Photosynthesis:

Energy from Sunlight to Sugar

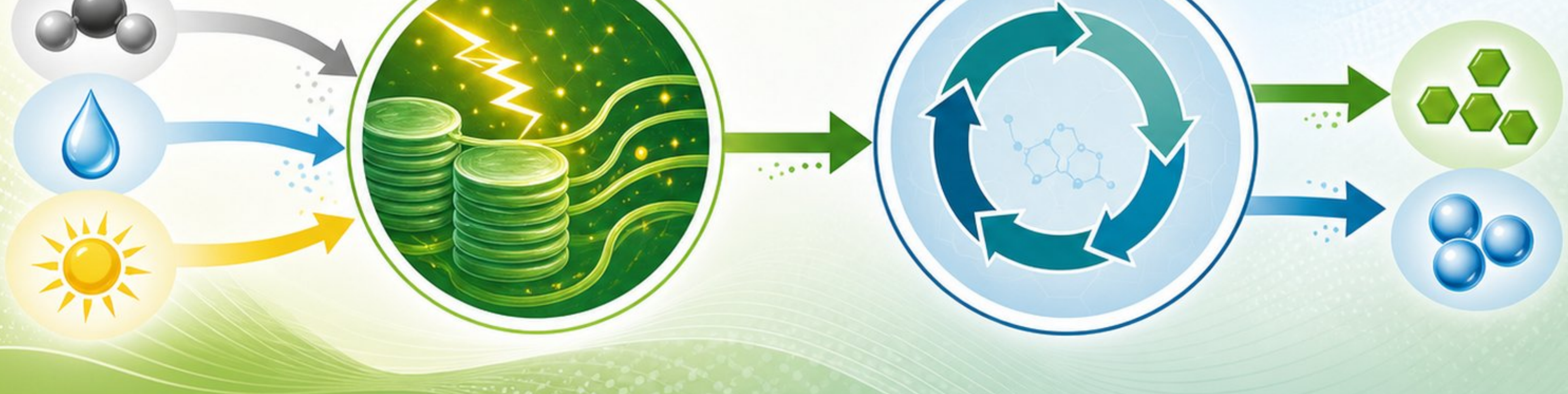
• - Converts light energy into chemical energy stored as sugar

• - Produces oxygen and powers nearly all food chains on Earth

• - Occurs in plants, algae, and cyanobacteria

• - Inputs: CO_2, water, light → Outputs: sugar, oxygen

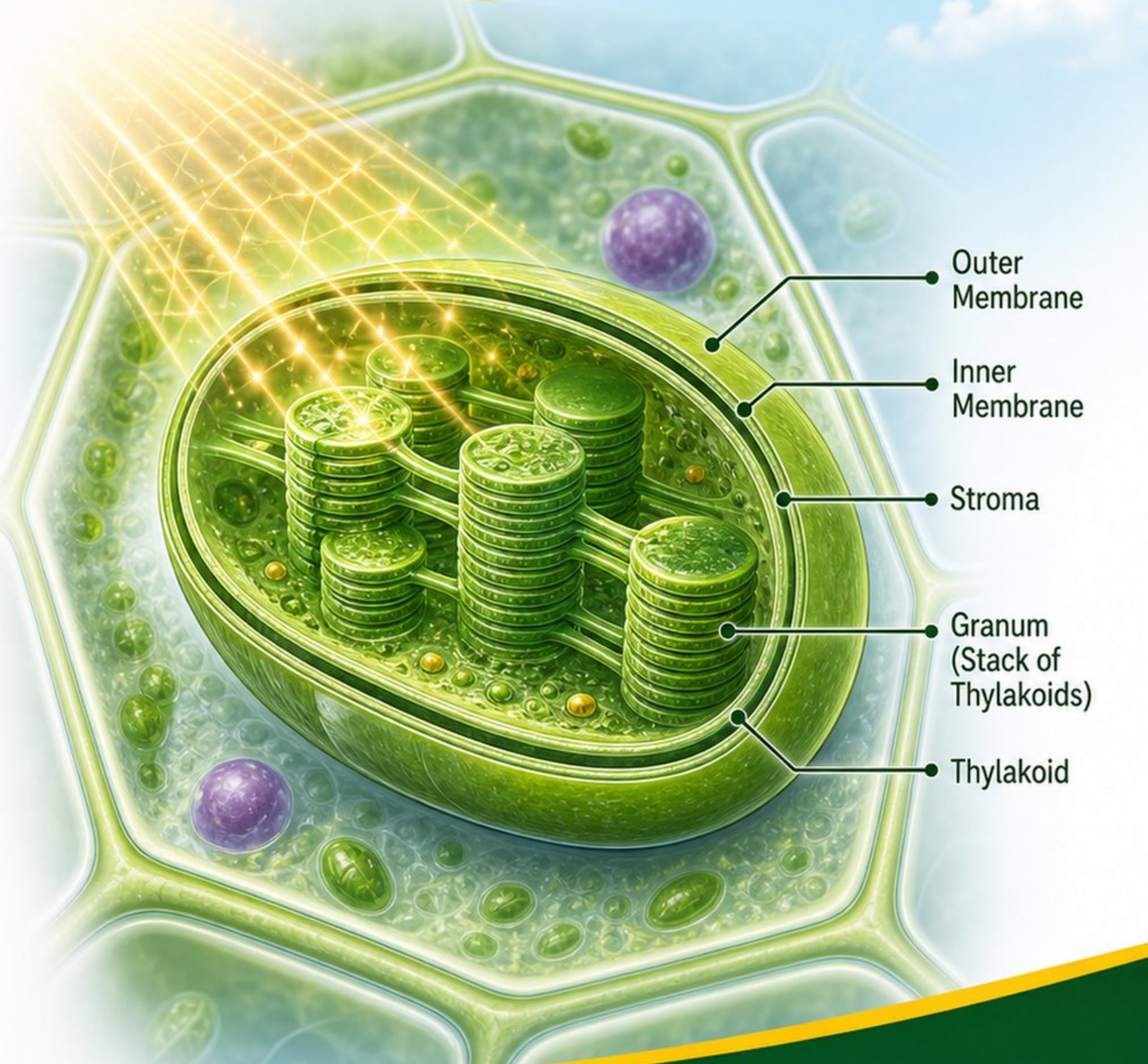
• - Two linked stages: light reactions and the Calvin cycle



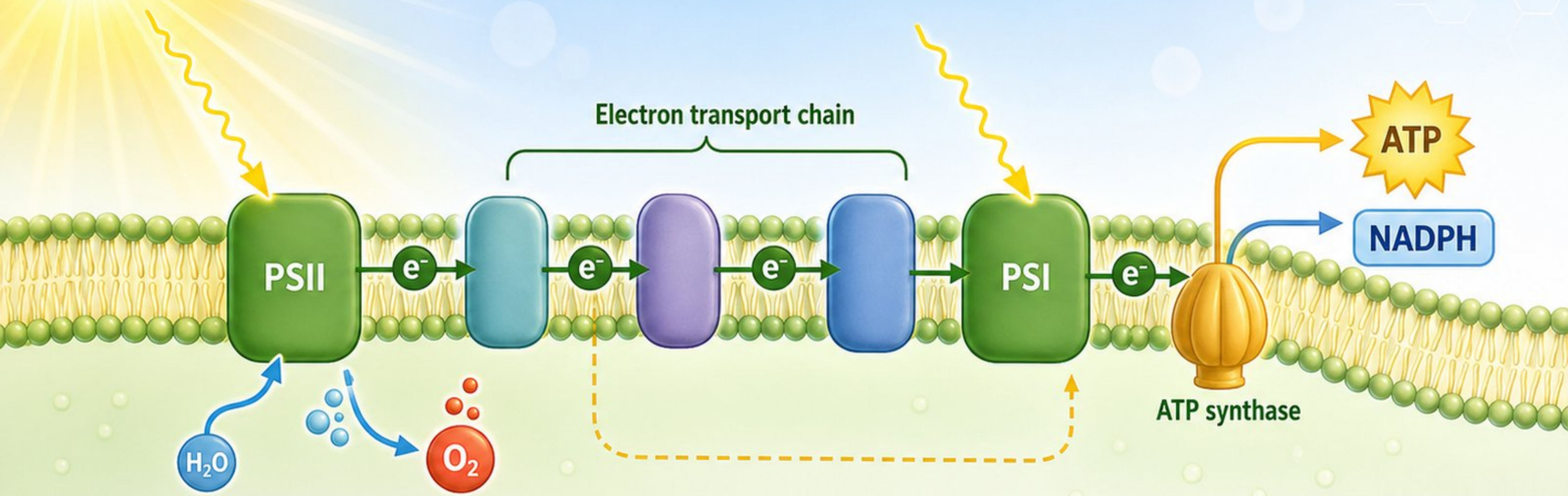
What Is Photosynthesis? Core Concepts

Where It Happens: The Leaf and Chloroplast

- Leaf captures light: epidermis, mesophyll, and stomata for gas exchange
- Chloroplasts are the cellular site of photosynthesis, a type of plastid
- Internal structure includes thylakoids, grana, stroma, and double membrane
- Chlorophyll and accessory pigments absorb light energy for conversion
- Leaves appear green because chlorophyll reflects green wavelengths

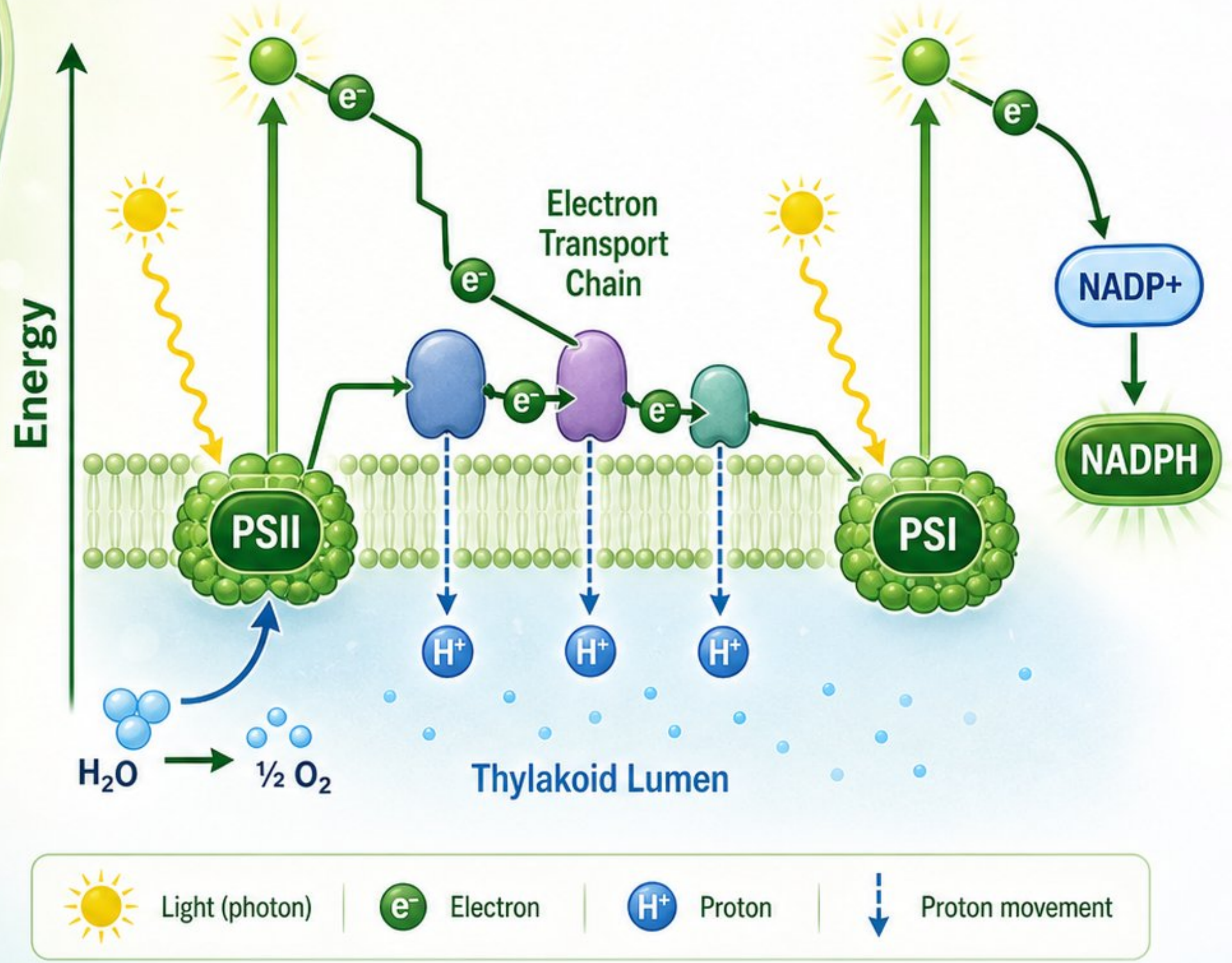


The Light-Dependent Reactions: Overview



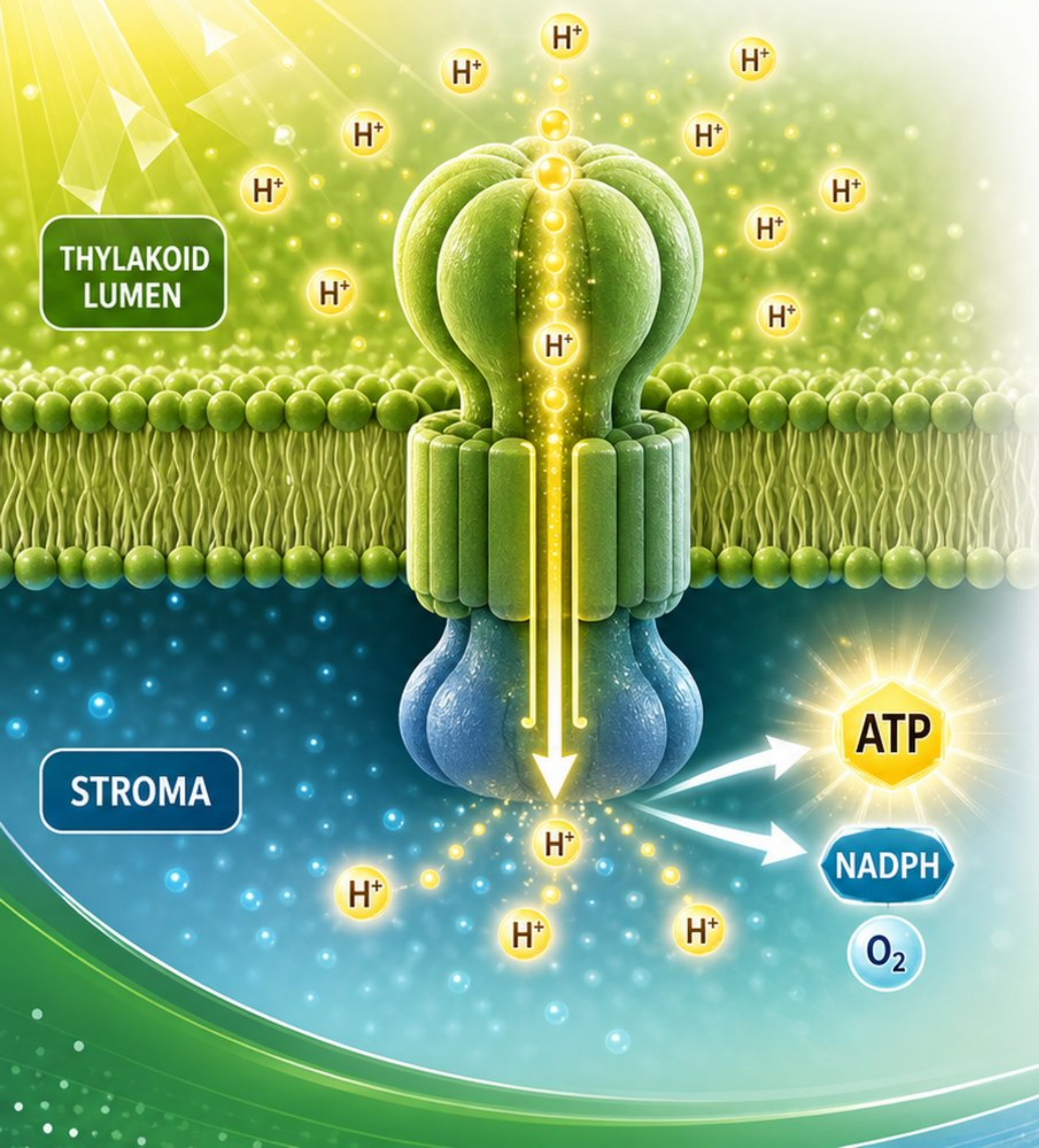
- **Location:** thylakoid membrane of the chloroplast
- **Purpose:** convert light energy to ATP and NADPH
- **Key players:** PSII, PSI, electron transport chain, ATP synthase
- Water splitting releases oxygen as a by-product
- **Flow:** light → electron transport → ATP and NADPH produced

Light Reactions: Photosystems and Electron Transport



- Photosystem II uses light energy to split water and excite electrons
- Electron transport chain pumps H^+ into the thylakoid lumen
- Photosystem I re-energizes electrons with a second photon of light
- $NADP^+$ is the final electron acceptor, reduced to NADPH
- The Z-scheme summarizes energy changes in electron transport

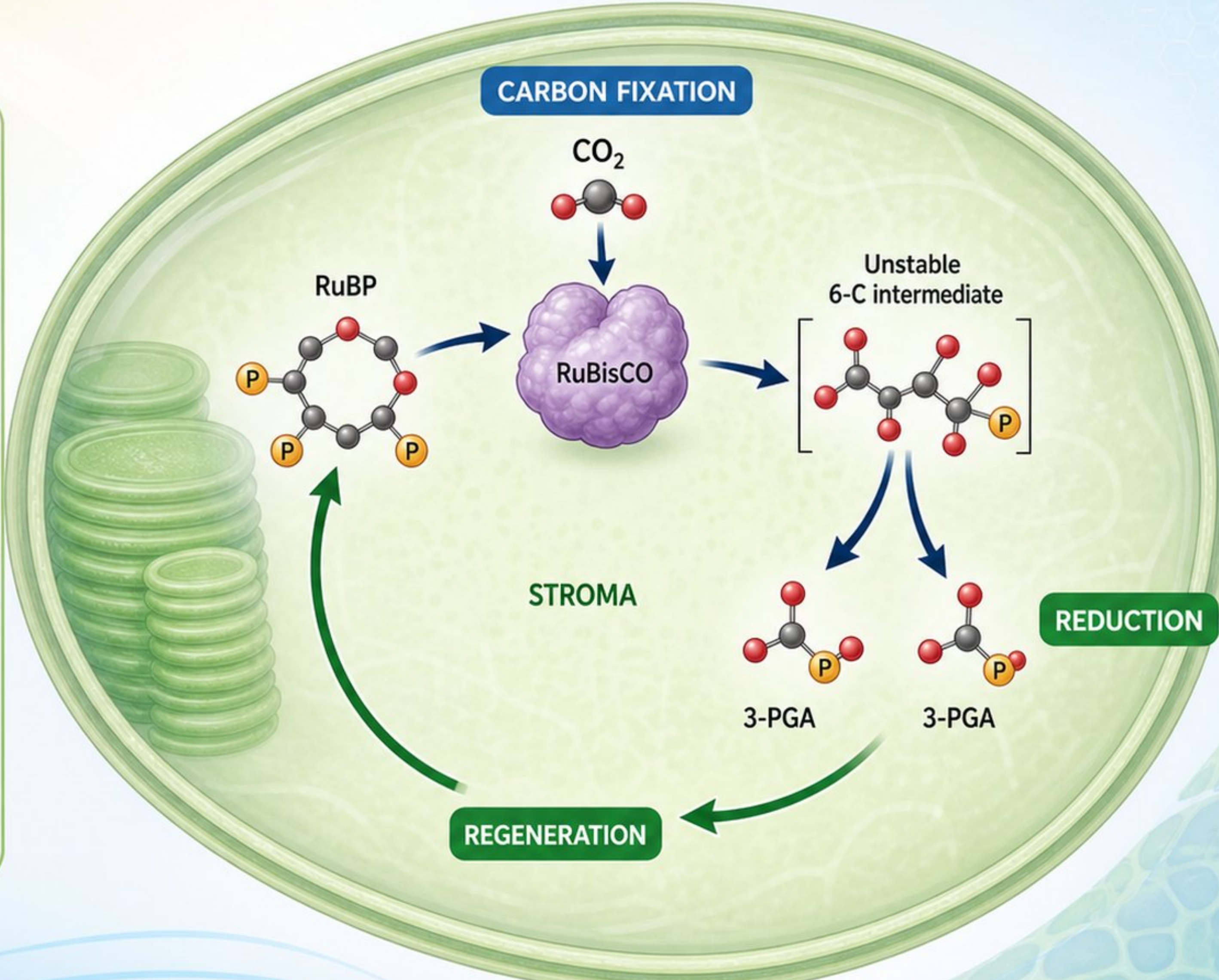
Light Reactions: Chemiosmosis and ATP Synthesis



- H^+ ions accumulate inside the thylakoid lumen, creating a gradient
- H^+ flows back into the stroma through ATP synthase
- ATP synthase uses this flow to phosphorylate ADP into ATP
- Light reactions yield ATP, NADPH, and O_2 as products
- Similar chemiosmotic mechanism as mitochondrial ATP production

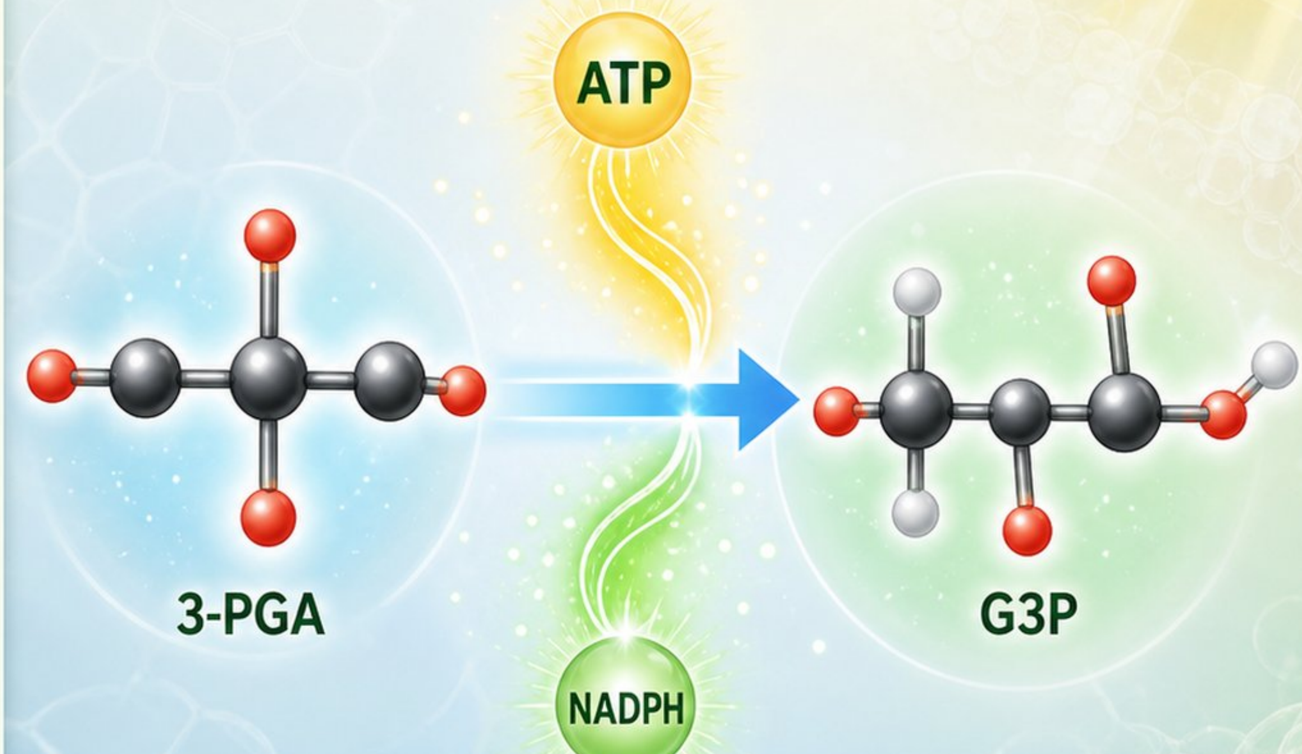
The Calvin Cycle: Overview and Carbon Fixation

- Occurs in the stroma of the chloroplast
- Uses ATP and NADPH to convert CO_2 into sugar
- Three phases: carbon fixation, reduction, regeneration
- Phase 1: RuBisCO attaches CO_2 to RuBP
- Unstable 6-C molecule splits into two 3-PGA molecules

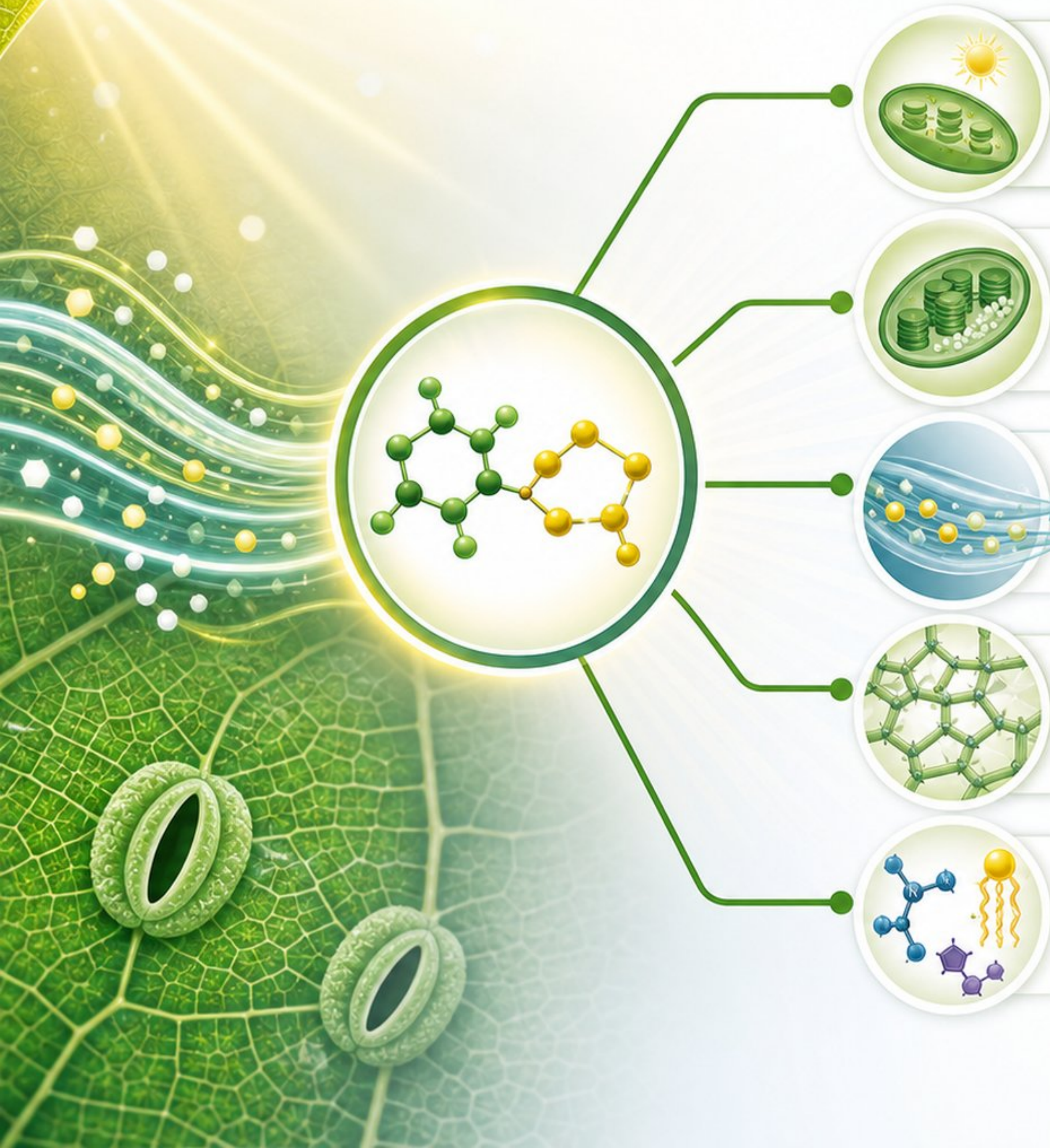


The Calvin Cycle: Reduction and Regeneration

- Phase 2 uses ATP and NADPH to convert 3-PGA into G3P sugar
- G3P is a three-carbon building block for glucose and other carbohydrates
- Phase 3 regenerates RuBP using ATP so the cycle can continue
- Three turns of the cycle produce one net G3P molecule for export
- Inputs: CO_2, ATP, NADPH; Outputs: G3P, ADP, $NADP^+$



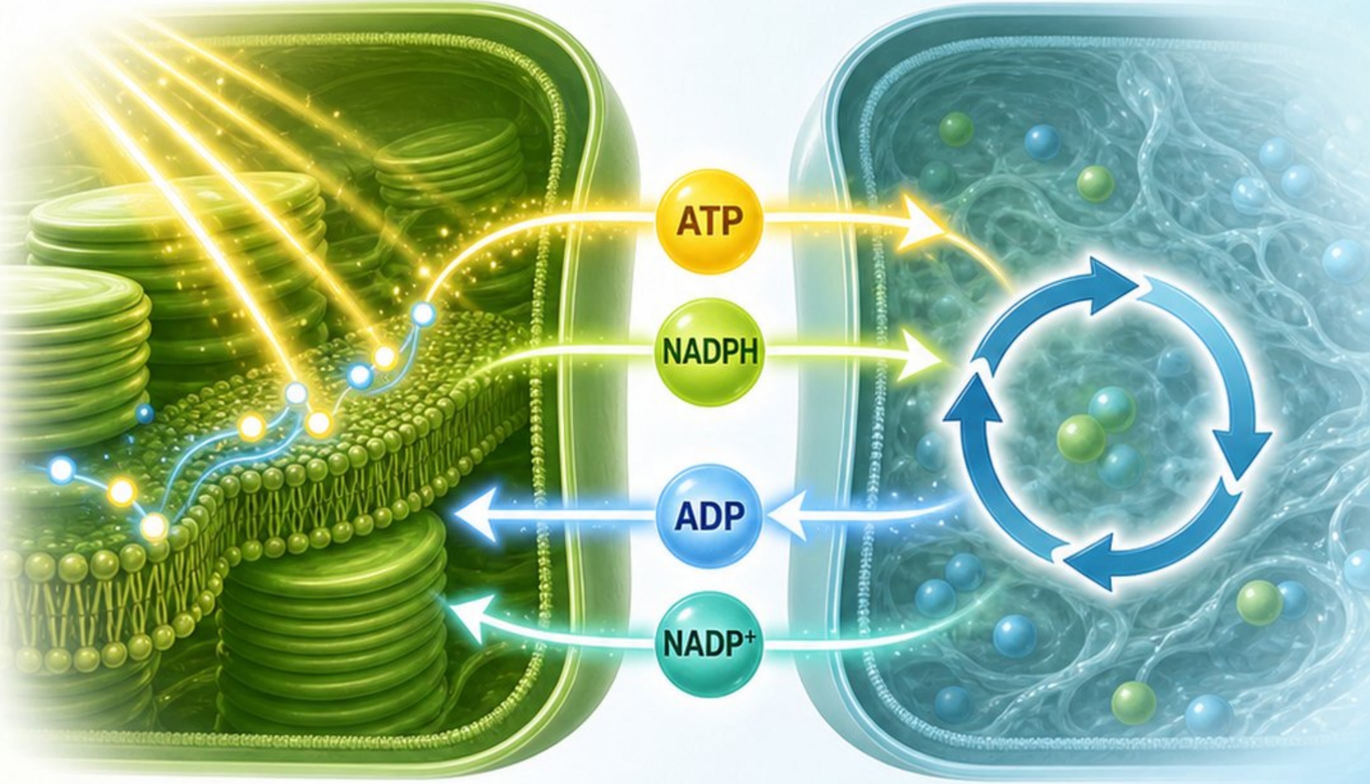
What the Plant Does with Its Sugar

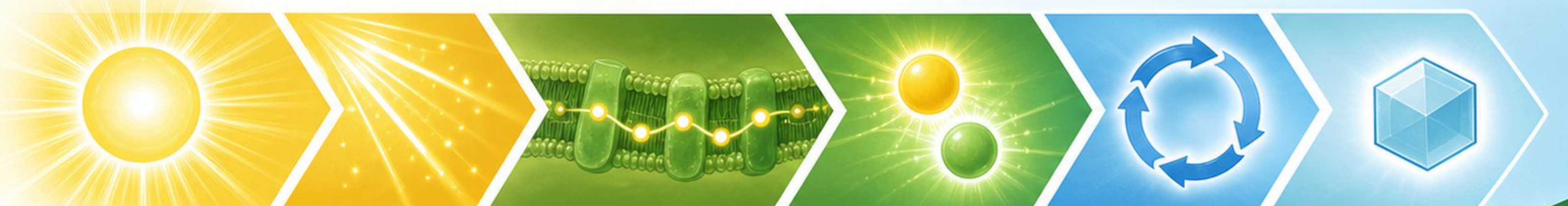


- G3P can be converted to glucose for immediate energy
- Glucose units form starch for short-term storage in chloroplasts
- Sucrose is the main sugar exported to other plant parts
- Sugars are used to synthesize cellulose for cell walls
- Sugars feed into pathways for amino acids, lipids, and nucleotides

Putting It All Together: Light and Dark Reactions

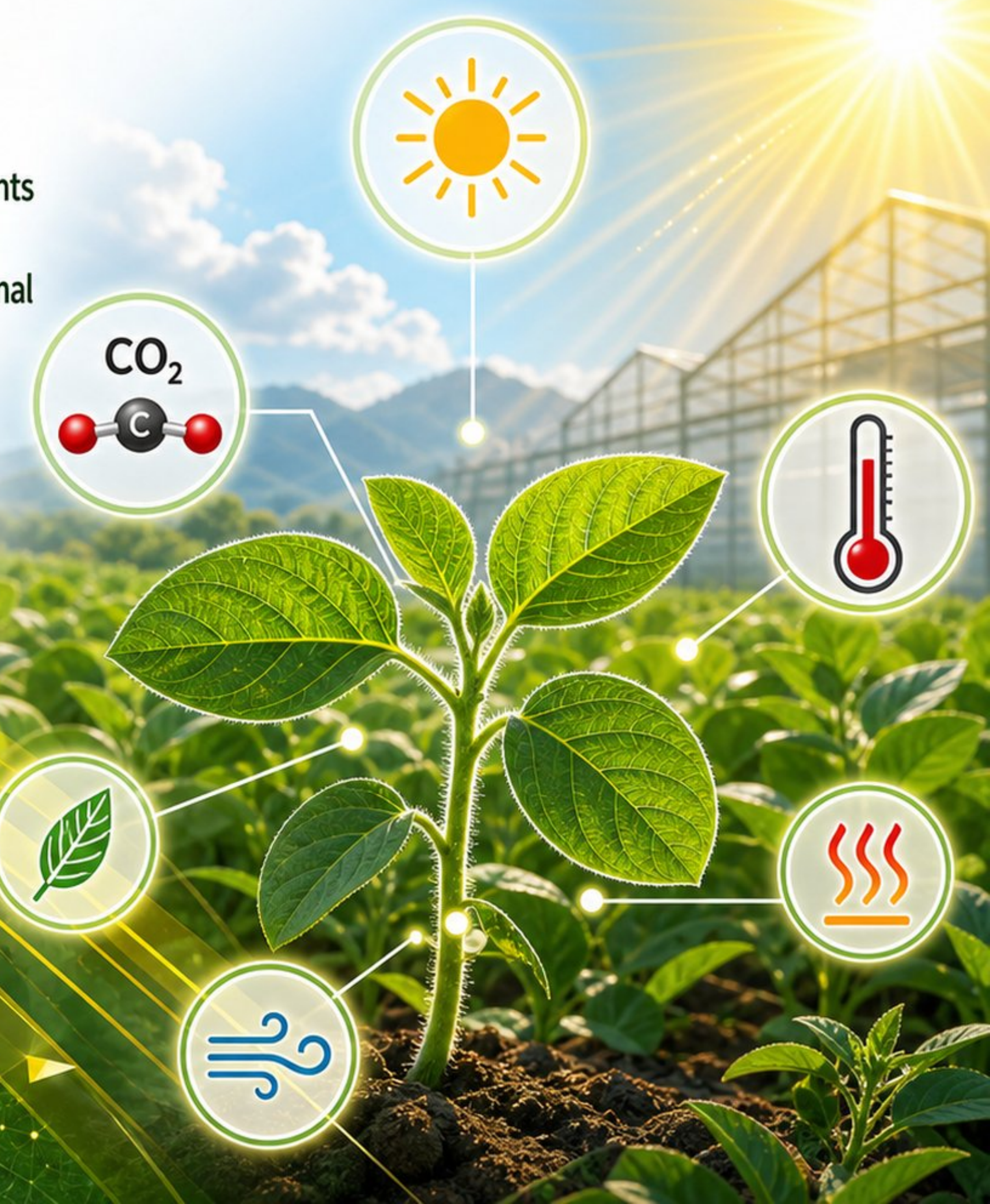
- ATP and NADPH link light reactions to the Calvin cycle
- Light reactions produce ATP/NADPH; Calvin cycle returns ADP/NADP⁺
- Light reactions occur in thylakoid membrane; Calvin cycle in stroma
- Full journey: sunlight → electron transport → ATP/NADPH → sugar
- Both stages essential: no carriers without light; no sugar without cycle





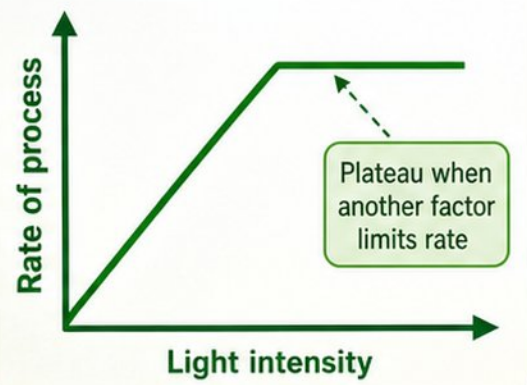
Real-World Factors: Light, CO_2, and Temperature

- **Light intensity:** rate rises until another factor limits it
- **CO_2 concentration:** atmospheric ~0.04% often limits C3 plants
- **Temperature:** affects Calvin cycle enzymes; 25–30°C is optimal
- Above ~40°C, enzymes denature and rate drops sharply
- **Law of Limiting Factors:** rate set by factor in shortest supply

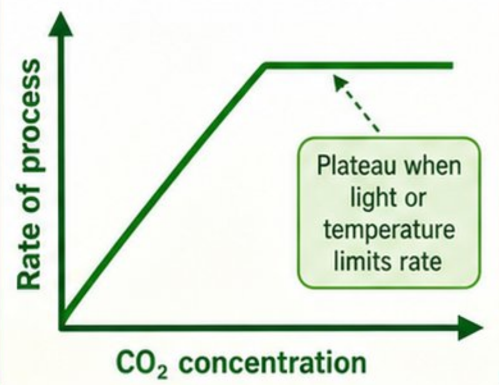


Interpreting Limiting Factor Graphs

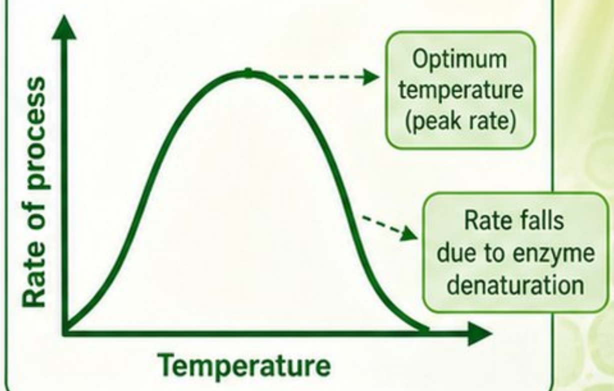
Light intensity graph: linear rise, then plateau as another factor limits rate



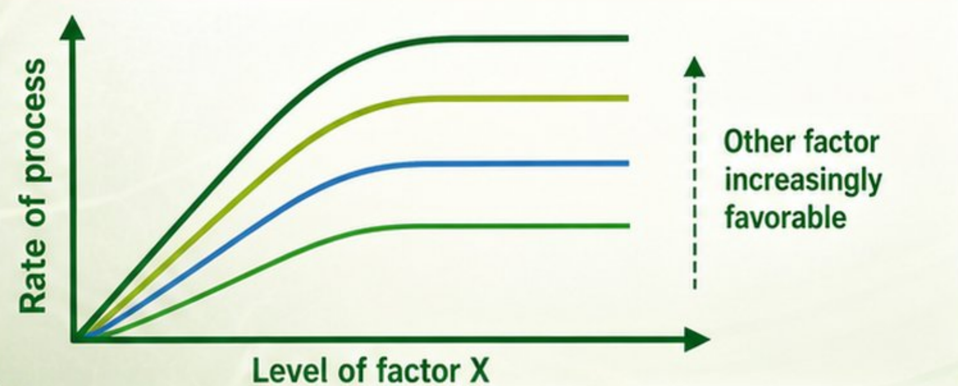
CO_2 graph: similar shape; plateau when light or temperature limits rate



Temperature graph: bell curve peaks at optimum, then falls due to enzyme denaturation



Multiple factor graphs: shifting curves show interactions between factors

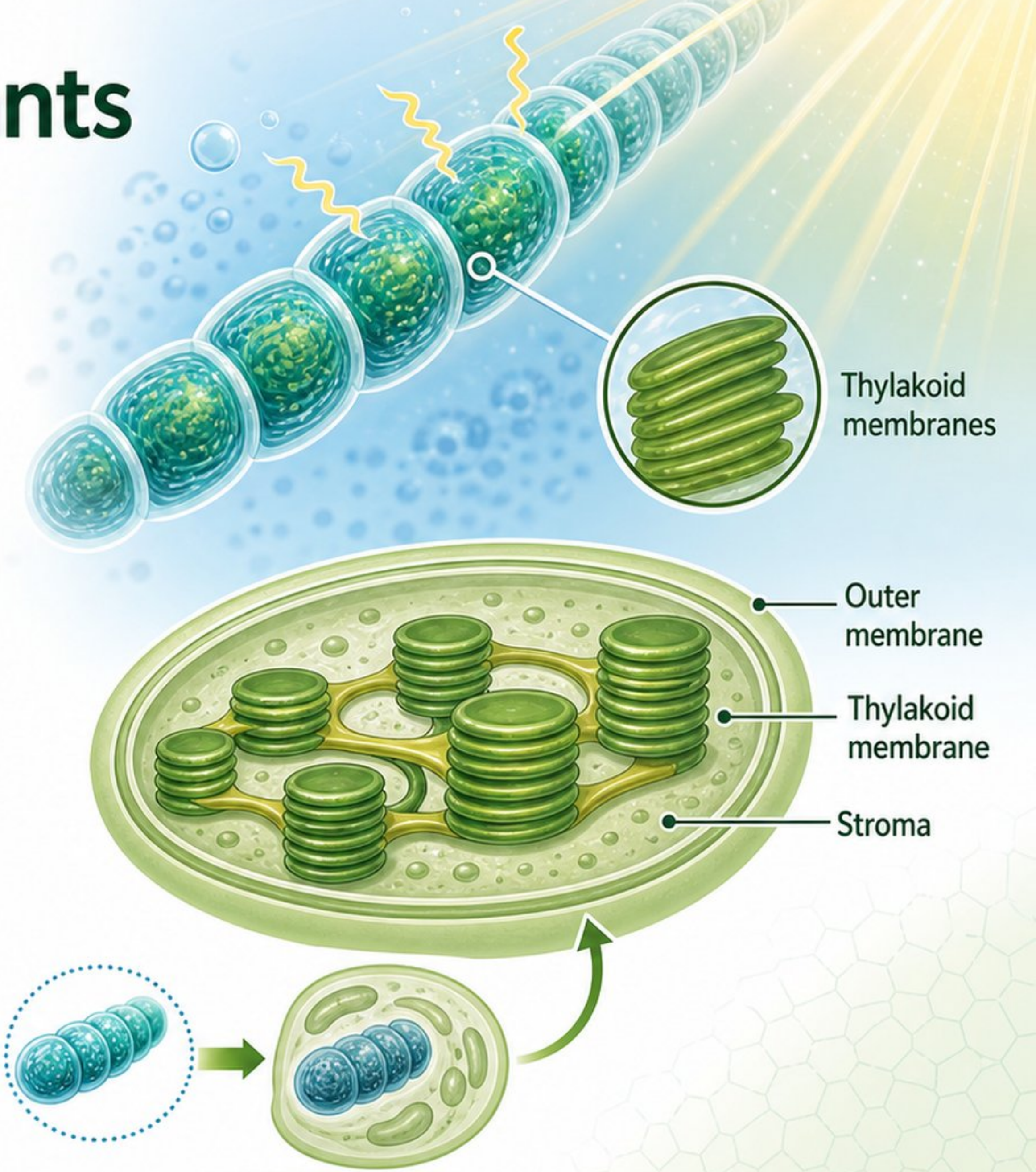


Rising section: x-axis factor is limiting

Plateau: a different factor is limiting

Photosynthesis Beyond Land Plants

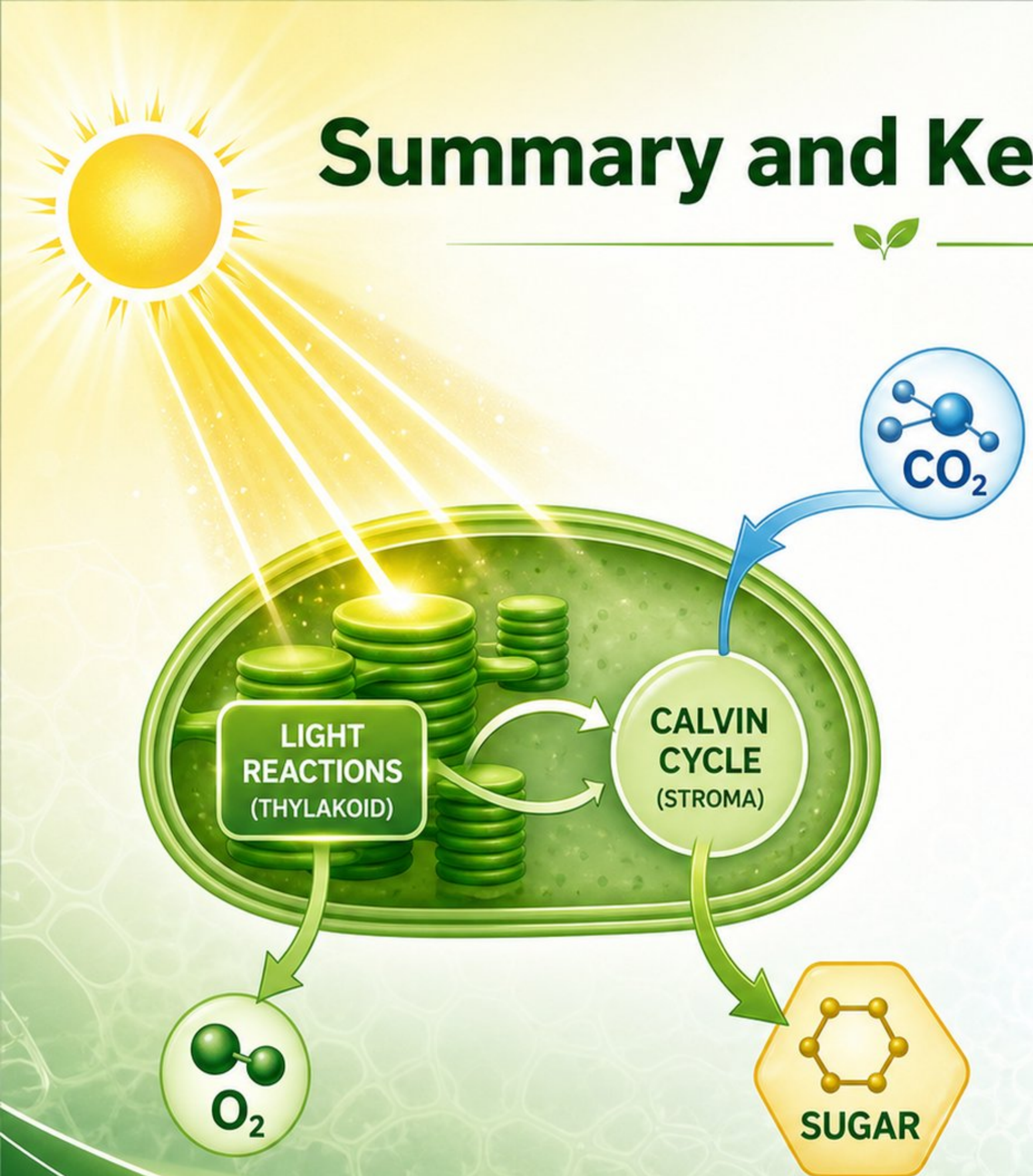
- Algae: single-celled and multicellular aquatic photosynthetic organisms
- Cyanobacteria: free-living photosynthetic bacteria; chloroplast ancestors
- Ocean phytoplankton produce a major portion of Earth's oxygen
- Chloroplast shapes vary from cup-shaped to spiral across algae species
- Endosymbiotic theory: chloroplasts evolved from ancient engulfed cyanobacteria



Photosynthesis and the Global Carbon Cycle

- Photosynthesis removes CO_2 from the atmosphere and fixes it into organic matter
- Cellular respiration returns CO_2 to the atmosphere, completing the carbon cycle
- Photosynthesis is the primary entry point of carbon into the biosphere
- Acting as a carbon sink, photosynthesis helps regulate Earth's climate
- Supports crops, biofuels, air quality, and overall ecosystem health

Summary and Key Takeaways



- Photosynthesis: light energy → chemical energy in sugar
- Two stages: light reactions (thylakoid) + Calvin cycle (stroma)
- Light reactions yield ATP, NADPH, O_2; Calvin cycle uses them to fix CO_2
- Sites: chloroplasts in plants/algae, and cyanobacteria
- Key limiting factors: light, CO_2, and temperature
- Foundational for food, oxygen, and the global carbon cycle