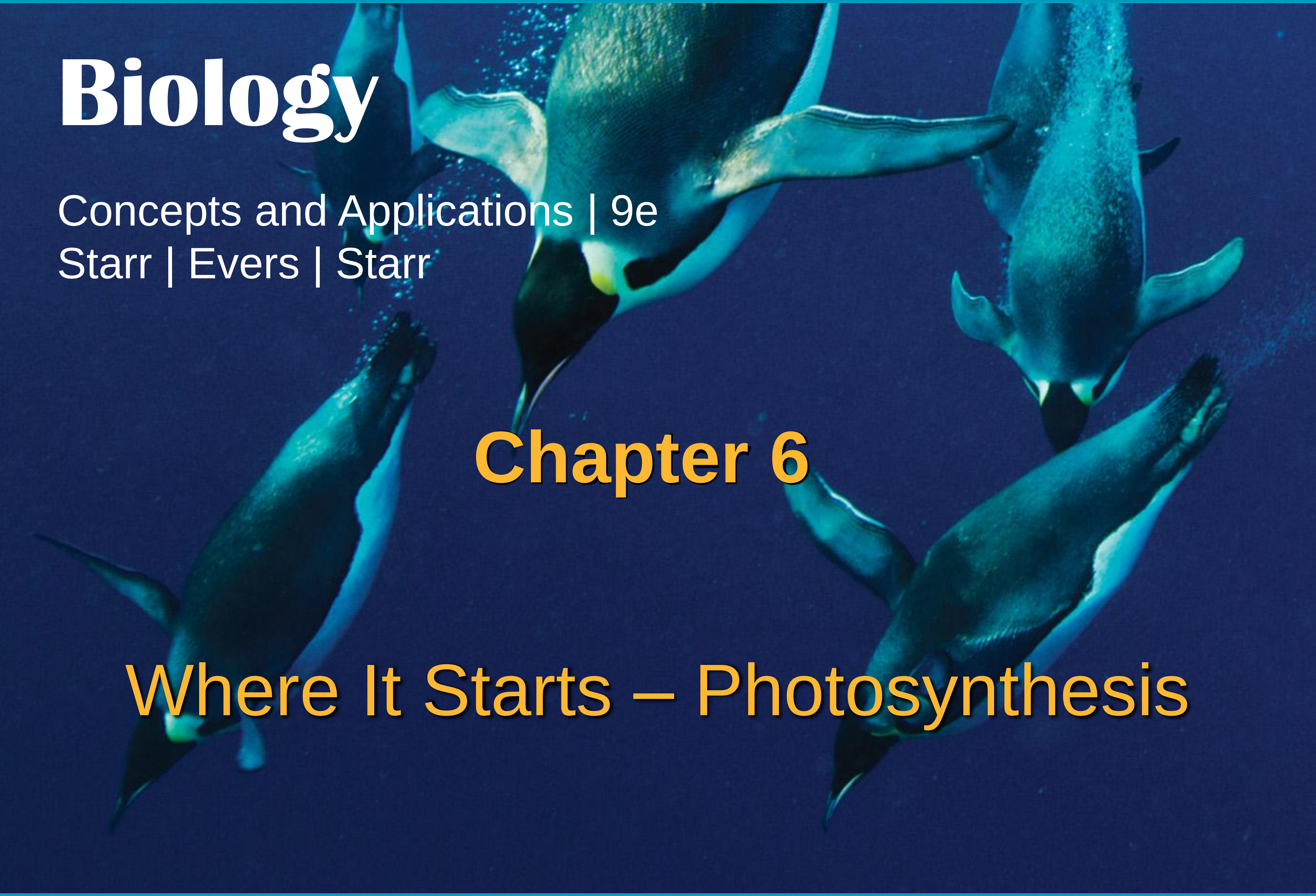

Biology

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Chapter 6

Where It Starts – Photosynthesis

6.1 How Do Photosynthesizers Absorb Light?

- Energy flow through ecosystems begins when photosynthesizers intercept sunlight
- Autotrophs are *producers*
  - Make food using energy from environment and carbon from inorganic molecules
- Heterotrophs are *consumers*
  - Obtain carbon from organic compounds assembled by other organisms

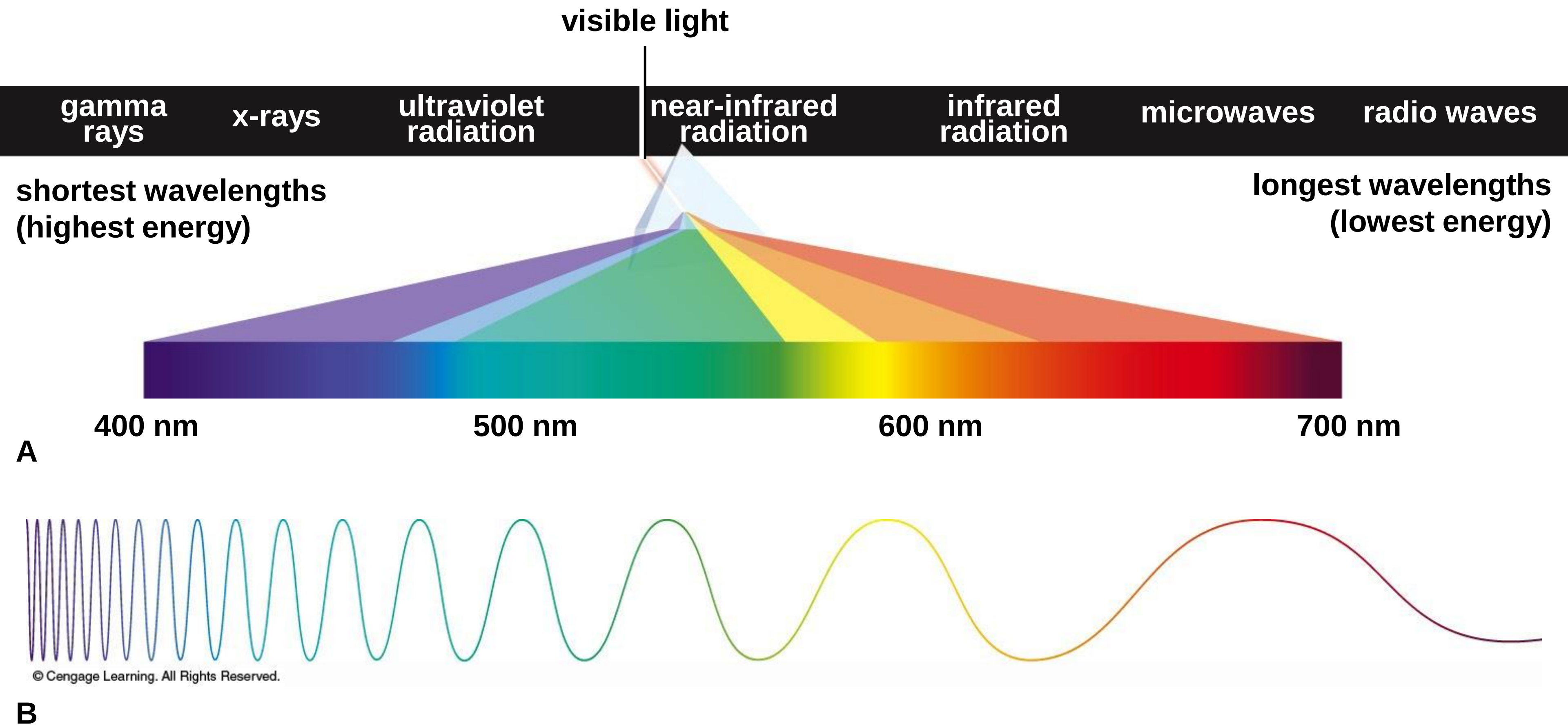
Properties of Light

- Light: electromagnetic radiation that moves through space in waves
  – Wavelength: distance between the crests of two successive waves
- Visible light:
  – Small part of the spectrum of electromagnetic radiation (380 to 750 nm)
  – Main form of energy that drives photosynthesis

Properties of Light (cont'd.)

- Light is organized in packets of energy known as photons
  - Long wavelengths are low in energy
  - Short wavelengths are high in energy

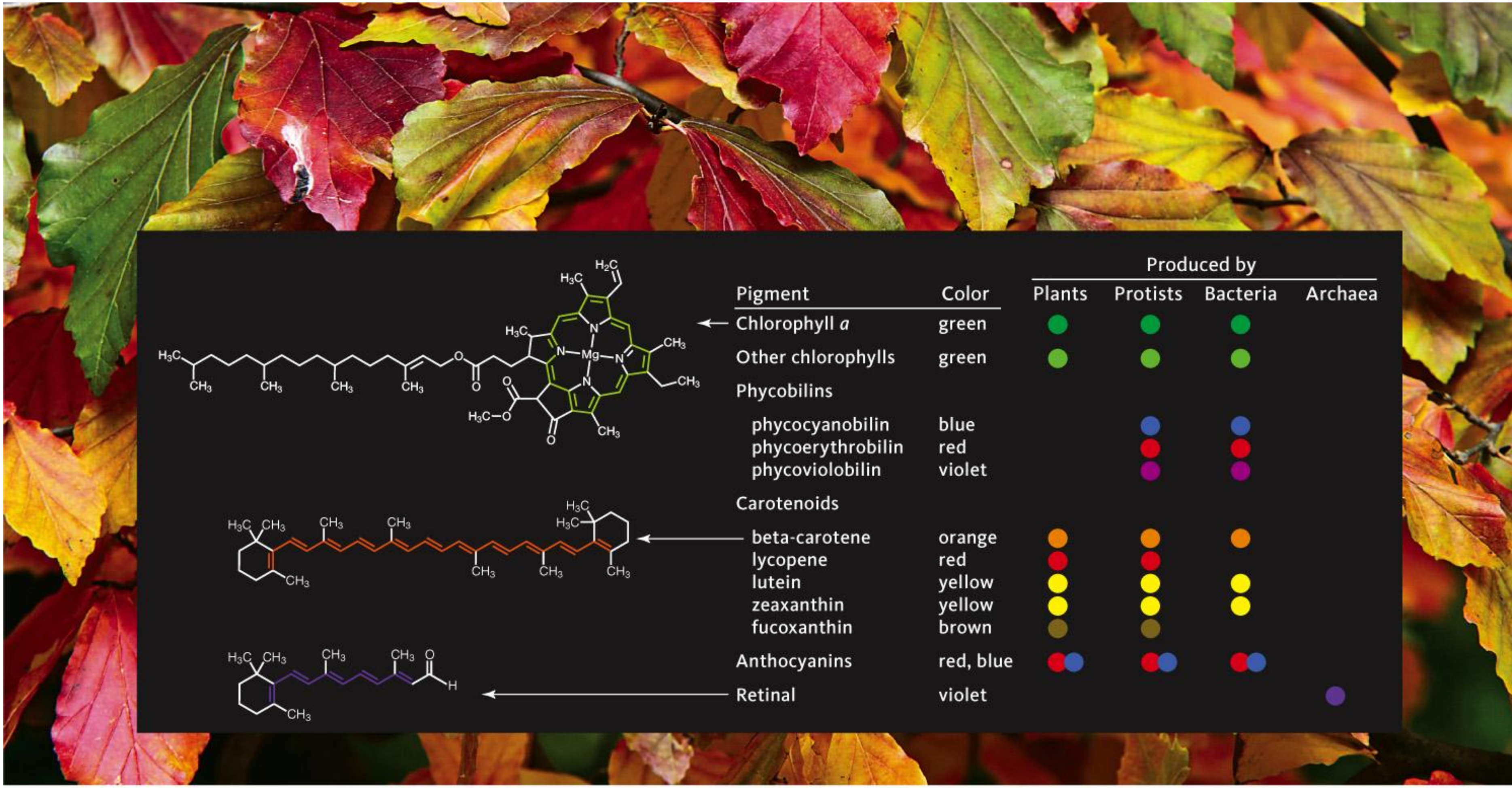
Properties of Light (cont'd.)



Capturing a Rainbow

- Photosynthesizers use pigments to capture light of specific wavelengths
- Chlorophyll *α*: most common photosynthetic pigment in plants and protists
  - Absorbs violet, red, and orange light
  - Reflects green light (appears as green)
- Accessory pigments harvest additional light wavelengths

Capturing a Rainbow (cont'd.)



Pigment	Color	Produced by: Plants	Protists	Bacteria	Archaea
Chlorophyll *a*	green	●	●	●	
Other chlorophylls	green	●	●	●	
Phycobilins					
phycocyanobilin	blue		●	●	
phycoerythrobilin	red		●	●	
phycoviolobilin	violet		●	●	
Carotenoids					
beta-carotene	orange	●	●	●	
lycopene	red	●	●		
lutein	yellow	●	●	●	
zeaxanthin	yellow	●	●	●	
fucoxanthin	brown	●	●		
Anthocyanins	red, blue	●●	●●	●●	
Retinal	violet				●

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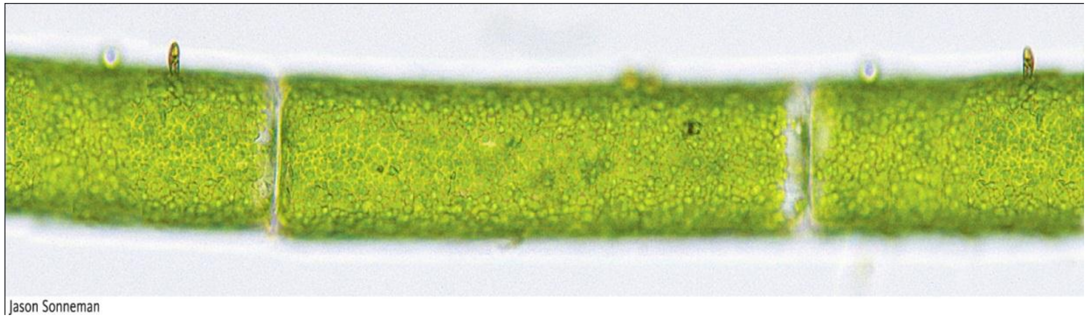
6.2 Why Do Cells Use More Than One Photosynthetic Pigment?

- In 1882, Theodor Engelmann tested the hypothesis that the color of light affects the rate of photosynthesis
  - Used motile, oxygen-requiring bacteria to identify where photosynthesis was taking place
  - Directed a spectrum of light across individual strands of green algae

Why Do Cells Use More Than One Photosynthetic Pigment? (cont'd.)

- In Engelmann's experiment, oxygen-requiring bacteria gathered where blue and red light fell across the algal cells
- Conclusion:
  - Blue and red light are best light for driving photosynthesis in these algal cells

Why Do Cells Use More Than One Photosynthetic Pigment? (cont'd.)



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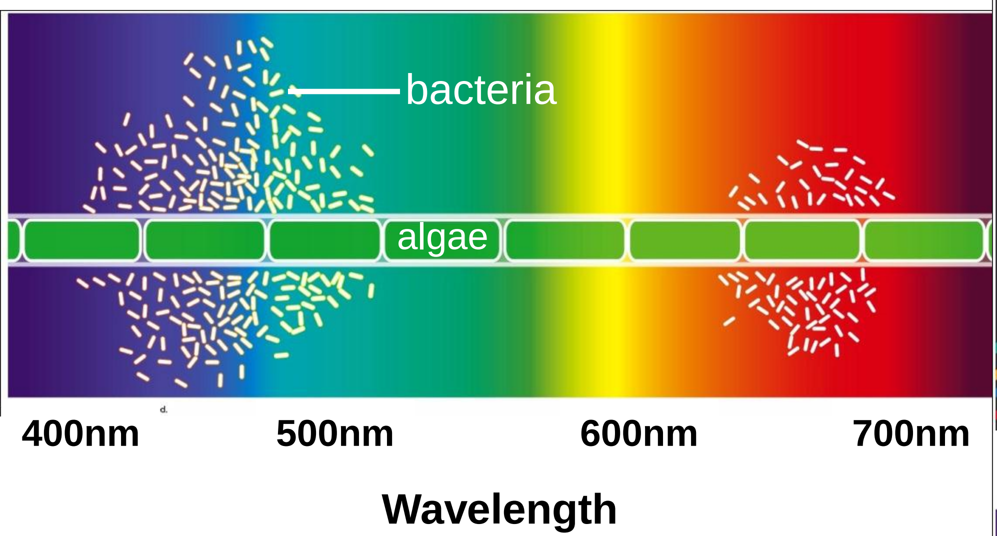

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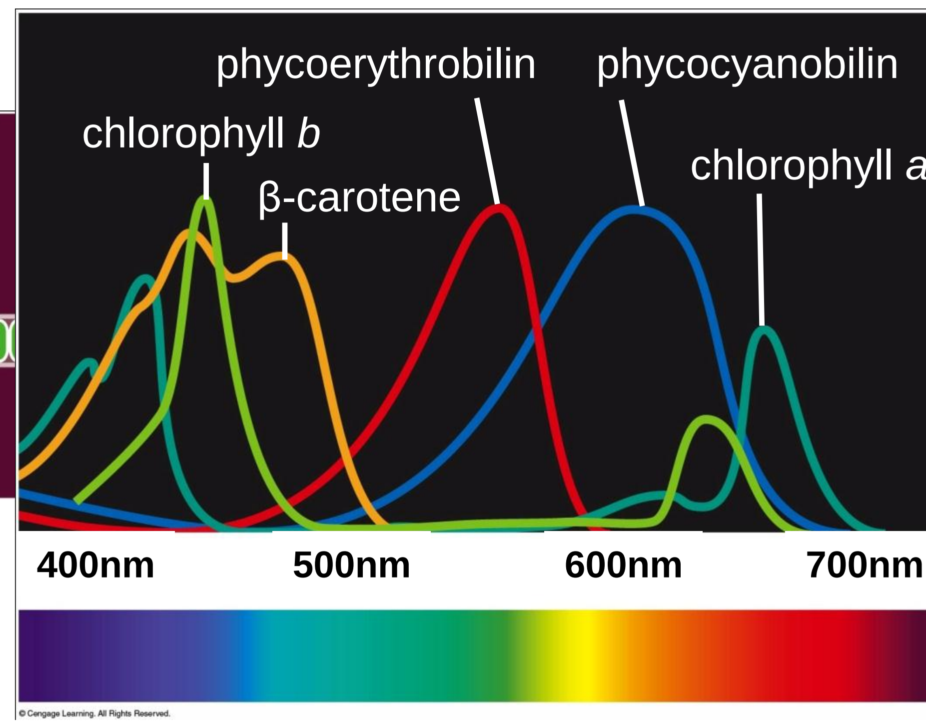

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Why Do Cells Use More Than One Photosynthetic Pigment? (cont'd.)

- The combination of pigments used for photosynthesis differs among species
  - Photosynthetic species are adapted to the environment in which they evolved
  - Light that reaches different environments varies in its proportions of wavelengths

6.3 What Happens During Photosynthesis?

- Photosynthesis converts the energy of light into the energy of chemical bonds
- Unlike light, chemical energy can power the reactions of life, and it can be stored for use at a later time

What Happens During Photosynthesis? (cont'd.)

- In eukaryotes, photosynthesis takes place in chloroplasts
  - Thylakoid membrane: a chloroplast's continuous highly folded inner membrane system
  - Stroma: cytoplasm-like fluid between the thylakoid membrane and the two outer membranes of a chloroplast

ANIMATED FIGURE: T. Englemann's experiment

What Happens During Photosynthesis? (cont'd.)

- Photosynthesis is often summarized as:
  - $CO_2 + \text{water} \xrightarrow{\textit{light energy}} \text{sugars} + O_2$

What Happens During Photosynthesis? (cont'd.)

- Photosynthesis is a two-stage reaction:
  - Light-dependent reactions:
    - Occur in thylakoid membrane
    - Converts light energy to ATP and NADPH
  - Light-independent reactions:
    - Occur in the stroma
    - ATP and NADPH drive synthesis of sugars from water and CO_2

What Happens During Photosynthesis? (cont'd.)

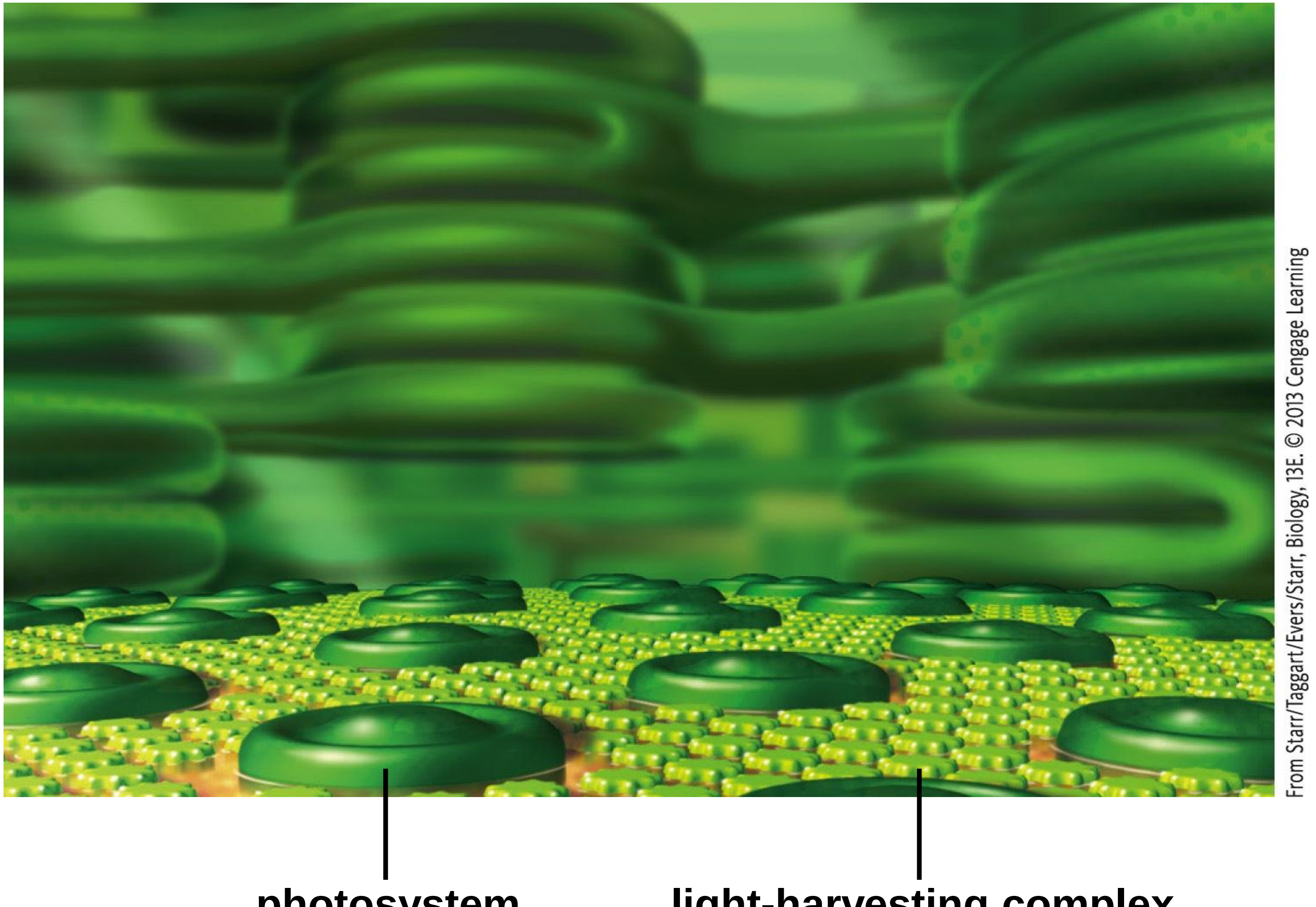
6.4 How Do The Light-Dependent Reactions Work?

- Thylakoid membranes contain millions of light-harvesting complexes
  - Circular arrays of chlorophylls, various accessory pigments, and proteins
- After light absorption, light-harvesting complexes pass energy back and forth

How Do The Light-Dependent Reactions Work? (cont'd.)

- Photosystem: group of hundreds of chlorophylls, accessory pigments, and other molecules
  - Photosynthesis begins when energy from light-harvesting complexes reaches a photosystem

How Do The Light-Dependent Reactions Work? (cont'd.)



How Do The Light-Dependent Reactions Work? (cont'd.)

- Light-dependent reactions involve:
  - – Noncyclic pathways
  - – Cyclic pathways

The Noncyclic Pathway

- Steps of noncyclic pathway:
  1) Light energy ejects electrons from photosystem II
  2) Photosystem II pulls electrons from water molecules and breaks them apart into oxygen and hydrogen ions
     - Photolysis: process by which light energy breaks down a molecule

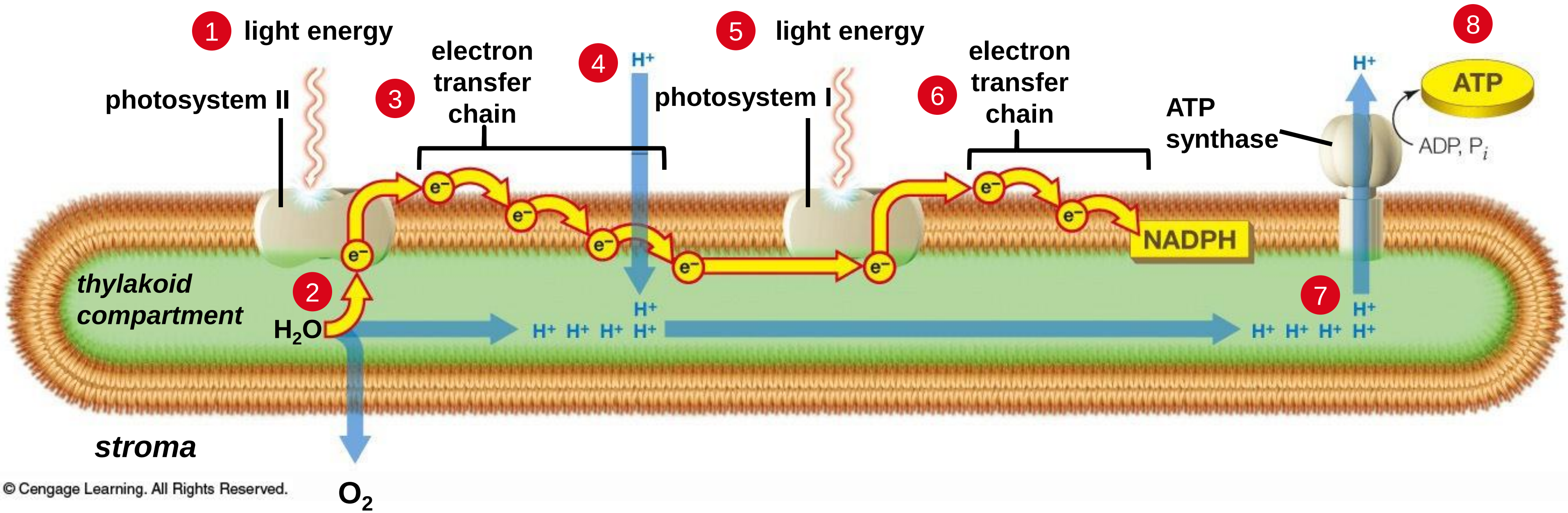
The Noncyclic Pathway (cont'd.)

- Steps of noncyclic pathway (cont'd.):
  3) Electrons enter an electron transfer chain in the thylakoid membrane
  4) Hydrogen ion gradient forms across the thylakoid membrane
  5) After electrons move through first electron transport chain, light energy ejects electrons from photosystem I

The Noncyclic Pathway (cont'd.)

- Steps of noncyclic pathway (cont'd.):
  6) Ejected electrons move through a second electron transfer chain; NADPH forms
  7) Hydrogen ions in the thylakoid compartment are propelled through ATP synthases
  8) ATP synthases phosphorylate ADP; ATP is formed in the stroma
     - Electron transfer phosphorylation: process by which electron flow through electron transfer drives ATP formation

The Noncyclic Pathway (cont'd.)



The Noncyclic Pathway (cont'd.)

The Cyclic Pathway

- Electrons ejected from photosystem I enter an electron transfer chain, and then return to photosystem I
- Similarities with noncyclic pathway:
  - Hydrogen ions are moved into the thylakoid compartment, driving ATP formation
- Differences from noncyclic pathway:
  - NADPH and oxygen gas are not produced

The Cyclic Pathway (cont'd.)

6.5 How Do The Light-Independent Reactions Work?

- The Calvin–Benson cycle:
  - Build sugars in the stroma of chloroplasts
  - Not powered by light energy
  - Driving force is ATP and NADPH that formed in the light-dependent reactions
  - Uses carbon atoms from CO_2 to make sugars
    - Carbon fixation: carbon from an inorganic source gets incorporated into an organic molecule

The Calvin-Benson Cycle

- Steps of the Calvin–Benson cycle:
  1) The enzyme rubisco fixes carbon by attaching CO_2 to RuBP (ribulose bisphosphate)
  2) Twelve PGA (phosphoglycerate) molecules form

The Calvin-Benson Cycle (cont'd.)

- Steps of the Calvin–Benson cycle (cont'd.):
  3) Twelve PGAL (phosphoglyceraldehyde) molecules form
     - Two PGAL may combine to form one six-carbon sugar (such as glucose)
  4) Ten remaining PGAL regenerate the starting compound, RuBP

ANIMATION: Noncyclic pathway of electron flow

To play movie you must be in Slide Show Mode

PC Users: Please wait for content to load, then click to play

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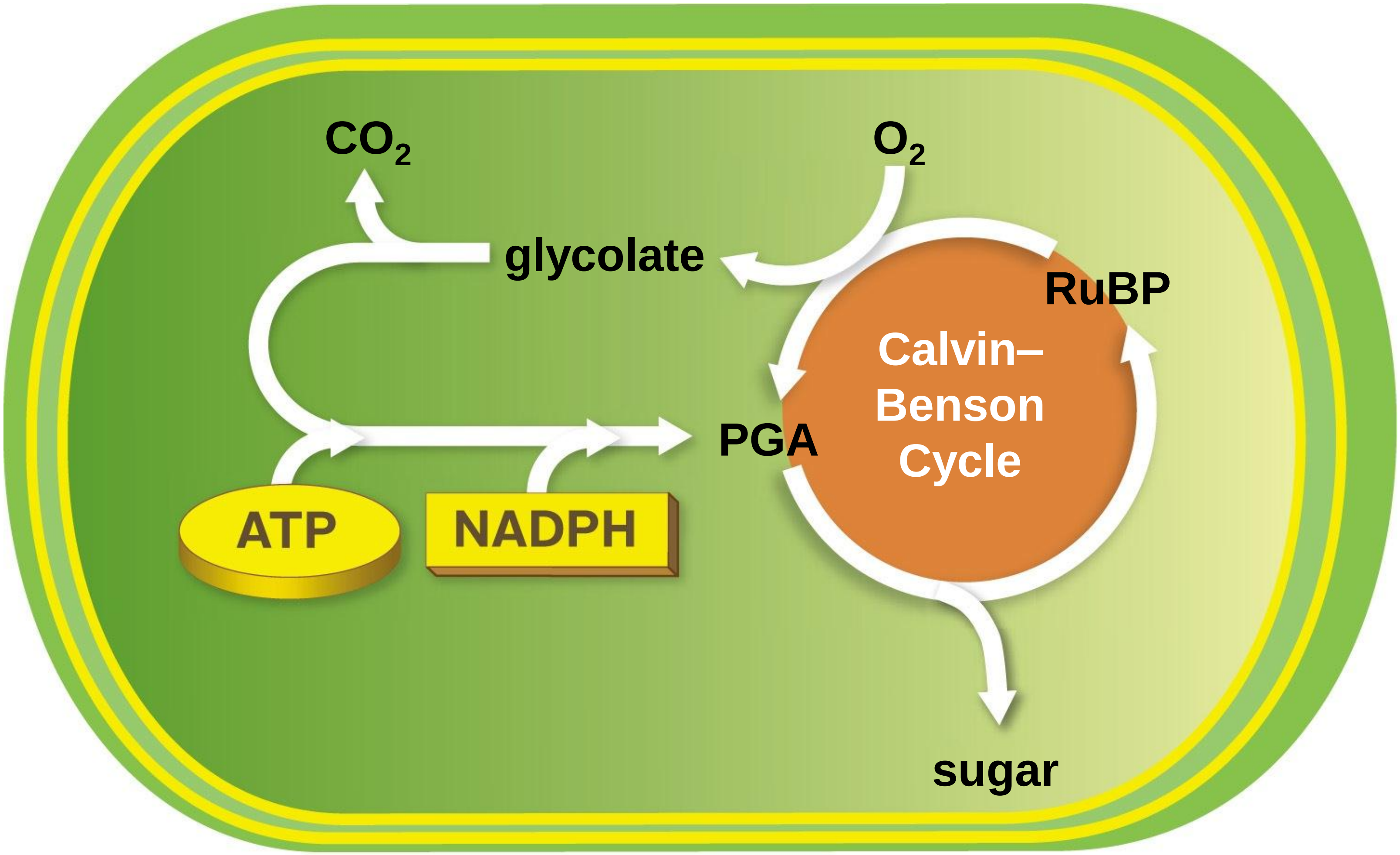
Adaptations to Climate

- Stomata are tiny gateways for gases
  - Open stomata:
    - Allow CO_2 to diffuse from the air into photosynthetic tissues
    - Allow O_2 to diffuse out of these tissues into the air
  - Closed stomata:
    - Conserve water on hot, dry days
    - Limit the availability of CO_2 for the light-independent reactions; sugar synthesis slows

Adaptations to Climate (cont’d.)

- C3 plants:
  - Use only the Calvin–Benson cycle to fix carbon
  - When CO_2 concentration declines, rubisco uses oxygen as a substrate in photorespiration
  - When stomata are closed during the day, C3 plants lose carbon instead of fixing it
  - Extra energy is required to make sugars
  - Contain high levels of rubisco

Adaptations to Climate (cont'd.)



CREDITS: (9A) © Cengage Learning; (9B left) Masahiro Yamada, Michio Kawasaki, Tatsuo Sugiyama, Hiroshi Miyake, Mitsutaka Taniguchi; Differential Positioning of C4 Mesophyll and Bundle Sheath Chloroplasts: Aggregative Movement of C4 Mesophyll Chloroplasts in Response to Environmental Stresses: Plant and Cell Physiology; (2009) 50(10): 1736–1749; (9B right) Eri Maai, Shouu Shimada, Masahiro Yamada, Tatsuo Sugiyama, Hiroshi Miyake, Mitsutaka Taniguchi; The avoidance and aggregative movements of mesophyll chloroplasts in C4 monocots in response to blue light and abscisic acid; *Journal of Experimental Botany*, doi:10.1093/jxb/err008, by permission of Oxford University Press

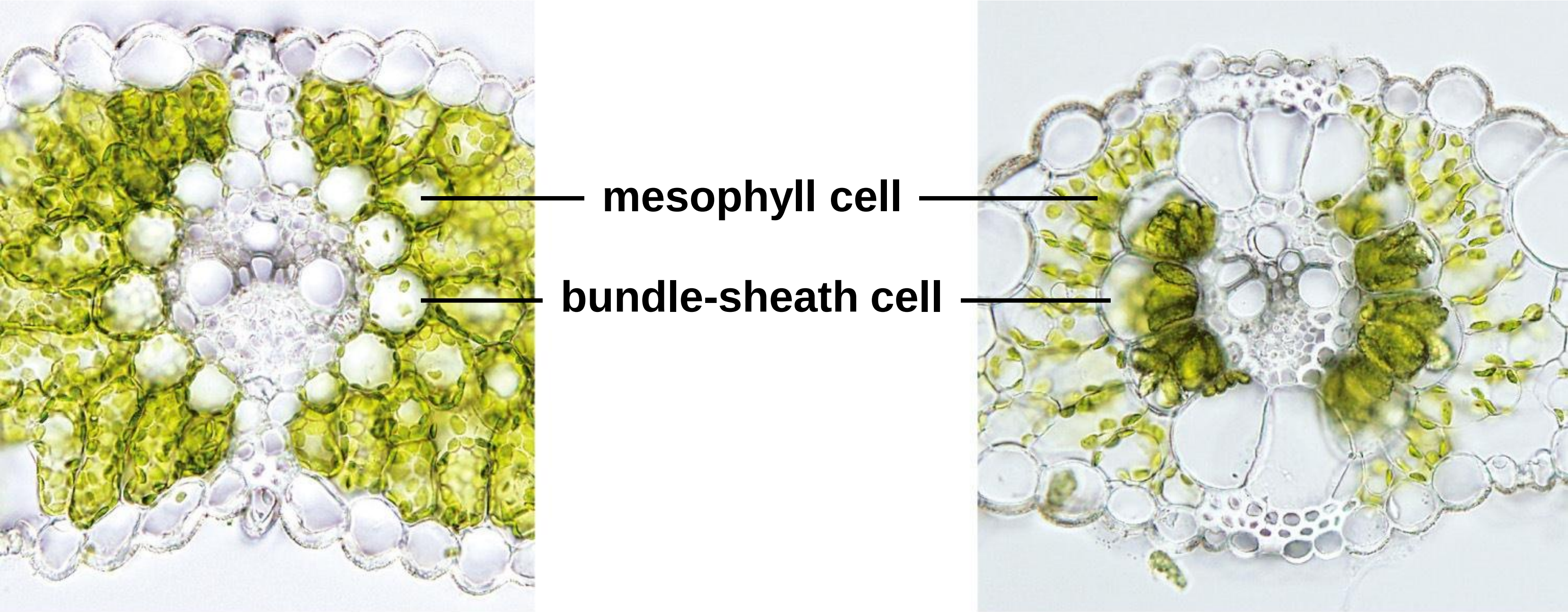
Adaptations to Climate (cont'd.)

- C4 plants:
  - Close stomata on dry days, but their sugar production does not decline
  - Minimize photorespiration by fixing carbon twice in two cell types
    - Mesophyll cells
    - Bundle-sheath cells
  - Examples: corn, switchgrass, and bamboo

Adaptations to Climate (cont'd.)

- CAM plants:
  - C4 plant that conserves water by fixing carbon twice, at different times of day
  - Conserve water even in desert regions with extremely high daytime temperatures
  - Open stomata at night when lower temperatures minimize evaporative water loss

Adaptations to Climate (cont’d.)



Adaptations to Climate (cont'd.)

Image courtesy msuturfweeds.net.

6.6 Application: Green Energy

- With fossil fuel prices soaring, there is an increasing demand for biofuels:
  - Oils, gases, or alcohols made from organic matter that is not fossilized
- Most materials we use for biofuel production today consist of food crops:
  - Mainly corn, soybeans, and sugarcane

Application: Green Energy (cont'd.)

- Fossil fuels:
  - Petroleum, coal, and natural gas
  - Formed from the remains of ancient swamp forests that decayed and compacted over millions of years
  - Consist of molecules originally assembled by ancient plants

Application: Green Energy (cont'd.)

- The process of using fossil fuels or biofuels are fundamentally the same:
  - Release energy by breaking the bonds of organic molecules
  - Use oxygen to break those bonds
  - Produce carbon dioxide

Application: Green Energy (cont'd.)

- Biofuels are a renewable source of energy
  - Growing more plants creates more sources of biofuels

Application: Green Energy (cont'd.)

- Biofuels do not contribute to global climate change
  - Growing plant matter for fuel recycles carbon that is already in the atmosphere

Application: Green Energy (cont'd.)

- Corn and other food crops are rich in oils, starches, and sugars that can be easily converted to biofuels
  - Starch from corn kernels can be broken down to glucose, which is converted to ethanol by bacteria or yeast

Application: Green Energy (cont'd.)

- Making biofuels from some plants require additional steps, because these materials contain a higher proportion of cellulose
  – Researchers are currently working on cost-effective ways to break down the abundant cellulose in fast-growing weeds

Application: Green Energy (cont'd.)

Photo by Peggy Greb/USDA.

Application: Green Energy (cont'd.)

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Application: Green Energy (cont'd.)

- According to tropical forest scientist Willie Smits, the Arenga sugar palm has the potential to serve as the core of a waste-free system
  - Produces premium organic sugar and ethanol for fuel
  - Provides food products and jobs to villagers
  - Helps preserve the existing native rain forest

Application: Green Energy (cont'd.)

Photograph courtesy Eric Rasmussen.