UNIT 3

Matter and Energy in Living Systems

Kelp forests are important aquatic ecosystems.

FIGURE 1: These terrariums are self-sustaining environments.

Many terrariums are closed, self-sustaining systems. The organisms in these terrariums are able to produce all of the materials needed for survival. Earth is also a closed system. Very little matter is added to or lost from the Earth system.

Predict How do plants and animals grow if no new matter is added to the system?

DRIVING QUESTIONS

As you move through the unit, gather evidence to help you answer the following questions. In your Evidence Notebook, record what you already know about these topics and any questions you have about them.

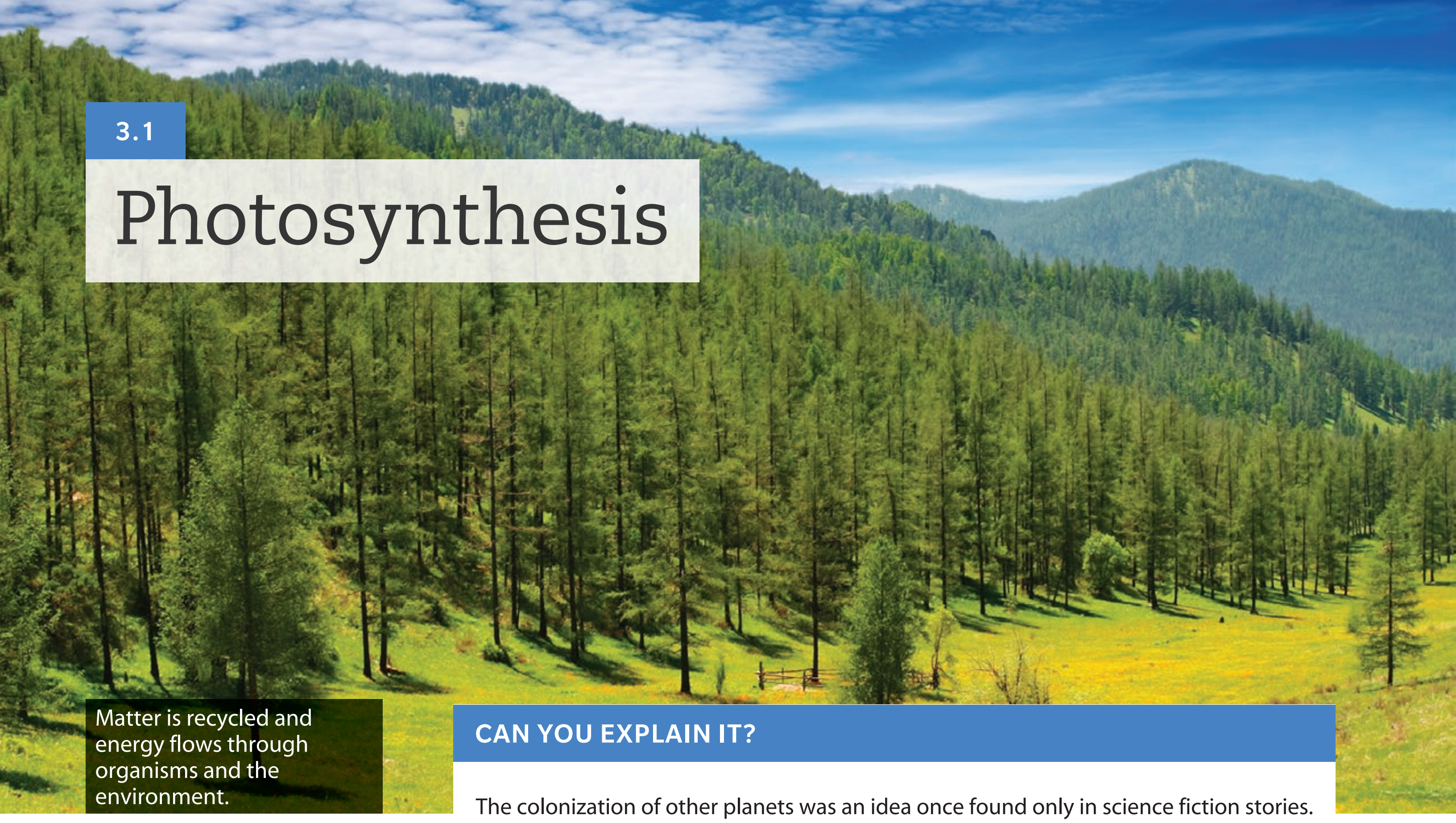
1. What do plants need to survive? How do plants obtain energy?
2. How do animals obtain energy to grow?
3. How are energy and matter transferred through organisms and their environment?

UNIT PROJECT

Bottle Biome

Go online to download the Unit Project Worksheet to help plan your project.

How do energy and matter cycle through a closed system such as the Earth system? How do the plants and animals survive? Make your own closed biological system inside a bottle, and investigate how the plants and animals survive with no materials being added to the system. Can you explain how the bottle represents Earth?



3.1

Photosynthesis

Matter is recycled and energy flows through organisms and the environment.

CAN YOU EXPLAIN IT?

The colonization of other planets was an idea once found only in science fiction stories. Today, this idea is closer to becoming a realistic pursuit. One of the problems that must be solved before the colonists leave Earth is this—where will the colonists get food? One line of inquiry involves figuring out what it takes to grow plants in an environment different from Earth.

Gather Evidence As you explore the lesson, gather evidence to describe the inputs and outputs of matter and the transfer and transformation of energy in photosynthesis.

FIGURE 1: Astronauts from NASA and around the world have been growing plants in space to learn how to someday grow them on other planets, such as Mars.

Explore Online

Predict Imagine you are colonizing another planet, and you want to grow plants there as a food source. What do you need to bring, and what questions would you ask about the planet in order to refine your list?

Image Credits: (t) ©Pichugin Dmitry/Shutterstock; (b) ©NASA Kennedy Space Center

Matter and Energy in Photosynthesis

Living systems take in energy and matter and convert them to forms they can use. Plants, for example, are producers that capture light energy and convert it to chemical energy to carry out cell processes within the plant. The chemical energy takes the form of chemical bonds in sugar molecules. When a consumer, such as a panda, eats plant matter, it obtains this energy and other nutrients it needs for cell processes and growth through the process of digestion. Any matter that cannot be digested is excreted as waste.

FIGURE 2: This panda is a consumer that gets its energy and nutrients from eating leaves.

Explain Describe the transformation of energy as it is transferred from the sun to the panda.

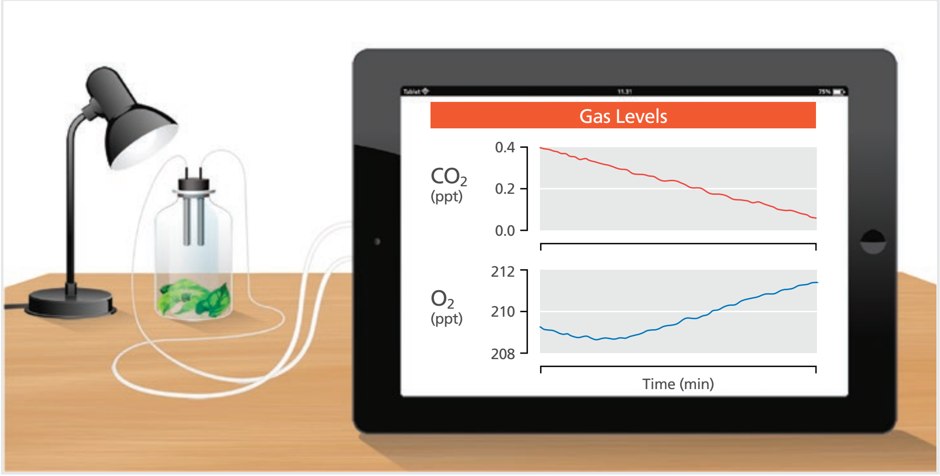
Modeling Photosynthesis

Plants, algae, and some bacteria use a process called photosynthesis to capture and transform light energy from the sun and store it in high-energy sugar molecules. Both plant cells and animal cells use sugars made by photosynthesis as an energy source. However, photosynthesis is not just important to organisms—it also helps regulate Earth's environment. Photosynthesis produces the oxygen we breathe, and it removes carbon dioxide from Earth's atmosphere.

Organisms are complex living systems. Organisms live and interact in ecosystems, which are systems within the biosphere. All organisms play different roles in the cycling of matter and the transfer of energy in their ecosystem. To better understand the relationship between organisms and the environment, scientists collect many different types of data.

Collaborate Discuss with a partner why it would be beneficial to human survival to have plants on a planet where oxygen levels are low and carbon dioxide levels are high.

FIGURE 3: This setup shows a plant in a closed system. Sensors are measuring carbon dioxide and oxygen concentrations in the chamber. The gas concentrations are shown in parts per thousand.



Gather Evidence Identify inputs and outputs for this system. How can the data help scientists understand the relationship between plants and the environment?

Photosynthesis is important to life on Earth. Nearly all organisms on Earth depend on this process. So understanding the relationship between organisms and photosynthesis is critical. Using equipment to measure the rate of photosynthesis, for example, is one way to study the impact that organisms have on the process. Using models is another way to understand processes like photosynthesis. Scientists can study the relationship between the inputs and outputs.

Energy and Matter

Model Draw a plant and label the inputs and outputs of photosynthesis. Where should the labels for enzymes and light be placed?

The process of photosynthesis can be modeled in various ways. For example, a chemical equation is one way to represent photosynthesis.

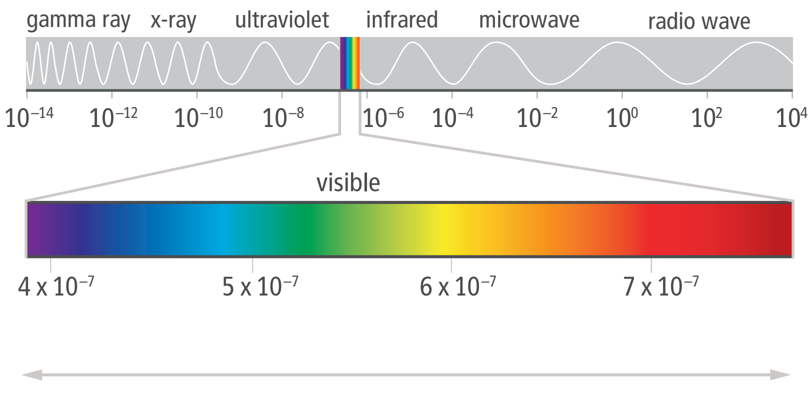
$$6CO_2 + 6H_2O \xrightarrow[\text{light}]{\text{enzymes}} 6O_2 + C_6H_{12}O_6$$

This model shows the inputs and outputs as reactants and products. The multiple arrows indicate that the process of photosynthesis has many steps. Light and enzymes are placed over the arrows to indicate that they must be present for this reaction to take place. In this equation, carbon dioxide and water are reactants, and oxygen and glucose are products. Plant cells use glucose to form complex carbohydrates such as starch and cellulose, which the plant uses for growth and maintenance.

Light and Photosynthesis

Light is a form of energy known as electromagnetic radiation. Electromagnetic radiation travels in waves of various wavelengths, as shown in Figure 4. Plants absorb only visible light to use for photosynthesis. Even in the visible portion of the electromagnetic spectrum, not all wavelengths are absorbed by plants. Visible light consists of different wavelengths that correspond to different colors of light.

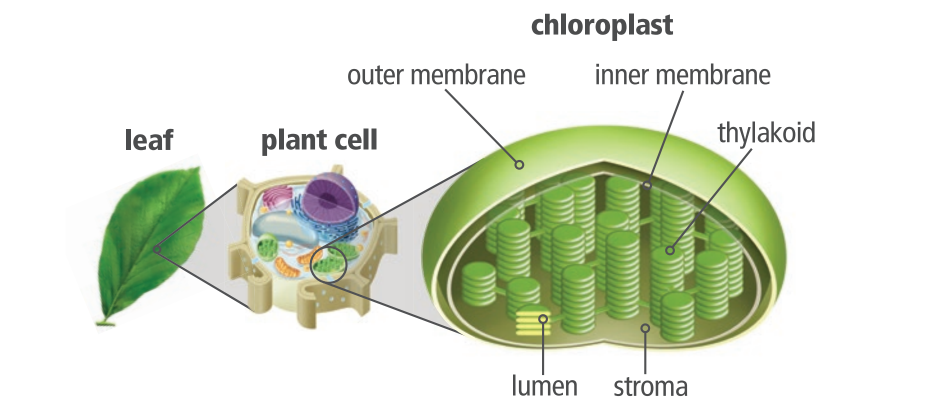
FIGURE 4: The Electromagnetic Spectrum



Analyze Think about light as a form of energy and answer the following questions: What are microwaves used for? What are radio waves used for? What do you think might happen if visible light were blocked from Earth? How would photosynthesis be impacted?

In plant cells, light absorption and photosynthesis take place inside an organelle called a chloroplast. Inside the inner membrane of the chloroplast are stacks of disc-shaped sacs called thylakoids, which contain pigment molecules called chlorophyll.

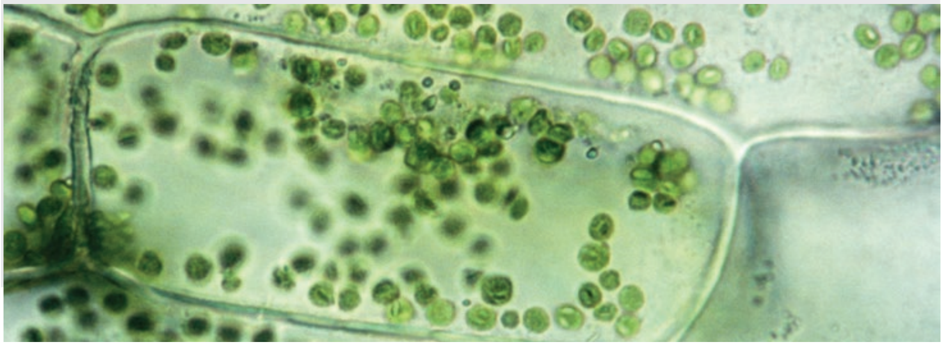
FIGURE 5: The area inside the chloroplast is the stroma. The area inside the thylakoid sac is called the lumen. The stages of photosynthesis occur across the thylakoid membrane that separates the stroma and the lumen.



> **Explain** Place these systems in order from largest to smallest, beginning with Earth, and explain your reasoning: tree, biosphere, plant cell, chloroplast, leaf

Different types of chlorophyll absorb different wavelengths of light, transforming the light energy into chemical energy through photosynthesis. Unabsorbed wavelengths get reflected by the plant's pigments, and our eyes detect these as the plant's color.

FIGURE 6: Chlorophyll is a pigment molecule in chloroplasts. Plants have two main types of chlorophyll, called chlorophyll *a* and chlorophyll *b*.



> **Analyze** Which colors of light are absorbed, and which colors are reflected by most plants?

Engineering

Choosing a Light Source

Scientists and engineers may study the inputs and outputs of a system as part of optimizing the system. For example, different light sources can affect the rate of photosynthesis in a plant system. Different light sources emit light with a variety of wavelengths. Light emitting diodes, or LEDs, can be designed to only give off certain colors, such as red, blue, or green, which correspond to different wavelengths of visible light. Applying specific light sources to plants is one way to optimize the rate of photosynthesis.

Explore Online

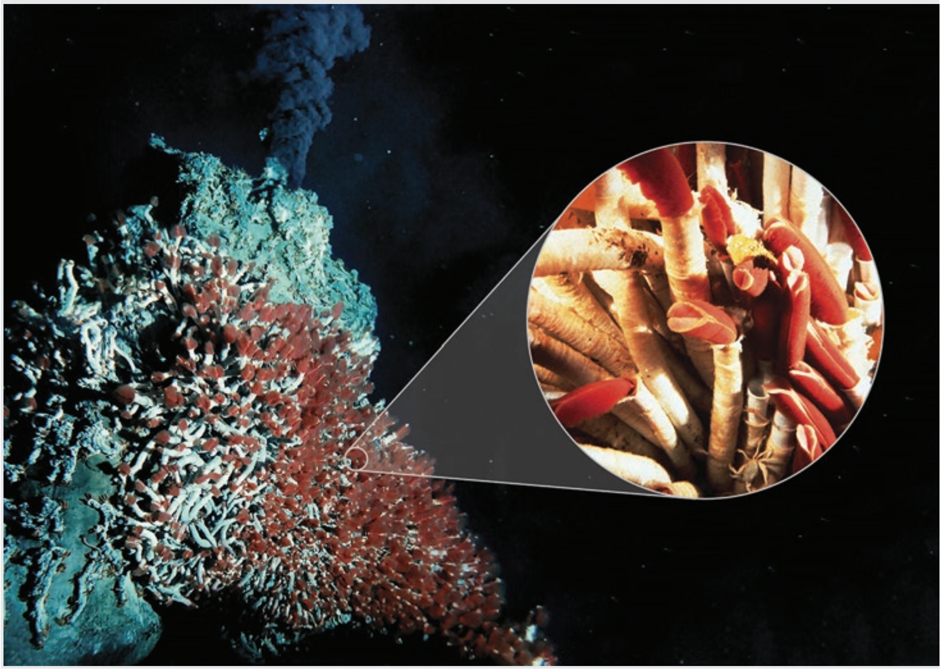
Hands-On Lab

Investigating Light Sources and Photosynthesis Design an experiment to investigate the effect of different light sources on the rate of photosynthesis.

Comparing Producers

Most, but not all, organisms rely directly or indirectly on sunlight and photosynthesis. Places such as deep oceans and dark caves have thriving populations despite never receiving any sunlight. The very hot water found near cracks in the ocean floor, called hydrothermal vents, is one such environment. These vents release chemical compounds such as hydrogen sulfide (H_2S) that serve as an energy source. Hydrothermal vents support a dense ecosystem made up of organisms completely dependent on the chemicals coming out of the sea floor.

FIGURE 7: Chemosynthetic microbes live on or below the sea floor, and inside the bodies of other vent animals. Tubeworms grow in clumps around the vents.



Chemosynthesis is the process of using chemical energy to make sugars from carbon dioxide for energy storage. Like plants that rely on photosynthesis, chemosynthetic organisms make their own food, but the raw materials differ.

The producers that live around hydrothermal vents carry out a process represented by the following chemical equation. The process produces the carbohydrates these producers need for energy.

$$6CO_2 + 24H_2S + 6O_2 \longrightarrow C_6H_{12}O_6 + 24S + 18H_2O$$

Model Make a graphic organizer to compare the inputs and outputs for chemosynthesis and for photosynthesis.

Analyze Think back to the question about growing plants on another planet and answer the following questions:

1. What inputs would you need to provide in order for plants to carry out photosynthesis?
2. What are the outputs from plants that are needed for human survival?
3. How would producers that carry out chemosynthesis differ from photosynthetic producers as a possible food source?

Transforming Light Energy into Chemical Energy

So far you have seen that plants transform energy from sunlight into chemical energy stored in the chemical bonds of sugar molecules. But, how does this transformation of energy happen? Chloroplasts in cells are like solar-powered chemical factories. They transfer light energy to energy-carrying molecules called ATP and NADPH. Cells use these molecules as energy currency for cell processes. In plant cells, they are used to convert carbon dioxide into sugars.

Predict How do you think plant cells transfer energy from sunlight to the energy-carrying molecules ATP and NADPH?

FIGURE 8: Two energy-carrying molecules are used in photosynthesis. ATP stores energy in a phosphate-phosphate bond, and NADPH carries high-energy electrons.

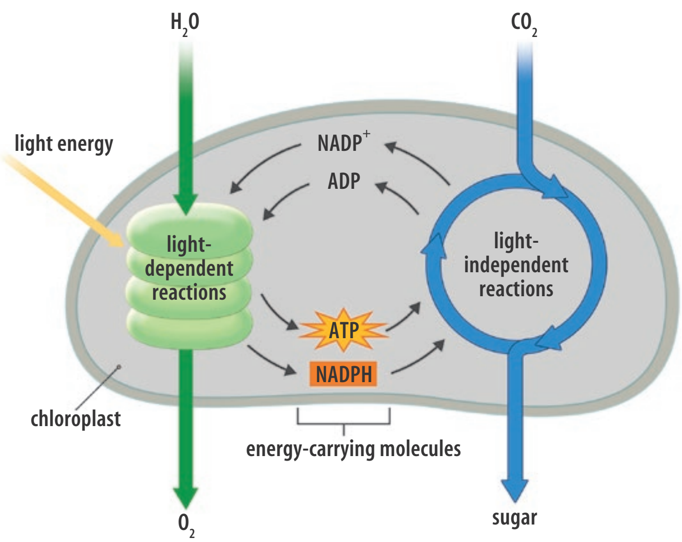
$$\text{ADP} + \text{P} \rightarrow \text{ATP}$$

$$\text{NADP}^+ + \text{H}^+ + 2\,e^- \rightarrow \text{NADPH}$$

Stages of Photosynthesis

Photosynthesis can be broken into two stages – the light-dependent reactions and the light-independent reactions. The light-dependent reactions take place within and across the membrane of the thylakoids, which are stacked inside the chloroplast. The light-independent reactions take place in the stroma, the area outside the thylakoids.

FIGURE 9: The two stages of photosynthesis, light-dependent reactions and light-independent reactions, occur in the chloroplast.



Gather Evidence Examine the diagram of the chloroplast. How does alternating between light-dependent and light-independent reactions help the cell conserve energy and matter? Cite evidence from the diagram to support your answer.

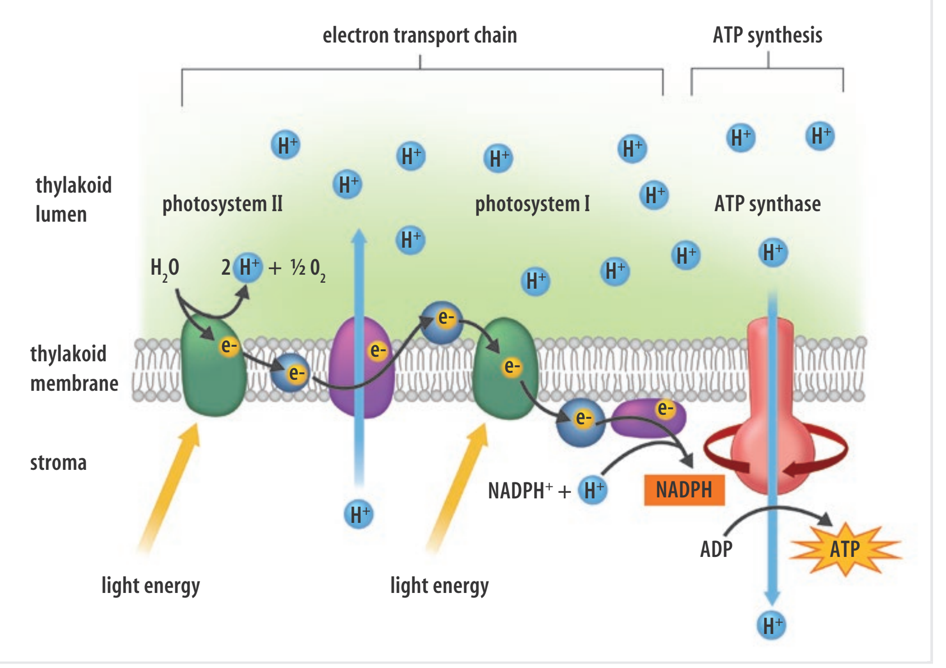
Analyze Identify the inputs and outputs for both stages of photosynthesis. Specify for both energy and matter.

The Light-Dependent Reactions

The light-dependent reactions are the *photo* part of photosynthesis. The main functions of the light-dependent reactions are to capture and transfer energy. Light energy is captured and transferred in the thylakoid membrane by two groups of molecules called photosystem II and photosystem I. They are named for the order in which they were discovered, not the order in which they occur.

FIGURE 10: The Light-Dependent Reactions

Explore Online



The light-dependent reactions are summarized in the steps below.

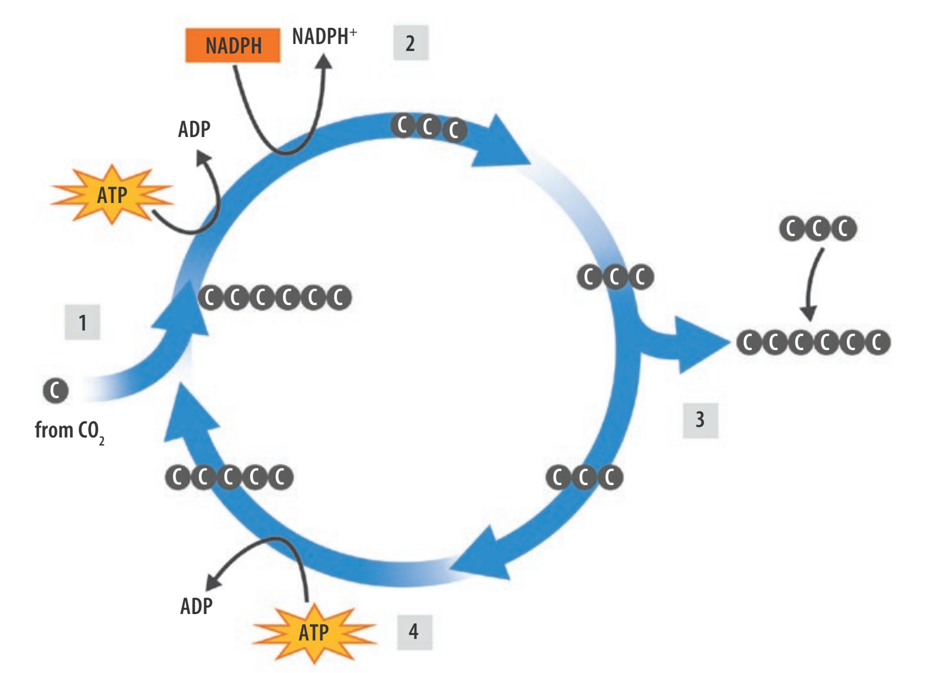
1. **Energy absorbed from sunlight**—In photosystem II, chlorophyll and other pigment molecules in the thylakoid membrane absorb energy from sunlight. The energy is transferred to electrons (e^-). These high-energy electrons leave the chlorophyll and enter the electron transport chain, a series of proteins in the thylakoid membrane.
2. **Water molecules split**—Enzymes break down water molecules. Electrons from water molecules replace the electrons that left the chlorophyll. Hydrogen ions (H^+) remain inside the thylakoid, and oxygen is released as a waste product.
3. **Hydrogen ions transported**—Energized electrons move from protein to protein in the electron transport chain. Their energy is used to pump hydrogen ions across the thylakoid membrane. The result is a buildup of hydrogen ions inside the thylakoid, establishing a concentration gradient, which is a form of stored energy. The electrons move on to photosystem I.
4. **Energy absorbed from sunlight**—In photosystem I, chlorophyll and other pigment molecules in the thylakoid membrane absorb energy from sunlight. Energized electrons leave the pigment molecules.
5. **NADPH produced**—The energized electrons from photosystem I are added to $NADP^+$ to form NADPH, an energy-carrying molecule, by an enzyme.
6. **Hydrogen ion diffusion**—Hydrogen ions diffuse out of the thylakoid through the ATP synthase protein channel. Diffusion of the hydrogen ions is powered by the concentration gradient. ATP synthase uses energy from the concentration gradient to make ATP by adding a phosphate group to ADP.

Model Make a simple flow chart to show how energy is transferred from light to ATP in the light-dependent stage of photosynthesis.

The Light-Independent Reactions

The second stage of photosynthesis uses energy from the light-dependent reactions to make sugars. As the name for this stage implies, the light-independent reactions do not need sunlight. These reactions can take place any time energy is available. The energy sources for the light-independent reactions are the molecules ATP and NADPH formed during the light-dependent reactions. This energy is needed for a series of chemical reactions called the Calvin cycle, named for the scientist Melvin Calvin, who discovered the process. The Calvin cycle is the *synthesis* part of photosynthesis. Its chemical reactions use the energy carried by the ATP and NADPH produced by the light-dependent reactions to make simple sugars.

FIGURE 11: The Light-Independent Reactions



The light-independent reactions are summarized in the steps below.

1. **Carbon dioxide added**—A CO_2 molecule is added to a 5-carbon molecule already in the cycle, yielding a 6-carbon molecule.
2. **Three-carbon molecules formed**—The 6-carbon molecule splits, forming two 3-carbon molecules. ATP and NADPH provide the energy to rearrange these 3-carbon molecules into higher-energy molecules that also have 3 carbons each.
3. **Three-carbon molecules exit**—One high-energy 3-carbon molecule leaves the cycle while the rest remain. One 6-carbon sugar molecule is formed from every two 3-carbon molecules that exit the cycle.
4. **Three-carbon molecules recycled**—Energy from ATP is used to change five 3-carbon molecules into three 5-carbon molecules, which stay in the Calvin cycle to accept new CO_2 molecules that enter the cycle.

Collaborate A common misconception is that the bulk of a plant's material comes from soil or water. Explain where the carbon in sugars actually comes from, citing evidence from the Calvin cycle to support your answer.

Explain How does the Calvin cycle act as a bridge between carbon in the atmosphere and carbon-based molecules in the food you eat?

Model Develop a model to illustrate how photosynthesis transforms light energy into chemical energy. In your model, show how energy from sunlight is transformed to energy stored in sugars, and identify the inputs and outputs for each stage of the process.

Guided Research

Variation in Photosynthesis

Not all plants carry out photosynthesis in exactly the same way. There are three different pathways of photosynthesis that depend on the carbon-based compound first produced when CO_2 enters the light-independent reactions. Recall the light-independent reactions, or Calvin cycle, use energy from ATP and NADPH to build sugars from smaller molecules. Carbon enters the Calvin cycle as CO_2 molecules, which are rearranged during chemical reactions to form sugar. Early in the process, 3-carbon molecules are formed and exit the cycle to form 6-carbon sugars. The formation of 3-carbon molecules occurs in most plants, resulting in the name C3 plants. This is one pathway in which carbon is rearranged in plants. A second pathway results in 4-carbon molecules being formed early in the Calvin cycle. These plants are called C4 plants. Finally, a third pathway takes in CO_2 and incorporates the carbon in organic acids called crassulacean acids, named after the plant types in which this process occurs. Crassulacean plants include the succulent, or water-storing plants, such as cacti.

Explain How are the three pathways of photosynthesis similar in terms of carbon and the formation of carbon-based molecules?

Nearly all land plants exchange gases through openings called stomata. Carbon dioxide enters and oxygen exits through these openings. At the same time, water that has been absorbed through the plant roots transpires, or is given off as water vapor through the open stomata. So the stomata play an important role in regulating the input of CO_2 and the output of oxygen as part of photosynthesis, as well as overall water loss.

FIGURE 12: Stomata are found on above-ground parts of plants, including the petals of flowers, stems, and leaves.

The stomata do not stay open all the time. Instead, the stomata open and close in response to homeostatic mechanisms in the plant. This helps the plant conserve water when water availability is limited. In general, plants lose water fastest during intense sunlight, especially when the temperature is warm, or when the air is dry, or in windy conditions. The variations among C3, C4, and CAM plants are mainly based on plant adaptations to different climates.

Plants can be classified by the way their photosynthetic pathways are adapted to environmental conditions. Most plants are C3 and C4 plants, which open their stomata during the day, losing most of the water taken up by their roots. But CAM plants are adapted for life in extremely hot and arid climates. These plants generally keep their stomata closed during the day to reduce the amount of water that is lost in transpiration. The stomata often are open through the night, when it is cooler and more humid. CAM plants fix CO_2 at night, avoiding water loss by not opening their stomata during the day. The CO_2 is released during the day to be used in photosynthetic reactions.

Predict How would you expect the abundance of C3 plants to change as regions around the world become warmer and drier?

FIGURE 13: Three Pathways of Photosynthesis

C3 Plants	C4 Plants	CAM Plants
		
rice, wheat, oat, soybean, cotton, most trees and lawn grasses	corn, nutgrass, and tumbleweed	succulents, cacti, bromeliads, and orchids
stomata open in daytime	stomata open in daytime	stomata open at night

Language Arts Connection Carry out further research to learn more about these variations in photosynthesis. Prepare a presentation to explain the differences between C3, C4, and CAM plants. In your presentation, include information about how each type of plant carries out photosynthesis, and how the differences help plants survive in different environments. Use text, visuals, and interactive components to make the concepts in your presentation engaging and easy to understand.

A multimedia presentation combines text, sounds, and images. A successful multimedia presentation includes:

- a clear and consistent focus
- ideas that are presented clearly and logically
- graphics, text, music, video, and sounds that support key points
- an organization that is appropriate to its purpose and audience

INVESTIGATING LIGHT SOURCES AND PHOTOSYNTHESIS | THE COLOR OF PLANTS ON OTHER PLANETS | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

As scientists and engineers plan for the next phase of space exploration—traveling to and colonizing other planets, they must devise ways of meeting the needs of humans. Today's astronauts are studying how plants grow in space. Their results will help scientists determine the best way to keep plants alive until they arrive at the new planet. The next step in this process will be to determine how plants might grow in the new planet's environment.

FIGURE 14: Growing plants in space is important not only as a long-term food source, but also as a connection to life on our home planet, Earth.

Explain Use what you have learned to further explain how plants could be grown on other planets. Address the following in your explanation:

1. What inputs do plants need to carry out photosynthesis, and how might you provide these on another planet?
2. What outputs do plants produce from photosynthesis, and how do these benefit humans?
3. How do plants transfer energy from light to sugar molecules?
4. What questions would you ask about the planet to refine your list of necessary materials?

CHECKPOINTS

Check Your Understanding

1. Which of these are the result of producers performing photosynthesis? Select all correct answers.
   a. Makes oxygen available for cellular respiration
   b. Tranfers carbon dioxide back to the atmosphere
   c. Transfers energy from sunlight to consumers
   d. Cycles carbon through the biosphere

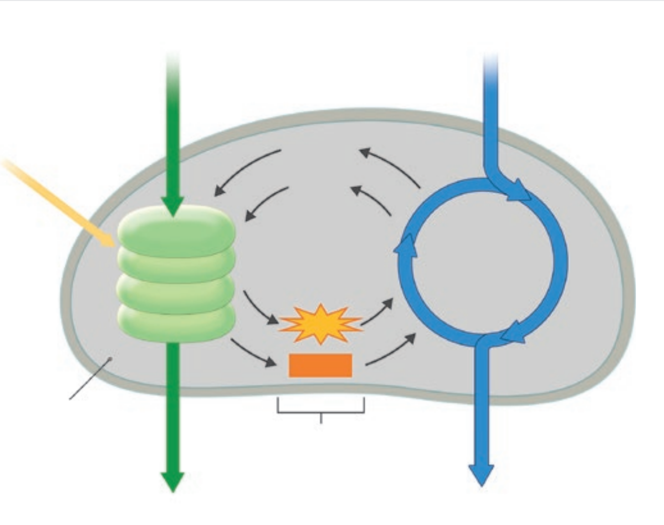
2. Write the overall chemical equation for photosynthesis. Be sure to show the relationship of light and enzymes to the reaction.

3. Use the terms below to complete this paragraph:
   NADPH, ATP, thylakoids, chlorophyll, chloroplasts, electrons

   Light energy is absorbed by __ found in the membranes of __, which are saclike structures inside __. The light energy dislodges __, which are used to make __. Energy from this process is used to make __. The electrons and energy are used to make sugars, which the plant stores or consumes for energy.

4. Draw a Venn diagram to compare chemosynthesis to photosynthesis.

FIGURE 15: The two stages of photosynthesis, light-dependent reactions and light-independent reactions, occur in the chloroplast.



5. Draw the diagram above, and add the following labels to illustrate the transfer of matter and energy in photosynthesis:
   NADPH, NADP$^+$, sugars, light, ADP, O_2, H_2O, ATP, CO_2

6. Draw a simple ecosystem made up of at least one producer and one consumer. Add arrows and labels to show how energy and matter flow from the sun to the producer and from the producer to the consumer.

7. Draw a diagram showing the interaction between light and chlorophyll. The diagram should show how this interaction results in the transfer of energy and electrons through photosystem I and photosystem II.

8. Is it true that all organisms on Earth depend on the sun as their energy source? Explain your answer.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

Photosynthesis is a process used by most producers to transform light energy into stored chemical energy.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how the models for photosynthesis you have used in this lesson can be used to explain changes in energy and matter. Explain these changes in terms of energy flow and matter cycling within and between systems.

3.2

Cellular Respiration

Cars need energy to move. A mixture of oxygen and gasoline, when ignited by a spark, produces a small, controlled explosion in the engine's cylinder that moves the axle.

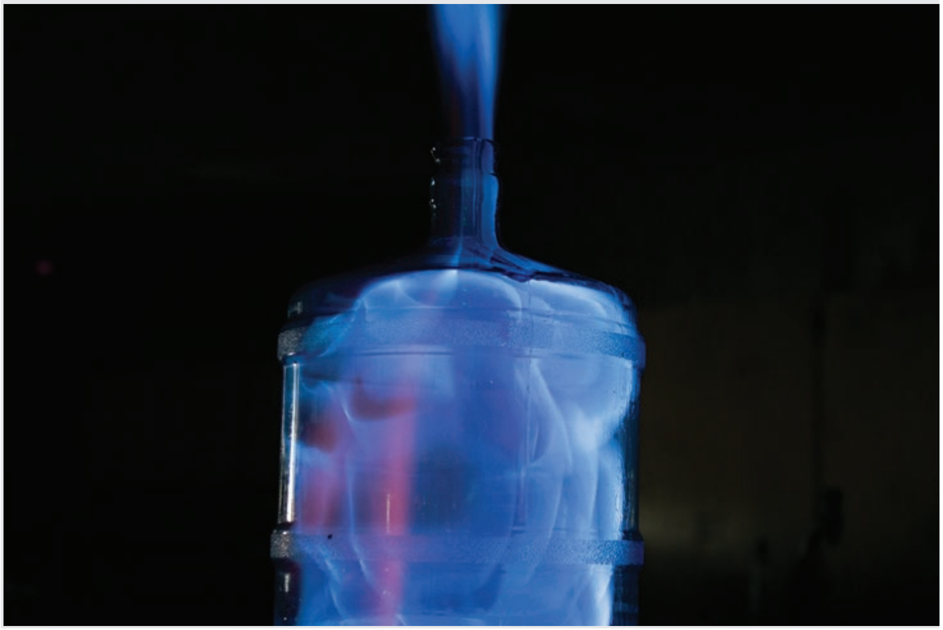
CAN YOU EXPLAIN IT?

Both cars and your body need fuel. Most cars use gasoline as a fuel, which often includes ethanol in addition to gasoline. For a car or a human body to use fuel, the energy in the chemical bonds of the fuel must be released. A combustion reaction in a car's engine releases this energy. Your body uses a similar reaction in which it releases the energy contained in the chemical bonds of the food you eat.

Gather Evidence As you explore the lesson, gather evidence that bonds are broken and new bonds are formed in the process of cellular respiration.

FIGURE 1: The ignition of a mixture of ethanol and oxygen in the air produces a combustion reaction, which releases energy in the forms of heat and light.

Explore Online



Predict How is the process of fuel combustion in a car engine similar to the way the cells in your body release energy stored in fuel?

Matter and Energy in Cellular Respiration

Fuel is any material that reacts to release energy to be used for work. Not all fuels are alike. They have many different chemical structures.

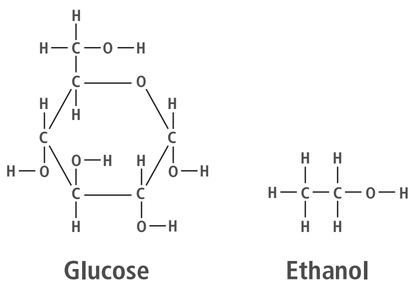


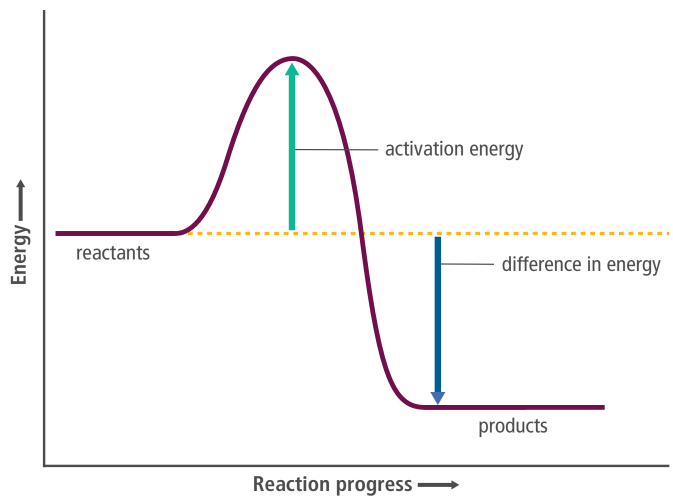
FIGURE 2: Ethanol is a fuel made from plant material, such as corn. As a renewable energy source, it helps reduce petroleum use. Glucose is a simple sugar that living things use for energy.

Analyze How are glucose and ethanol similar in structure and function? How do they differ?

Energy in Living Systems

Whether food for organisms or fuel for cars, almost all the energy on Earth has its origins in the sun. In the process of photosynthesis, plants transform light energy from the sun into chemical energy in the form of glucose. When an organism eats a plant, any energy the plant has not used can be used by the consumer.

Ancient plants and animals that died decomposed and were buried under soil, rock, and sometimes sea water. These organisms decomposed into organic materials that contain unused stored energy. Over millions of years, heat and pressure transformed these remains into the fossil fuels we use today. Chemical bonds must be broken for the stored energy to be released. In cars, a combustion reaction provides the energy needed to break these bonds and release energy. In cells, a similar process called cellular respiration releases chemical energy from sugars and other carbon-based molecules to make ATP when oxygen is present.



Exothermic Reaction

FIGURE 3: Activation energy is the energy needed to start a chemical reaction. An exothermic reaction releases more energy than it absorbs. Cellular respiration is an exothermic reaction.

Gather Evidence Explain why cellular respiration is an exothermic reaction. Cite evidence from the graph shown in Figure 3 to support your explanation.

Hands-On Lab

Cellular Respiration and Exercise

Burning fuel through either combustion or cellular respiration requires oxygen. In each process, bonds break and new bonds form. In this lab, you will use an indicator called bromothymol blue to gather evidence to support a claim about the inputs and outputs of cellular respiration. Bromothymol blue changes color in the presence of an acid.

Predict What evidence could there be to support the claim that during cellular respiration, chemical bonds are broken and new bonds are formed?

SAFETY

Do not consume any of the materials used in this lab. Be careful not to breathe in through the straw.

MATERIALS

- bromothymol blue solution
- cups or beakers (2)
- straw
- timer

PROCEDURE

1. Place the amount of bromothymol blue solution specified by your teacher in a cup or beaker.
2. Get the timer ready. Slowly blow through the straw into the bromothymol blue solution, and record how long it takes for the solution to change from blue to yellow. Be sure not to inhale when the straw is in the solution.
3. Place the amount of bromothymol blue solution specified by your teacher in a second cup or beaker.
4. Run in place for approximately one minute.
5. Get the timer ready again. Slowly blow through the straw into the bromothymol blue solution, and record how long it takes for the solution to turn yellow.

ANALYZE

The water turned acidic when you blew into it because carbon dioxide in your breath reacted with water to form carbonic acid.

1. How do your findings support the claim that bonds were broken and new bonds were formed to produce the gas you breathed out?
2. When you exercised, what was different about the time it took the solution to change color? Explain why this happened.

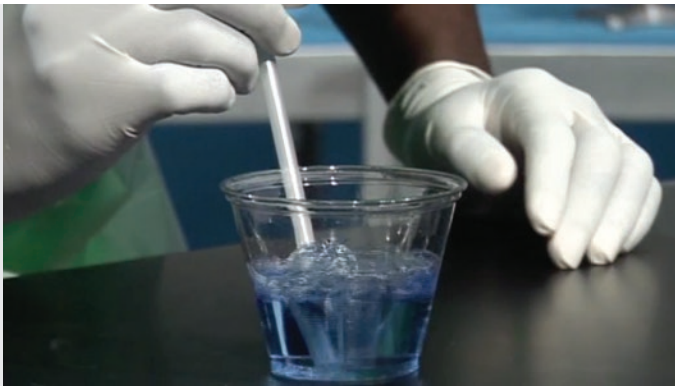


FIGURE 4: Bromothymol blue is an indicator that changes color in the presence of an acid.

The Process of Cellular Respiration

During cellular respiration, the breakdown of glucose and other carbon-based molecules releases energy stored in their chemical bonds. The stored energy is transferred to ATP, which we can think of as the cell's "energy currency." Energy in the form of heat is also released in the process. The release of heat accounts for why the body temperatures of mammals range from 36 to 39°C (97–103°F).

Cellular respiration is an aerobic process, which means that it requires oxygen to take place. Some organisms can produce small amounts of ATP through anaerobic processes, or processes that do not require oxygen. However, the presence of oxygen allows cellular respiration to produce far more ATP from each glucose molecule. The inputs and outputs of cellular respiration are shown in Figure 5.

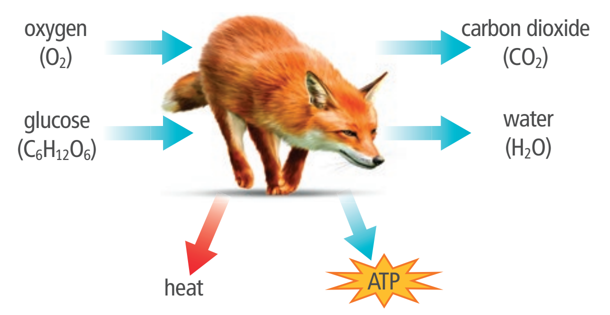


FIGURE 5: Inputs and Outputs of Cellular Respiration

Explain What is the role of the organism in this model of cellular respiration? Explain your answer.

Energy and Matter The balanced chemical equation for cellular respiration is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow \rightarrow \rightarrow 6CO_2 + 6H_2O + \text{heat} + \text{ATP}$$

1. How does this equation represent the law of conservation of matter—that matter cannot be created or destroyed?
2. How does this equation represent the law of conservation of energy—that energy cannot be created or destroyed? Consider the role of photosynthesis in your answer.

Mitochondria

Cellular respiration takes place inside an organelle called the mitochondrion (plural *mitochondria*), shown in Figure 6. Mitochondria release the chemical energy required to make ATP. Both plant and animal cells contain mitochondria, because both plants and animals carry out cellular respiration.

Collaborate With a partner, cite evidence that supports the claim that mitochondria are the "powerhouses of the cell."

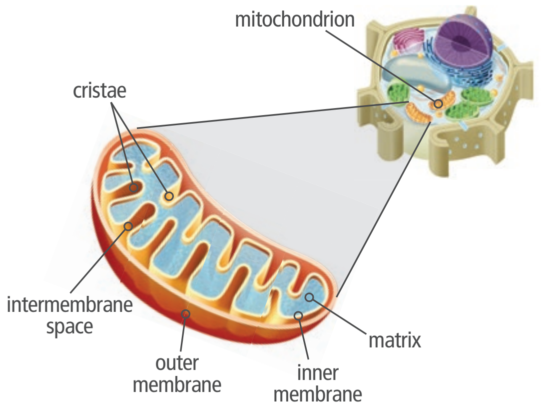


FIGURE 6: The mitochondrion has an inner membrane with many folds, called cristae. The outer membrane separates the mitochondrion from the rest of the cell. The space between the two membranes is called the intermembrane space.

Explore Online

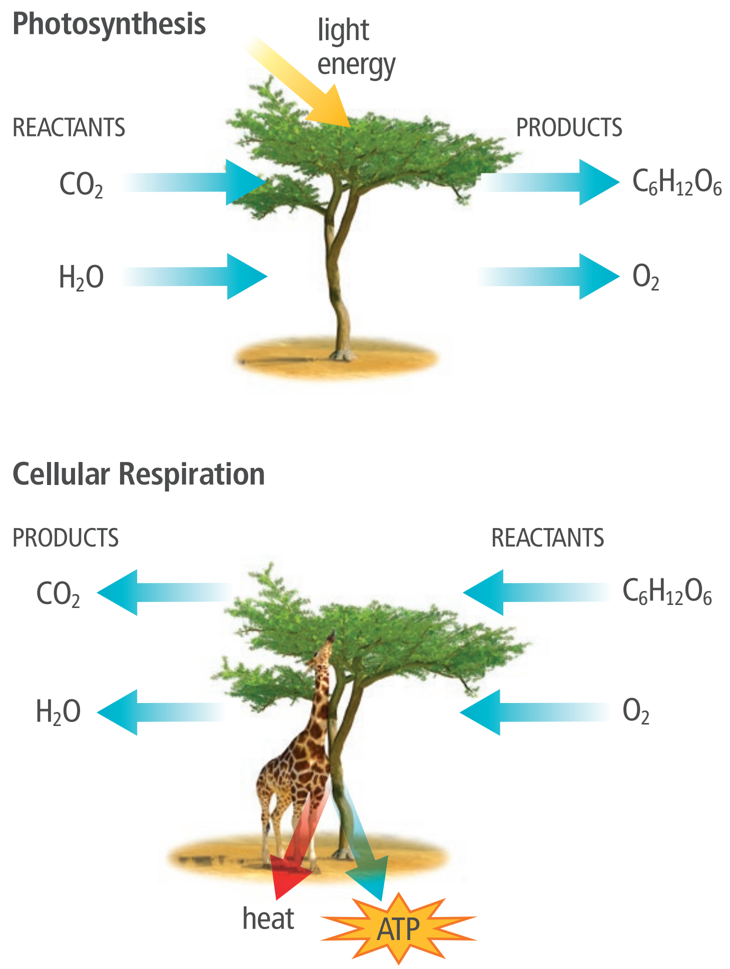
Hands-On Lab

Investigating Photosynthesis and Cellular Respiration Design an experiment to determine which organisms (pond snails or *Elodea*) produce carbon dioxide and which use carbon dioxide.

Cellular Respiration and Photosynthesis

Almost all energy for living things comes from photosynthesis, either directly or indirectly. Producers absorb light energy from the sun and transform it using photosynthesis to a usable form of energy, or food. This energy is then passed from producers to consumers. Although only producers carry out photosynthesis, both producers and consumers carry out cellular respiration. Photosynthesis stores energy from sunlight as chemical energy. In contrast, cellular respiration releases stored energy as ATP and heat.

FIGURE 7: A Comparison of Photosynthesis and Cellular Respiration



Analyze What is the relationship between the inputs and outputs of photosynthesis and cellular respiration?

Model Sort the following terms into those that occur during photosynthesis and those that occur during cellular respiration. Then place the terms in the correct order.

- absorption of sunlight
- ATP production
- production of sugars
- breakdown of sugars

Using Chemical Energy

One way that organisms maintain homeostasis is through cellular respiration, which releases energy to carry out cell processes and helps maintain body temperature. Bonds in food molecules and oxygen molecules are broken and new molecules are formed that transfer energy in forms that the organism can use. Cellular respiration transfers chemical energy stored in the bonds of glucose and other molecules to ATP.

Analyze Identify the inputs and outputs of glycolysis and the two stages of cellular respiration.

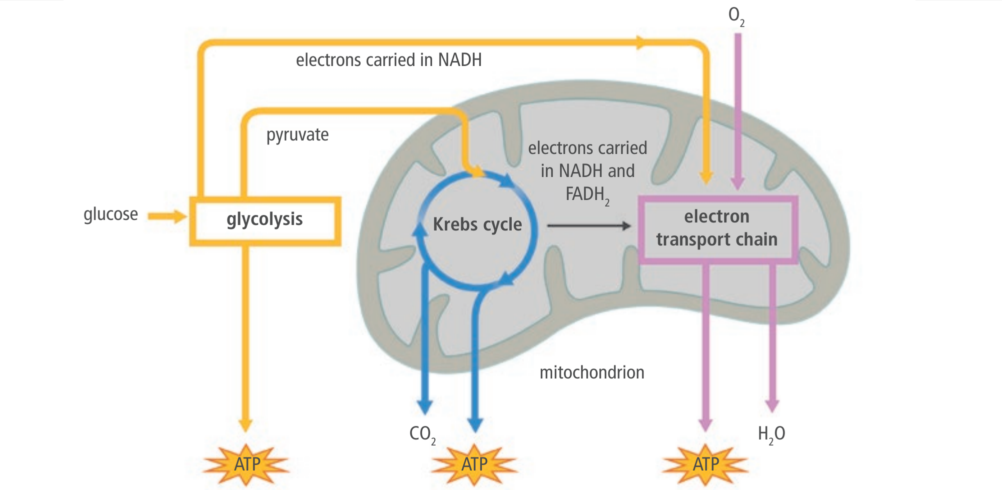
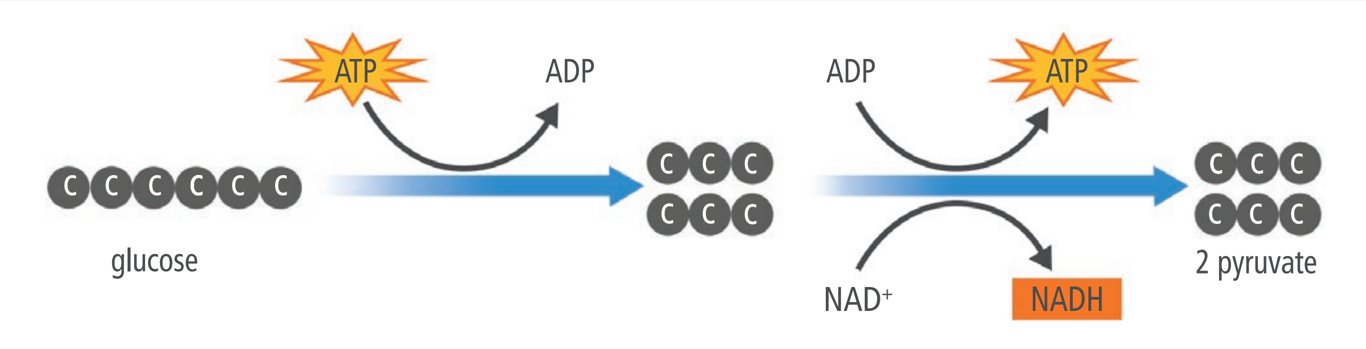


FIGURE 8: The process of glycolysis occurs before the two main stages of cellular respiration: the Krebs cycle and the electron transport chain.

Glycolysis and the Stages of Cellular Respiration

Cellular respiration occurs in mitochondria. Before it can take place, however, glucose must be broken down into compounds the mitochondria can use. This process occurs in the cytoplasm of the cell. Glycolysis, shown in Figure 9, is an anaerobic process that uses a series of enzyme-catalyzed reactions to break glucose into two three-carbon molecules, called pyruvate. Mitochondria use the pyruvate molecules to fuel cellular respiration.

FIGURE 9: Glycolysis

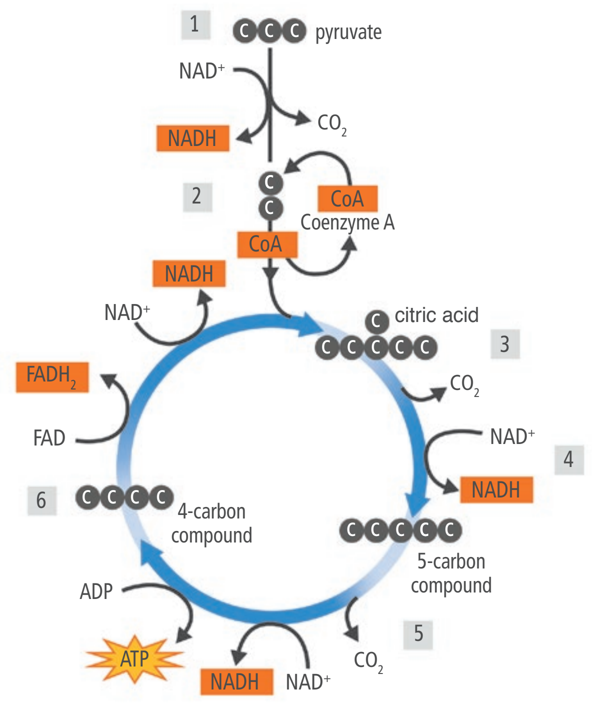


Gather Evidence Summarize evidence that bonds are broken and new bonds are formed in glycolysis.

Krebs Cycle

The Krebs cycle, sometimes called the citric acid cycle, is the first set of reactions in cellular respiration. The function of the Krebs cycle is to complete the breakdown of glucose started in glycolysis and fuel the production of ATP. This is done by transferring high-energy electrons to the electron transport chain.

FIGURE 10: The Krebs Cycle



The Krebs cycle is summarized in the steps below.

1. **Pyruvate is broken down** A 3-carbon pyruvate molecule is split into a 2-carbon molecule and a carbon dioxide molecule, which is given off as waste. High-energy electrons are transferred to NAD^+, forming a molecule of NADH. The NADH moves to the second stage of cellular respiration, the electron transport chain.
2. **Coenzyme A is added** A molecule called coenzyme A bonds to the 2-carbon molecule, forming an intermediate molecule.
3. **Citric acid is formed** The 2-carbon part of the intermediate molecule is added to a 4-carbon molecule to form the 6-carbon molecule called citric acid.
4. **Citric acid is broken down** The citric acid molecule is broken down by an enzyme, and a 5-carbon molecule is formed. A molecule of NADH is made, which moves out of the Krebs cycle. A molecule of carbon dioxide is given off as a waste product.
5. **Five-carbon molecule is broken down** The 5-carbon molecule is broken down by an enzyme. A 4-carbon molecule, a molecule of NADH, and one ATP are formed. Carbon dioxide is given off as a waste product.
6. **Four-carbon molecule is rearranged** Enzymes rearrange the 4-carbon molecule, releasing high-energy electrons. Molecules of NADH and $FADH_2$, another electron carrier, are made. They leave the Krebs cycle, and the 4-carbon molecule remains.

Analyze How is the Krebs cycle a bridge between the energy in sugars and energy-carrying molecules?

Explain During the hands-on lab, which product of the Krebs cycle caused the bromothymol blue solution to change color?

The Krebs cycle is a continual series of reactions. All the carbon atoms in glucose eventually end up as carbon dioxide, a waste product expelled from the cell. The role of the electron carriers NADH and $FADH_2$ is to transfer electrons to the electron transport chain in the next stage of respiration. The transferred electrons will fuel the formation of ATP.

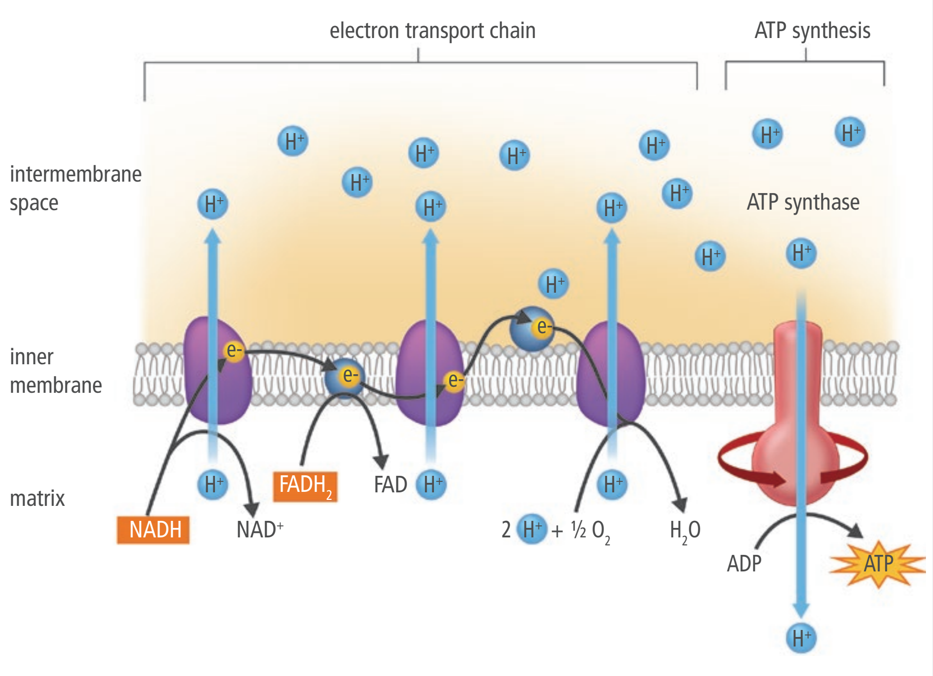
The Electron Transport Chain

The second stage of cellular respiration, the electron transport chain, uses proteins embedded in the inner membrane of the mitochondrion. It is similar to the electron transport chain stage of photosynthesis. The energy carried by the NADH and $FADH_2$ molecules produced in the Krebs cycle is used to make ATP. A number of enzymes are involved in this process.

Model Make a simple flow chart to summarize the energy transfer from energy-carrying molecules to ATP.

FIGURE 11: The Electron Transport Chain

Explore Online



The electron transport chain is summarized in the steps below.

1. **Electrons are transferred** Proteins inside the inner membrane of the mitochondrion take high-energy electrons from NADH and $FADH_2$.
2. **Hydrogen ions are transported** High-energy electrons travel from protein to protein in the electron transport chain. The proteins use energy from the electrons to pump hydrogen ions across the inner membrane to produce a gradient, just as in photosynthesis. The hydrogen ions build up in the intermembrane space.
3. **ATP is produced** Like in photosynthesis, the flow of hydrogen ions is used to make ATP. Hydrogen ions diffuse through a protein channel in the inner membrane of the mitochondrion. The channel is part of the ATP synthase enzyme. ATP synthase adds phosphate groups to ADP to make ATP molecules.
4. **Water is formed** Oxygen picks up electrons and hydrogen ions to form water. The water molecules are given off as a waste product.

Together, glycolysis and cellular respiration produce up to 38 ATP molecules for every glucose molecule.

Collaborate With a partner, discuss how the electron transport chain depends on the Krebs cycle. Consider the role of energy in your discussion.

Fermentation

The cells in your body cannot store large amounts of oxygen for cellular respiration. The amount of oxygen that is provided by breathing is enough for your cells during normal activities. When you are doing high levels of activity, such as playing a game of basketball as shown in Figure 12, your body cannot bring in enough oxygen for your cells, even though you breathe faster. How do your cells function without oxygen to keep cellular respiration going?

The production of ATP without oxygen continues through the anaerobic processes of glycolysis and fermentation. Fermentation does not make ATP, but it allows glycolysis to continue. Fermentation removes electrons from NADH molecules and recycles NAD^+ molecules for glycolysis. Why is this process important? Because glycolysis, just like cellular respiration, needs a molecule that picks up electrons. It needs molecules of NAD^+.

The role of fermentation is simply to provide the process of glycolysis with a steady supply of NAD^+. If you've ever felt your muscles "burn" during hard exercise, that is a result of fermentation. Lactic acid is a waste product of fermentation that builds up in muscle cells and causes that burning feeling. Once oxygen is available again, your cells return to using cellular respiration. The lactic acid is quickly broken down and removed from the cells.

Analyze What is the role of anaerobic respiration in organisms? What is the role in ecosystems?

FIGURE 12: During strenuous or prolonged activity, athletes may not be able to sustain the oxygen levels their bodies need. If not enough oxygen is supplied to the cells, anaerobic respiration takes over.

FIGURE 13: Bifidobacteria live in the digestive tracts of animals, including humans.

Not all organisms rely on oxygen for respiration. Organisms that use anaerobic respiration have an important role in an ecosystem, because they can live in places where most other organisms cannot. For example, microorganisms, such as the bifidobacteria shown in Figure 13, live in the digestive tracts of animals and help in the process of digestion. They must get their ATP from anaerobic processes because oxygen is not available.

Explain Summarize the evidence that you have gathered to explain how molecules are rearranged and energy is transferred in the process of cellular respiration.

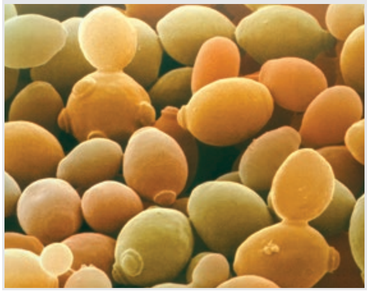
1. Cite evidence to support the claim that bonds are broken and new bonds are formed in each stage of cellular respiration.
2. Explain how energy is transferred from the bonds of food molecules to cellular processes.

Hands-On Lab

Aerobic and Anaerobic Processes in Yeast

The species used in this investigation, *Saccharomyces cerevisiae,* like other species of yeast, is a facultative anaerobe. It can break down sugars using either aerobic or anaerobic processes, depending on the presence of oxygen. When oxygen is not present, yeast carry out ethanol fermentation. This process produces carbon dioxide and ethanol, a type of alcohol.

FIGURE 14: Yeast are single-celled organisms that belong to the group of organisms called fungi.



Predict How will you know whether aerobic or anaerobic processes are occurring in the bottle?

SAFETY

Obtain and wear goggles for this lab. Do not eat any materials used in this lab.

MATERIALS

- active dry yeast (1 package)
- balance (optional)
- balloon, round
- funnel
- graduated cylinder
- marker
- ruler, metric
- string, 30 cm
- sugar, granulated
- tablespoon (optional)
- timer
- water, very warm (40°C)
- water bottle, plastic, 500 mL
- weighing boat (optional)

PROCEDURE

1. Blow up the balloon a few times to stretch it.
2. Using the funnel, pour 150 mL of warm water into the bottle. Dry the funnel.
3. Using the dry funnel, add 1 packet of yeast to the water. Swirl the mixture gently.
4. Using the funnel, add 1 tablespoon (12 g) of sugar to the yeast solution, swirl, and quickly cover the bottle with the balloon. Allow the mixture to react for 5 minutes.
5. After 5 minutes have passed, use the string, marker, and ruler to measure the circumference of the balloon.
6. In a data table, record the circumference of the balloon, along with all of your observations of what is happening in the bottle. Continue making and recording observations every 5 minutes for the next 30 minutes.
7. Dispose of waste according to your teacher's instructions.

ANALYZE

1. Describe evidence, if any, that aerobic respiration took place in the bottle.
2. How does matter cycle during aerobic respiration? Explain how the reactants are rearranged to form the products. What is the source of energy, how is the energy transferred, and how is it used in the cell?
3. Describe evidence, if any, that fermentation took place in the bottle.
4. How does matter cycle during fermentation? Explain how the reactants are rearranged to form the products. What is the source of energy, how is the energy transferred, and how is it used in the cell?

EVIDENCE FOR ENDOSYMBIOSIS | INVESTIGATING PHOTOSYNTHESIS AND CELLULAR RESPIRATION | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

Explore Online

FIGURE 15: Because ethanol burns more cleanly than gasoline, it is added to gasoline to help reduce the emission of greenhouse gases produced by combustion engines in cars. Like gasoline, ethanol contains energy in its chemical bonds that can be released by the process of combustion.

Combustion and cellular respiration are both exothermic reactions that result in the release of energy. The energy is released when chemical bonds that store energy are broken. Combustion is a fast process that results in the production of energy in the forms of heat and light.

$$CH_3CH_2OH + O_2 \rightarrow \rightarrow \rightarrow 2CO_2 + 3H_2O + \text{heat}$$

In contrast, cellular respiration is a slow process, with energy being released over a series of several steps. This makes energy available for use whenever cells of the body need it to carry out cellular activities.

$$C_6H_{12}O_6 + 6O_2 \rightarrow \rightarrow \rightarrow 6CO_2 + 6H_2O + \text{heat} + \text{ATP}$$

Explain A scientist named Antoine Lavoisier demonstrated that cellular respiration is a combustion process. Recall that car engines use a combustion reaction to release energy. Construct an explanation for how the breakdown of fuel in a car engine compares to the breakdown of fuel in your body's cells. Answer the following questions:

1. Look carefully at the equations for both combustion and cellular respiration, and compare the inputs and outputs. How can the different inputs result in the same outputs based on what you know about chemical bonds and atoms?
2. What is missing from the process of combustion that makes it an imperfect model for cellular respiration? Explain your answer.

CHECKPOINTS

Check Your Understanding

1. How does carbon flow between photosynthesis and cellular respiration?
   a. Photosynthesis produces carbon dioxide from glucose generated by the process of cellular respiration.
   b. Cellular respiration produces carbon dioxide from glucose generated by the process of photosynthesis.
   c. Photosynthesis produces carbon dioxide from ATP generated by the process of cellular respiration.
   d. Cellular respiration produces carbon dioxide from ATP generated by the process of photosynthesis.

2. Which of the following are the main inputs, or reactants, in cellular respiration? Select all correct answers.
   a. pyruvate
   b. glucose
   c. carbon dioxide
   d. oxygen

3. Which of the following are the main outputs, or products, of cellular respiration? Select all correct answers.
   a. water
   b. energy
   c. oxygen
   d. carbon dioxide

4. Before cellular respiration, glucose must be broken down by the process of
   a. photosynthesis.
   b. glycolysis.
   c. electron transport.
   d. fermentation.

5. During which process is lactic acid formed when there is not enough oxygen present for cellular respiration to take place?
   a. fermentation
   b. glycolysis
   c. Calvin cycle
   d. Krebs cycle

6. Use the following terms to complete the statement: *ATP, cellular respiration, electron transport chain, glycolysis, Krebs cycle, photosynthesis*

   Living things require energy to grow and reproduce and to carry out different cell processes. Certain cells can capture energy from the sun through the process of ___________. Through a series of reactions, that energy is transferred to organisms. Through the process of ___________, the energy currency of the cell, ___________, is produced. This is a three-part process, beginning with ___________ in the cell cytoplasm and proceeding within the mitochondrion with the ___________ and, finally, the ___________.

7. How do you know that energy and matter are conserved during the process of cellular respiration? Explain.

8. Energy is transferred in several different ways during the process of cellular respiration. Give two examples of ways that energy is transferred during this process.

9. Is oxygen necessary for the production of ATP in your cells? Why or why not?

10. How are photosynthesis and cellular respiration related?

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

Cellular respiration is a process that breaks down food molecules to release energy to fuel cellular processes in organisms.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how molecules are rearranged and energy is transferred during the process of cellular respiration.

3.3

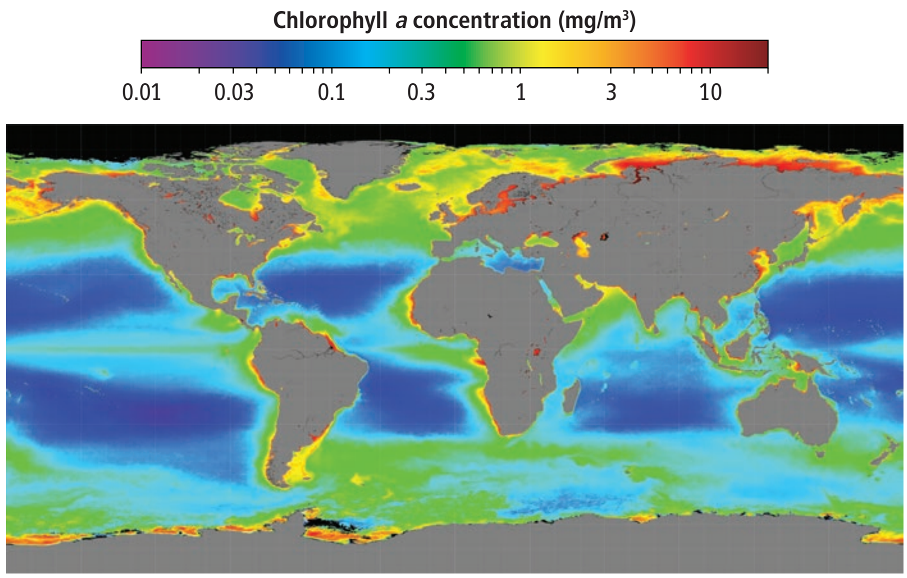
Modeling Matter and Energy in Ecosystems

This green sea turtle takes in energy and matter by eating sea grass.

CAN YOU EXPLAIN IT?

Phytoplankton are single-celled organisms that live in aquatic environments. Many species of marine animals feed on phytoplankton as their main food source. Phytoplankton are producers that use chlorophyll to carry out photosynthesis. Figure 1 shows a global map of the concentration of chlorophyll in the ocean. Greater chlorophyll concentrations correlate to larger populations of phytoplankton.

FIGURE 1: Global Concentration of Chlorophyll *a*



Gather Evidence As you explore the lesson, gather evidence to explain how energy and matter flow through ecosystems.

Phytoplankton produce nearly half of all oxygen in the atmosphere and use a large amount of carbon dioxide during photosynthesis. Scientists have discovered that the global population of phytoplankton has been decreasing.

Predict How might a decrease in the phytoplankton population affect the global flow of energy and matter?

Introduction to Ecosystems

As its name suggests, an ecosystem is a system—it has boundaries, components, inputs, and outputs. Every living thing requires specific resources and conditions. The gray fox shown in Figure 2 requires certain types of food, shelter, temperatures, and other factors to survive. Gray foxes live in dens located in underground burrows, under rock crevices, or in caves. They eat plants, insects, and small mammals, such as mice and rabbits. Many types of internal and external parasites live on and in gray foxes, including ticks and tapeworms. Coyotes prey upon gray foxes, but the foxes can climb trees to escape.

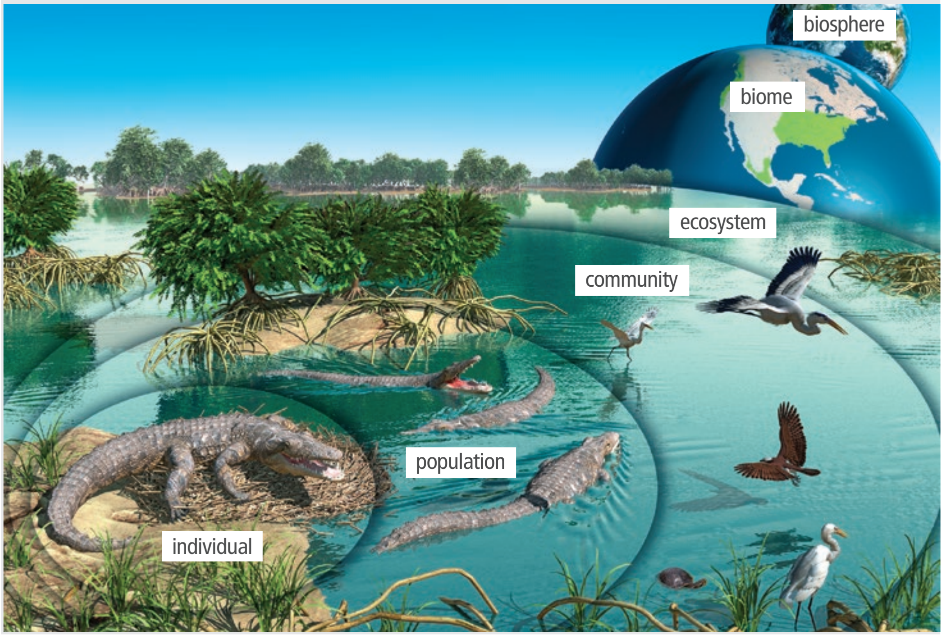
FIGURE 2: A gray fox emerges from its den.

Analyze What types of living and nonliving things does a gray fox's ecosystem include?

Ecosystem Structure

The Florida Everglades, illustrated in Figure 3, is an example of a complex ecosystem that can be difficult to study as a whole. To understand the complicated relationships that make up ecosystems, scientists break them down into smaller parts.

FIGURE 3: The Florida Everglades is an aquatic ecosystem that is found in the temperate deciduous forest biome.



Ecologists can study ecosystems at different scales. They may study an individual alligator to learn more about factors that affect that species. They may also study an entire population of alligators. A population is a group of the same species that lives in the same area. Multiple populations of different species form a community. In the Everglades, an ecologist may study how a community of alligators, turtles, and birds in a certain area Interacts with one another.

Language Arts Connection Before they were listed as an endangered species, alligators in the Florida Everglades were hunted to near extinction. Use library and Internet resources to find information and write a report about how human activities have affected organisms, populations, and communities in the Florida Everglades ecosystem.

An ecosystem includes all of the biotic, or living, and abiotic, or nonliving, components in a given area. Energy and matter cycle through these various components during processes such as photosynthesis, cellular respiration, and decomposition. Similar to other systems, an ecosystem also has feedback mechanisms that keep it in equilibrium and restore it to a balanced state when equilibrium is disrupted.

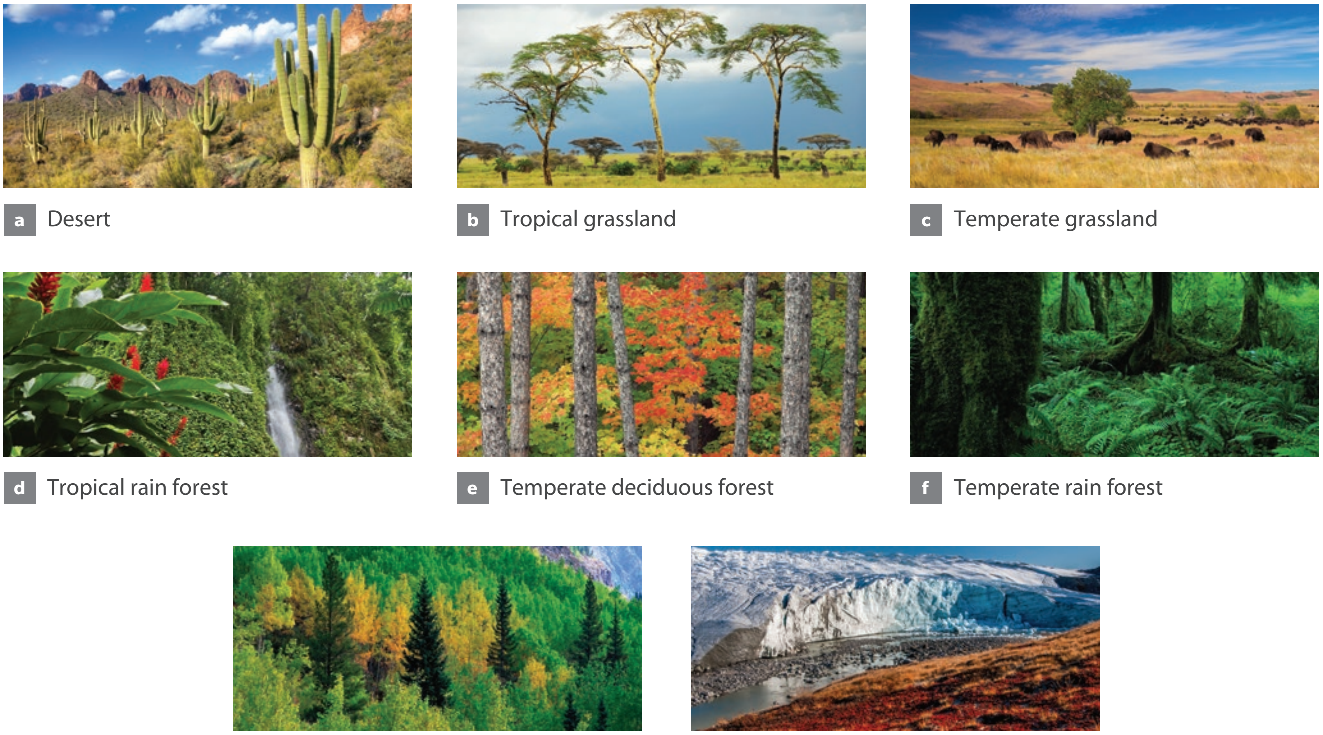
Explain What biotic and abiotic components are found in the ecosystem where you live, and how do they interact?

Biomes and Biodiversity

A biome is a major regional or global distribution of organisms adapted to living in that particular environment. Many different ecosystems make up a biome, and changes in one ecosystem may significantly affect the entire biome. At the largest scale, all life on Earth is part of the biosphere.

Biodiversity is a measure of the number of different species found within a specific area. An area with a high level of biodiversity, such as a tropical rain forest, has a large assortment of species living near one another. The amount of biodiversity found in an area depends on many factors, including moisture and temperature. The complex relationships in ecosystems mean that a change in one biotic or abiotic component can have many effects, both small and large, on a number of different species.

FIGURE 4: World Biomes



a Desert

b Tropical grassland

c Temperate grassland

d Tropical rain forest

e Temperate deciduous forest

f Temperate rain forest

g Taiga

h Tundra

There are many different types of biomes. Scientists categorize biomes in several ways, such as by the climate conditions and plant communities that thrive in them. This makes each biome's biodiversity different and unique. For the most part, the plants and animals that live in one biome are not found in any other biome. Although biomes can be categorized separately, they are still connected. Each of these broad biome types can be further divided into more specific zones. For example, a prairie is a type of temperate grassland. Frozen polar ice caps and high, snow- and ice-covered mountain peaks are not considered biomes because they lack specific plant communities.

Model Using your knowledge of photosynthesis, cellular respiration, and ecosystem structure, model how cutting down a tropical rain forest will affect surrounding biomes. Consider how the loss of the rain forest will affect the rate of photosynthesis in the area and how habitat loss will affect the rate of cellular respiration by animals in the forest. Then, model how the change in amounts of CO_2 and O_2 could affect surrounding ecosystems. What other ways might ecosystems be affected by such a loss?

Not all ecosystems are terrestrial, or land-based. About 71 percent of Earth's surface is covered with water, and it, too, is home to animal and plant life. These water-based ecosystems are called *aquatic ecosystems*. There are two main categories of aquatic ecosystems: salt water, or marine, and freshwater.

Collaborate Biodiversity tends to decrease the farther an ecosystem is located from the equator. Discuss this pattern of biodiversity in terms of different biomes and climate characteristics.

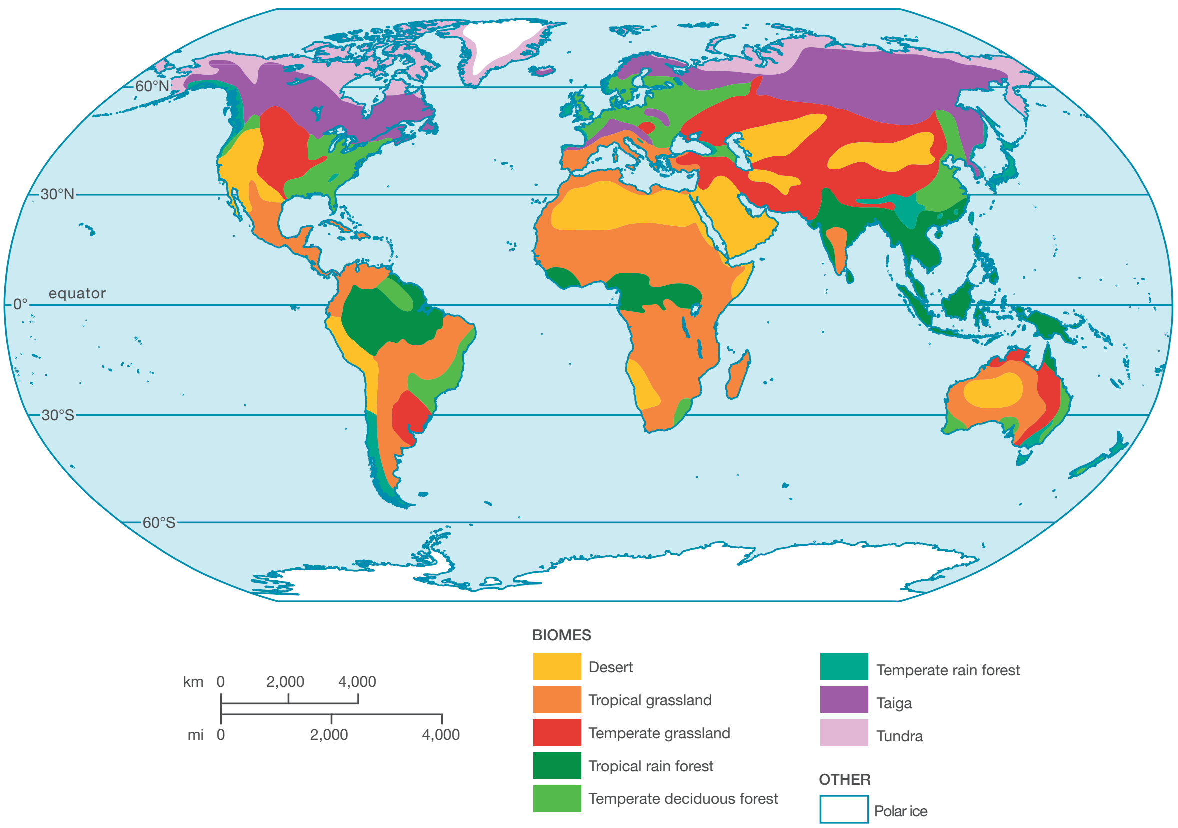
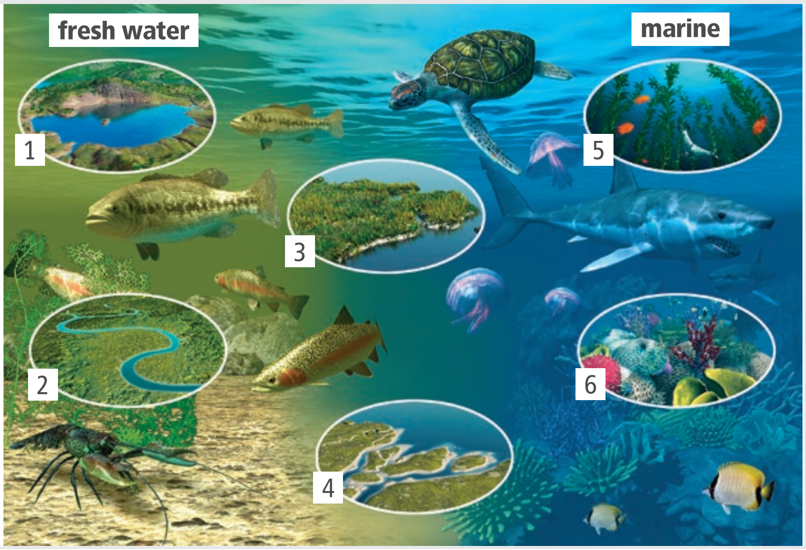


FIGURE 5: Like terrestrial ecosystems, aquatic ecosystems vary widely in size, location, and abiotic and biotic components.

1 lakes and ponds
2 rivers
3 wetlands
4 estuaries
5 kelp forests
6 coral reefs



Some types of aquatic ecosystems are shown in Figure 5. Marine ecosystems include the open ocean, coral reefs, kelp forests, and estuaries. Oceans spread from coastal shallows to the great depths of deep-sea vents. Most coral reefs grow within tropical zones. Kelp forests exist in cold, nutrient-rich waters. Estuaries occur where freshwater and salt water mix together.

Analyze How could rising ocean temperatures affect coral reef ecosystems?

Freshwater ecosystems include rivers, streams, lakes, ponds, and wetlands. Rivers and streams are flowing freshwater, while lakes and ponds are standing bodies of water. Wetlands are land that is saturated by surface water for at least part of the year.

Each of these ecosystems has unique groups of plants and animals that inhabit them. The plants and animals that live in these ecosystems are often highly specialized. Remember that aquatic plants utilize photosynthesis to convert sunlight into usable energy. They can only grow to water depths where sunlight can penetrate.

Cause and Effect

FIGURE 6: Discarded plastics pollute Bicaz Lake in Romania.

Analyzing Human Impacts

Human activities impact ecosystems, sometimes in severe ways. We produce wastes, such as plastics, that are a major source of pollution. Humans destroy habitats to build cities, grow crops, and mine resources. Most of these activities impair the air, water, soil, and biodiversity in ecosystems. How do you impact your ecosystem?

Explain Describe how changing a biotic or abiotic factor can influence an entire biome. Could changing biotic or abiotic factors be responsible for the decrease in phytoplankton populations introduced at the beginning of this lesson? Explain.

Energy and Matter Flow in Ecosystems

All organisms need a source of energy to survive. Energy is essential for metabolism, which is all of the chemical processes that build up or break down materials in an organism's body.

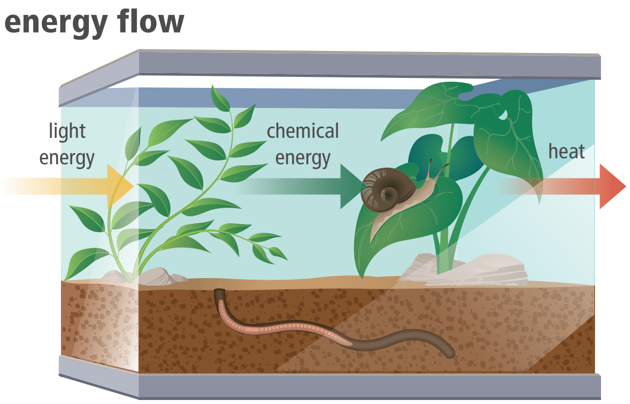
FIGURE 7: Tropical rain forest.

Predict Describe two ways that energy and matter flow in the tropical rain forest ecosystem shown in Figure 7.

Energy in Ecosystems

A terrarium, as shown in Figure 8, is a simple way to model the flow of energy in an ecosystem. Life in an ecosystem requires an input of energy. The law of conservation of energy states that energy cannot be created or destroyed. Energy changes form as it flows within an ecosystem, but the amount of energy does not change.

FIGURE 8: Energy changes form as it flows through an ecosystem.



Explain How does energy flow in this terrarium in terms of photosynthesis and cellular respiration?

Energy and Matter

Explore Online

Energy and Matter Flow Through Organisms

The kingfisher and the fish shown in Figure 9 are components of an ecosystem. Each organism has a role in the transfer of energy and matter within that ecosystem. In addition to the kingfisher and the fish, plants, soil, and temperature also affect the flow of energy and matter. As in a terrarium, energy and matter change form as they cycle through this ecosystem, but they are not destroyed.

FIGURE 9: A kingfisher dives underwater to catch a fish.

Model What is the relationship between energy and matter in the kingfisher? Make a model that shows how matter and energy cycle through this ecosystem.

An ecosystem is a complex web of interconnected biotic and abiotic components. Changing one component in an ecosystem can affect many others. Imagine what would happen if a chemical spill occurred at the lake the kingfisher depended upon as a source of food. If the spill killed all the plants, this change would affect the insects that ate the plants, the fish that ate the insects, and the kingfisher that ate the fish. Thus one change can destabilize an entire ecosystem.

As part of the ecosystem, humans, like other species, rely on their environment for survival. If residents of a local town also eat fish from this ecosystem, these changes will negatively impact them. All species are affected by changes to the biotic and abiotic factors in an ecosystem.

Food Chains

Feeding relationships are a major component of the structure and dynamics of an ecosystem. Food chains and food webs are useful ways to model the complex structure of an ecosystem to better understand how energy is transferred between organisms. The simplest way to look at the transfer of food energy in an ecosystem is through a food chain, as shown in Figure 10. A food chain is a sequence that links species by their feeding relationships. This simple model follows the connection between one producer and a single chain of consumers within an ecosystem.

FIGURE 10: Food chains help scientists understand the transfer of energy in an ecosystem.

a Producer | b Herbivore | c Carnivore

Predict What might happen in an ecosystem if all the decomposers were suddenly removed?

Not all consumers are alike. Herbivores, such as desert cottontails, are organisms that eat only plants. Carnivores are organisms that eat only animals. Western diamondback rattlesnakes are carnivores that eat desert cottontails. Omnivores are organisms that eat both plants and animals. In a desert ecosystem, kangaroo rats are omnivores that eat both seeds and insects. Detritivores are organisms that eat detritus, or dead organic matter. Earthworms are detritivores that feed on decaying organic matter in soil.

Decomposers are organisms that break down organic matter into simpler compounds. These organisms include fungi, certain microbes in the soil, and earthworms. Decomposers are important to the stability of an ecosystem because they return vital nutrients back into the environment for other organisms to use.

FIGURE 11: Decomposers break down dead organic matter, including plants and animals.

Model Draw a food chain that includes organisms in the area where you live. Identify the producer and consumers, and describe the flow of energy in the food chain.

Trophic Levels

Trophic levels, shown in Figure 12, are the levels of nourishment in a food chain. The first trophic level is occupied by the producer. The second level is occupied by the primary consumer, usually an herbivore. The third and fourth levels contain secondary and tertiary consumers, and so on, which can be omnivores or carnivores.

FIGURE 12: Each organism in a food chain occupies a different trophic level.

a Producer | b Primary consumer | c Secondary consumer | d Tertiary consumer

Explain Does energy transfer completely from one trophic level to another? Use evidence from this lesson to support your answer.

Energy flows up the food chain from the bottom trophic level to the top. Food chains are limited in length because energy is lost as heat at each trophic level. Organisms use the remaining energy to carry out life functions such as cellular respiration and growth. In this way, less and less energy is available for the next organism in the chain. Eventually, there is not enough energy to support another trophic level.

Collaborate Think about a typical meal you eat. With a partner, discuss what trophic level you occupy within that food chain.

Data Analysis

Population Size

A scientist sampled a small cross section of a grassland ecosystem. Her data for each trophic level are shown in the table.

Trophic Level	Producers	Primary Consumers	Secondary Consumers	Tertiary Consumers
Population Count	6,025,682	723,082	98,541	4

Analyze Answer the following questions in your Evidence Notebook:

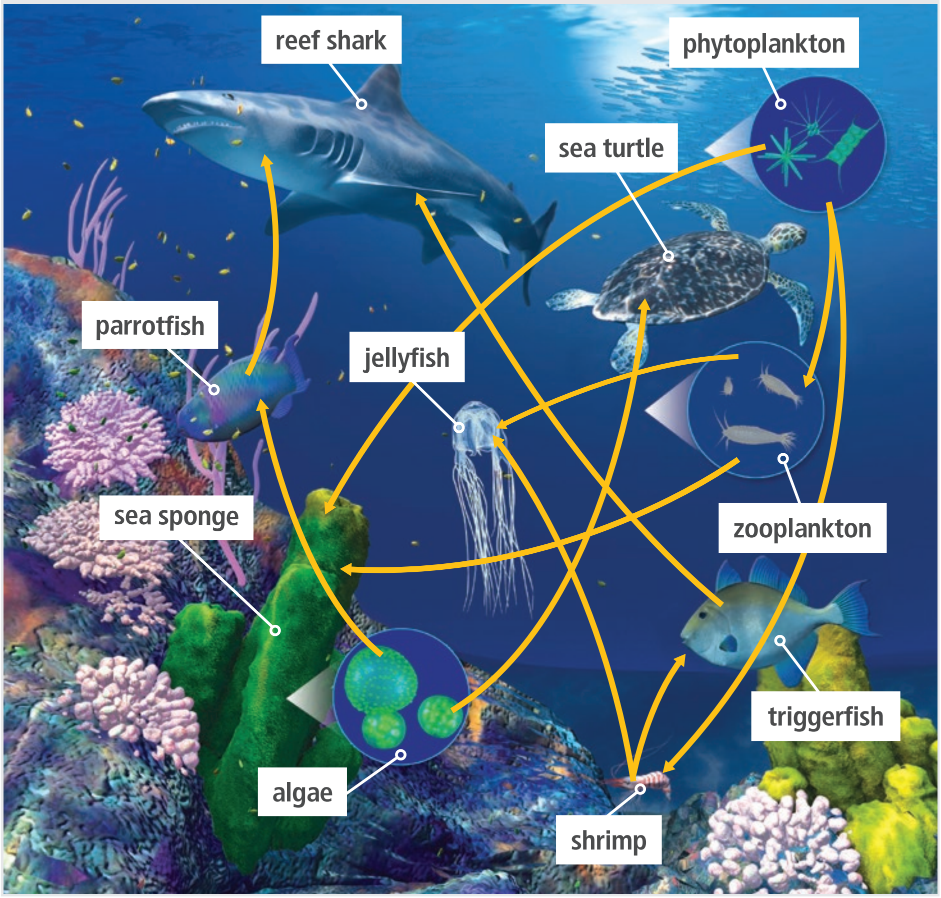
1. How does the population size change at each trophic level in this sample?
2. What is the relationship between trophic level and population size?
3. Predict what would happen if a quaternary consumer were added to this ecosystem.

Food Webs

Food chains are not isolated units but are linked together in food webs. Each organism in an ecosystem may feed on or be eaten by several other organisms and may be part of many different food chains.

Gather Evidence How would the food web be affected if the triggerfish were removed from the ecosystem? What about the algae?

FIGURE 13: A food web is made up of several different food chains.



Model Expand the food chain of the area where you live to make a food web.

A food web models the complex network of feeding relationships between trophic levels within an ecosystem. A food web represents the flow of energy within and sometimes beyond the ecosystem. The stability of any food web depends on the presence of producers, as they form the base of the food web. In the case of a marine ecosystem such as a coral reef, algae and phytoplankton are two of the producers that play this important role.

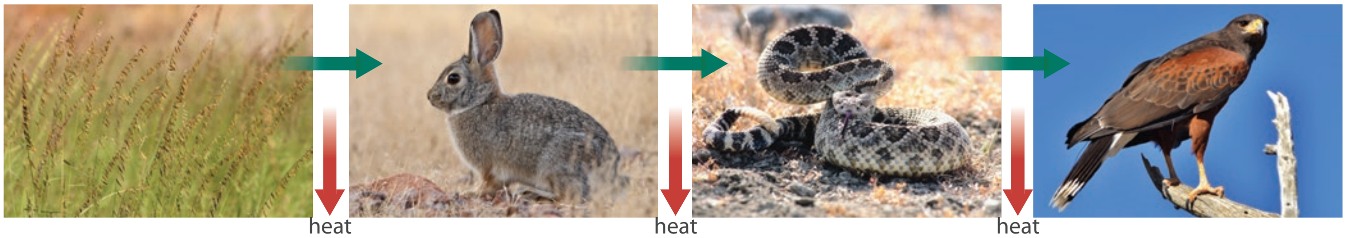
Explain Use the evidence you have gathered in this lesson to answer the following questions:

1. Scientists use both food chains and food webs to model energy and matter transfer in an ecosystem. Describe the pros and cons of using a food chain or a food web.
2. In the phytoplankton example from the beginning of the lesson, how will the decrease in phytoplankton affect the ecosystem's food web?

Energy and Matter Distribution in Ecosystems

Ecosystems get their energy from sunlight. Producers use energy from sunlight to make food. Herbivores eat the plants but burn some energy in the process. The energy is given off as heat, which escapes into space. Carnivores then eat the herbivores but again, a portion of the energy is converted to heat, leaving it unavailable for use by the organism. Each level in the food chain obtains much less energy than the level below it. Fortunately, the sun provides a constant flow of energy into the system and allows life to continue.

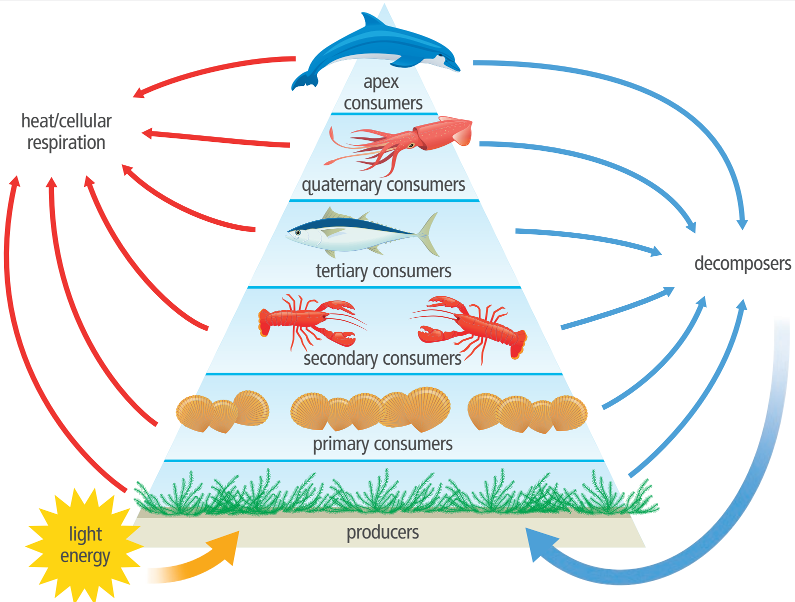
FIGURE 14: Energy and matter transfer between trophic levels, but some energy is lost as heat.



Reduction of Available Energy

When a consumer eats food, the energy it contains undergoes a transformation. Some energy is used for cellular respiration, which provides energy for movement and maintenance of the organism. Some is converted to new biomass, or growth. Of the remaining energy, some is released to the environment as heat, and the rest is excreted as waste, as illustrated in Figure 15. Although energy changes to different forms in this process, the total amount of energy remains unchanged or is conserved.

FIGURE 15: As trophic level increases, the amount of available energy is reduced because some is converted to heat or excreted as waste.



Analyze How does the amount of energy at each trophic level compare? Use evidence to support your reasoning.

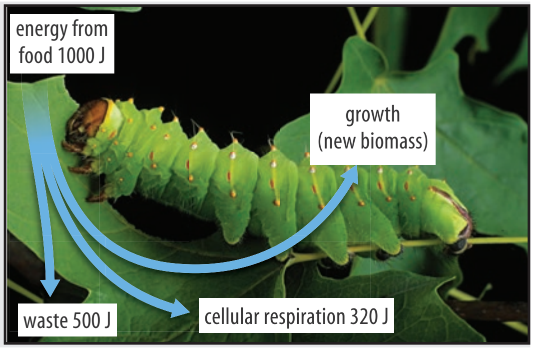
Data Analysis

Energy Calculations

SAMPLE PROBLEM

Energy can be measured using calories (cal), kilocalories (kcal), and joules (J). A caterpillar consumes 1000 J of energy from the plant it eats. However, the caterpillar cannot digest all the plant matter, so 500 J of energy are lost as bodily waste. Additionally, 320 J of energy are converted to heat or used for metabolism. What percentage of energy remains for the caterpillar to use for biomass, or growth?

FIGURE 16: A large amount of the energy a caterpillar consumes is converted to heat via cellular respiration or excreted as waste.



ANALYZE

To determine the amount of energy left for the caterpillar to use, subtract the amount converted to heat and excreted as waste from the total amount consumed:

$$1000\text{ J} - 500\text{ J} - 320\text{ J} = 180\text{ J}$$

The caterpillar has 180 J left over to convert into biomass.

SOLVE

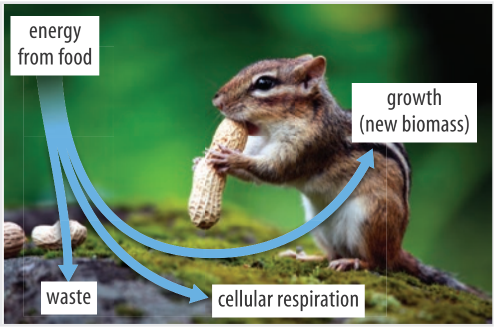
To determine the percentage of energy that is usable, divide the amount of available energy by the total amount of energy and multiply by 100 percent:

$$\frac{180\text{ J}}{1000\text{ J}} \times 100\% = 18\%$$

So 18 percent of the total energy consumed by the caterpillar is available for growth, and 82 percent of the energy is converted to other forms. Only a small percentage of the energy in the food was converted to new biomass.

PRACTICE PROBLEM

FIGURE 17: The energy a chipmunk consumes is also largely converted to heat or excreted as waste.



The chipmunk consumes 1000 J of energy from food, loses 177 J as waste, and loses 784 J to cellular respiration.

1. How many joules of energy are available to convert into new biomass?
2. What percentage of the total energy was available to become new growth?
3. What percentage of the total energy consumed was converted to unusable forms via cellular respiration, heat, and waste?
4. Make a model that supports the idea that energy is conserved. Use evidence from this example to support your claim.

Pyramid Models

The same pattern of energy and biomass distribution at the organism level also occurs at the ecosystem level. Biomass is a measure of the total dry mass of organisms in a given ecosystem at the time of measurement.

Pyramid models are useful for showing the productivity of an ecosystem and can illustrate the distribution of energy, biomass, and number of organisms. Productivity is the percentage of energy entering the ecosystem that is incorporated into biomass at a particular trophic level. Modeling ecosystem productivity with a pyramid allows scientists to compare the distribution of energy, biomass, or numbers of organisms between trophic levels.

Gather Evidence What information do scientists need in order to determine how much energy is converted into biomass at different trophic levels?

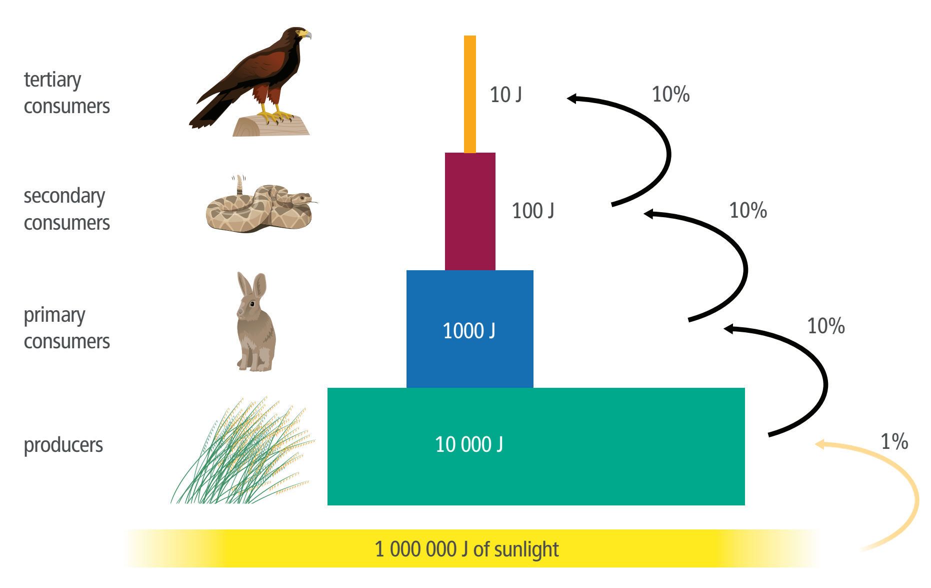
Energy Pyramids

Trophic efficiency is the percentage of energy transferred from one trophic level to the next. Remember that energy transfer from one organism to another is not efficient.

An energy pyramid models the transfer of energy beginning with producers and working up the food chain to the top-level consumer. The pyramid illustrates how available energy is distributed among trophic levels in an ecosystem. A typical energy pyramid has a very large section at the base for producers, and sections become progressively smaller above. Because energy is converted to heat lost to the environment at each level of the pyramid, the more levels there are in the ecosystem, the greater the loss of energy. The energy used by producers far exceeds the energy used by the consumers they support.

In the simplified energy pyramid shown in Figure 18, energy flows from one trophic level to the next. In this example, only 10 percent of energy produced is transferred to the next trophic level. Notice that only 0.1 percent of the energy in the producer level transfers to the tertiary consumer level.

FIGURE 18: An idealized energy pyramid of a grasslands ecosystem.



Data Analysis

According to this model, if the producer level contained 5000 J of energy, how many joules of energy would be present at the tertiary consumer level? Using this information, can you explain why the energy pyramid is shaped the way it is?

The simplified pyramid in Figure 18 shows a trophic efficiency of 10 percent for each link in the food chain. A simplified pyramid like this can help scientists make models and hypotheses. In reality, the energy transfer between trophic levels, or the trophic efficiency, can range from 5 to 20 percent, depending on the type of ecosystem.

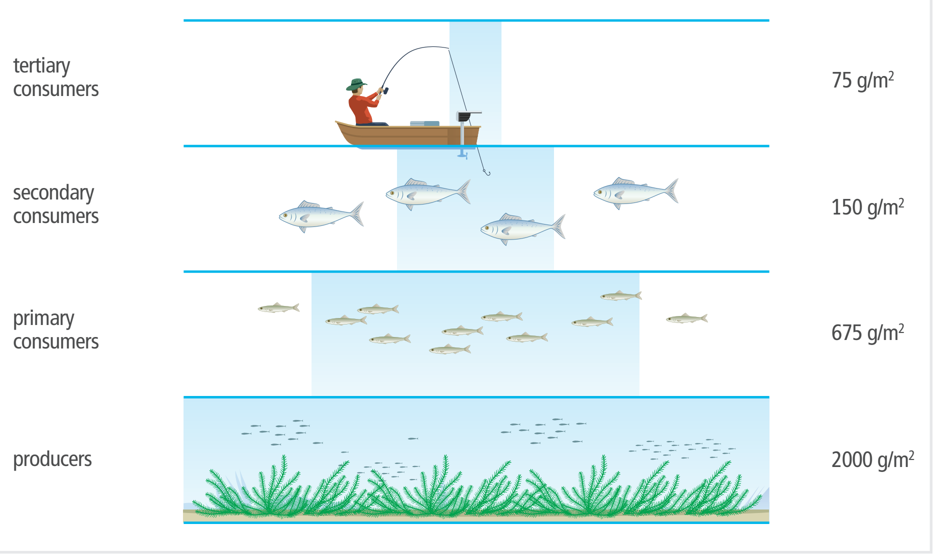
Producers convert only about 1 percent of the energy available from sunlight into usable energy. This is because not all of the sunlight hits the leaves of a plant, not all wavelengths of light are absorbed, and photosynthesis and cellular respiration in plants require large quantities of energy.

Gather Evidence Why is there a limit to the number of trophic levels in an ecosystem? Is energy conserved in an ecosystem?

Biomass Pyramid

A biomass pyramid, such as the one shown in Figure 19, compares the biomass at different trophic levels within an ecosystem. It illustrates the mass of producers needed to support primary consumers, the mass of primary consumers required to support secondary consumers, and so on. Biomass is measured as the total mass per unit of area. The biomass measurement includes living organisms and dead organic matter. As organisms die and decompose, the nutrients and matter in their bodies are cycled back through the biomass pyramid by decomposers.

FIGURE 19: A biomass pyramid depicts the total dry mass of organisms found at each trophic level. In this example the biomass is measured as g/m^2.



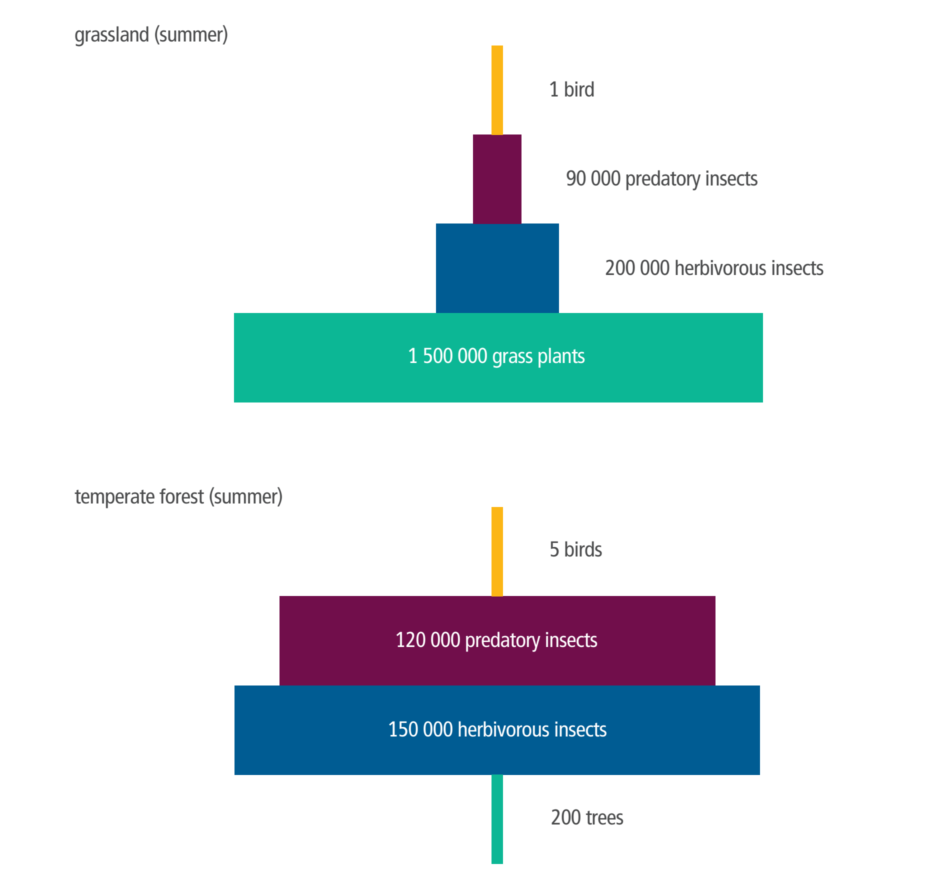
The amount of energy and biomass decreases in a biomass pyramid as you move up the trophic levels. In an energy pyramid, the percentage of energy transferred from one trophic level to the next is approximately the same at every level. In a biomass pyramid, the percentage of biomass transferred to the next trophic level depends on the types of organisms present in each trophic level and the level of consumption and the availability of that biomass for consumption. For example, leaf biomass is more available and useful for herbivores than wood.

Model Create a model that demonstrates the relationship between biomass and energy in an ecosystem.

Pyramid of Numbers

A pyramid of numbers shows how many individual organisms are present at each trophic level in an ecosystem. Two examples of a pyramid of numbers are shown in Figure 20. This type of pyramid is effective in showing the vast number of producers required to support even a few top-level consumers. Ecosystems vary in the number and types of organisms in each level. These organisms also vary in their rates of growth and reproduction, as well as in the amount of biomass each species needs to sustain life and growth. A trophic level that contains organisms that reproduce and grow rapidly often has less biomass at any given time than one in which reproduction and growth rates are slow. The size of the organisms also plays a role in the shape of the various pyramids. The larger the individual organism, the fewer that are needed to support the next trophic level.

FIGURE 20: A pyramid of numbers models how many organisms are at each trophic level.



Analyze According to the grassland pyramid, how many grass plants would be needed to support 12 birds?

Think about why a pyramid of numbers or a biomass pyramid might appear in an upside-down or diamond formation. A single tree in a rain forest would be greatly outnumbered by the primary and secondary consumers, such as insects and birds, that live on the tree. The upper layers of the pyramid of numbers would be larger than the bottom layer representing the single tree. If a secondary or tertiary consumer, such as a condor, were added to the top of the pyramid, a diamond shape would result.

Explain Compare and contrast the different ways to model energy and matter flow in an ecosystem. If you were a scientist studying an ecosystem, explain how you would use each type of pyramid and what information you could gain from each one.

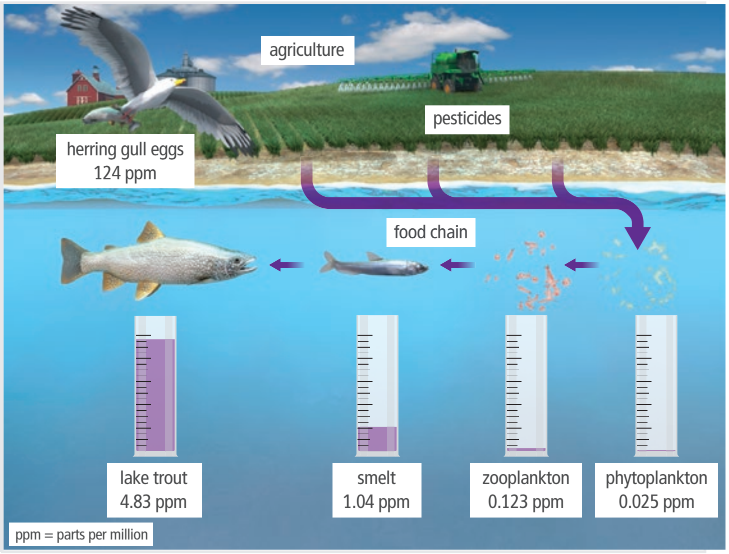
Hands-on Activity

Biomagnification

MATERIALS
- beads, large (16)
- beaker, 500 mL
- marker
- tape, masking
- paper cups (4 small, 2 medium, 1 large)
- pencil, sharpened
- salt

Harmful chemicals enter aquatic ecosystems from the runoff of silt, pesticides, and fertilizers. These chemicals enter the food chain and build up in the bodies of organisms through a process known as biomagnification. Scientists study this process by measuring the amount of chemicals in each trophic level in parts per million.

FIGURE 21: Biomagnification in an aquatic ecosystem.



Predict How will the beads, or pollutants, transfer between the cups? How is this a model of biomagnification? How are contaminants magnified up the food chain?

PROCEDURE

1. Label the small cups "Smelt," the medium cups "Trout," and the large cup "Gull." With just the pencil tip, punch one or two small holes in the bottom of each cup, and cover them with tape.
2. Fill each of the cups halfway with salt. Add four beads to each small cup.
3. Hold each of the small cups over the beaker and remove the tape. Allow the salt to flow through the holes into the beaker.
4. Pour the remaining contents of two small cups into one medium cup. Pour the contents of the other two small cups into the second medium cup. Repeat Step 3 with the medium-sized cups.
5. Pour the remaining contents of both medium cups into the large cup.

ANALYZE

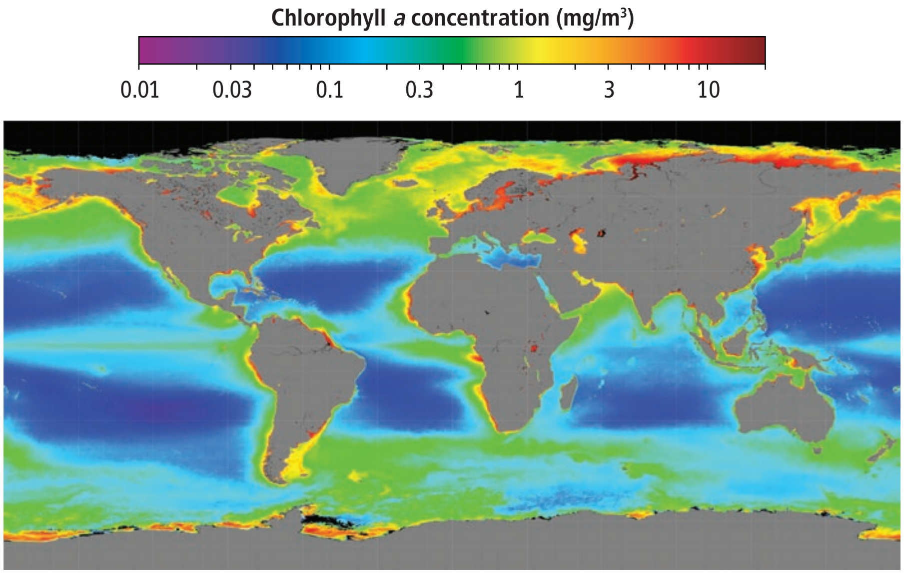
1. What pattern did you notice for the transfer of pollutants between trophic levels?
2. Why would tertiary consumers have the highest concentrations of toxins?
3. How are humans affected by biomagnification? Use evidence from this activity to explain why this is a concern.

WHAT DO ALLIGATORS EAT? | IS YOUR DIET ENERGY EFFICIENT? | AQUATIC PRIMARY PRODUCTIVITY | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 22: Global Concentration of Chlorophyll *a*



Phytoplankton are tiny photosynthetic organisms that live in marine environments. They serve as the base for the aquatic ecosystem food web and are an integral part in the energy and matter flow in aquatic ecosystems. Through their role in the production of approximately half of Earth's oxygen, phytoplankton are important to terrestrial food webs and pyramids.

Explain Refer to your notes in your Evidence Notebook to explain how the flow of energy and matter through an ecosystem is modeled. Using this information, answer the following questions:

1. Explain the relationship between the phytoplankton population and chlorophyll concentration.
2. How can a decrease in the phytoplankton population affect life on Earth?
3. How might this change affect the flow of energy and matter in the biosphere?

CHECKPOINTS

Check Your Understanding

1. In a prairie ecosystem, which of the following populations has the most stored energy for use by other organisms?
   a. hawks
   b. buffalo
   c. prairie dogs
   d. prairie grasses

2. Which food chain correctly shows the direction that energy and matter flow through a forest ecosystem?
   a. fruit—insect—sparrow—hawk
   b. hawk—fruit—insect—sparrow
   c. insect—sparrow—hawk—fruit
   d. insect—hawk—fruit—sparrow

3. Which of the following terms are in the correct order, from smallest to largest?
   a. population, organism, community, ecosystem, biome, Earth, biosphere
   b. organism, community, population, ecosystem, biome, biosphere, Earth
   c. organism, population, community, ecosystem, biome, biosphere, Earth
   d. ecosystem, organism, population, community, biome, biosphere, Earth

4. Consider a pyramid model with a producer level, a primary consumer level, a secondary consumer level, and a tertiary consumer level. Which of the following statements are correct?
   a. The sun is the ultimate source of energy in an ecosystem.
   b. Matter cycles and is generally conserved within or among ecosystems.
   c. Energy flows through ecosystems, but only a certain amount of energy is transformed into biomass.
   d. Energy flows through ecosystems, but some is lost to the environment as heat.
   e. Matter and energy are completely conserved and transformed into biomass within an ecosystem.

5. What is the relationship between a food chain and trophic levels?
   a. A food chain demonstrates how the organisms at the highest trophic levels have the most energy.
   b. Food chains illustrate the flow of energy from one trophic level to the next.
   c. A food chain models the energy flow within a single trophic level.

6. A consumer eats 1500 J of food energy. The consumer uses 15 percent of the food energy for new biomass and the rest for cellular respiration and waste. Use this information to answer the following questions:
   a. How many joules of food energy were converted into new biomass?
   b. How many joules of food energy are converted to heat and excreted as waste?
   c. What percentage of the food energy was converted to heat and excreted as waste?

FIGURE 23: Desert

7. Why is a desert in North America, such as Arizona's Sonoran Desert (Figure 23), considered to be the same biome as a desert in Africa?

8. What biotic and abiotic factors influence the flow of matter and energy in different biomes?

9. Do you think it is possible for a biome to change from one type to another due to human activities? Explain a situation in which this might happen.

10. A student thinks that populations higher in a food chain are larger because they deplete the populations of organisms lower in the chain. Using evidence from this lesson, explain why this student's thinking is incorrect.

FIGURE 24: Rabbits are herbivorous and hawks are carnivorous.

a Primary Consumer

b Tertiary Consumer

11. Think about the trophic efficiency, or percentage of transferred energy between trophic levels, in an ecosystem. Why is an herbivorous diet more energy efficient than a carnivorous diet? Use the example of the rabbit and the hawk shown in Figure 24 to help explain your answer.

12. An aquatic ecosystem contains 10,000 freshwater shrimp, 1000 sunfish, 100 perch, 10 northern pike, and 1 osprey. Draw a pyramid of numbers that represents this ecosystem.

13. Describe how energy and matter flow, interact, and change forms throughout the Earth system.

14. In your Evidence Notebook, make a model that explains the relationship between river, estuary, and ocean ecosystems. How do matter and energy flow within and among these ecosystems?

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

Life in an ecosystem requires a source of energy. The flow of energy and matter in an ecosystem can be demonstrated by food chains, food webs, and pyramid models.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how food chains, food webs, and pyramid models show the flow of energy and matter through trophic levels in an ecosystem.

3.4

Cycling of Matter and Energy in Ecosystems

Oceans cycle energy and matter through the water cycle.

CAN YOU SOLVE IT?

The curious-looking buildings shown in Figure 1 are part of a research facility located in Arizona called Biosphere 2. The tightly sealed glass and steel structure currently serves as a place where scientists study Earth's ecosystems to better understand carbon and oxygen cycles, coral reef health, water recycling, and more.

FIGURE 1: Biosphere 2 is a research facility located in Arizona.

On September 26, 1991, eight research scientists began a two-year adventure living in Biosphere 2. The researchers, known as "biospherians," were completely sealed off from the outside environment to simulate living in a closed ecosystem. But the results of the experiment were unexpected. The biospherians had to cope with inadequate food, decreasing oxygen levels, and increasing carbon dioxide levels. The imbalances resulted in many plants and animals dying, providing evidence that ecosystems are much more complex and dynamic than originally thought.

Predict Why do you think researchers had problems with low oxygen levels and increasing carbon dioxide levels in Biosphere 2? How would you solve this problem?

Gather Evidence As you explore the lesson, gather evidence to explain the relationship between the cycling of matter and the transfer of energy through ecosystems.

Matter Cycles Through Ecosystems

Earth is an open system in terms of energy, as it gains energy from the sun. In contrast, Earth is a closed system in terms of matter. All of the matter on Earth has more or less been here for billions of years. Matter and energy cannot be created or destroyed, only transformed into other forms.

Predict Matter and energy move through ecosystems between different organisms. Where does this matter come from and how does it travel through an ecosystem or through Earth's spheres?

Energy and Matter in the Earth System

The Earth system includes all of the matter, energy, processes, and cycles within Earth's boundary with space. Energy from the sun drives the cycling of matter in Earth's spheres and in the many ecosystems within those spheres. Producers use only about one percent of the sun's energy that enters Earth's atmosphere.

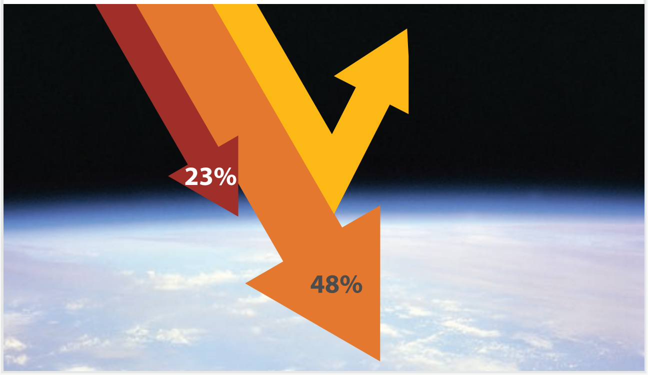
Math Connection

Solar Radiation

When solar radiation enters Earth's atmosphere, about 23 percent is absorbed in the atmosphere and about 48 percent is absorbed at the surface.

Collaborate With a partner discuss these questions: If energy is conserved, what percent of the solar energy should be reflected back into space? How do you think Earth's ecosystems would be different if more or less solar radiation was reflected by the atmosphere?

FIGURE 2: Earth's atmosphere absorbs and reflects energy.



Like energy, matter in the Earth system cycles within and among Earths' spheres: the atmosphere, geosphere, hydrosphere, and biosphere. A relatively small amount of matter is lost into space from the very top of the atmosphere, but scientists generally think of the Earth system as closed in terms of matter.

Matter also changes form as it cycles through the Earth system, but like energy, it cannot be destroyed. For example, organisms metabolize food using chemical reactions. These reactions break bonds and form new chemical bonds among the same atoms to make new substances. The organism can use these new substances for growth and cell processes. Some matter is excreted as waste, which is recycled in the environment. The total amount of matter in the system remains unchanged.

FIGURE 3: The Earth system is closed.

Using food webs and pyramid models, you can see matter cycles through different trophic levels in an ecosystem. As one organism consumes another, that matter is transferred into higher trophic levels. When organisms die, their matter is cycled back through lower trophic levels. In this way, no new matter is created, but matter continually moves through and between ecosystems, as illustrated in Figure 3.

The Water Cycle

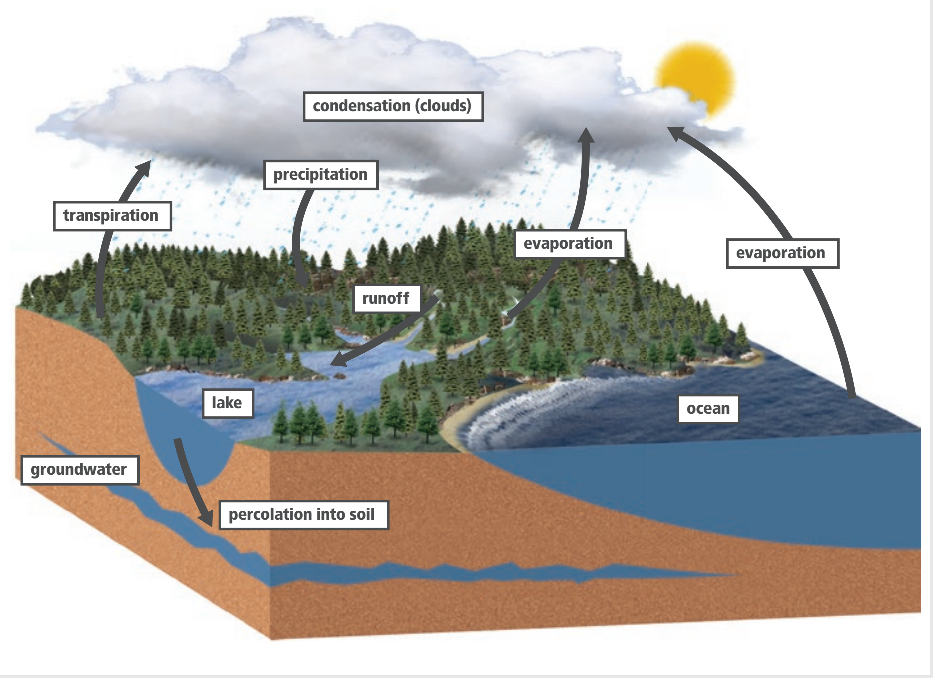
Scientists model specific chemical cycles in order to better understand the cycling of matter in the Earth system. The hydrologic cycle, also known as the water cycle, is the circular pathway of water on Earth from the atmosphere, to the surface, below ground, and back into the atmosphere.

As shown in Figure 4, within the hydrologic cycle, water moves by different processes between reservoirs, such as oceans or lakes. Reservoirs are any location where cycling matter is stored. Water molecules might be stored in a reservoir for a long period of time, such as in a glacier, or for shorter periods of time, such as in a cloud. Evaporation and precipitation are examples of processes that move water between reservoirs.

Analyze If the total amount of water on Earth does not change, why are there concerns about global shortages of fresh water?

FIGURE 4: The hydrologic cycle transfers water molecules between reservoirs.

Explore Online



In the hydrologic cycle, heat from the sun causes water to evaporate from reservoirs such as the ocean and to evaporate from plant leaves through transpiration. As water rises into the atmosphere it cools and condenses into clouds. Water then falls back to Earth in the form of precipitation, such as rain, snow, or hail. Precipitation seeps in the ground or flows into streams or rivers. Water ends up in a reservoir where it is stored until the process starts again.

Explain Choose two reservoirs in the diagram and, for each location, explain how water cycles through the system.

Biogeochemical Cycles

Many elements are essential for the functioning and growth of organisms. These elements include oxygen, hydrogen, carbon, nitrogen, and phosphorus. Just like water, these elements cycle through the Earth system, ecosystems, and organisms.

A biogeochemical cycle is the movement of a particular chemical through the biotic and abiotic components of an ecosystem. The sun and heat from within Earth provide energy that drives these cycles. Like the hydrologic cycle, the matter in biogeochemical cycles flows between reservoirs where it is stored for a period of time. In contrast to the water cycle, bonds are broken, and atoms are rearranged into new molecules in biogeochemical cycles. The main biogeochemical cycles are the oxygen cycle, the carbon cycle, the nitrogen cycle, and the phosphorus cycle.

Explore Online

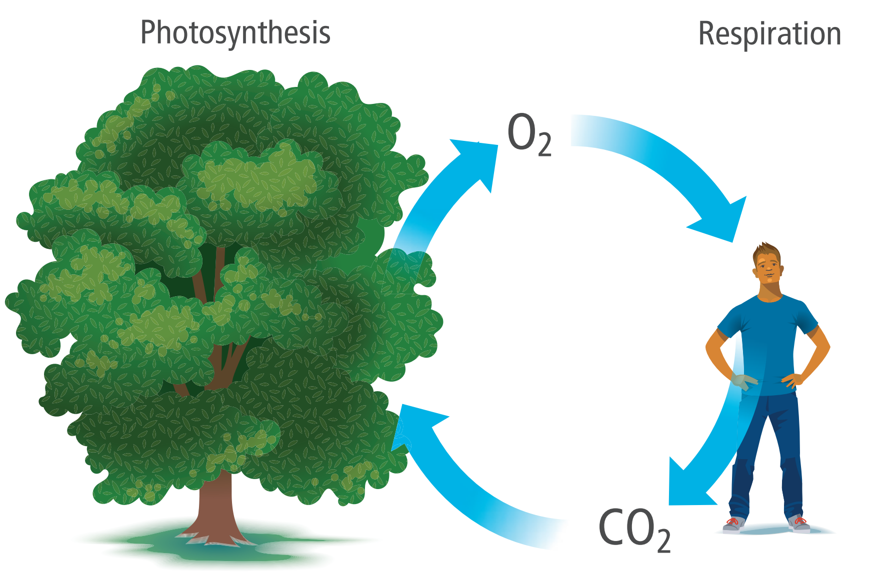
Hands-On Activity

Winter Water Chemistry Model summer and winter lake conditions to determine how surface ice affects the water chemistry of a lake.

The Oxygen Cycle

Oxygen (O_2) is released into the atmosphere as a product of photosynthesis. The atmosphere serves as a reservoir for oxygen until it is taken in by an organism for use in cellular respiration. Humans, and other organisms, also take in oxygen as part of respiration, or breathing.

FIGURE 5: The oxygen cycle is driven by photosynthesis and cellular respiration.



Collaborate With a partner, discuss how a drought caused by a decrease in precipitation might affect the oxygen cycle. Use evidence from previous lessons to support your answer.

Some of the oxygen is incorporated into compounds that remain in the organism. Thus the organism becomes a reservoir for the oxygen. Carbon dioxide (CO_2) is released back into the atmosphere as a byproduct of cellular respiration. Carbon dioxide is then taken up by plants and used for photosynthesis, and oxygen is released back into the atmosphere. Each cycle on Earth interacts with other cycles. For example, the water cycle interacts with the oxygen cycle, because water is necessary for photosynthesis.

Gather Evidence In the Biosphere 2 project, oxygen concentration decreased over time and carbon dioxide reached dangerous levels. Describe a possible solution to this problem, and explain how it relates to processes in the oxygen cycle.

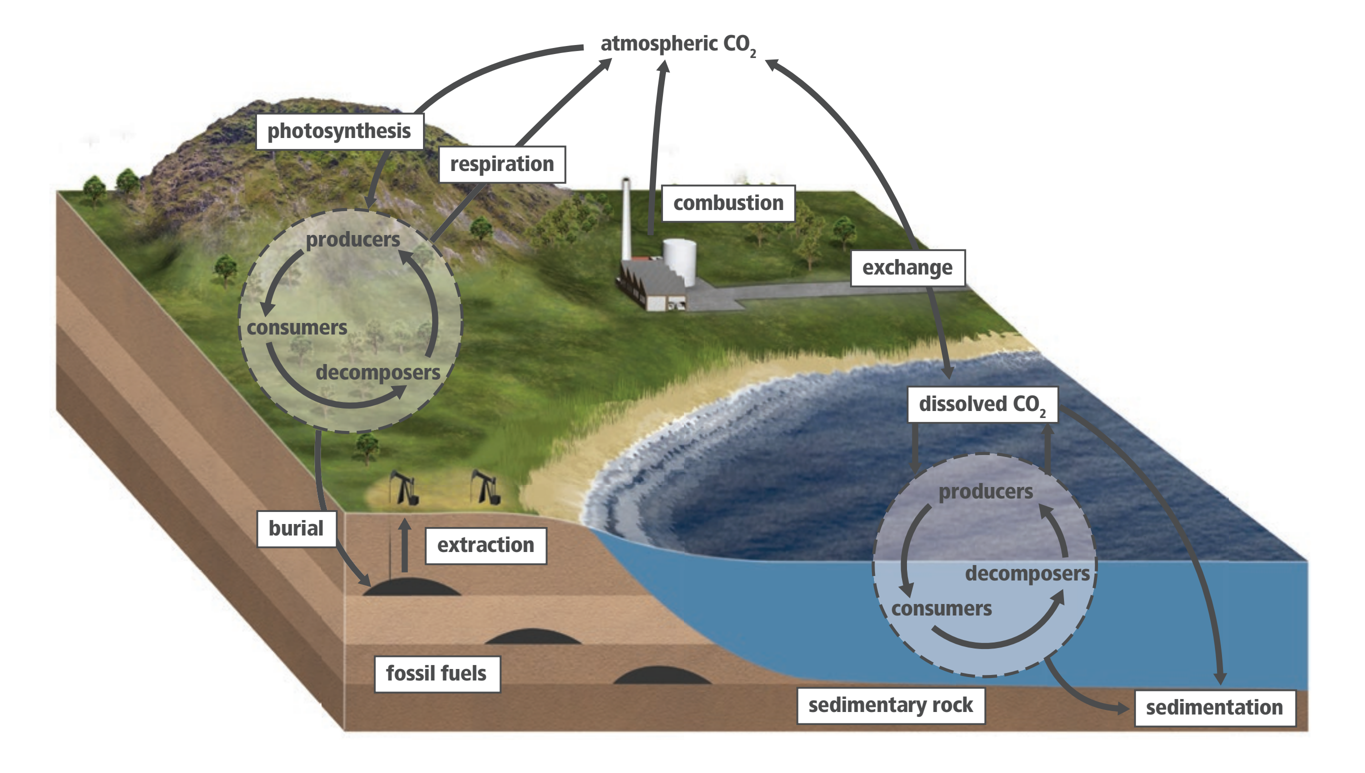
The Carbon Cycle

Gather Evidence Without humans, could carbon in these reservoirs be accessed?

Carbon is present in most chemical compounds that make up living things. Carbon is also stored in abiotic components of the Earth system. For example, CO_2 in the atmosphere, fossil fuels such as oil and coal, dead matter in the soil, and chemical compounds in rocks are carbon reservoirs.

FIGURE 6: Processes such as photosynthesis and combustion drive the cycling of carbon.

Explore Online



Producers remove CO_2 from the atmosphere through photosynthesis. Photosynthetic organisms incorporate the carbon into carbohydrates to store in their tissues. When consumers eat producers, they obtain the carbon, storing some of it in their tissues and releasing some back into the atmosphere through cellular respiration. When the consumers die, decomposers break down the organic matter and release carbon back into the atmosphere through cellular respiration. Carbon is also released into the soil.

Some of the carbon in the organic matter may become fossilized. Under certain conditions, the burial process stores that carbon in Earth's crust where, over millions of years, it becomes fossil fuel. Since the 1800s, humans have extracted this carbon and combusted it, releasing large amounts of carbon back into the atmosphere.

Carbon dioxide diffuses into the ocean from the atmosphere. Oceans are carbon sinks that absorb and hold large amounts of carbon. Carbon enters the aquatic biotic cycle when algae and phytoplankton convert it during photosynthesis. Some dissolved CO_2 is used in the processes of sedimentation and burial to form different types of sedimentary rock. These processes are very slow, taking millions of years, but they form extremely large carbon reservoirs.

Explore Online

Hands-On Activity

Lungs of the Planet
Why are rain forests called the "Lungs of the Planet"? Investigate with Dr. Mike and Dr. Oberbauer to determine if this claim is valid by measuring rates of photosynthesis of rain forest plant life.

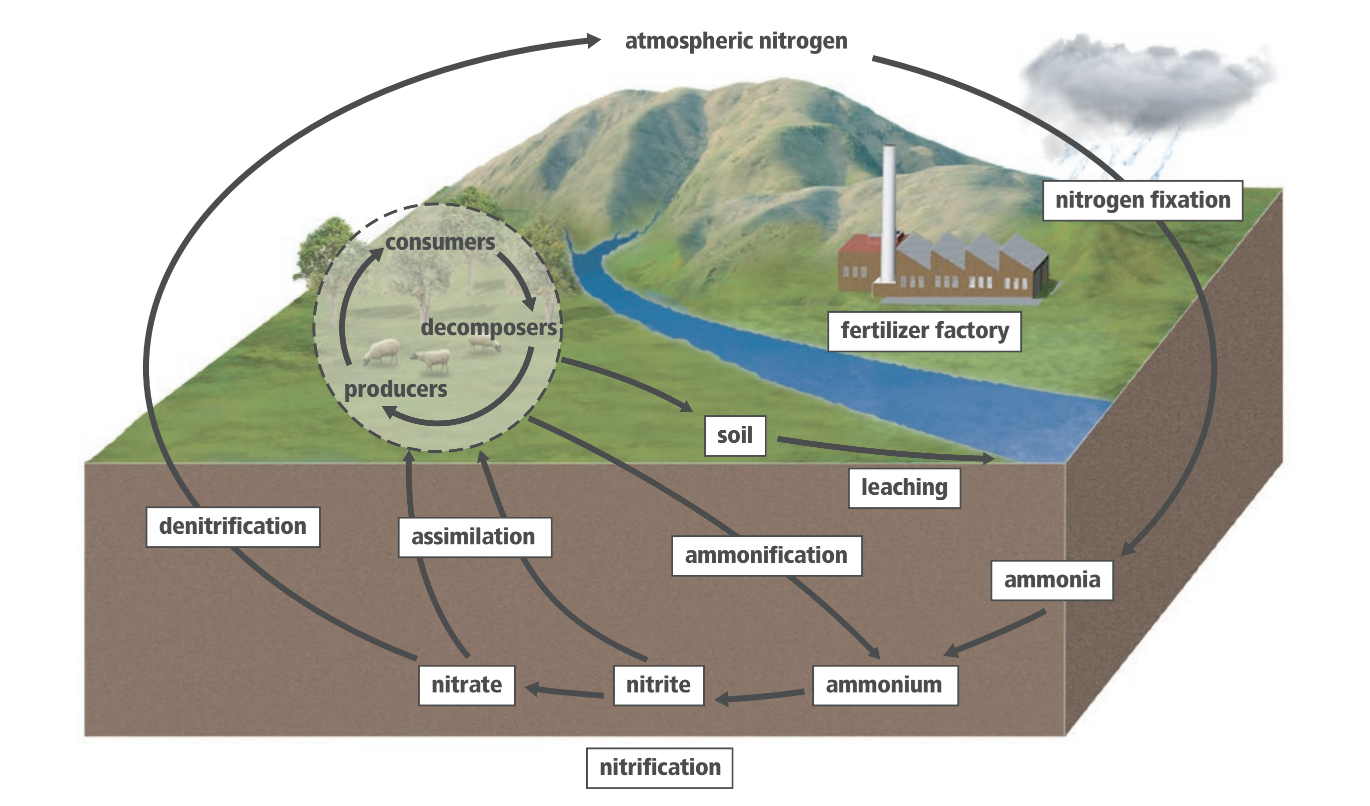
Model Make a model illustrating the roles of photosynthesis and cellular respiration in the cycling of carbon among Earth's spheres. Be sure to include the inputs and outputs for both processes in your model.

The Nitrogen Cycle

About 78% of Earth's atmosphere is composed of nitrogen gas (N_2). However, most organisms are not able to use nitrogen in this form to build organic molecules. The nitrogen must be fixed, or incorporated into other molecules that organisms can use. Bacteria, which are involved in many steps of the nitrogen cycle, fix nitrogen into ammonia, nitrite, nitrate, and other chemicals that organisms can use. As shown in Figure 7, much of the nitrogen cycle takes place below ground.

FIGURE 7: The nitrogen cycle is made up of many processes that move nitrogen from the atmosphere to the biosphere and back again.

Explore Online



Certain types of bacteria convert gaseous nitrogen into ammonia (NH_3) through a process called nitrogen fixation. Some of these bacteria are aerobic, which means they use oxygen. Other bacteria are anaerobic, which means they do not use oxygen. In aquatic ecosystems, this task is performed by a few types of cyanobacteria. Some nitrogen-fixing bacteria on land live in small outgrowths, called nodules, on the roots of plants such as beans and peas. Other nitrogen-fixing bacteria live freely in the soil. The ammonia released by these bacteria is transformed into ammonium (NH_4^+) by the addition of hydrogen ions found in acidic soil. Some ammonium is taken up by plants, but most is used by nitrifying bacteria as an energy source. These bacteria change ammonium into nitrate (NO_3^-) through a process called nitrification.

Nitrates released by soil bacteria are taken up by plants through assimilation, which converts them into organic compounds such as amino acids and proteins. Nitrogen continues along the cycle as animals eat plant or animal matter. When decomposers break down animal excretions or dead animal and plant matter, nitrogen is returned to the soil as ammonium, in a process called ammonification. Denitrifying bacteria use nitrate as an oxygen source, releasing nitrogen gas back into the atmosphere as a waste product via denitrification.

Scale, Proportion, and Quantity

Bacteria are microscopic organisms, but they are essential to life on Earth. Using evidence from the nitrogen cycle, explain how the microscopic fixation of nitrogen can have such a large impact on life.

Explore Online

Hands-On Lab

Nitrogen Fixation Investigate the role of nitrogen-fixing bacteria by observing prepared slides of legume root nodules.

Nitrogen fixation can occur through biological processes carried out by special types of bacteria, but it can also occur through industrial processes such as the production of fertilizer. Some nitrogen also enters the soil as a result of atmospheric fixation by lightning. Energy from lightning breaks apart nitrogen molecules in the atmosphere. Nitrogen recombines with oxygen in the air, forming nitrogen monoxide. The combination of nitrogen monoxide with rainwater forms nitrates, which are absorbed by the soil. Nitrates in the soil may be moved by water, eventually settling at the bottom of lakes, swamps, and oceans in a process called leaching.

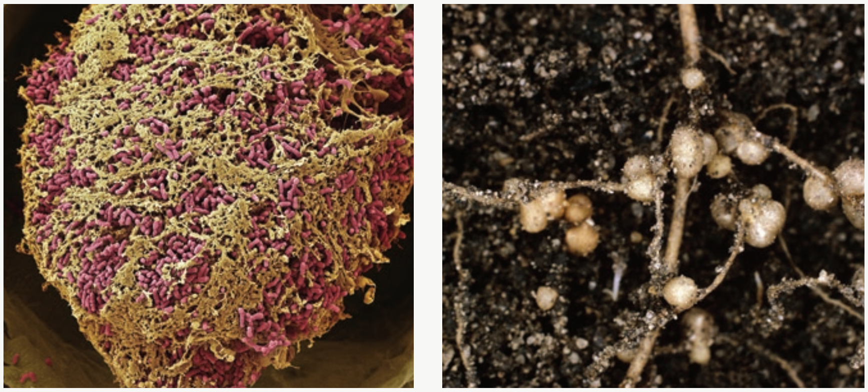
Analyze Organisms in a fish tank can become unhealthy if too much ammonium from their waste builds up in the water. Explain why it is beneficial to add bacteria and plants to a fish tank. Use evidence from the nitrogen cycle model to support your claim.

Energy and Matter

Rhizobia Bacteria

Gather Evidence Legumes are often planted and harvested as crops. When this happens, the plants are not left to decompose into the soil. How does removing the legumes from the ecosystem affect the nitrogen cycle?

FIGURE 8: Nitrogen-fixing bacteria live in a pea plant nodule.



a Rhizobia bacteria (colored SEM)

b Pea plant nodules

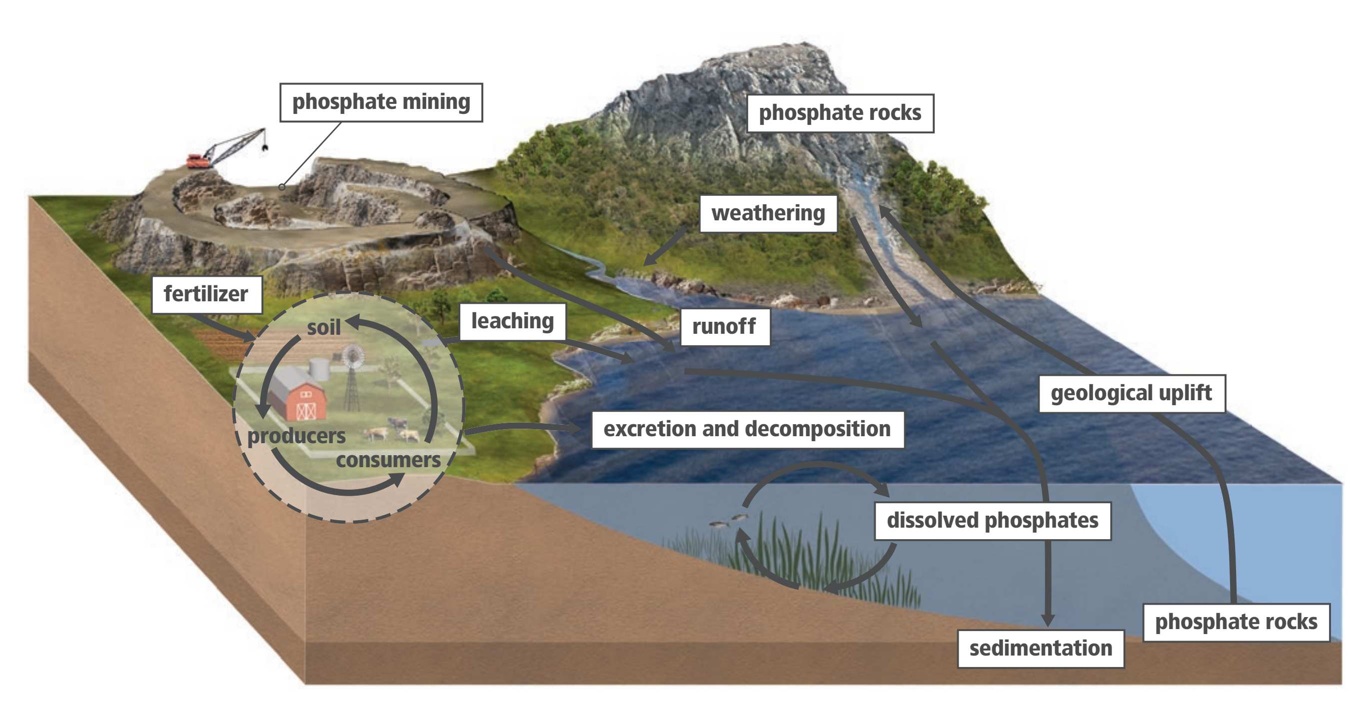
Nitrogen-fixing bacteria live symbiotically, or in close relationship, with certain types of plants, particularly those in the legume family. Rhizobia bacteria live in the nodules on the roots of legumes, as shown in Figure 8. The plant provides essential nutrients to the bacteria and, in return, the bacteria fix nitrogen into ammonia, which the plant absorbs. Most of the ammonia made by the bacteria is kept by the plant and very little is released into the soil until the plant dies. Then, decomposers convert the ammonia molecules into other nitrogen compounds and release some of that nitrogen back into the atmosphere as nitrogen gas.

The Phosphorus Cycle

Phosphorus is an important element for living things. It is a component of phosphate groups in ATP, DNA, and phospholipids in cell membranes. Phosphorus occurs in the form of phosphate salts found in ocean sediments and rocks. Geologic processes expose these rocks, and water and wind break them down, making them available to plants and animals.

FIGURE 9: The phosphorus cycle interacts with the rock cycle through processes such as geologic uplift and weathering.

Explore Online



Analyze Which of Earth's spheres is not part of the phosphorus cycle?

As shown in Figure 9, weathering of phosphate rocks by rain releases phosphate compounds in soil and water. On land, plants can take up phosphate compounds from the soil and consumers gain phosphorus by eating the producers. Decomposers then return phosphorus to the soil and water when they break down the organic matter and wastes of the producers and consumers.

Water can transport phosphorus to aquatic ecosystems through runoff and leaching. Phosphorus compounds dissolve into phosphates where they can be taken up by algae and then consumed by other aquatic organisms. Some dissolved phosphates settle at the bottom of oceans in a process called sedimentation, becoming phosphate rocks over millions of years.

Certain geologic processes expose the phosphate rocks at the bottom of the ocean to the atmosphere. The rocks then undergo weathering, releasing phosphate compounds back into the ecosystem, and continuing the phosphorus cycle. Humans also introduce phosphates into the ecosystem by mining them to make fertilizers and cleaners. Excess phosphates from human activities can enter aquatic ecosystems through runoff and leaching. Very little phosphate is naturally available in most bodies of water and any increases can lead to significant changes in the ecosystem.

Collaborate Discuss this question with a partner: When the water at Biosphere 2 became polluted with too many nutrients, researchers treated the water by running it over mats of algae. Why did they do this, and how does this action relate to the nitrogen and phosphorus cycles?

Explain How do the hydrologic cycle and the different biogeochemical cycles relate to one another? How can a change in one cycle affect all of the other cycles?

Human Impact on Earth's Cycles

FIGURE 10: Easter Island

Easter Island, located in the southeastern Pacific Ocean, was first inhabited between 400 CE and 700 CE. The human colony grew quickly over the next 1000 years, cutting down the forests for lumber and for building boats. The forests were cleared faster than they could grow back, and eventually the island was left with no trees. Without trees, there was no wood for shelter or boats, the soil washed away, and habitat for the island's animal populations was lost. With no food and the island resources nearly gone, the Easter Islanders disappeared. Today, a small population of people live on the island. The stone monuments placed by the first inhabitants, shown in Figure 10, are a major tourist attraction.

Predict What effect did the human population have on Easter Island? How did they change the island's natural cycling of matter and energy?

Gather Evidence As you read, record evidence to support or refute the idea that atoms are rearranged in biogeochemical cycles.

Air Pollution

Without human activity, the cycling of carbon, phosphorus, and nitrogen in the Earth system would be in a relatively steady state. Each year humans add synthetic chemicals and materials to Earth, and many of these chemicals cannot be integrated into normal ecosystem functions. The harmful effect of these pollutants can be immediate or delayed, but these effects may add up over time and can disrupt ecosystem functions.

FIGURE 11: Engine combustion contributes to air pollution.

The most common air pollution comes from the waste products produced by burning fossil fuels, such as gasoline and oil that contain carbon, nitrogen, and phosphorus. Burning fossil fuels releases carbon dioxide, methane, nitrous oxide, and other chemicals that pollute the air. Smog is a type of air pollution caused by the interaction of sunlight with pollutants produced by fossil fuel emissions. The nitrogen dioxide in smog reacts with oxygen to produce ozone, O_3. The ozone produced by reactions of nitrogen dioxide and oxygen tends to stay close to the ground, where it can be harmful to human health and ecosystem functions. However, ozone also exists naturally in the upper atmosphere. There, it acts as a shield protecting Earth's biosphere against harmful ultraviolet rays found in sunlight.

Algal Blooms

The production of fertilizers and detergents through industrial nitrogen fixation and phosphate mining has increased greatly over the last few decades. When these fertilizers are added to food crops or lawns, rain causes excess nitrogen and phosphorus to run off into nearby streams or lakes. The addition of nitrogen to an ecosystem alters the nutrient balance, which can lead to increases in producers such as algae, causing what is known as an algal bloom.

Algal blooms affect the overall health of an ecosystem, and in the case of aquatic ecosystems, deplete oxygen through a process called eutrophication. When algae die, decomposers break down their bodies, consuming oxygen in the process. The lack of oxygen harms aquatic organisms, and can even lead to major die-off events.

Cause and Effect

FIGURE 12: Eutrophication harms aquatic ecosystems.

Excess Fertilizer

In many cities, residents over-fertilize their lawns. The excess nitrogen and phosphorus are washed into lakes, streams, and ponds and can lead to eutrophication, as shown in Figure 12. Some cities make efforts to educate their citizens about how to test their soil so they apply just the right amount of nutrients when fertilizing their lawns.

Model Make a model describing how over-fertilizing leads to eutrophication. Then use your model to suggest one possible solution to this problem.

Climate Change

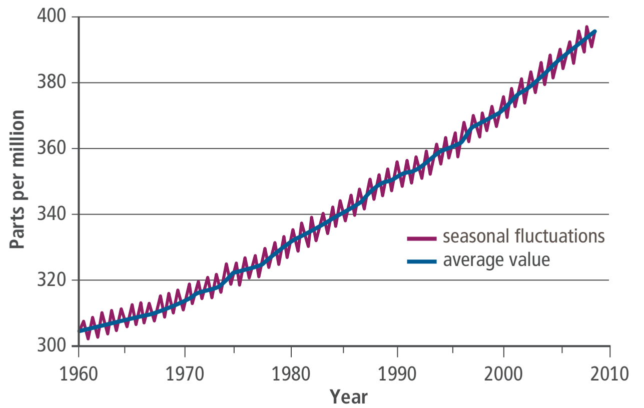
Carbon dioxide emissions released from the burning of fossil fuels have led to a substantial increase in atmospheric CO_2, as shown in Figure 13. The rate at which carbon dioxide enters the atmosphere as a result of human activities is much faster than the rate at which it is removed by other processes. Combusting fossil fuels and clear-cutting forests are two examples of human activities that lead to increased carbon dioxide levels in Earth's atmosphere.

Analyze As carbon dioxide is added to the atmosphere, more carbon dioxide also enters the ocean through diffusion. Carbon dioxide reacts with water to produce carbonic acid, which lowers the pH of the water. What effects do you think this might have on marine life?

Carbon dioxide is one of several greenhouse gases. These gases act in a similar manner to a greenhouse for growing plants: They allow sunlight to pass through and provide energy for plant growth, but keep infrared radiation, or heat, from escaping. Increasing the amount of carbon dioxide in the atmosphere has been linked to increasing global temperatures, which has a devastating effect on ecosystems. Some species have already been observed moving into new areas because the changes in the climate make it difficult for these species to continue living in their natural range. Increased carbon dioxide concentrations have also caused the polar ice caps to shrink and sea levels to rise as a result.

Atmospheric CO_2 at Mauna Loa Observatory

FIGURE 13: Atmospheric carbon dioxide levels have risen substantially since 1960.



Source: Scripps Institution of Oceanography, NOAA Earth System Research Laboratory

Explain Many scientists worry that the influence humans have on the biogeochemical and hydrologic cycles will cause lasting damage to Earth. Make a list of the activities you perform in a day that may impact one of these cycles. Explain how you are interacting with the cycle and how that could be affecting your local ecosystem. What can you do to decrease your impact?

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Guided Research

Evaluating Solutions to Human Impacts

Scientists and engineers are working to develop solutions to human impacts on the hydrologic and biogeochemical cycles. Burning fossil fuels for energy has one of the largest impacts on these cycles. Finding alternatives to fossil fuel energy is key to decreasing human impact and making lasting changes.

Currently engineers and scientists are investigating solar, wind, water, biological, and geothermal energies as potential alternatives to fossil fuels. You may have already heard of wind and solar farms. Scientists must ask many questions when they consider implementing new energy sources such as these, including:

- **Costs** - Is the solution cost effective? Can a similar solution be reached in a less costly manner without losing quality?
- **Safety** - Is the solution safe for humans and other living things?
- **Reliability** - Is the solution going to hold up over time in the given conditions? Will it need large amounts of upkeep to be maintained over time?
- **Aesthetics -** Does the solution add to or detract from the natural visual beauty of the area?
- **Social and cultural impacts** - How does the solution impact human societies and cultures? Are there any concerns about these impacts?

FIGURE 14: These wind turbines capture energy from the wind and convert it to electricity. Wind energy is an alternative to energy from fossil fuels.

- **Environmental impacts** - How does the solution impact the environment? Are there any concerns about these impacts?
- **Meeting criteria** - Does the solution solve the problem and meet the needs of those who will use the new energy source?
- **Evidence to support the solution** - How well does the evidence provided support the claims that are being made about this solution and how it will work?

Language Arts Connection
Choose an alternative energy source and research how it impacts the biogeochemical and hydrologic cycles or how it reduces human impact on these cycles. Write a blog entry detailing your research. Explain how the alternative energy source will work for human populations in terms of its trade-offs, such as cost, reliability, and impact on society and the environment. Gather evidence from multiple sources and describe specific evidence from each source.

LUNGS OF THE PLANET | NITROGEN FIXATION | WINTER WATER CHEMISTRY | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU SOLVE IT?

FIGURE 15: Biosphere 2

The Biosphere 2 research center was originally built with five separate ecosystems: rain forest, ocean, wetlands, grassland, and desert. Scientists thought that by replicating Earth's ecosystems they would be able to make a self-sustaining ecosystem in which humans could live and grow their own food. Almost immediately, however, Biosphere 2 began suffering from a lack of oxygen and increased carbon dioxide concentrations.

Explain Refer to the notes in your Evidence Notebook to explain how matter changes form as it flows within the Biosphere 2 system. Use this information to help you answer the following questions:

1. How do matter and energy change form as they cycle through ecosystems and Earth's spheres?
2. Why do you think researchers had problems with low oxygen in Biosphere 2?
3. How would you solve this problem?

The Biosphere 2 experiment never recovered. The scientists built CO_2 scrubbers to try to remove excess carbon dioxide from the air and eventually had to pump in oxygen to stay alive. The ecosystems inside Biosphere 2 suffered and never flourished as scientists had hoped they would. The original purpose of the experiment failed: A group of people could not survive in a self-sustained system. However, scientists did learn that Earth's ecosystems are extremely complex and there is much the scientific community has yet to learn. Today researchers use Biosphere 2 as a place to study Earth's ecosystems to better understand carbon and oxygen cycles, water recycling, and more.

CHECKPOINTS

Check Your Understanding

1. The steps of the carbon cycle are described below. Place the steps in the correct order.
   a. Animals and plants release carbon dioxide and water as a result of cellular respiration.
   b. Carbon dioxide is released by plants and animals and moves into the biosphere.
   c. Plants use water and carbon dioxide from the atmosphere to make sugar and oxygen through the process of photosynthesis.
   d. Animals and plants use sugar and oxygen for the process of cellular respiration.
   e. Cellular respiration transforms sugar and oxygen into carbon dioxide and water.

2. Which statement describes a difference between the nitrogen and carbon cycles?
   a. The carbon cycle involves only plants.
   b. The nitrogen cycle requires a process called fixation that is carried out by certain bacteria.
   c. The carbon cycle requires that temperatures be above 27 °C (80 °F).
   d. The nitrogen cycle occurs entirely in the ocean.

3. What are the potential effects of introducing too much nitrogen and phosphorus into an aquatic ecosystem? Select all correct answers.
   a. Fish populations would increase.
   b. Aquatic organisms would die off.
   c. Water would become clearer.
   d. Algae would grow out of control.
   e. Oxygen levels would increase.

4. Which of the following things are common to all of the biogeochemical cycles? Select all correct answers.
   a. reservoirs and processes
   b. an atmospheric component
   c. photosynthesis and respiration
   d. living things as a reservoir
   e. the sun as a source of energy
   f. can be affected by human activities

5. Complete the sentence by filling in the correct substance in each blank.

   In the carbon cycle, the role of photosynthesis is to take in ____________, and the role of cellular respiration is to give off ____________.

6. Recently, some areas in the United States have seen an increase in trees due to reforestation efforts. Draw a "before" and "after" model to show how the carbon cycle might be altered after a large-scale reforestation effort.

7. Draw a diagram of the water cycle, labeling each process. Add arrows and labels to show how energy drives the cycle and is transferred through it.

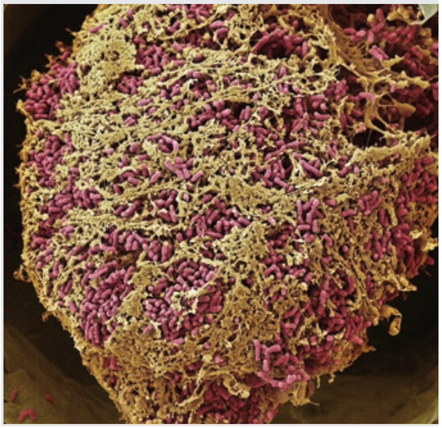
FIGURE 16: Biosphere model

8. How is matter changing form in the biosphere model shown in Figure 16? How many different types of matter cycles do you think are being shown in the model?

9. There is evidence that the increasing carbon dioxide levels in the atmosphere are affecting phytoplankton, which are tiny photosynthetic organisms in the ocean. Explain how the carbon cycle might be affected if phytoplankton were to decrease in number.

10. Decomposers are an important part of many biogeochemical cycles. Some carry out aerobic respiration and some use anaerobic respiration as they break down organic matter. Explain why decomposers are so crucial for the cycling of matter in ecosystems. Cite specific examples to support your answer.

FIGURE 17: Rhizobia bacteria



11. Explain the crucial role bacteria, such as those shown in Figure 17, play in the nitrogen cycle. What would happen to the nitrogen cycle if the bacteria were no longer present?

12. How might Earth's biogeochemical cycles help scientists to understand the early history of life on Earth?

13. Develop a model that explains how energy from Earth drives the biogeochemical cycles.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

Biogeochemical cycles are processes that move matter through and among Earth's spheres. These cycles can be impacted by human activity.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

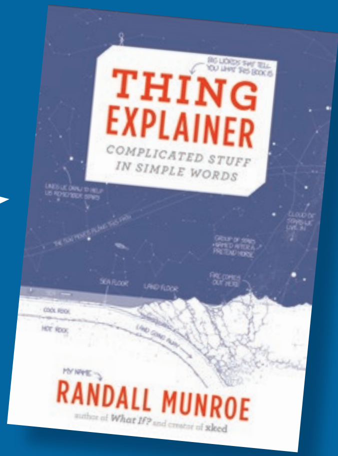
Consider how matter and energy transform, but are not destroyed, as they move through and among ecosystems and Earth's spheres.

TREE

A tree and the living and not living things around it

You know that a tree is a complex living thing. Trees also provide important habitats for a large variety of other living things, a biotic community. These symbiotic components make up the ecosystem in a tree. Here's an overview in simple terms.

A BOOK EXPLAINING COMPLEX IDEAS USING ONLY THE 1,000 MOST COMMON WORDS



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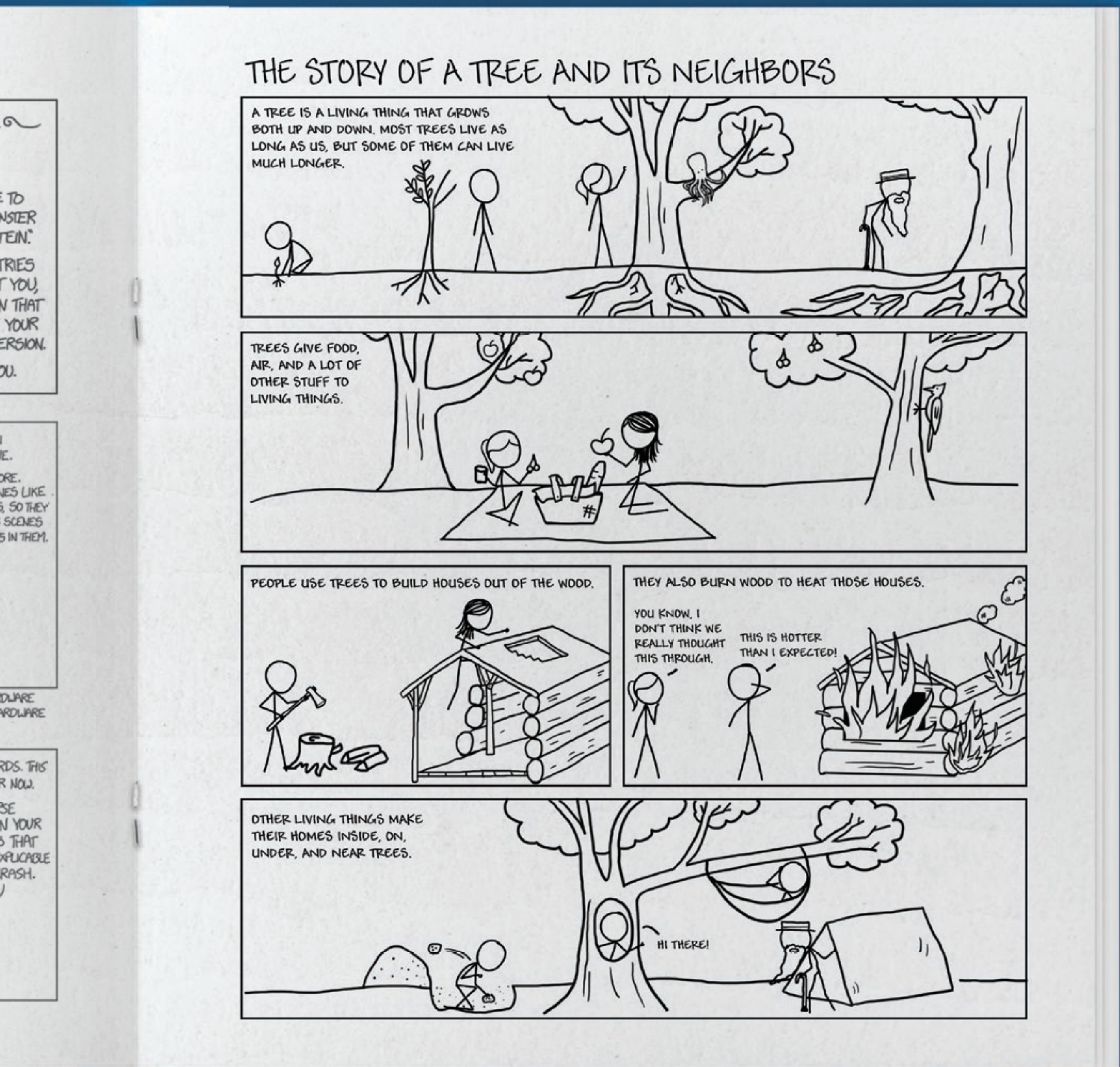
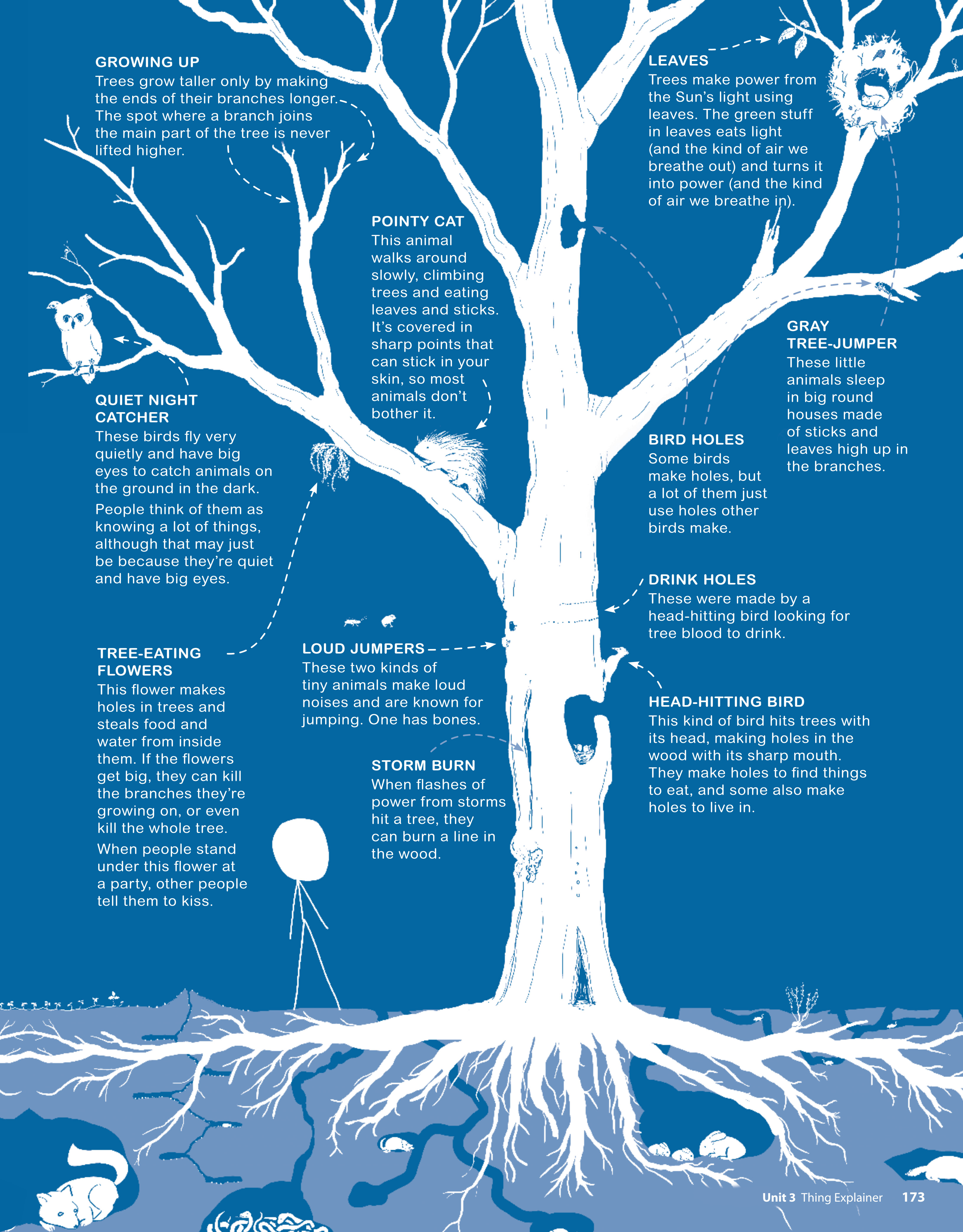
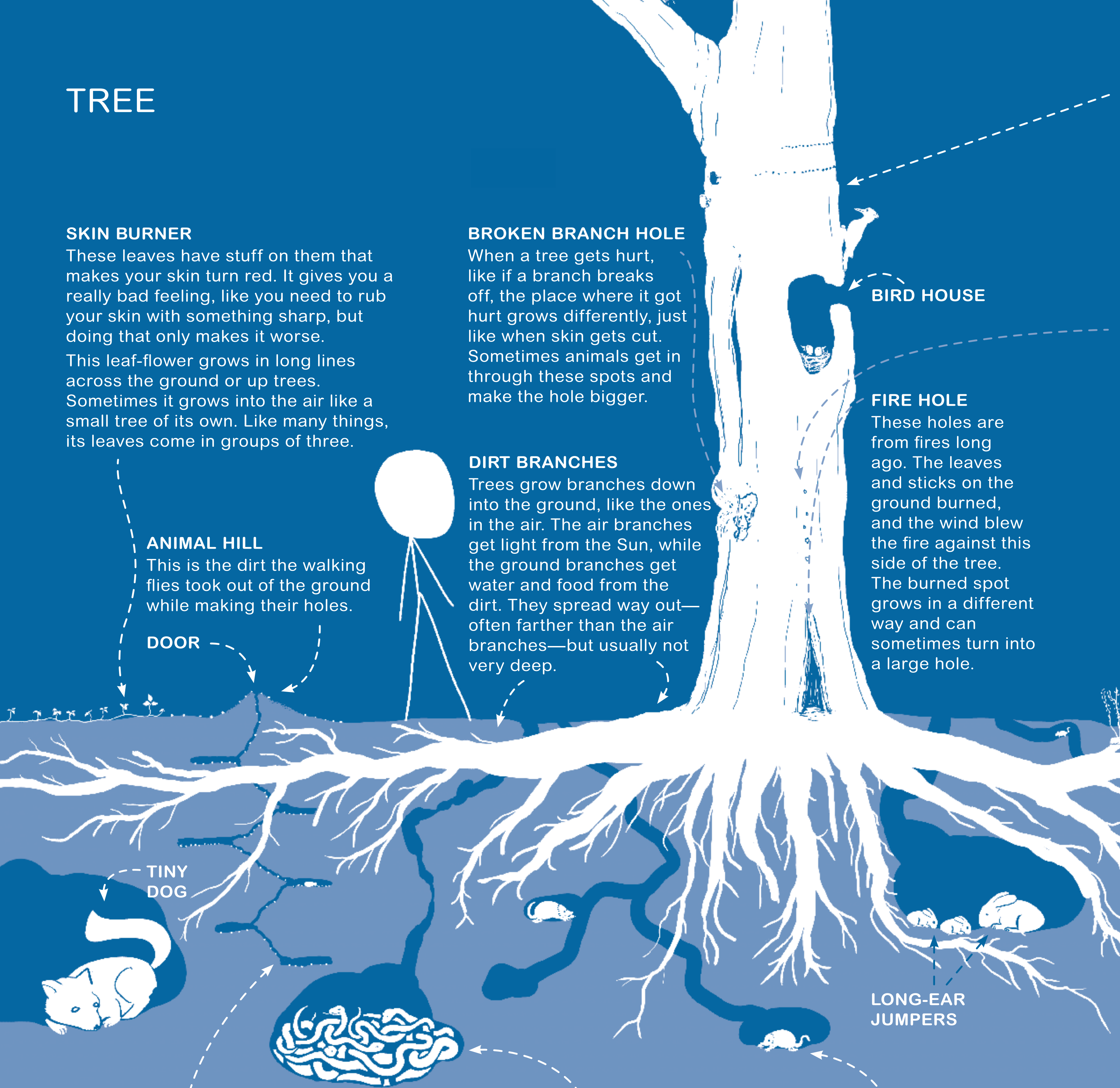



GROWING UP
Trees grow taller only by making the ends of their branches longer. The spot where a branch joins the main part of the tree is never lifted higher.
LEAVES
Trees make power from the Sun's light using leaves. The green stuff in leaves eats light (and the kind of air we breathe out) and turns it into power (and the kind of air we breathe in).
POINTY CAT
This animal walks around slowly, climbing trees and eating leaves and sticks. It's covered in sharp points that can stick in your skin, so most animals don't bother it.
GRAY TREE-JUMPER
These little animals sleep in big round houses made of sticks and leaves high up in the branches.
QUIET NIGHT CATCHER
These birds fly very quietly and have big eyes to catch animals on the ground in the dark.
People think of them as knowing a lot of things, although that may just be because they're quiet and have big eyes.
BIRD HOLES
Some birds make holes, but a lot of them just use holes other birds make.
DRINK HOLES
These were made by a head-hitting bird looking for tree blood to drink.
TREE-EATING FLOWERS
This flower makes holes in trees and steals food and water from inside them. If the flowers get big, they can kill the branches they're growing on, or even kill the whole tree.
When people stand under this flower at a party, other people tell them to kiss.
LOUD JUMPERS
These two kinds of tiny animals make loud noises and are known for jumping. One has bones.
HEAD-HITTING BIRD
This kind of bird hits trees with its head, making holes in the wood with its sharp mouth. They make holes to find things to eat, and some also make holes to live in.
STORM BURN
When flashes of power from storms hit a tree, they can burn a line in the wood.

TREE



SKIN BURNER

These leaves have stuff on them that makes your skin turn red. It gives you a really bad feeling, like you need to rub your skin with something sharp, but doing that only makes it worse.

This leaf-flower grows in long lines across the ground or up trees. Sometimes it grows into the air like a small tree of its own. Like many things, its leaves come in groups of three.

BROKEN BRANCH HOLE

When a tree gets hurt, like if a branch breaks off, the place where it got hurt grows differently, just like when skin gets cut. Sometimes animals get in through these spots and make the hole bigger.

FIRE HOLE

These holes are from fires long ago. The leaves and sticks on the ground burned, and the wind blew the fire against this side of the tree. The burned spot grows in a different way and can sometimes turn into a large hole.

ANIMAL HILL

This is the dirt the walking flies took out of the ground while making their holes.

DIRT BRANCHES

Trees grow branches down into the ground, like the ones in the air. The air branches get light from the Sun, while the ground branches get water and food from the dirt. They spread way out—often farther than the air branches—but usually not very deep.

WALKING FLIES

These tiny animals live in big groups and make holes. Most of them don't have babies; each family has one mother who makes all the new animals for the house.

They usually don't fly, and they're not much like house flies. They're in the same group with the kinds of flies whose back end has a sharp point that can hurt you.

LONG BITERS WITHOUT ARMS OR LEGS (SLEEPING)

These long thin cold-blooded animals don't usually hang out together, and sometimes eat each other.

During the winter, though, lots of different kinds come together and sleep all wrapped up together in big holes under the ground where it's warmer.

Go online for more about *Thing Explainer*.

SKIN

The outer skin of trees is where growing happens and where they carry food up and down. Cutting off a ring of skin all the way around a tree will kill it.

Trees grow by adding new layers, and grow differently in different parts of the year. If you cut open a tree, you can see old layers, and count them to tell how many years old the tree is.

OLD METAL

When people use metal to stick signs to trees, sometimes the tree grows around the metal and eats it up.

Then, many years later, if someone needs to cut down the tree, their saw can hit the metal and send tiny sharp pieces flying everywhere.

TREE-FOOD STEALER

Instead of growing dirt branches of their own, these flowers grow onto the dirt branches of other trees and steal food from them.

Some of these little flowers don't even have green leaves and can't make their own food from light.

TALL AND WIDE TREES

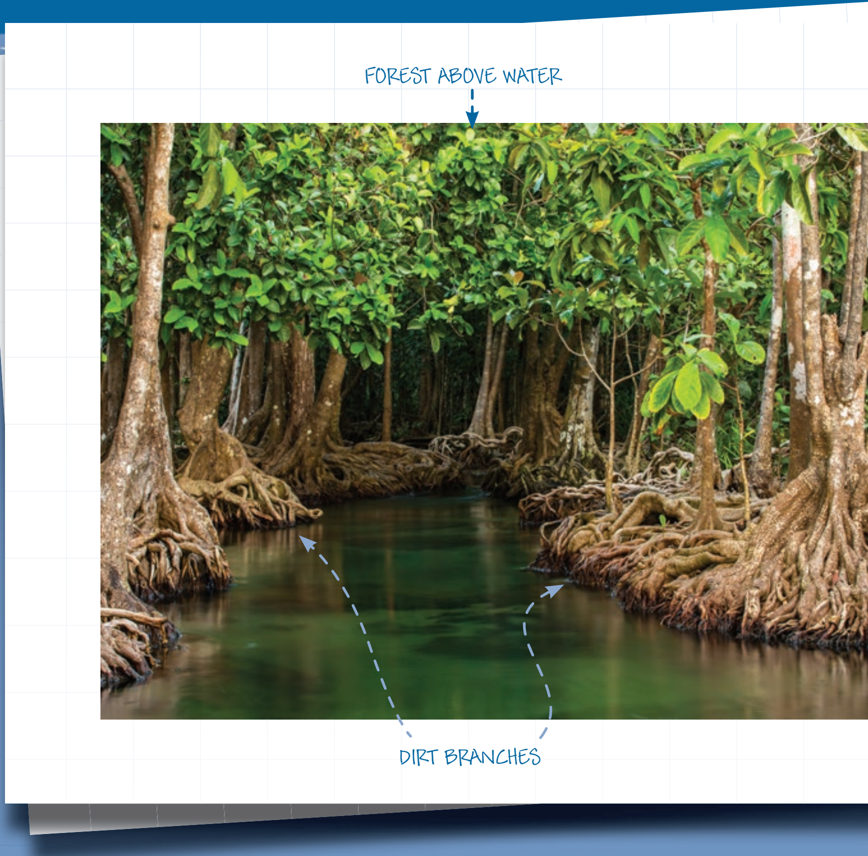
The same kind of tree can grow tall or wide. If there are other trees around, they'll grow mostly up, each one trying to get above the others to reach the Sun's light. If a tree is growing alone in a field, it will spread branches out to the sides so it can catch more light.

FIELD TURNING INTO FOREST

When people cut down a forest, sometimes they leave a few trees—to make a cool shadow area, or because the tree looks nice—and those trees will grow out into the new space.

If the forest grows back, the new trees—fighting with each other as they grow—will be tall and thin.

If you find a forest of tall thin trees with one wide tree with low branches in the middle, it might mean the forest you're in was someone's field a hundred years ago.



DIRT-BRANCH LIFE

Most trees and flowers have life growing on their dirt branches. This life helps them talk to the other trees and flowers around them. They can even use this life to share food or attack each other.

If something tries to eat one tree, it can tell other trees through messages carried by this ground life, and the other trees can start making bad water and other things to make themselves harder to eat.

Engineering Connection

Algae Biofuel Cars combust fossil fuels, releasing large amounts of carbon dioxide into the atmosphere. Carbon dioxide gas is one of the leading contributors to greenhouse gases and increasing global temperatures. To counteract this effect on the environment, engineers have been researching alternative fuels, such as algae biofuels, that do not release greenhouse gas emissions. Algae trap, transform, and store solar energy as oil through the process of photosynthesis. The oil can then be processed into biofuel.

Using library and Internet resources, research algae biofuels. Write a blog entry explaining the potential uses of algae biofuels. What impact could biofuels have on human-driven greenhouse gas emissions?

FIGURE 1: Algae biofuel production.

Social Studies Connection

BFFs: Black-Footed Ferrets As European settlers moved into the Great Plains, they converted prairie land into farmland. These farmers and ranchers found the prairie dogs that lived on that land a nuisance and killed them off in large numbers. The black-footed ferrets (BFFs), which feed almost exclusively on prairie dogs, were nearly eradicated in the process. BFFs are a key species in the ecosystem, and their health is a primary indicator of the overall health of that ecosystem.

The BFF population has undergone a large captive breeding program and is being reintroduced to the wild, with great success. Using library and Internet resources, research the story of the BFF and what its reintroduction into the ecosystem means. Make a pamphlet to document the history of the BFF, and explain any possible implications for local ranchers and farmers.

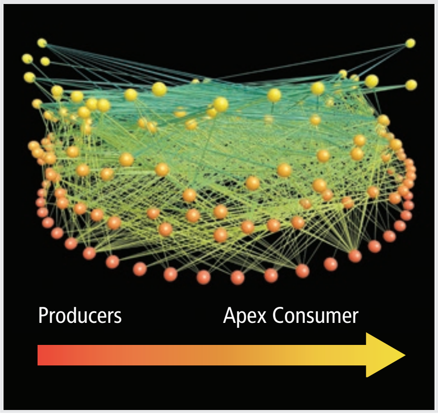
FIGURE 2: Black-footed ferrets released into the wild.

Computer Science Connection

Computational Ecology In recent years, advancements in computer modeling software and processing speed have allowed scientists to study the complexity of ecosystems in new depths. Historically, food webs had been presented as images of producers and consumers connected by a web of energy arrows. However, with new software, scientists can now model hundreds of interactions between species and build a complete ecosystem network, as shown in Figure 3.

With a partner or a small group, review the ecosystem network shown here. What are the pros and cons of making such a computer model of an ecosystem? Do you think a human could analyze this network without a computer? On your own, make a list of questions that, if you were a scientist, you would ask based on this model. Share your questions with your partner or group. Did you have similar questions?

FIGURE 3: A complex ecosystem network developed using network modeling computer software.



SYNTHESIZE THE UNIT

In your Evidence Notebook, make a concept map, graphic organizer, or outline using the Study Guides you made for each lesson in this unit. Be sure to use evidence to support your claims.

When synthesizing individual information, remember to follow these general steps:

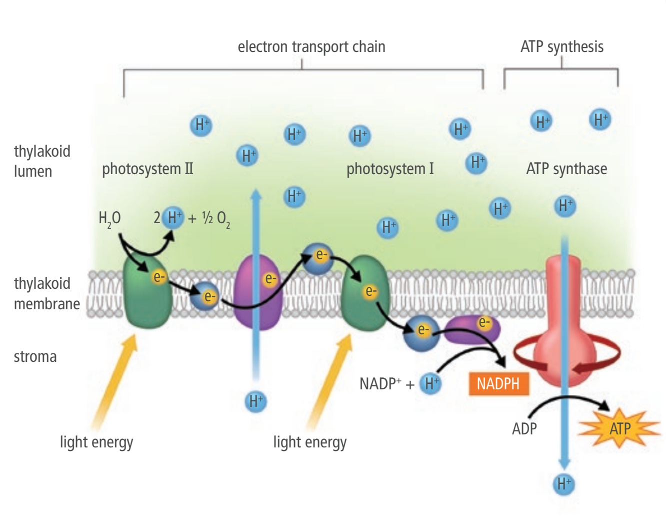
- Find the central idea of each piece of information.
- Think about the relationships between the central ideas.
- Combine the ideas to come up with a new understanding.

DRIVING QUESTIONS

Look back to the Driving Questions from the opening section of this unit. In your Evidence Notebook, review and revise your previous answers to those questions. Use the evidence you gathered and other observations you made throughout the unit to support your claims.

PRACTICE AND REVIEW

FIGURE 4: Energy transferred to electrons moves through the light-dependent reactions.



1. Solar panels capture energy from sunlight and convert it to electricity. As light hits the silicon atoms in a solar cell, the energy is transferred to electrons. The electrons are emitted from silicon atoms, and an electric field organizes the electrons into an electric current. Compare the way a solar cell works to the way a chloroplast works to capture and transfer energy.

2. The cell is a system in which processes such as photosynthesis and cellular respiration take place so that the cell can survive. Although photosynthesis only occurs in certain producers, how does this process contribute to the survival of other organisms, including humans?

3. Describe the relationship between cellular respiration and photosynthesis in terms of energy and matter.

4. In a pyramid of numbers, the highest-order organism has the smallest number of individuals in an ecological community. What might happen if the population of this organism increased significantly? In your Evidence Notebook, develop a model explaining the effect this increase would have on other members of the community.

Use the information in Figure 5 to answer Question 5.

5. If 90% of the energy is lost as heat between trophic levels, approximately how much energy is available to the secondary consumers in this energy pyramid?

FIGURE 5: Energy in trophic levels.

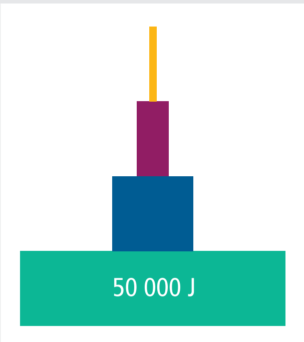


FIGURE 6: Matter and energy cycle through the Earth system.

6. Make a model in your Evidence Notebook to show how a biogeochemical cycle is connected to the transfer of matter and energy through a food chain. In your model, include media and text to convey the concepts of producers, consumers, decomposers, and the cycling of matter and energy.

7. An increase in energy can change the dynamics of a system. Explain how alterations to the carbon cycle result in an increase in the amount of energy contained in the Earth system. Discuss how this addition of energy would affect the cycling of matter in other biogeochemical cycles.

8. Why does the amount of energy in an ecosystem depend on its producers?

9. The nitrogen cycle relies on various organisms carrying out very specific functions. One vital group is the nitrogen-fixing bacteria. Which of the following explains how the nitrogen cycle would be disrupted if there were a sudden population explosion of nitrogen-fixing bacteria?
   - **a.** A population explosion of nitrogen-fixing bacteria would lead to a decrease in ammonium levels in the water.
   - **b.** A population explosion of nitrogen-fixing bacteria would cause dissolved nitrogen levels in the water to increase.
   - **c.** A population explosion of nitrogen-fixing bacteria would cause dissolved oxygen and dissolved carbon dioxide levels to decrease.
   - **d.** A population explosion of nitrogen-fixing bacteria would cause ammonia levels to rise, which can be detected by testing the ammonia levels in the water.

FIGURE 7: During strenuous or prolonged activity, athletes must sustain the oxygen levels their bodies need.

10. In your Evidence Notebook, make a model to explain how the energy content of food molecules can be traced back to the sun.

11. A forest fire began after a group of campers failed to extinguish their campfire completely. Forest fires release carbon, nitrogen, phosphorus, and sulfur that was sequestered in the biomass of the trees back into the atmosphere. In your Evidence Notebook, create a model that shows how each of the carbon, phosphorus, and nitrogen cycles in that area will be affected by the forest fire. Then explain how the changes in the biogeochemical cycle will affect the local ecosystem.

12. Hydroelectricity is a form of renewable energy that involves building dams on rivers and streams. Upstream of the dam, lakes are usually formed as the dam restricts the flow of water. Downstream, the amount of water is usually reduced. How does this activity affect the water cycle and the local ecosystems? Is hydroelectricity a sustainable source of energy?

UNIT PROJECT

Return to your unit project. Prepare your research and materials into a presentation to share with the class. In your final presentation, evaluate the strength of your hypothesis, data, analysis, and conclusions.

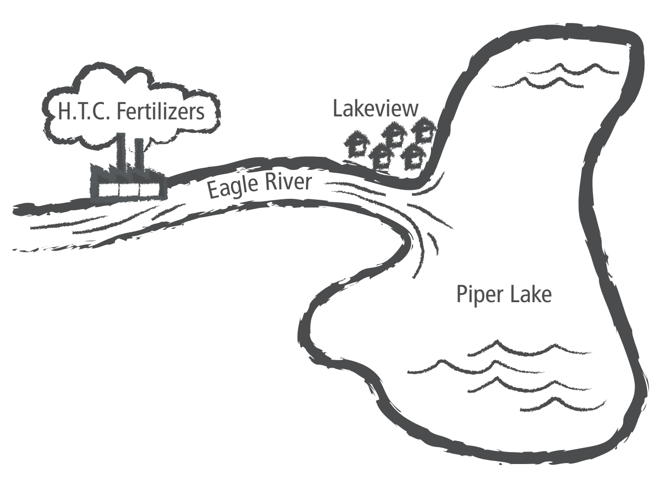
Remember these tips while evaluating:

- Look at the empirical evidence—evidence based on observations and data. Does the evidence support the explanation?
- Consider if the explanation is logical. Does it contradict any evidence you have seen?
- Think of tests you could do to support and contradict the ideas.

Analyzing Water Pollution

The small town of Lakeview is located on the shores of Piper Lake. The town relies on the lake for trout fishing, eagle watching, and recreational activities. Recently, a fertilizer plant, H.T.C. Fertilizers, was built upstream on Eagle River, which feeds into Piper Lake. The town has noticed an increase in algal blooms in the lake. They are concerned the fertilizer plant is dumping too much nitrogen into the river and their livelihood could be affected. Is the town right? Does the plant need to control the waste they put into the river?

FIGURE 8: The fertilizer plant is upstream from Piper Lake.



1. DEFINE THE PROBLEM

With your team, write a statement outlining the problem you've been asked to solve. Record any questions you have about the problem and the information you need to solve it.

2. CONDUCT RESEARCH

With your team, investigate the cause-and-effect relationship between nitrogen, algae blooms, and fish populations. Could the fertilizer plant be responsible for the changes the town is experiencing?

3. ANALYZE DATA

On your own, analyze the problem you've defined along with your research. Make a model to show how excess nitrogen cycles through the aquatic ecosystem. Your model should also show any effects the nitrogen may have on the ecosystem using a food web, energy pyramid, biomass pyramid, or pyramid of numbers.

4. COMMUNICATE

Present your findings to the town and the fertilizer company explaining whether or not the runoff from the fertilizer plant is adversely affecting the lake ecosystem. Your presentation should include images and data to support your claims.

CHECK YOUR WORK

A complete presentation should include the following information:

- a clearly defined problem with supporting questions that are answered in the final presentation
- a model of the effect of the fertilizer runoff
- an explanation based on your analysis of the runoff and whether or not it is adversely affecting the lake ecosystem
- images and data that further support your claims