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30 June 2024

NTR 306: Fundamentals of Nutrition

Chapter 7:

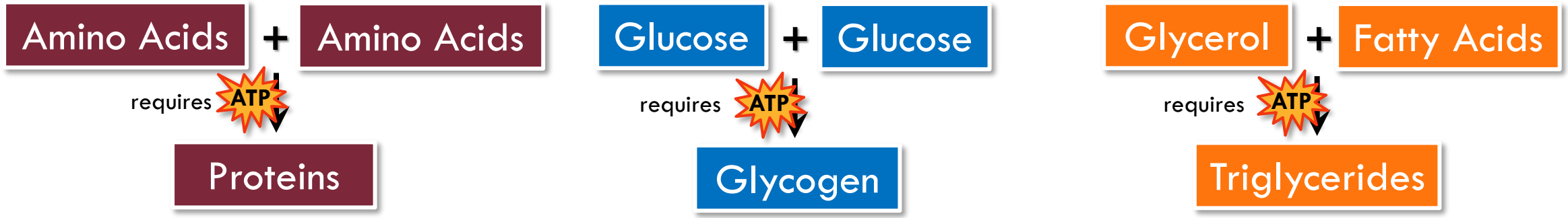
Energy Metabolism

Energy Metabolism Overview

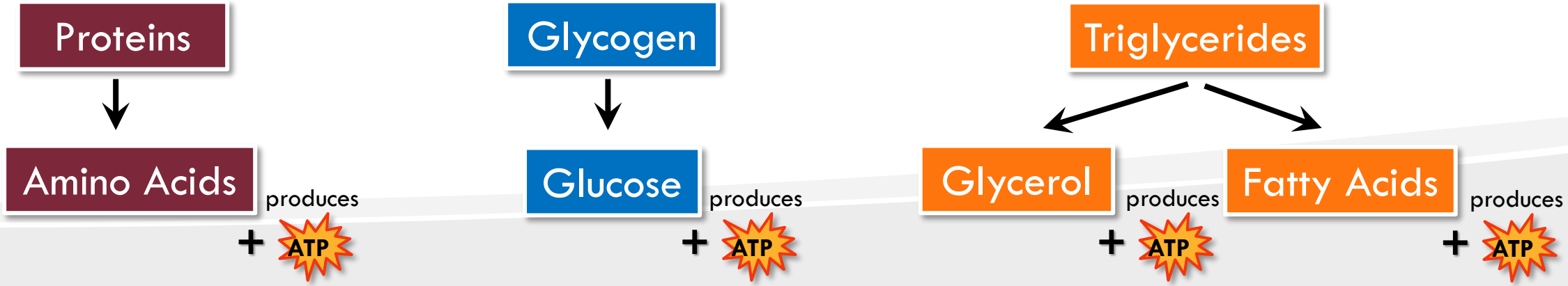
- Macronutrients are absorbed, then delivered to tissues for use
- *Metabolism*: sum of the processes by which substances are handled
  - Chemical changes to acquire energy to fuel crucial activities
  - Chemical changes to build new molecules/tissues
- Metabolic processes:
  - Anabolism: Synthesize macromolecules (energy requiring)
  - Catabolism: Breakdown of compounds (energy releasing)

Energy Metabolism - Reactions

Anabolic Reactions

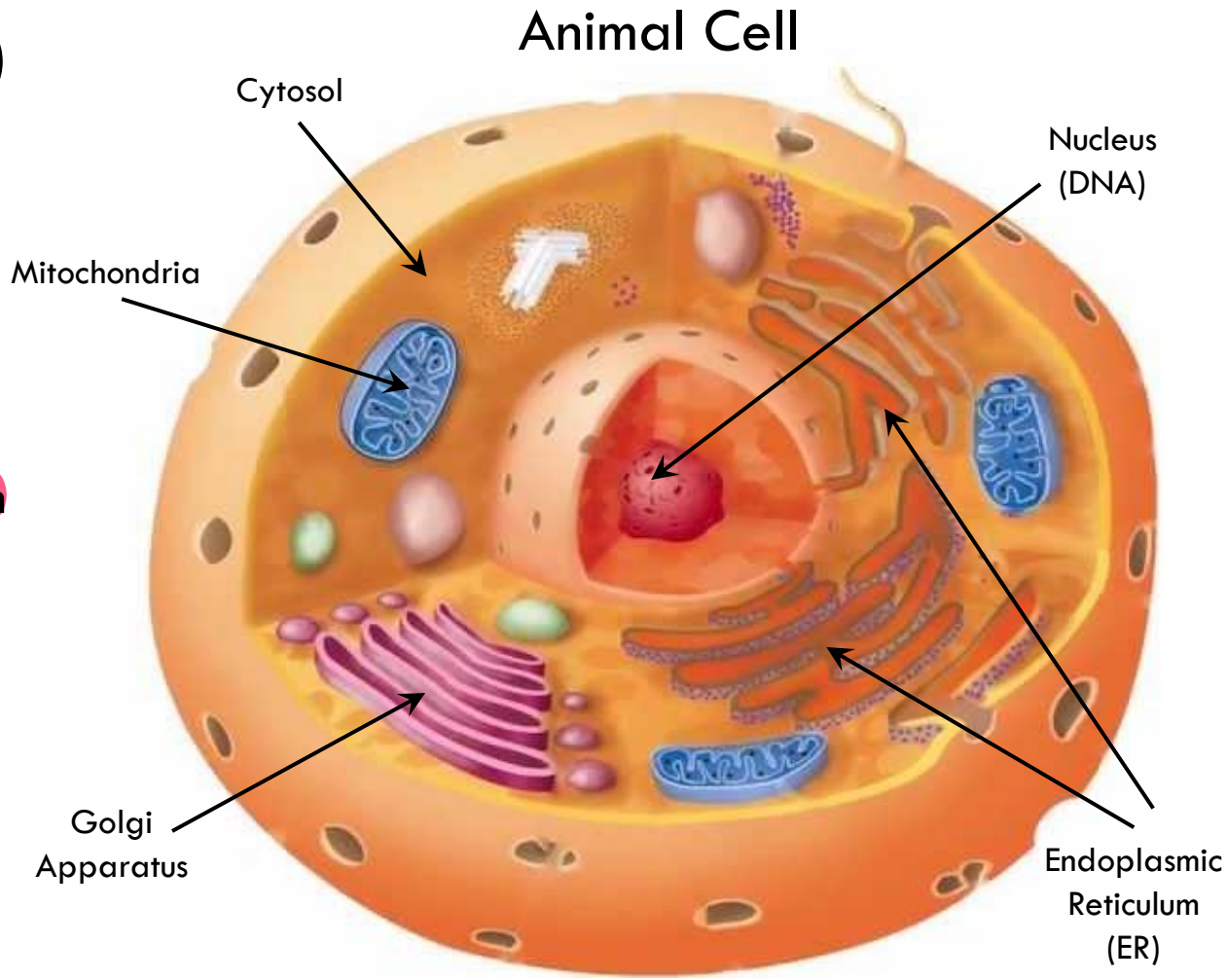


Catabolic Reactions

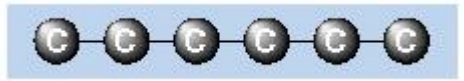
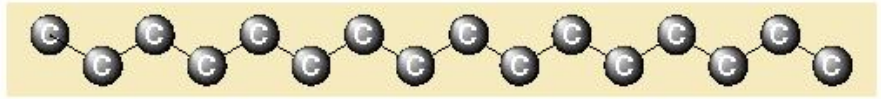
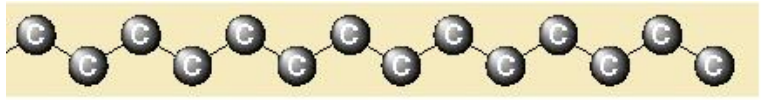
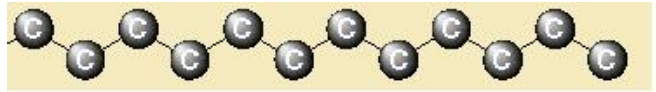


Where does Metabolism Occur?

- All cells of the body are capable of metabolism
  - EXCEPT: Red Blood Cells (no mitochondria)
- Key Organelles/Structures:
  - Cytosol (jelly-like fluid)
    - ✓ Glycolysis
  - Mitochondria: 'Power-house'
    - ✓ Pyruvate-Acetyl CoA; TCA cycle; FA oxidation
    - ✓ Electron Transport Chain (ATP)
  - Endoplasmic Reticulum (ER)
    - ✓ Lipid & Protein synthesis
  - Golgi Apparatus
    - ✓ Packages fat & protein for transport

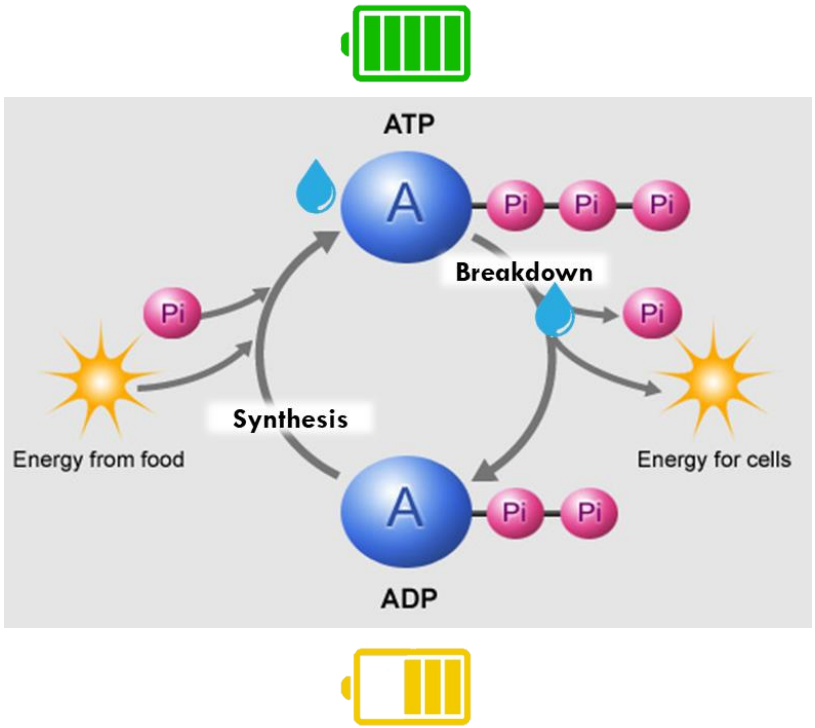


Who are the Key Players?

- CHOs (polysaccharides):
  - monosaccharides: glucose, fructose, galactose (6 C's): 
- Fats (triglycerides)
  - Fatty acids (even number 4-20 C's; usually 16-18 C): 
  - Glycerol (3C's): 


- Protein (polypeptides):
  - Amino Acids (varying C's + N): 

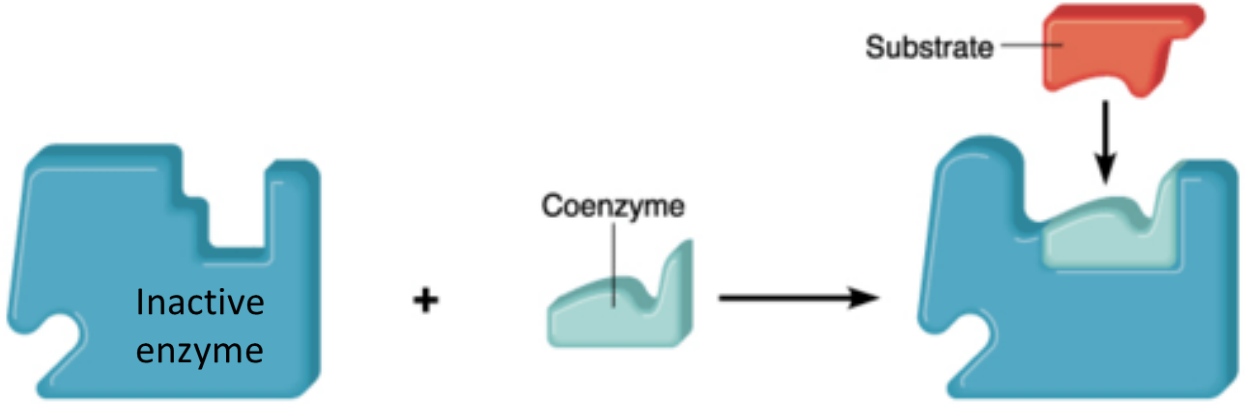
What is the Goal of Metabolism?

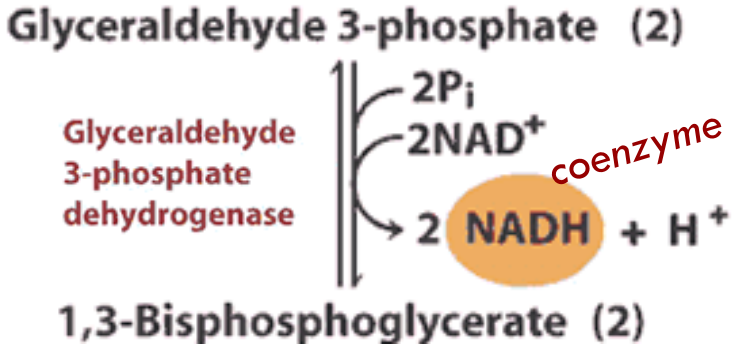
- Goal: Generate energy
- All cells (except RBCs) are capable of generating ATP
- **ATP**: Main molecule for storing and transferring energy in cells
  - Derived from breakdown of macronutrients
- ATP – ADP cycle: 100% renewable energy
  - ATP Breakdown: (hydrolysis reaction, releases energy)
  - ATP Synthesis: (condensation reaction, needs energy)
- Catabolism (of food) is key to generating electrons - needed for ATP synthesis



How Do Metabolic Reactions Occur?

- Enzymes
  - Facilitators of metabolic reactions
- Coenzymes ("little helpers")
  - Associated with specific enzymes
  - Enzyme activators
  - Many vitamins (B-complex) are coenzymes
  - ***Substrate***: *nutrient-containing compound (CHO, PRO, FAT) on which enzymes + coenzymes can act*





Fed-Fasting Cycle

- Different phases = different substrate uses from different places
- 24-h Cycle
  - Postprandial: Fed state, occurring 1-2 hrs following a meal/snack
  - Postabsorptive: 'Fasting' state, occurring 4-6 hrs following postprandial
  - Overnight Fasting: 'Fasting' state, occurring night-time sleep for ~8-12 hrs
- Prolonged Fasting
  - Generally about 24-h of not eating or drinking anything caloric
    - ✓ Severe energy restriction also considered fasting

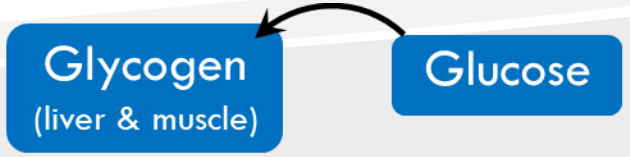
InstaPoll

What is the #1 metabolic ‘player’ (for fuel) during the fed-state?

- Glucose
- Amino Acids
- Fatty Acids
- Glycerol

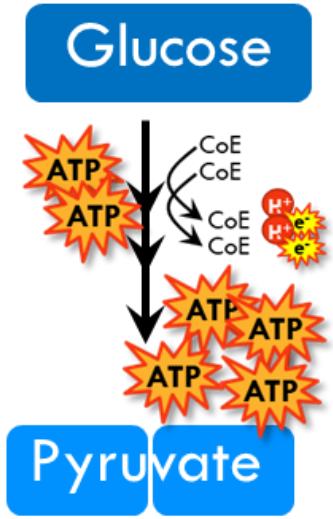
Systemic Metabolism, Fed State: CHOs

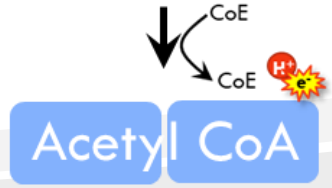
- Fasting to Fed state: switch from fat-burning to CHO-burning
- **Glucose** = major fuel source
- Liver = major site of CHO metabolism
- Purpose:
  - Generate ATP
  - Maintain circulating (blood) glucose
  - Convert glucose to stored form (glycogen) in the liver and muscle, via **Glycogenesis**
  - Excess goes where?



Systemic Metabolism, Fed State: CHOs

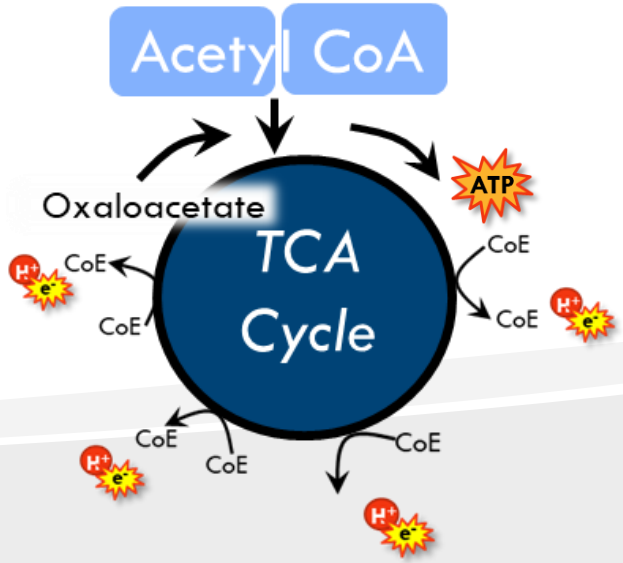
- Generating ATP
  - **Step 1: Glycolysis** = splitting glucose (6-C) into 2 **Pyruvate** (3-Cs)
    - ✓ ATP is required but is also released
    - ✓ These reactions require coenzymes which 'carry' hydrogens (H^+) and electrons (e-) needed to generate ATP
    - ✓ Called anaerobic respiration (oxygen is not needed)
    - ✓ Location: Cytosol
  - **Step 2: 2 Pyruvate** (3-Cs) to 2 **Acetyl CoAs** (2-Cs)
    - ✓ These reactions require coenzymes which 'carry' hydrogens (H^+) and electrons (e-) needed to generate ATP
    - ✓ Called aerobic respiration (oxygen is needed)
    - ✓ Location: Cytosol





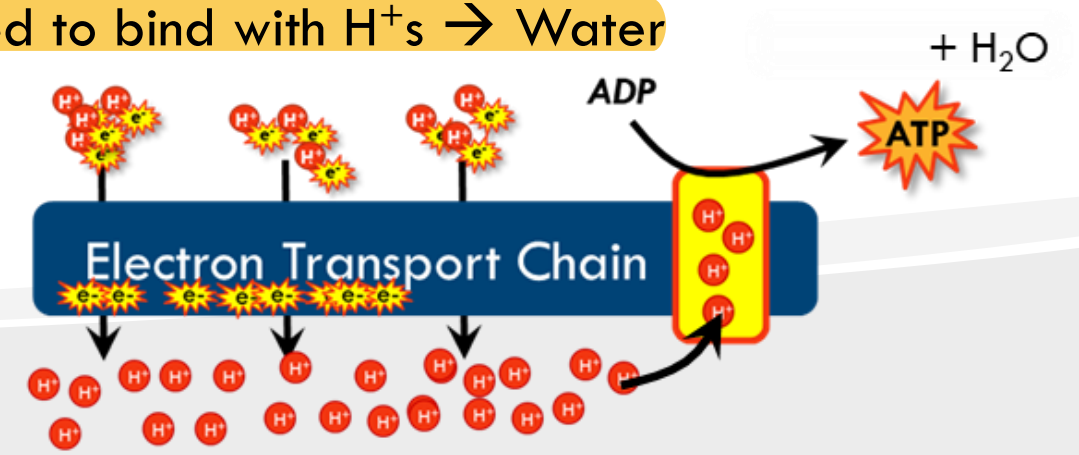
Systemic Metabolism, Fed State: CHOs

- Generating ATP
  - **Step 3: TCA Cycle** = process by which most precursors for ATP synthesis are generated
    - ✓ Oxaloacetate (4-C) joins with Acetyl CoA (2-C) from previous step
    - ✓ Compounds lose C's and coenzymes 'carry' hydrogens (H^+) and electrons (e-) needed to generate ATP
    - ✓ Generates some ATP
    - ✓ Also called Krebs Cycle and Citric Acid Cycle
    - ✓ Called aerobic respiration (oxygen is needed)
    - ✓ Location: Inside the Mitochondria



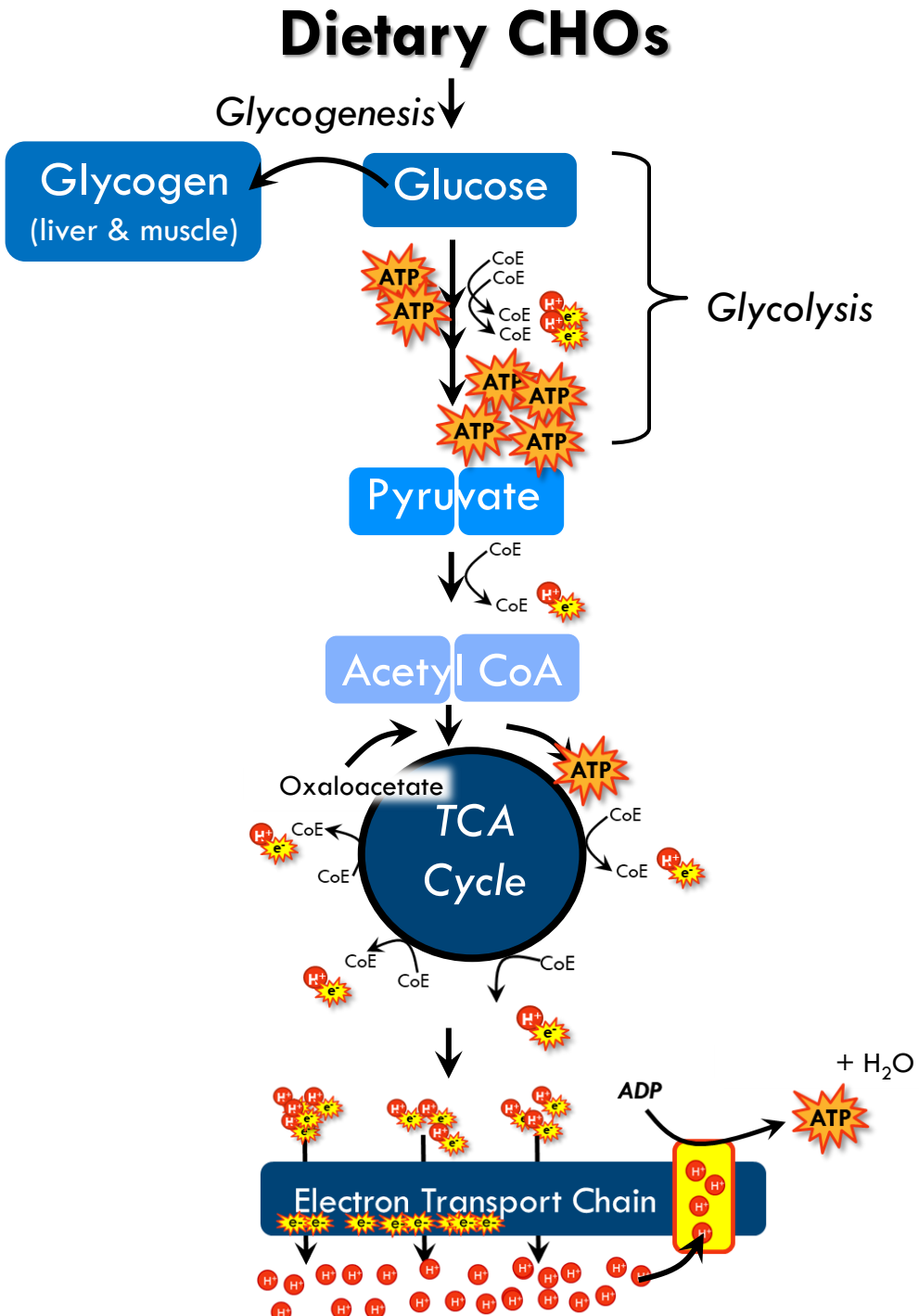
Systemic Metabolism, Fed State: CHOs

- Generating ATP
  - **Step 4: Electron Transport Chain** = process by which ATP is generated
    - ✓ All hydrogens (H^+) and electrons (e-) needed
      - Electrons 'generate energy' for transport of H^+'s across the membrane
      - H^+s move from high concentration to low concentration
        - Stimulates ADP to ATP reaction
    - ✓ Called aerobic respiration (oxygen is needed); used to bind with H^+s → Water
    - ✓ Location: Membrane of the Mitochondria
    - ✓ Generates 36 ATPs per 1 molecule of glucose

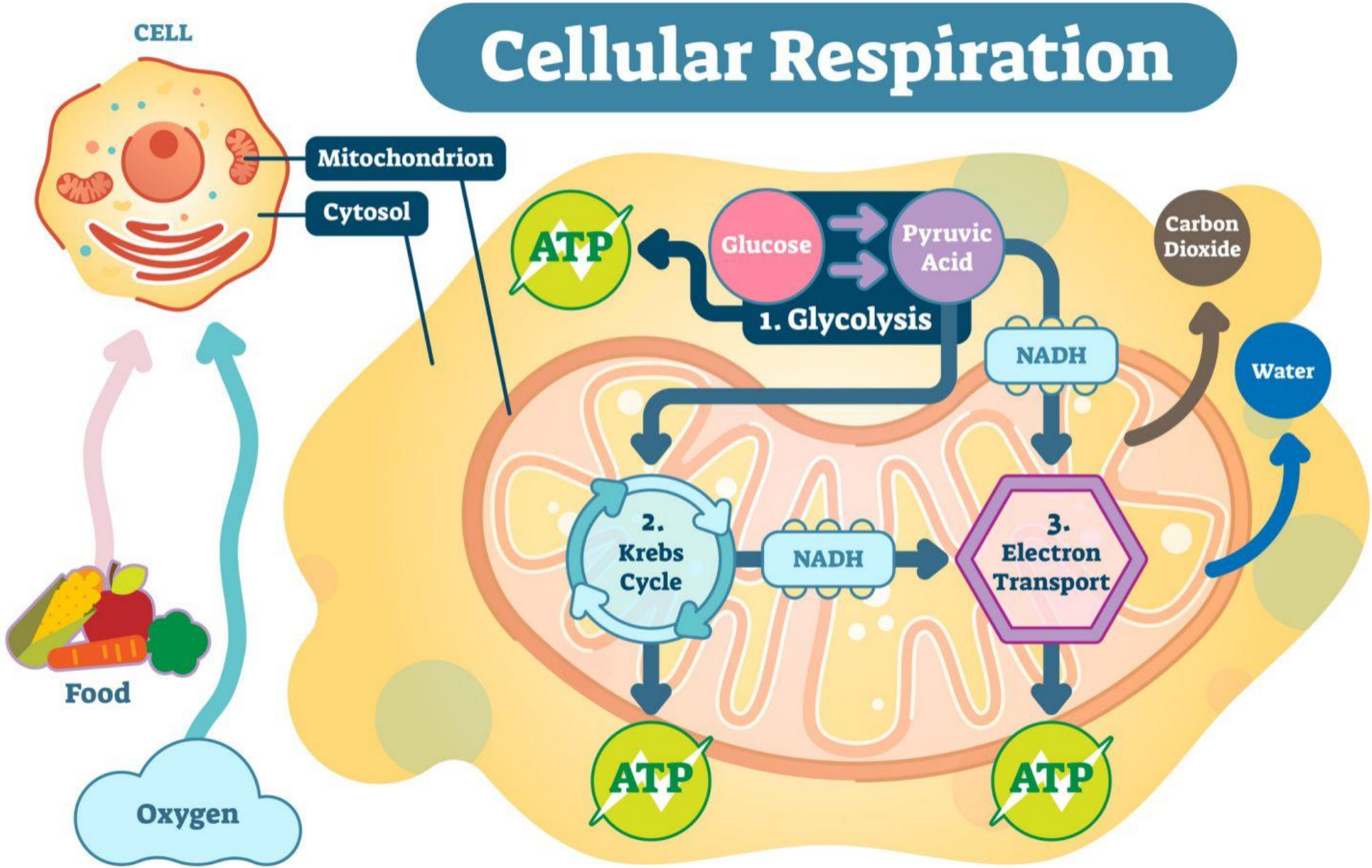


1-4 hrs Post-meal

FED STATE



FED STATE


Cellular Respiration
CELL
Mitochondrion
Cytosol
ATP
Glucose
Pyruvic Acid
1. Glycolysis
Carbon Dioxide
NADH
Water
2. Krebs Cycle
NADH
3. Electron Transport
ATP
ATP
Food
Oxygen

Systemic Metabolism, Fed State: PROs

- Fasting to Fed state: not much change
- Liver = major site of protein breakdown and synthesis
- Purpose:
  - Replace Amino Acids (AAs) in the AA "pool" that were metabolized/lost
  - Build protein from AAs
  - Excess goes where?

1-4 hrs Post-meal

FED STATE

Dietary Protein

AA Pool

Protein Synthesis ↕ *Protein Breakdown*

Body Protein

Dietary CHOs

Glycogenesis

Glycogen (liver & muscle)

Glucose

Glycolysis

ATP, CoE, H^+, e^-

Pyruvate

Acetyl CoA

Oxaloacetate

TCA Cycle

Electron Transport Chain

ADP

ATP

+ H_2O

Systemic Metabolism, Fed State: Lipids

- Fasting to Fed state: fat-burning to fat-storing
- Liver = major site of fat metabolism
- Purpose:
  - Store triglycerides (TGs) in adipose tissue (and liver), via **Lipogenesis**
    - ✓ Remember: TGs broken down into Fatty Acids (FAs) + Glycerol for absorption and transport, then repackaged for storage
  - Excess goes where?

1-4 hrs Post-meal

FED STATE

Dietary CHOs

Glycogenesis

Glycogen (liver & muscle)

Glucose

Glycolysis

Pyruvate

Acetyl CoA

Oxaloacetate

TCA Cycle

Electron Transport Chain

ADP

ATP

+ H_2O

Dietary Protein

AA Pool

Protein Synthesis

Protein Breakdown

Body Protein

Dietary Lipids

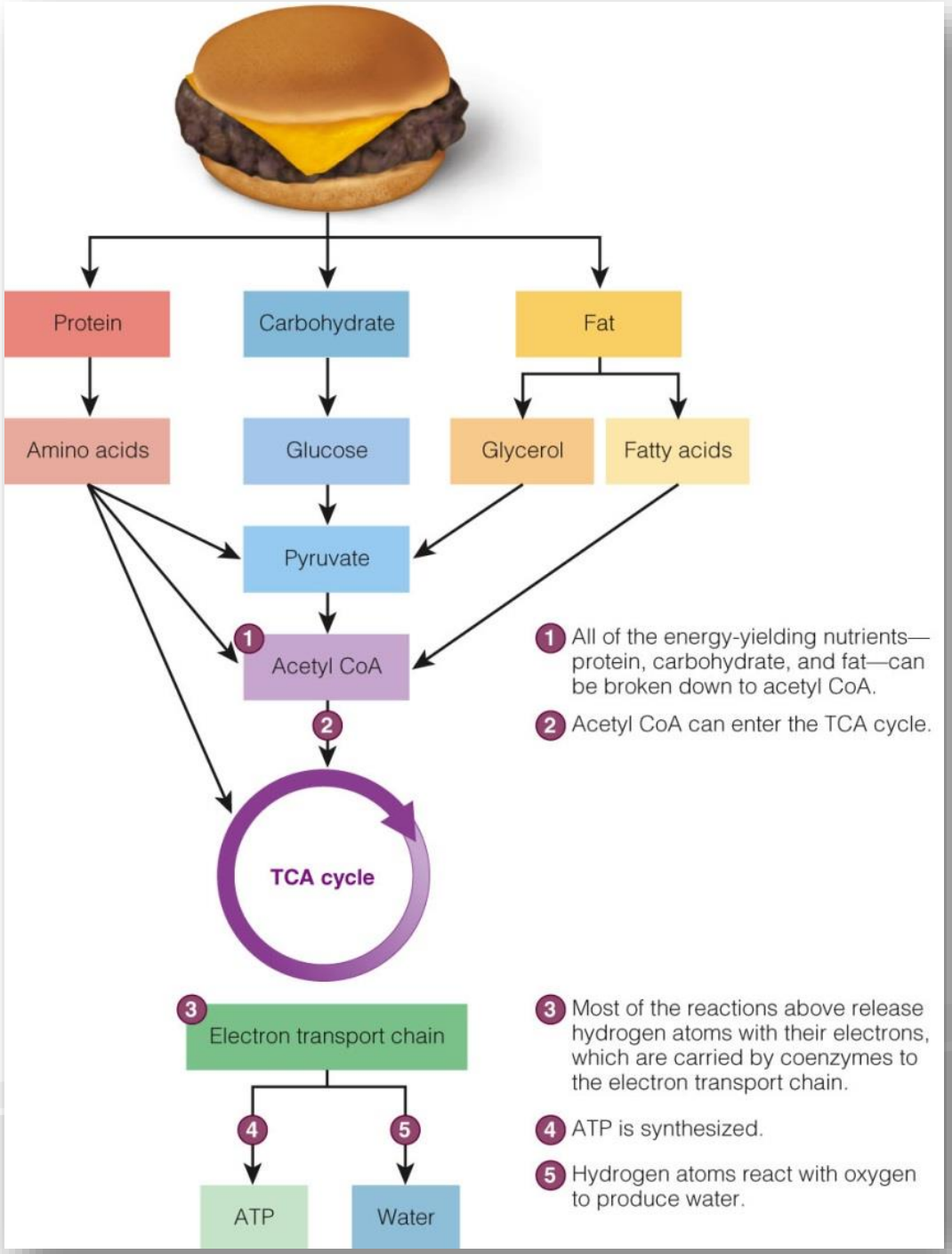
Glycerol

Fatty Acids

(Stored) TGs

Lipogenesis

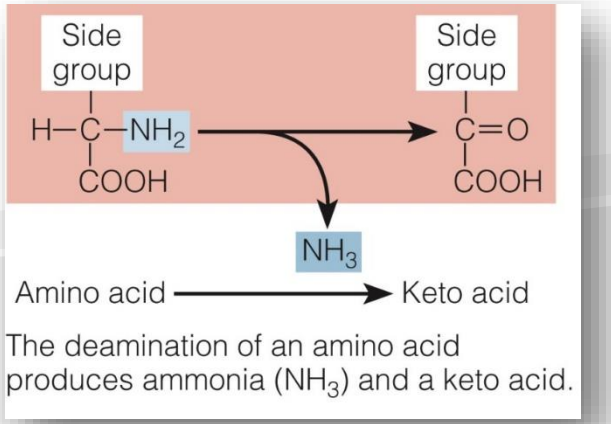
Simplified Version:



Whitney & Rolfes, Understanding Nutrition (15th ed.)

Systemic Metabolism, (Excess) Fed State

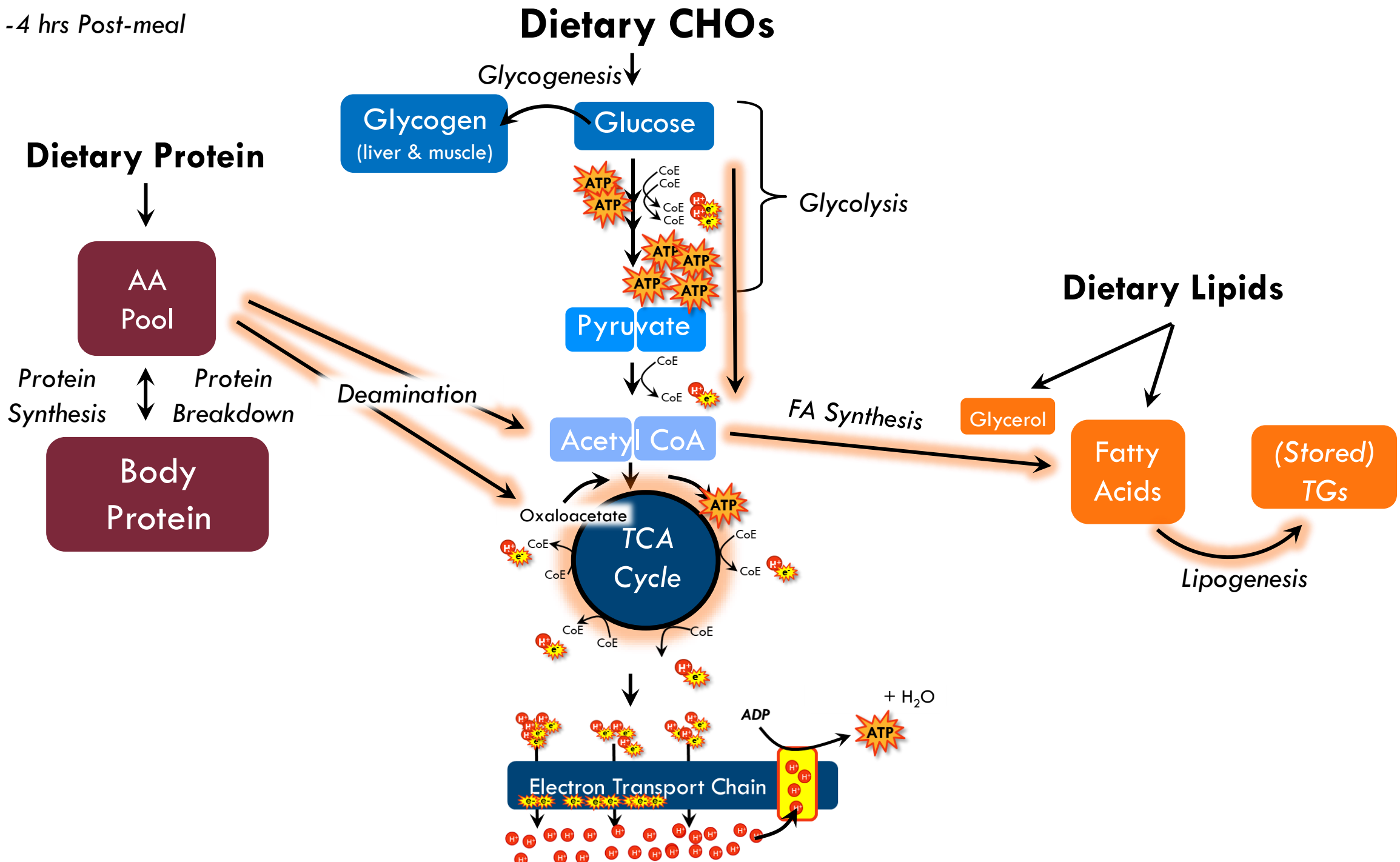
- Purpose: Converting to FAs to store as triglycerides (TGs)in liver + adipose tissue
  - Carbohydrates: Acetyl CoA & TCA compounds get converted to FAs via **Fatty Acid Synthesis**, then to TGs via **Lipogenesis**
  - Fats: Continue to store TGs via **Lipogenesis**
  - Proteins: Amino group is removed via **Deamination** leaving a 'keto acid' which can be:
    - ✓ Converted to Acetyl CoA → Fatty Acids via **Fatty Acid Synthesis**



The deamination of an amino acid produces ammonia (NH_3) and a keto acid.

1-4 hrs Post-meal

SURPLUS STATE



InstaPoll

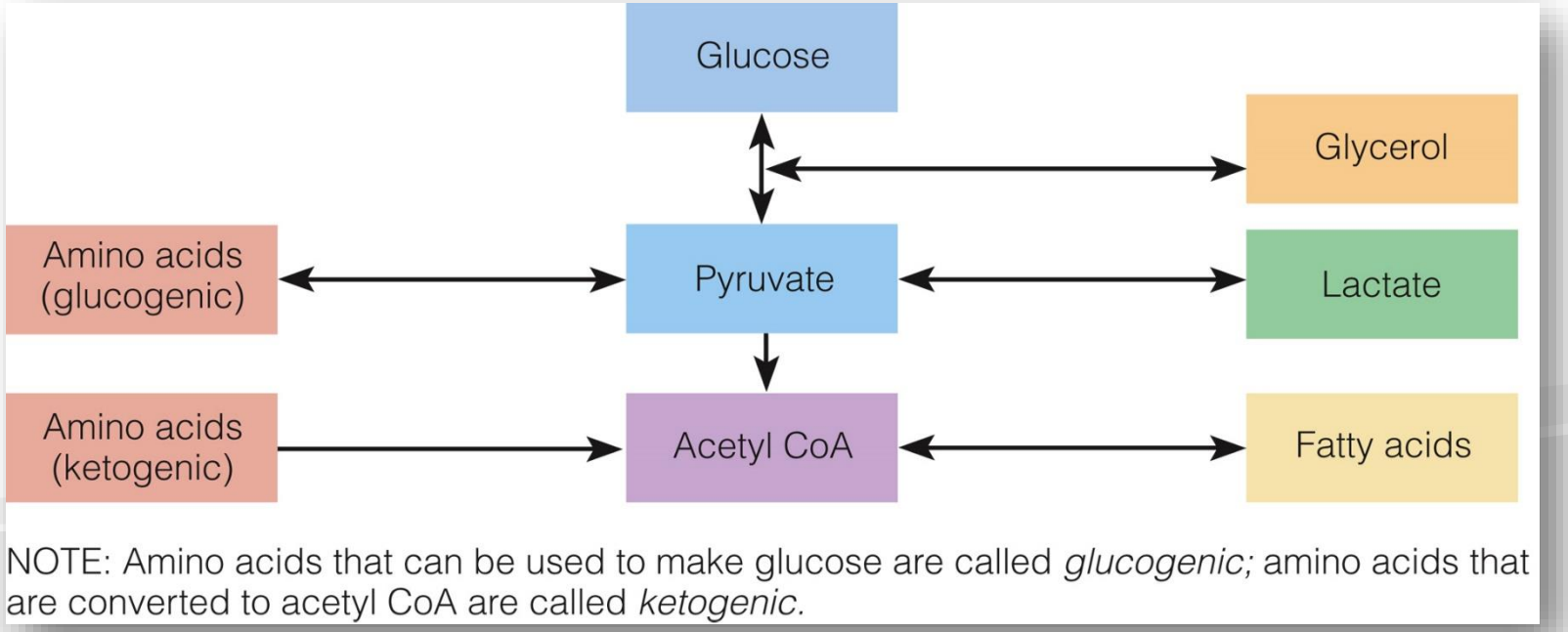
What is the #1 metabolic 'player' (for fuel) during the fasted-state?

- Glucose
- Amino Acids
- Fatty Acids
- Glycerol

Breaking Down Nutrients for Energy: Pyruvate

- Pyruvate
  - Formed from breakdown of glucose
  - Converted to acetyl CoA
  - Can be formed from breakdown of AAs or glycerol (when needed)
  - Can make glucose from pyruvate via **Gluconeogenesis** (making glucose from non-glucose compounds)

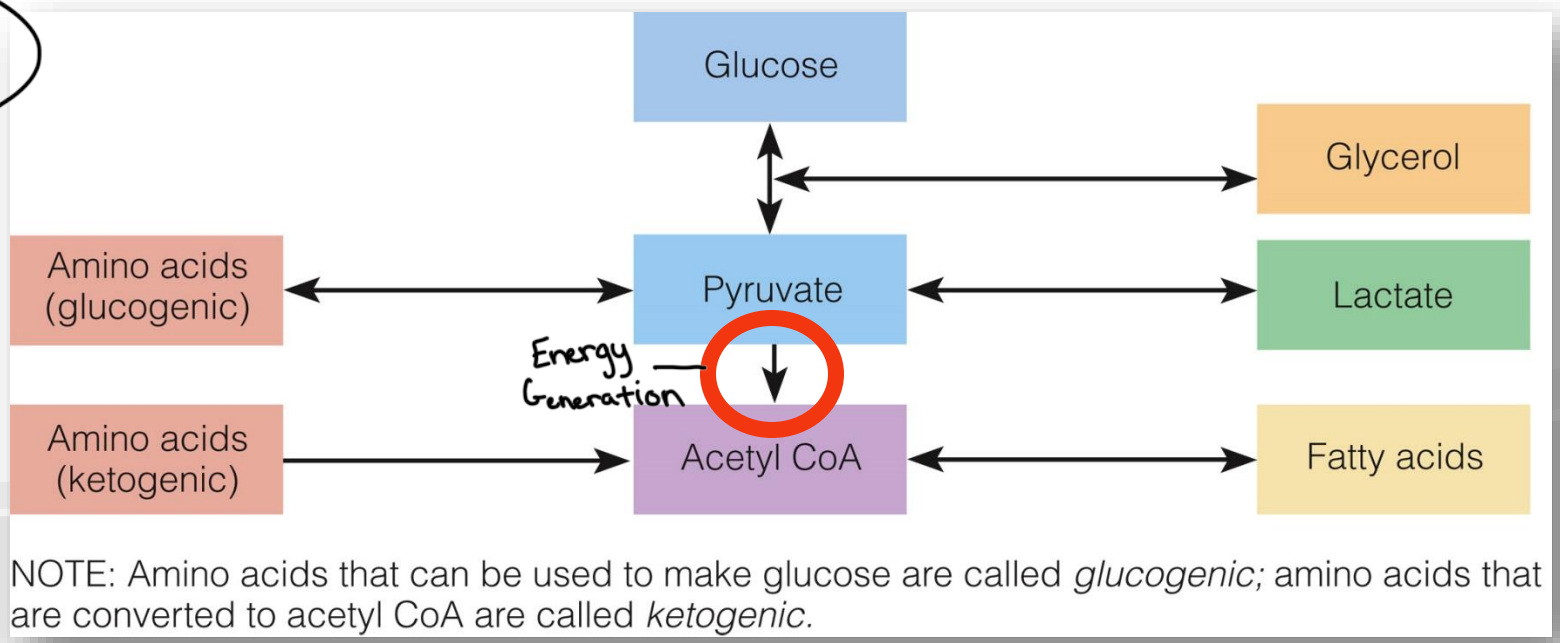
Alternate energy during fasting



Breaking Down Nutrients for Energy: Acetyl CoA

- Acetyl CoA
  - Formed from pyruvate, breakdown of AAs, and breakdown of FAs
  - If cell needs ATP: Acetyl CoA enters TCA cycle and begins the process…
  - Unlike Pyruvate, Acetyl CoA CANNOT be used to rebuild glucose*

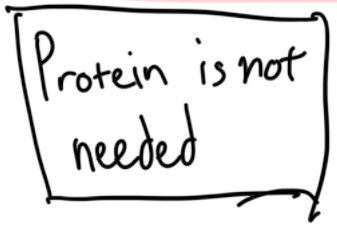
***FAs <u>cannot</u> make glucose (but AAs can)**

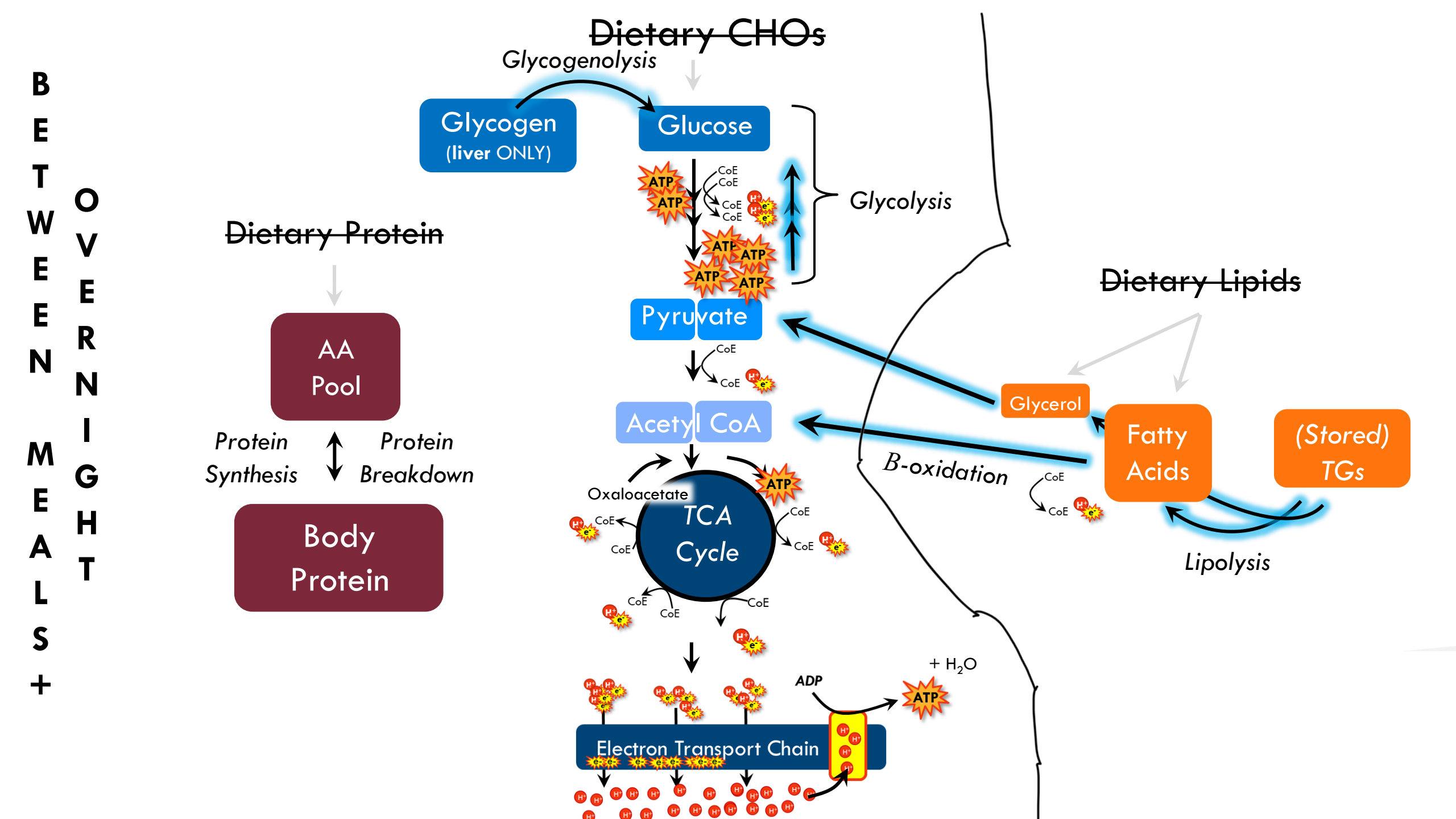


NOTE: Amino acids that can be used to make glucose are called *glucogenic;* amino acids that are converted to acetyl CoA are called *ketogenic.*

Systemic Metabolism, Post-absorptive/Overnight Fast

- Purpose: Maintain circulating (blood) glucose by pulling from energy reserves
  - Option A: Breakdown liver glycogen into glucose via **Glycogenolysis**
  - Option B: Breakdown stored TGs into FAs + glycerol via **Lipolysis**
    - ✓ FAs converted to Acetyl CoA
    - ✓ Glycerol converted to Pyruvate
  - No breakdown of body protein at this point

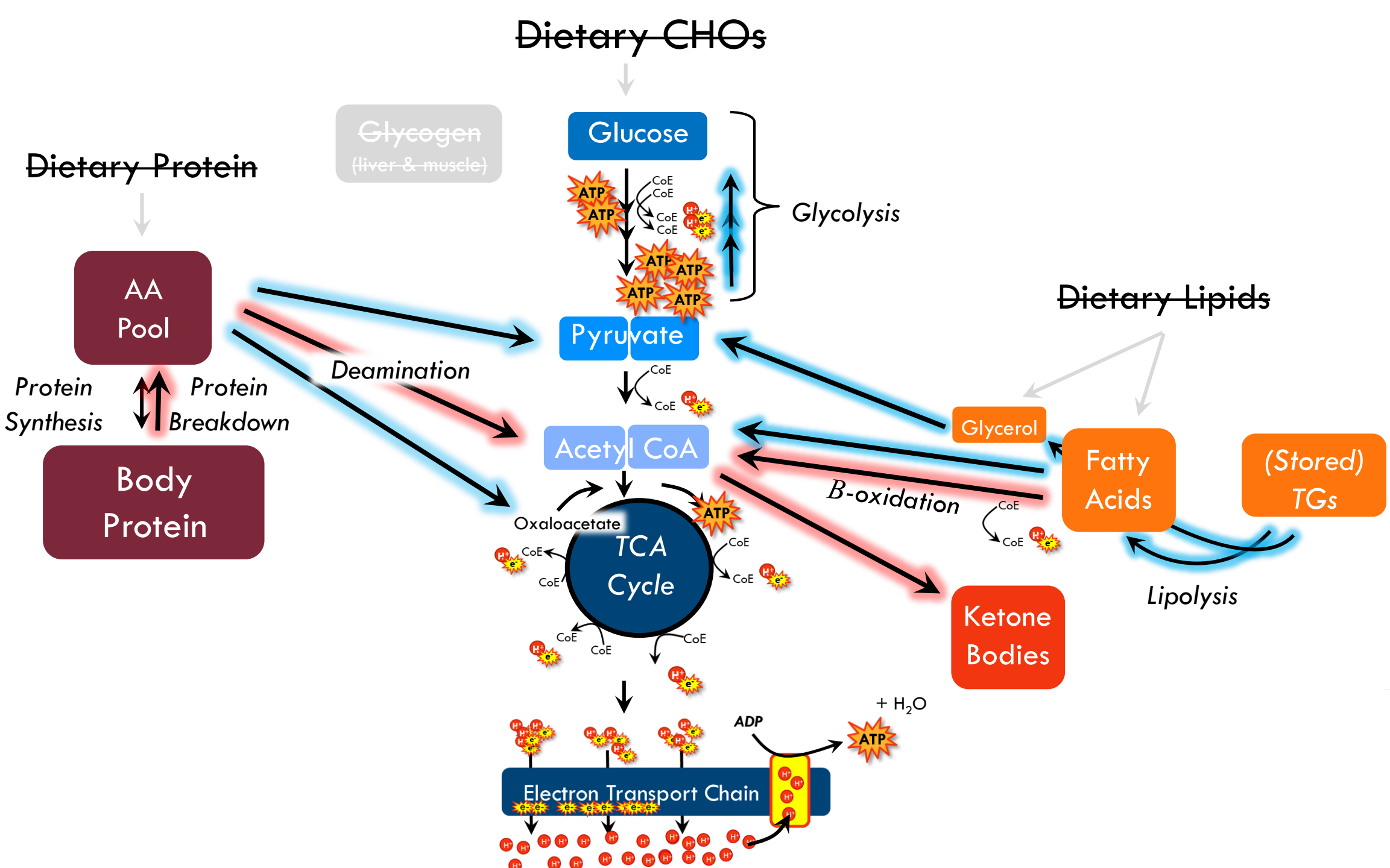



BETWEEN MEALS + OVERNIGHT
Dietary CHOs
Glycogenolysis
Glycogen
(liver ONLY)
Glucose
Glycolysis
Dietary Protein
AA
Pool
Protein
Synthesis
Protein
Breakdown
Body
Protein
Pyruvate
Acetyl CoA
Oxaloacetate
TCA
Cycle
Dietary Lipids
Glycerol
Fatty
Acids
(Stored)
TGs
B-oxidation
Lipolysis
Electron Transport Chain
ADP
ATP
+ H2O
CoE

Systemic Metabolism, Prolonged Fast

- Purpose: Maintain circulating (blood) glucose by pulling from energy reserves
  - Out of liver and muscle glycogen (remember, muscle glycogen is just for muscle use)
  - Option A: Breakdown stored TGs into FAs + glycerol via **Lipolysis**
    - ✓ FAs converted to Acetyl CoA → TCA cycle → ATP generation
      - Creation of Ketone Bodies (for energy) → slows (doesn't replace) body protein breakdown
    - ✓ Glycerol converted to Pyruvate to make glucose via **gluconeogenesis**
  - Option B: Breakdown body protein → expensive way to obtain glucose!
    - ✓ AAs converted to Pyruvate (glucogenic) then to Glucose via **gluconeogenesis**
    - ✓ AAs go directly to TCA cycle (glucogenic)
    - ✓ AAs converted to Acetyl CoA (ketogenic) then to Keto Acids → Ketone Bodies (energy)

PROLONGED FAST



Ketosis

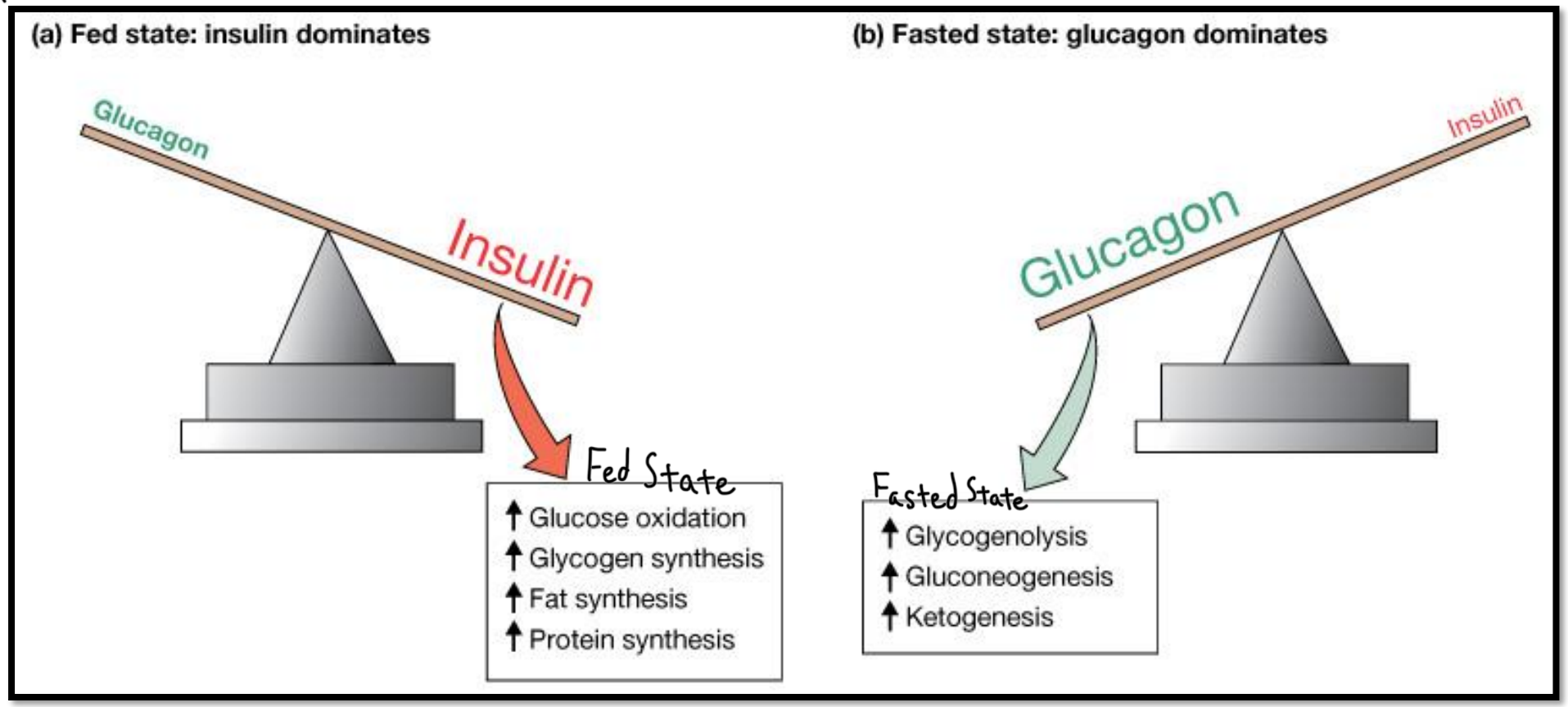
- Ketosis = metabolic state resulting from burning fat instead of glucose
- Ketosis results in:
  - Slowed metabolism, reduced energy output, reduced appetite
  - "Glucose-sparing": conserves (some) lean tissue
    - ✓ Still lose muscle (the brain prefers glucose over ketones)
- Issues:
  - Ketones are acidic
  - High concentration = blood pH drops (becomes more acidic)

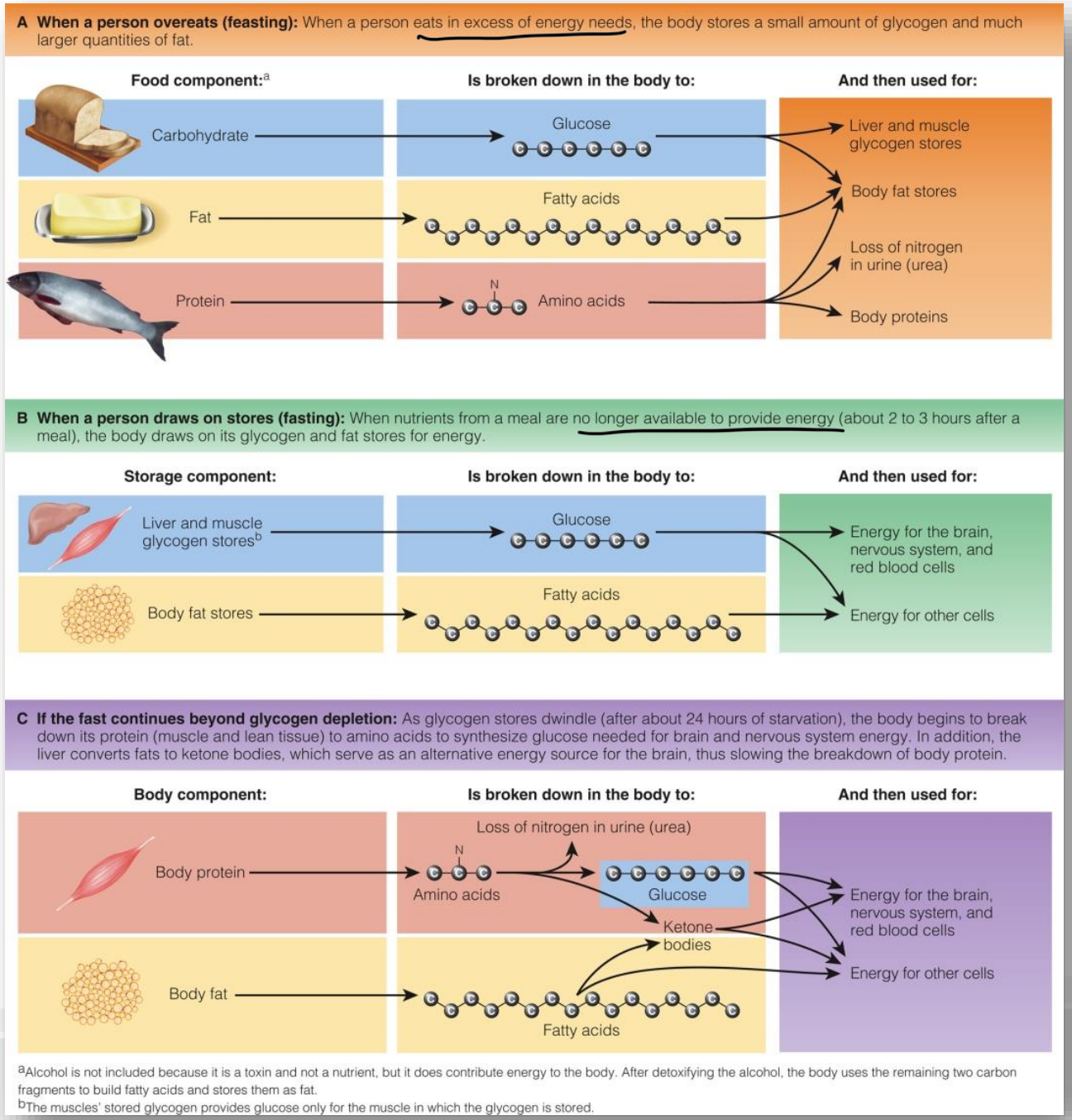
A form of muscle wasting???

Referenced in systemic metabolism, Prolonged Fast slide

Hormonal Regulation

- Shift in substrate (CHO/FAT/PRO) utilization is controlled by metabolism-regulating hormones
  - Insulin – Fed State
  - Glucagon – Fasted State





Fed-state

Produce Energy

Short-term or long-term

Fast-state

(Recommended)

Prolonged fast-state

Fuel daily activities

Energy State Overview

Whitney & Rolfes, Understanding Nutrition (15th ed.)