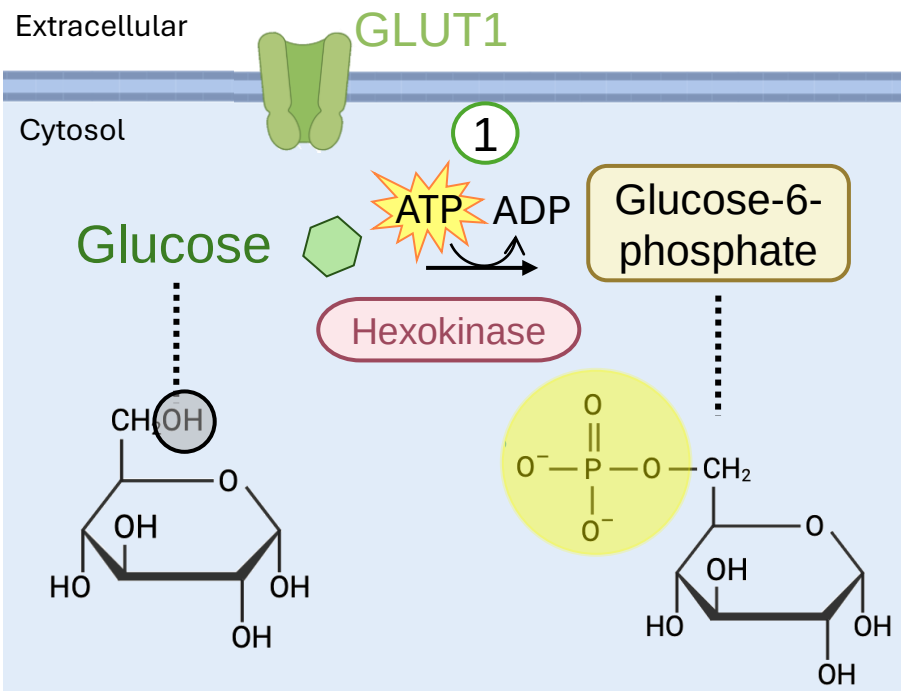
Glycolysis: Payoff Phase



Key steps of Glycolysis

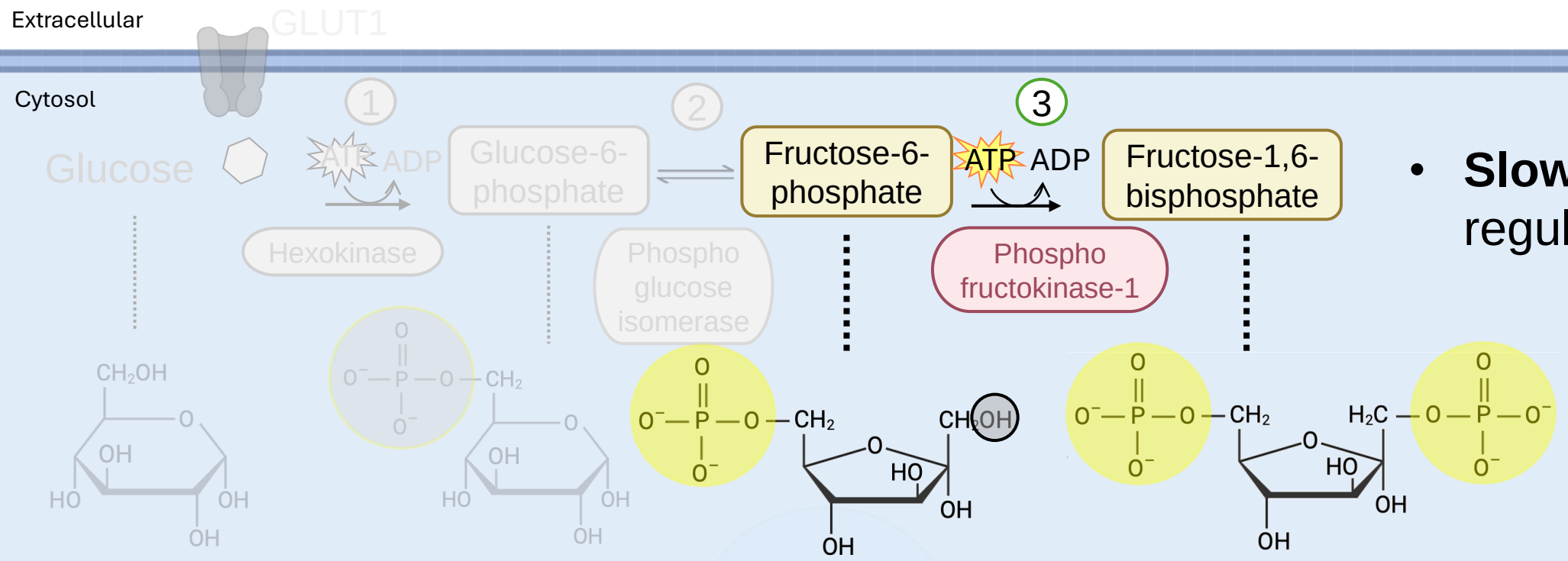


Key step of Glycolysis (glucose → glucose-6-phosphate)



- *Investment*: requires the input of ATP
  - ATP is the "currency" for our body as it provides the energy for non-spontaneous reactions to occur
- Addition of phosphate (PO_4^{3-}) to the -OH group by hexokinase *creates a negative charge* on glucose
  - Now impermeable to crossing the cell membrane

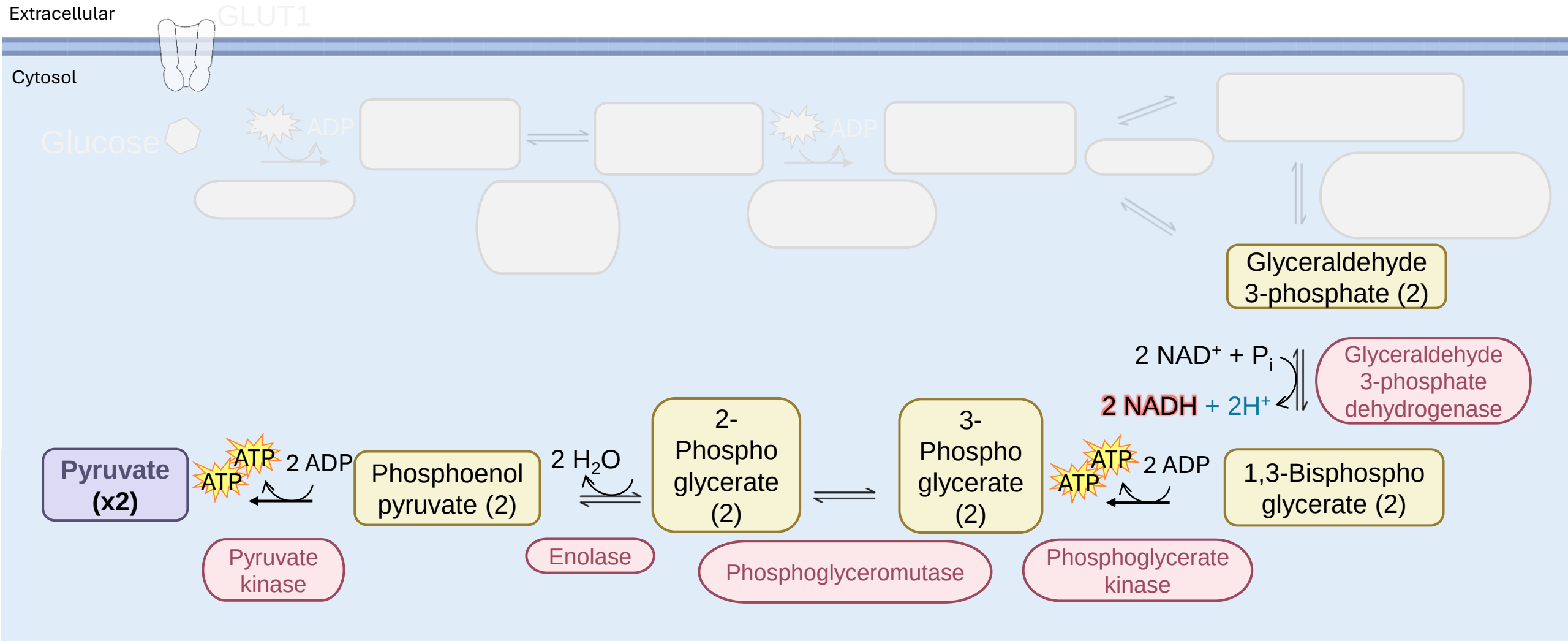
Rate limiting step of Glycolysis (fructose-6-phosphate → fructose-1,6-bisphosphate)



- **Slowest** and highly regulated step

- Phosphofructokinase-1 is highly sensitive to ATP levels in cells
  - ❖ ATP **high = Phosphofructokinase-1 activity is inhibited**
  - ❖ ATP **low = Phosphofructokinase-1 activity is activated**

Glycolysis: Payoff Phase

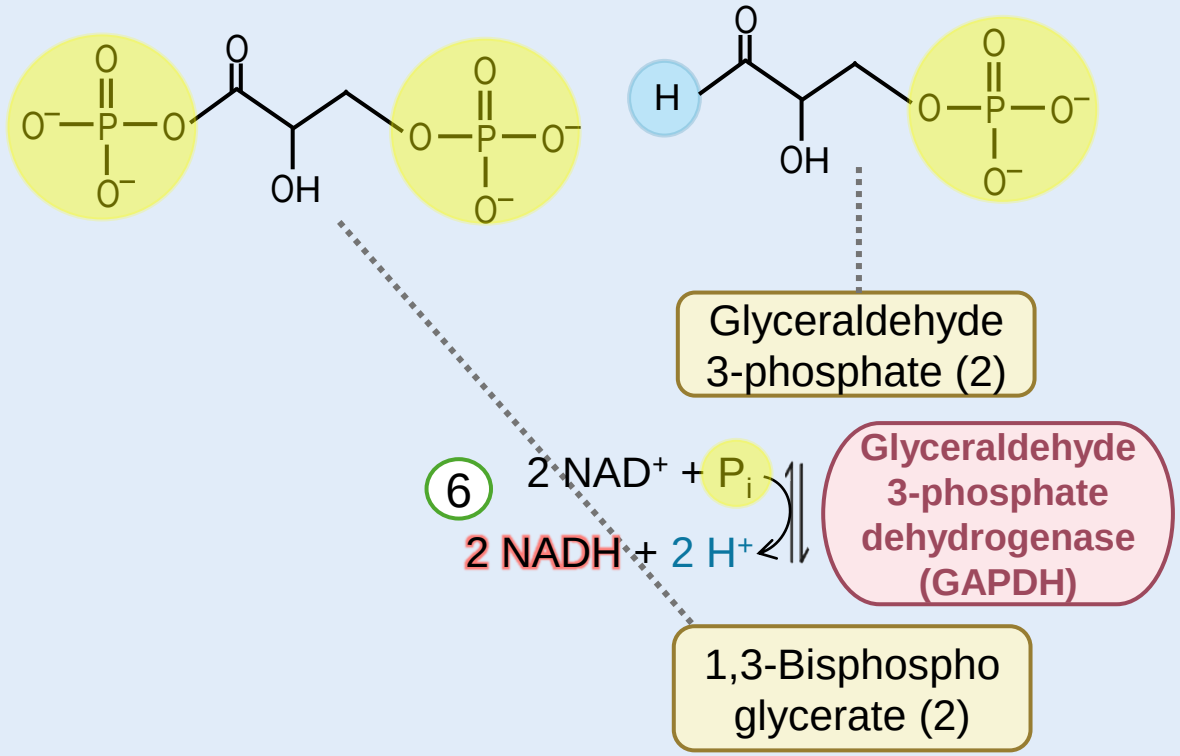


Key step of Glycolysis (oxidation of glyceraldehyde 3-phosphate)

Extracellular

Cytosol

- **GAPDH** facilitates *oxidation* of glyceraldehyde 3-phosphate to 1,3-bisphosphoglycerate
- This produces **NADH**, an activated carrier that stores energy similar to ATP
  - NAD^+ gets *reduced* to NADH
- Note that from this point we have **two** of *each of these compounds*, as the fructose ring has been broken

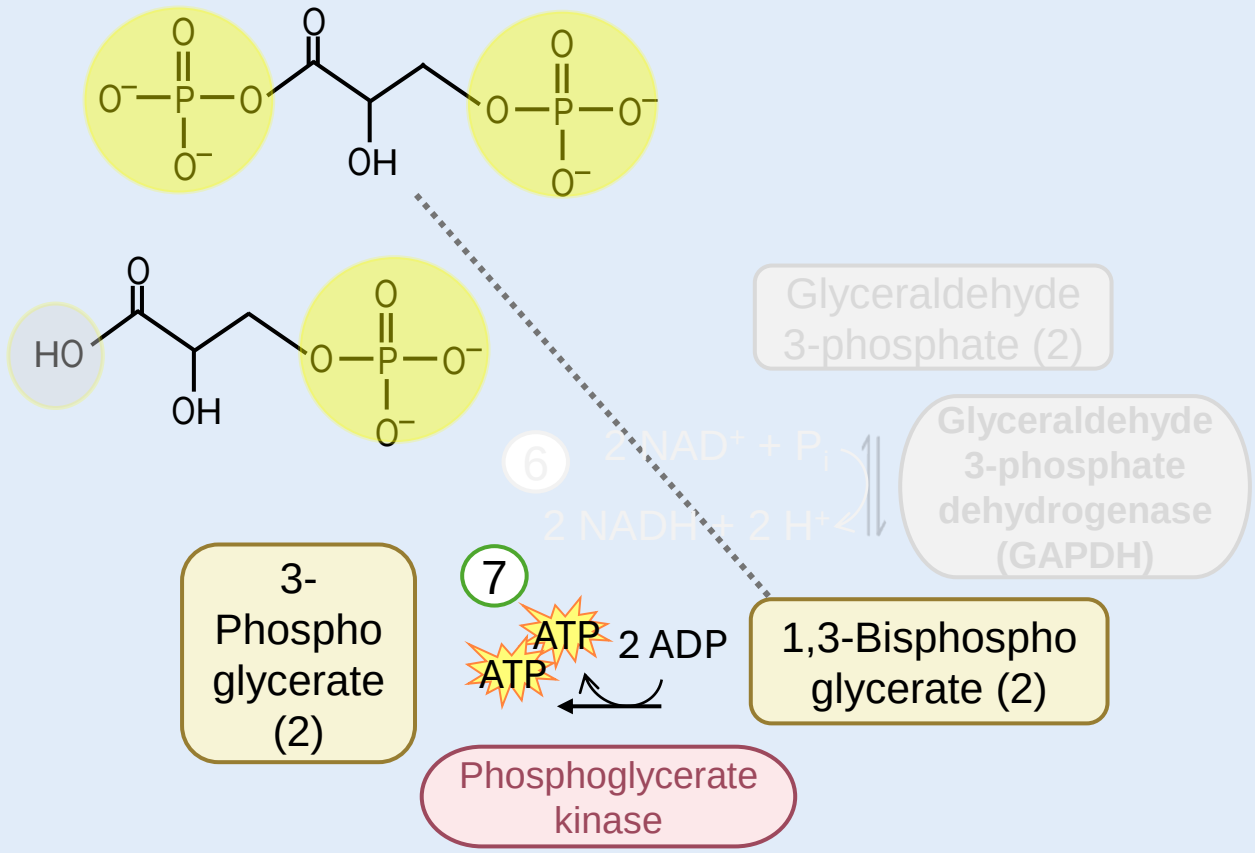


Key step of Glycolysis (1,3-Bisphosphoglycerate → 3-Phosphoglycerate)

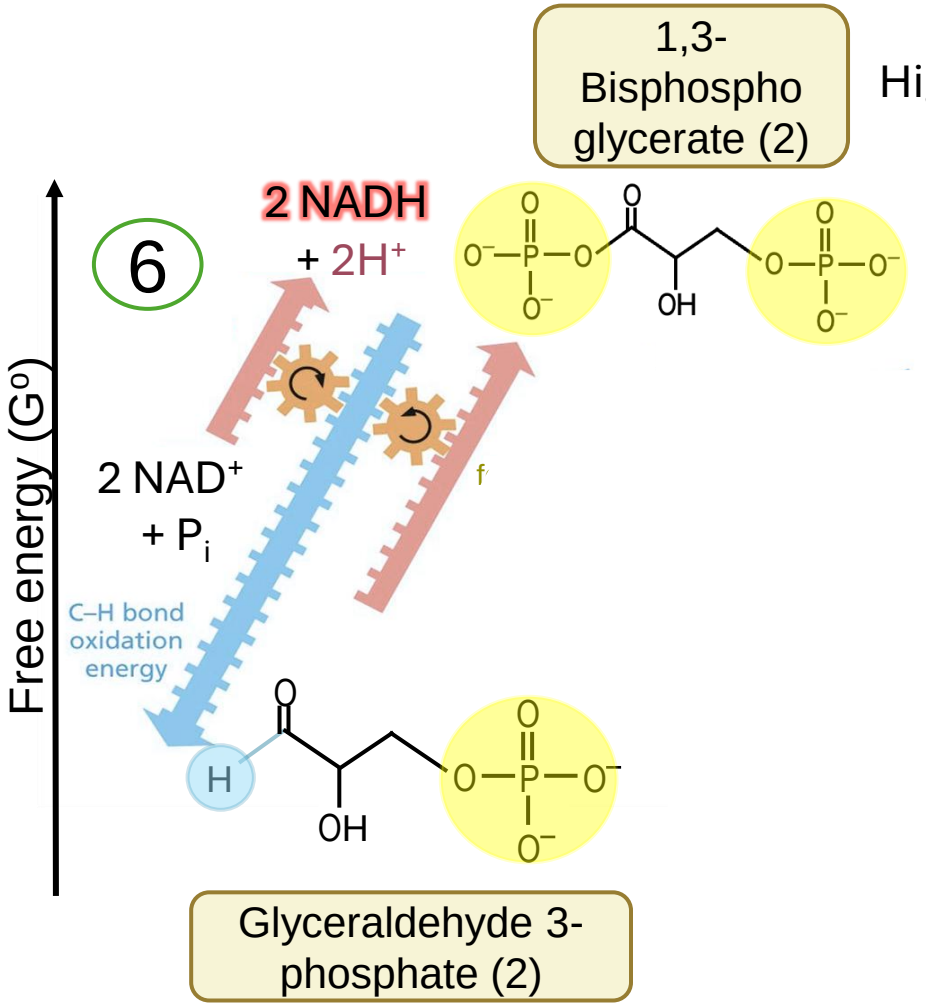
Extracellular

Cytosol

- 1st step of ATP production during glycolysis (payoff from our investment)
- Phosphoglycerate kinase transfers PO_4^{3-} group of 1, 3-Bisphosphoglycerate onto ADP, resulting in 3-phosphoglycerate and ATP



Glycolytic enzymes couple oxidation to energy storage in activated carriers (steps 6-7)



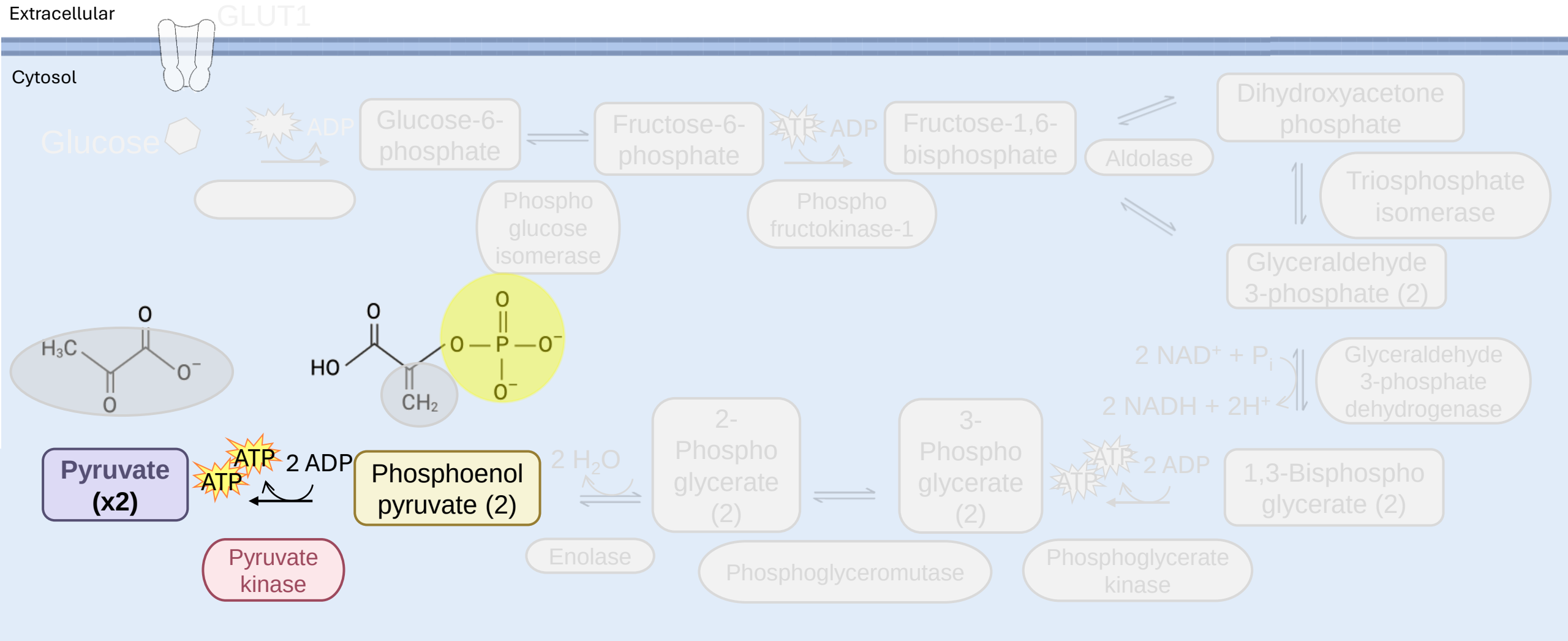
Total change in free energy (ΔG^o) for steps 6-7 of glycolysis = **-12.5 kJ/mole** = **energetically favorable**

TABLE 3–2 SOME ACTIVATED CARRIERS WIDELY USED IN METABOLISM

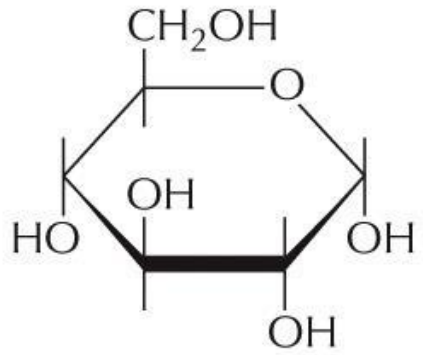
Activated Carrier	Group Carried in High-Energy Linkage
ATP	phosphate
NADH, NADPH, $FADH_2$	electrons and hydrogens
Acetyl CoA	acetyl group
Carboxylated biotin	carboxyl group
S-adenosylmethionine	methyl group
Uridine diphosphate glucose	glucose

Pyruvate: The Final Payoff of Glycolysis

- 2 **Pyruvate** molecules are formed per 1 molecule of **glucose**

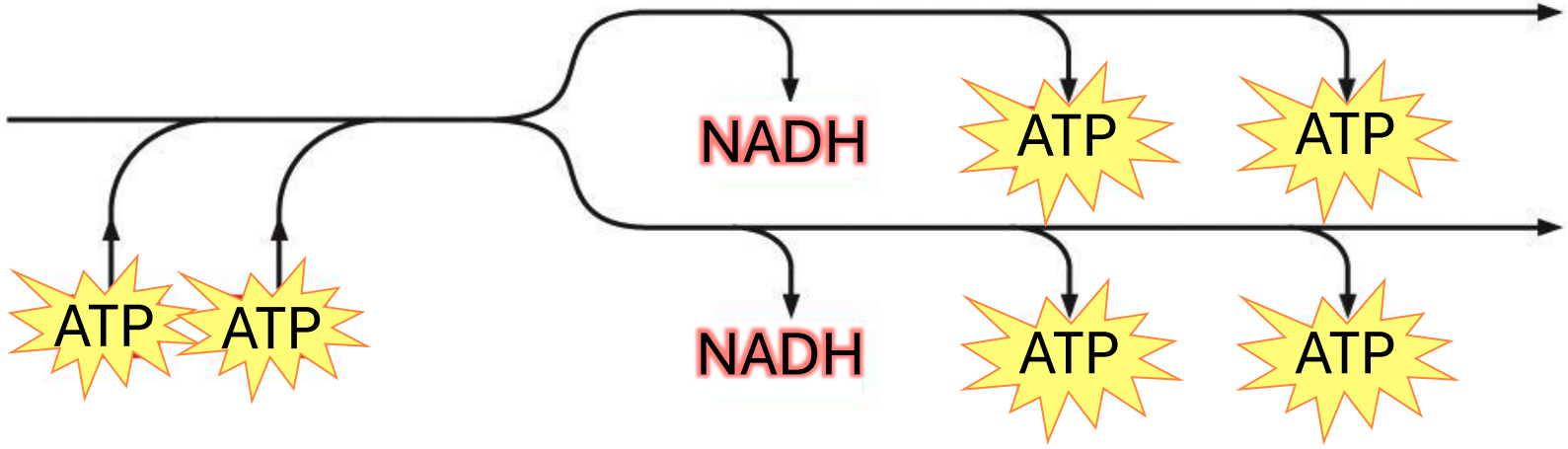


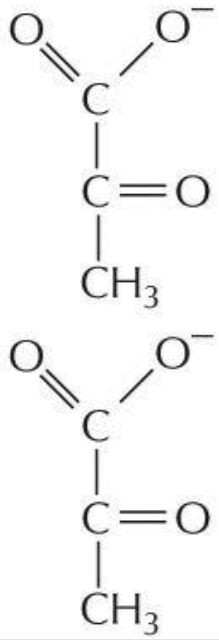
NET RESULT OF GLYCOLYSIS



Glucose

One molecule of Glucose





Pyruvate (x2)

<u>Net products</u> are 2 molecules of NADH, 2 molecules of ATP, and two molecules of pyruvate

Squarecap Q#1-2

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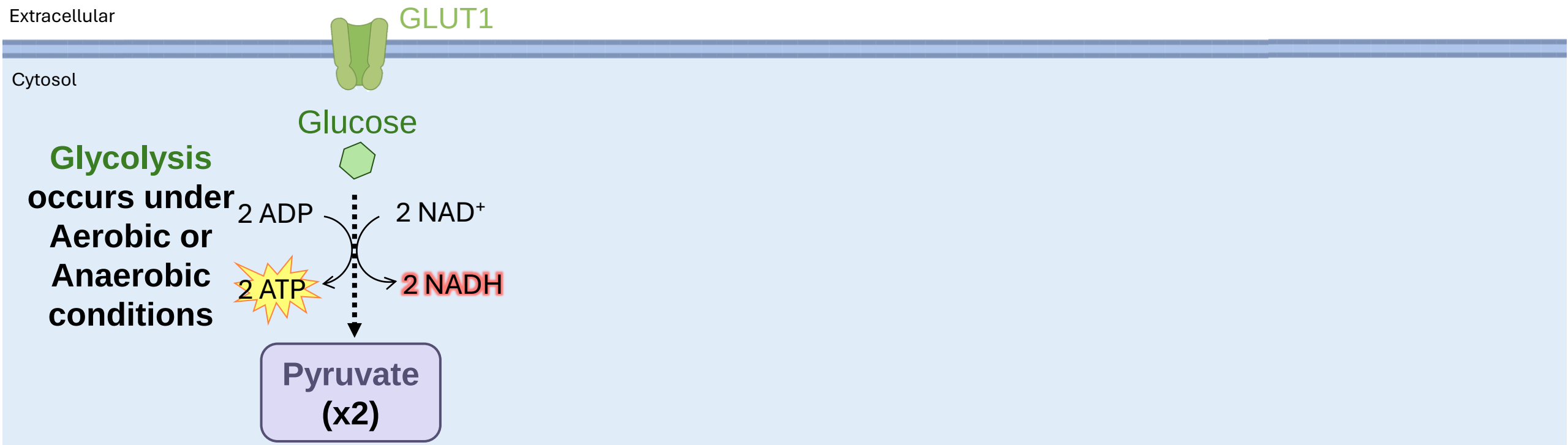
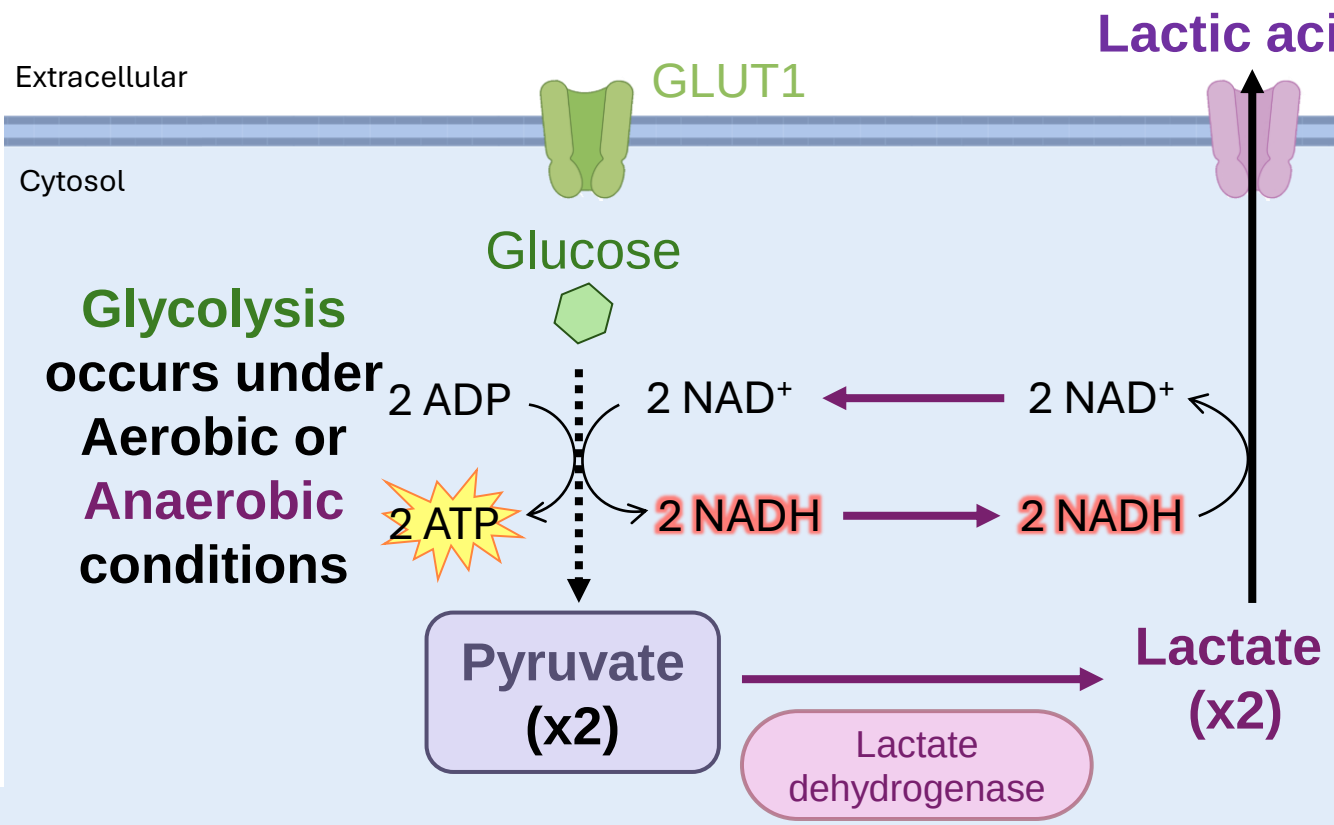
After glycolysis, pyruvate has two paths



Pyruvate can convert to lactate

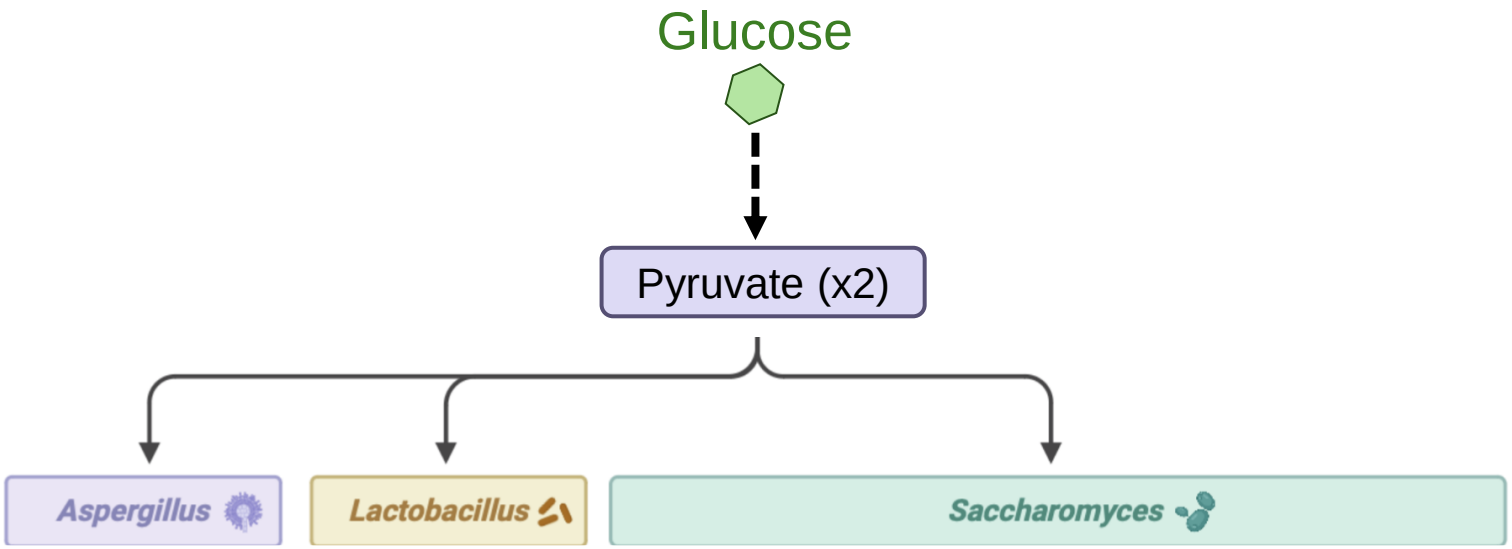


Anaerobic Glycolysis:

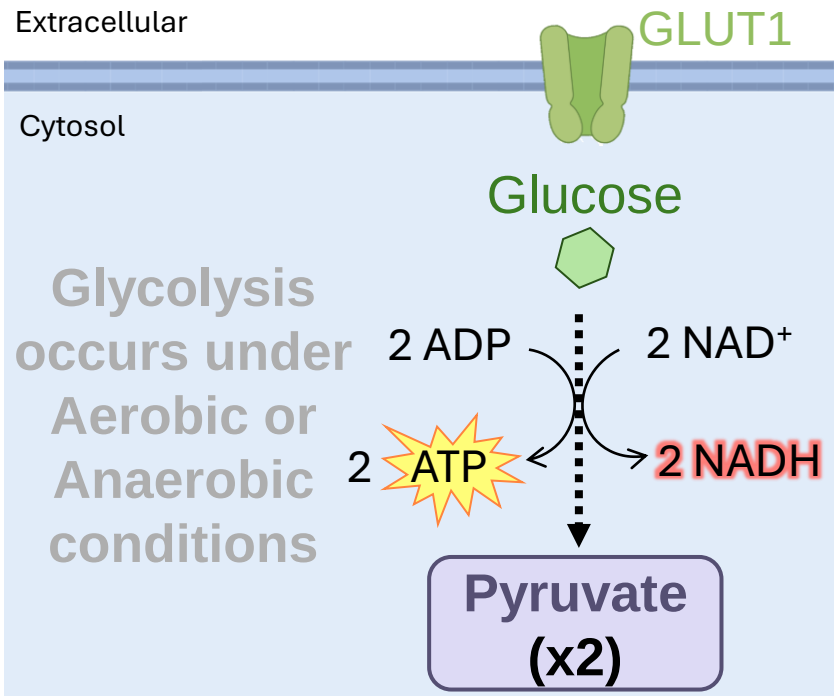
- Pyruvate converts to lactate when O_2 is limited
- Allows for the regeneration of NAD^+
- Lactic acid is an alternative energy source for cells (e.g., muscle cells when exercising)

- **Fermentation occurs under anaerobic conditions**
  - 2 types: Lactic acid and Alcoholic (ethanol) fermentation
  - ***Fermentation** and Anaerobic Glycolysis are often used interchangeably

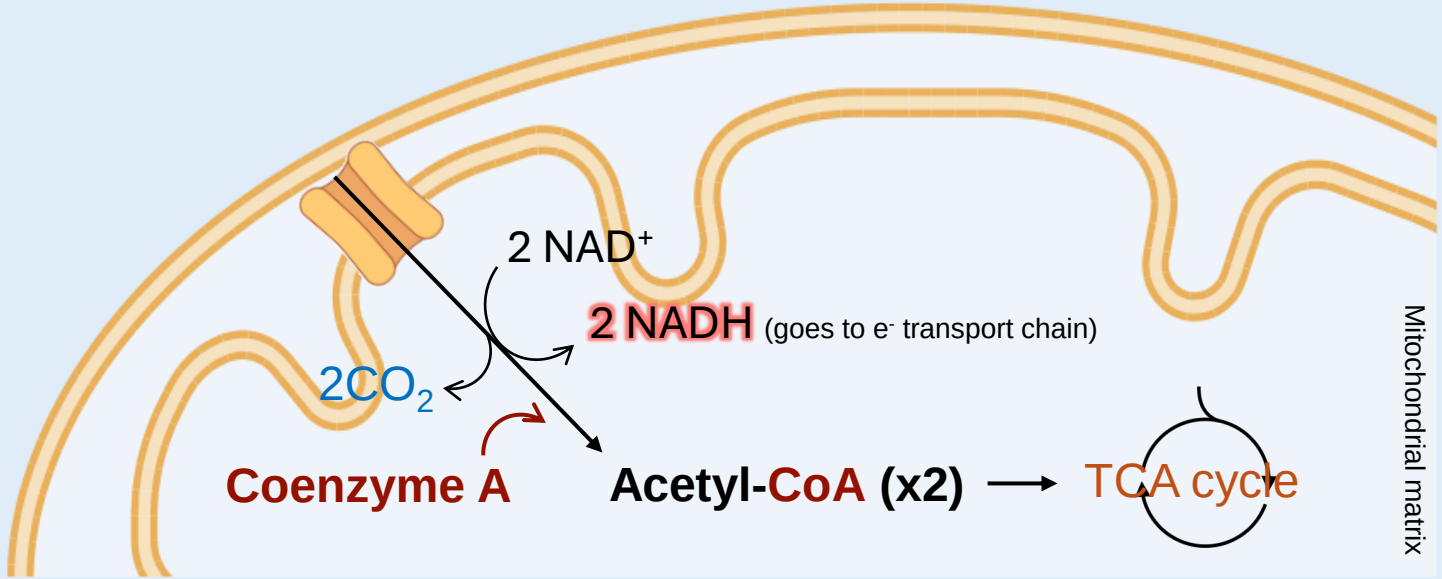
Microorganisms are essential for Fermentation



Pyruvate can be oxidized to Acetyl-CoA in the mitochondria



- Acetyl group from pyruvate is transferred to **Coenzyme A (CoA)** to produce **Acetyl-CoA**
  - This liberates one carbon dioxide molecule and produces one NADH **per pyruvate**



Conversion of pyruvate to Acetyl-CoA occurs *only in aerobic conditions*

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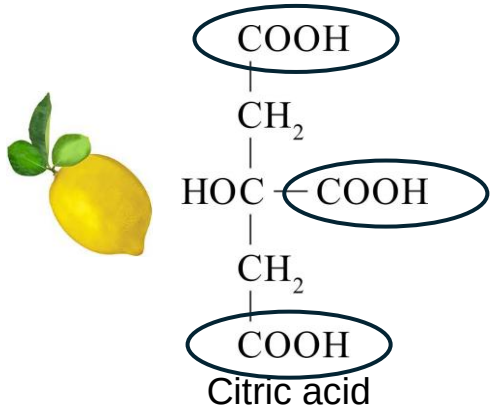
Tricarboxylic acid (TCA) Cycle



Citric acid

a.k.a

Citric Acid Cycle


Hans Krebs
1900-1981

a.k.a

Krebs Cycle

Food breakdown occurs in 3 stages

CARBOHYDRATES FATS PROTEINS

Stage 1

Simple sugars Fatty acids Amino acids

Stage 2

GLYCOLYSIS β-OXIDATION AMINO ACID CATABOLISM

Acetyl CoA

Stage 3

Acetyl CoA ----→ TCA Cycle

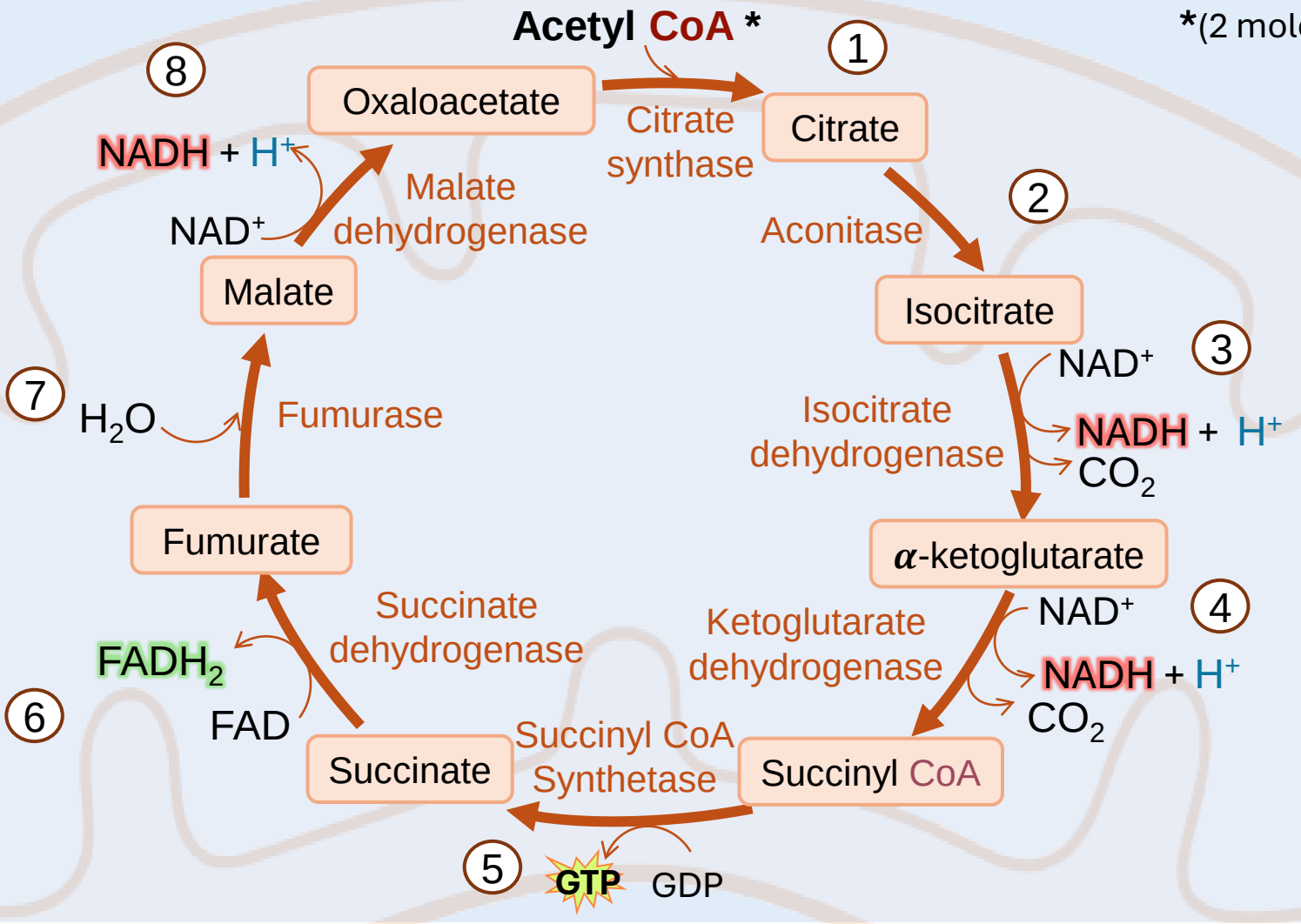
Complete oxidation of Acetyl-CoA into CO_2

The main purpose of the TCA Cycle is to produce high-energy activated carriers

Extracellular

Cytosol

- **Occurs only in aerobic conditions**



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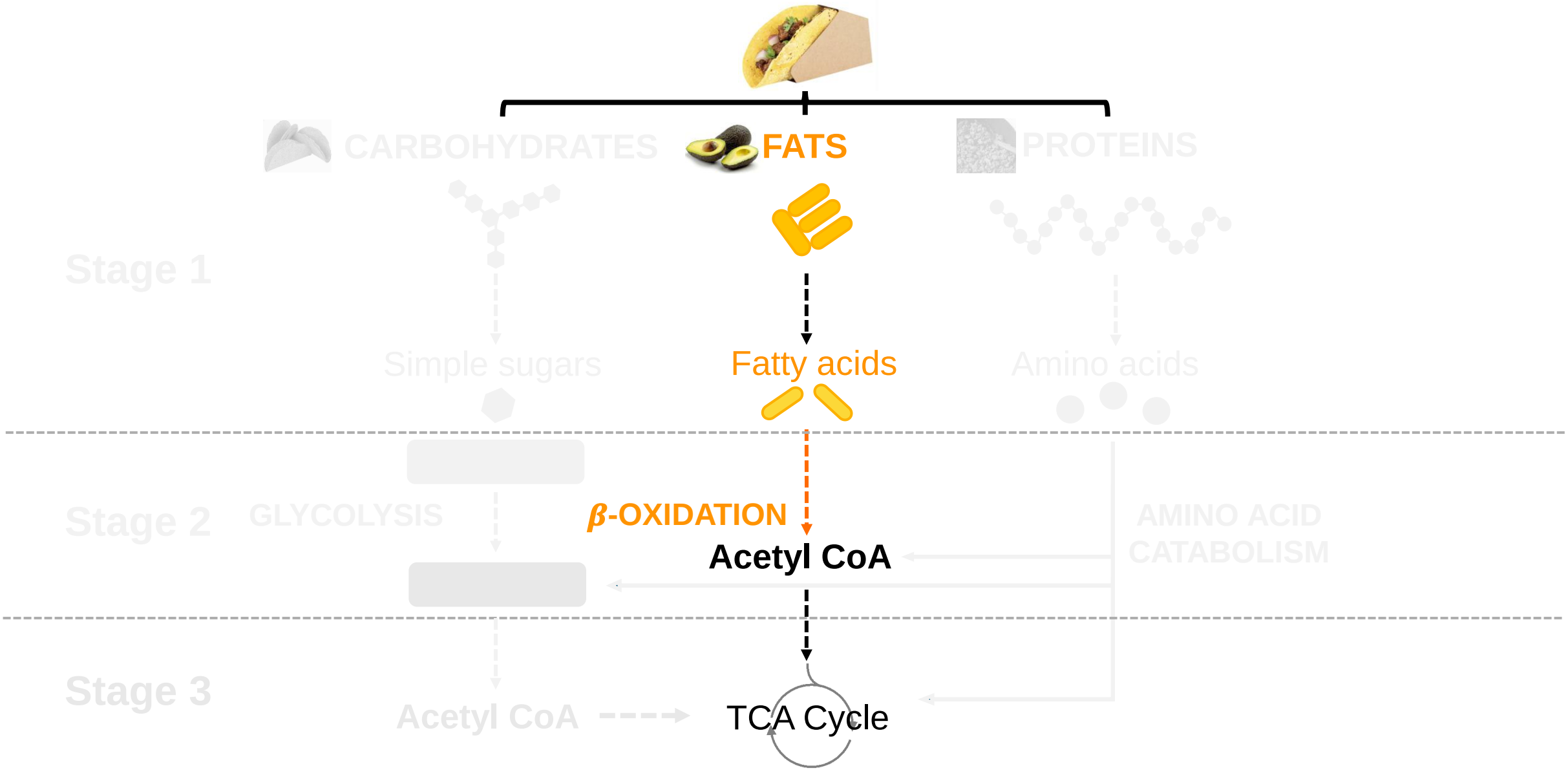
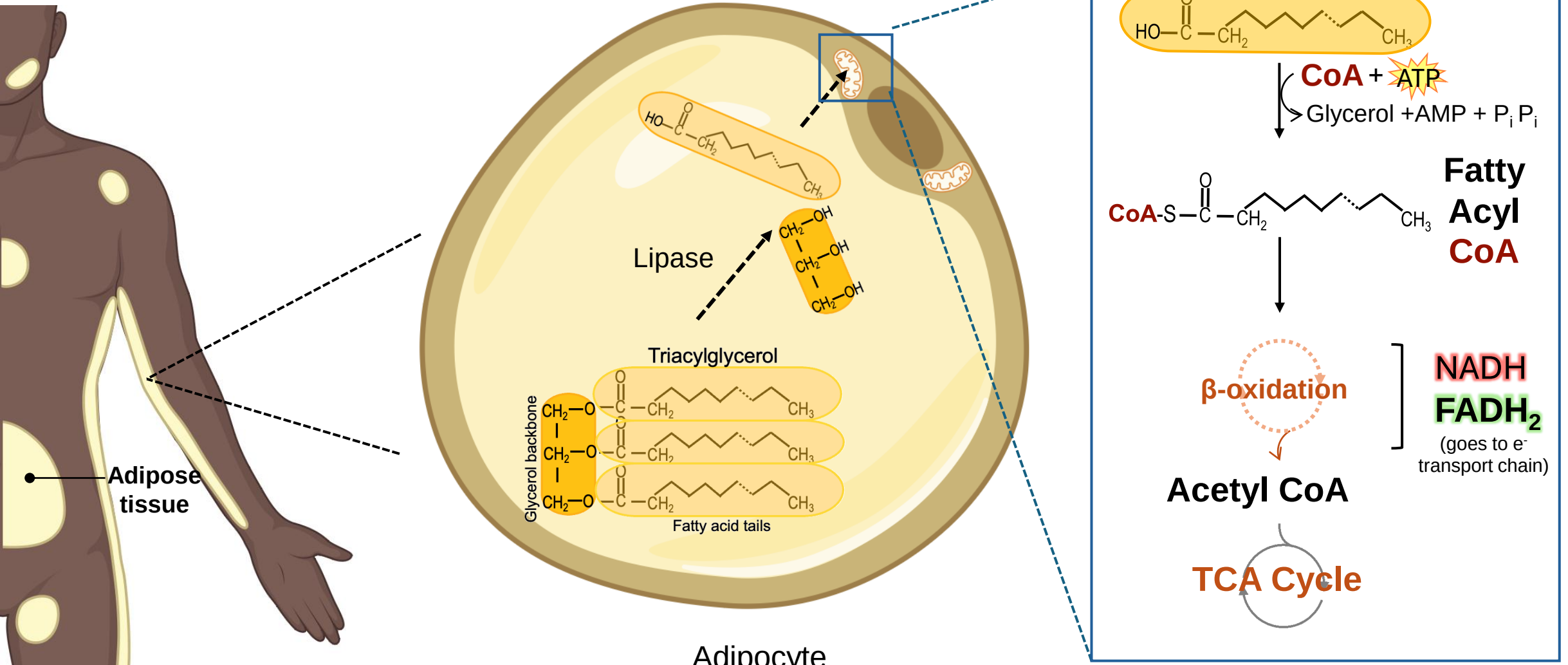
Breakdown of fats occurs via β-oxidation



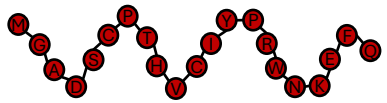
Fats are stored in adipocytes and undergo β-oxidation to generate Acetyl CoA



Amino acid metabolism produces intermediates used in cellular respiration

CARBOHYDRATES FATS

PROTEINS



Simple sugars Fatty acids

Amino acids

Stage 1

Stage 2

GLYCOLYSIS β-OXIDATION

AMINO ACID CATABOLISM

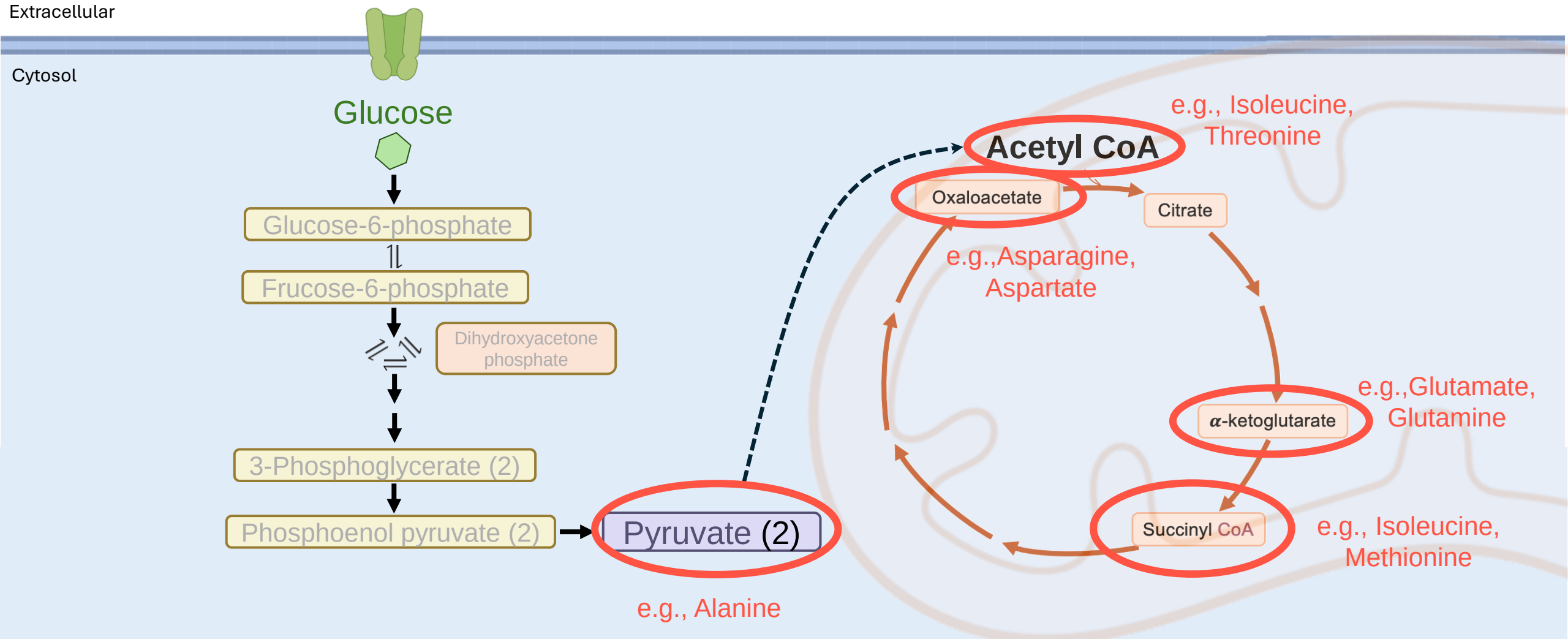
Acetyl CoA

Pyruvate

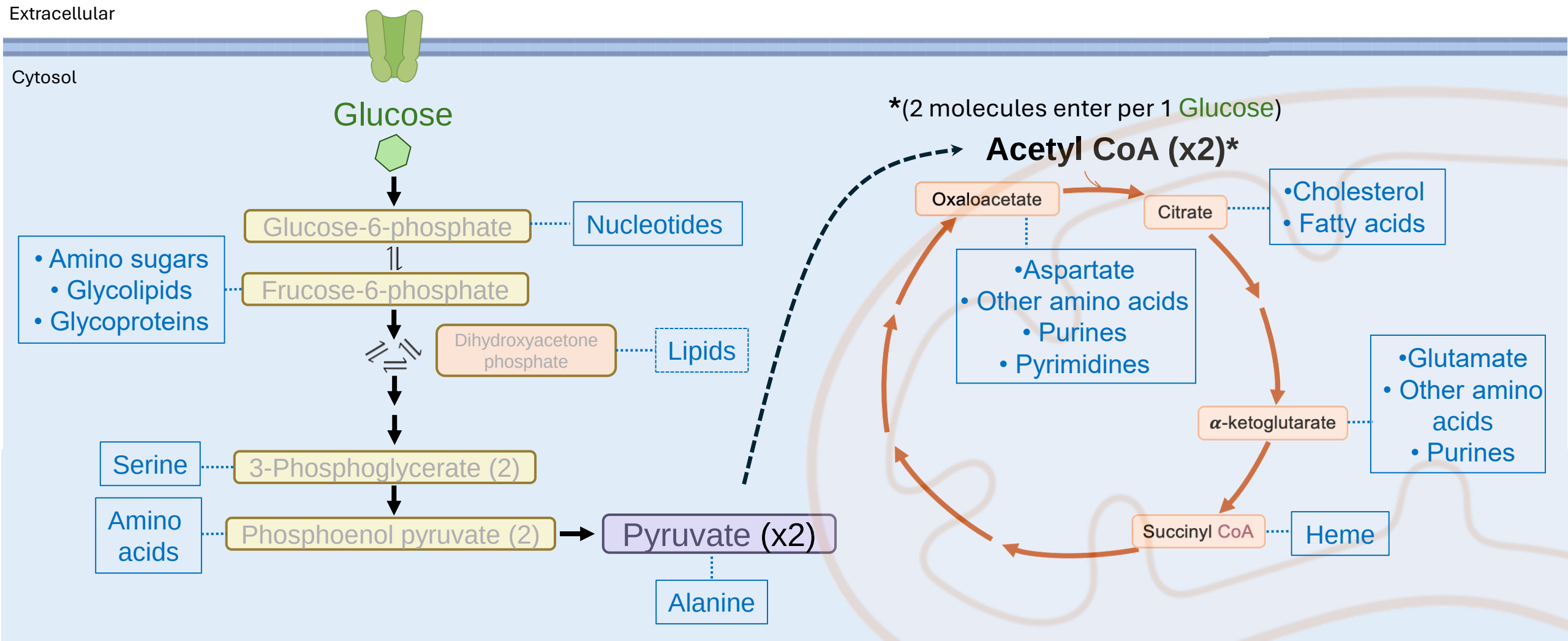
Stage 3

Acetyl CoA ----→ TCA Cycle

Amino acids catabolize (break down) into intermediates needed for Glycolysis and the TCA Cycle

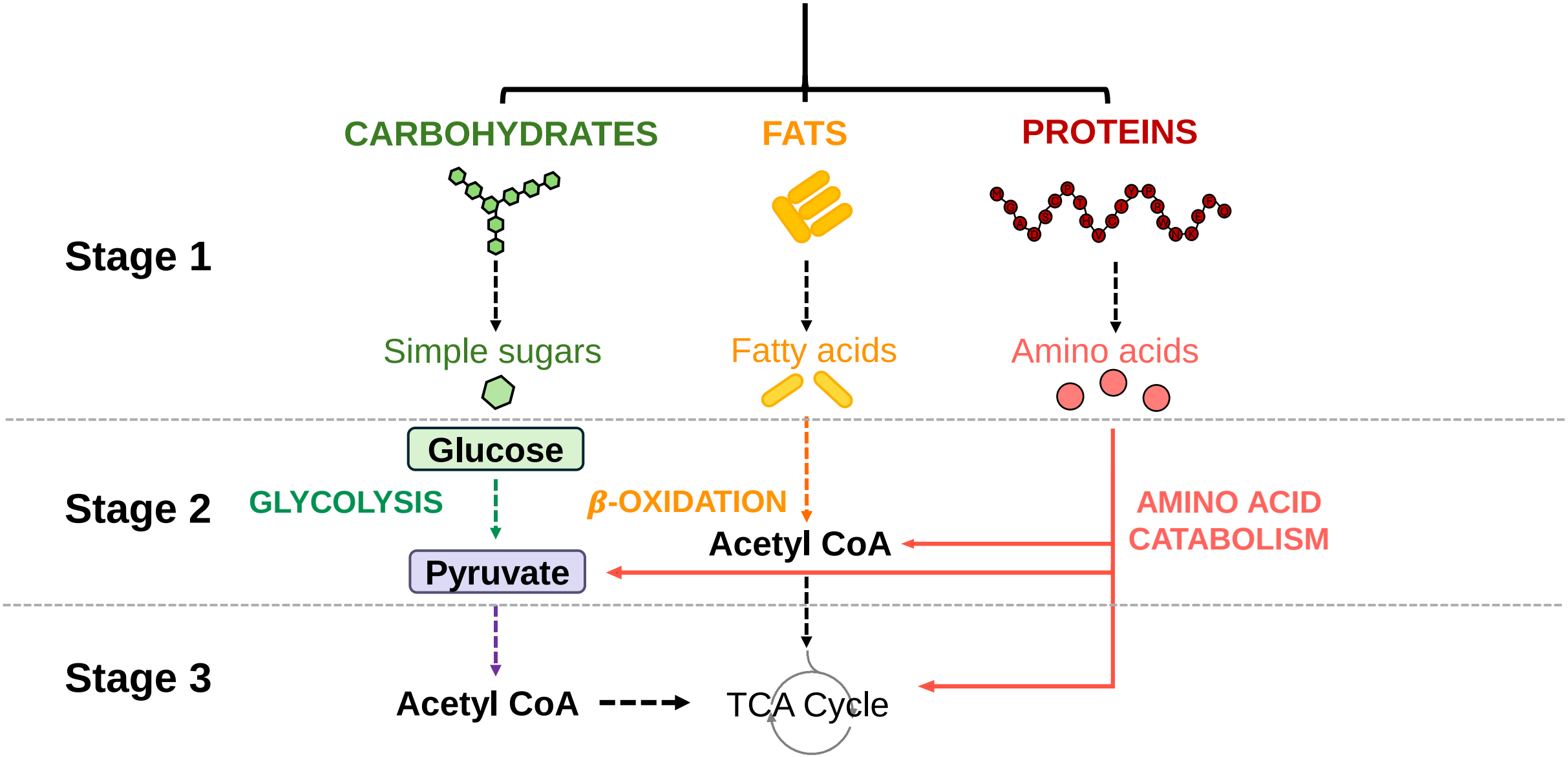


Glycolysis + TCA Cycle also generate metabolites used in other biological processes



Squarecap Q#3-4

The breakdown of FOOD occurs in 3 stages



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 (x2)

TCA CYCLE → GTP + 3 NADH + 1 $FADH_2$

OXIDATIVE PHOSPHORYLATION

Converting our high energy electrons into ATP

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

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Wednesdays 11-12pm

Check the syllabus for Zoom link!

Metacognitive Reflection Form