Reflect

Wind turbines, shown in the photo on the right, are large structures with blades that move in response to air movement. When the wind blows, the blades rotate. This motion generates energy that is converted into electricity. The wind turbine alone does not create energy; instead, it captures the energy of wind movement and converts that energy into a usable form: electricity.

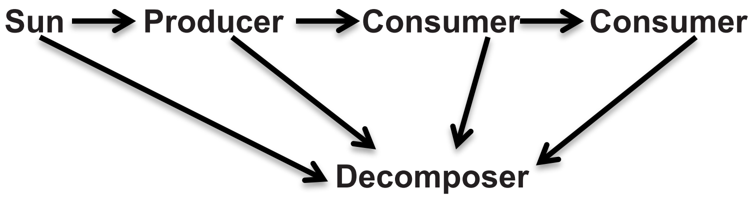
Organisms also transform energy. For example, plants rely on energy from the Sun to survive. They convert light energy from the Sun into chemical energy that is used to maintain life processes. This process is called photosynthesis.

How exactly do plants convert energy from one form to another? Do animals convert energy into usable forms? If so, how?

Energy in a System

Before discussing energy conversions among organisms, it is important to review the laws of bioenergetics. The first law states that energy cannot be created or destroyed. The total amount of energy in the universe is constant. Just as a wind turbine cannot itself create energy, an organism also cannot create energy. Like a wind turbine, the cell only converts (changes the form of) energy that already exists.

Energy can, however, move through a system. As mentioned earlier, it can also change forms. For example, chemical energy is a useful form of energy that powers life activities, allowing organisms to do work. When plants convert light energy to chemical energy, the energy changes forms but is not created in the process. Instead, energy flows in one direction from the Sun to producers, consumers, and, finally, decomposers.



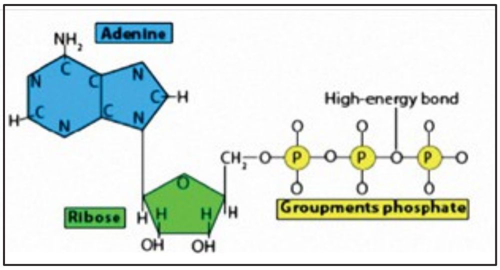
Energy moves from the Sun through the food chain.

As energy moves through a system, the amount of energy decreases at each step. The energy is not destroyed. Instead, it is lost to the environment, typically due to heat being released at each step.

Reflect

Organisms need to constantly convert energy in order to survive. Plants and animals have developed very different ways of addressing their energy requirements. However, all organisms rely on converting energy to a usable form.

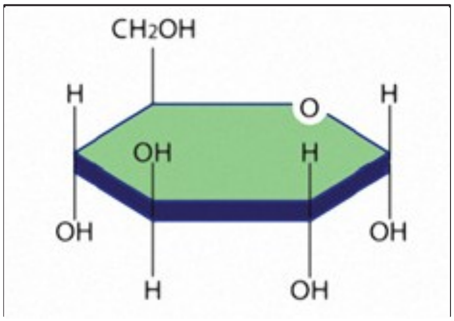
Adenosine Triphosphate: The Energy Currency



Cells use energy from adenosine triphosphate, or ATP, to perform work. ATP stores energy in the chemical bonds between the three phosphate groups attached to the ribose molecule. When a cell needs to perform work, such as transporting a molecule across a membrane or driving a chemical reaction, ATP provides the energy for these activities. When a cell needs energy, ATP is broken down into adenosine diphosphate (ADP) and inorganic phosphate (Pi), releasing the stored energy in the bond between the two outermost phosphate groups. This energy is used to drive cellular processes.

We now know that organisms use ATP as an energy currency to fuel cellular activity. But, where does ATP come from? First, plants convert energy from sunlight into chemical energy. Second, mitochondria in both plants and animals convert chemical energy into ATP.

Photosynthesis



During photosynthesis, plants convert light energy into chemical energy. The light energy comes from sunlight and the chemical energy is glucose, a 6-carbon monosaccharide shown in the diagram on the right.

The chemical reaction for photosynthesis is:

$$6CO_2 + 6H_2O + \text{(light energy)} \rightarrow C_6H_{12}O_6 + 6O_2$$

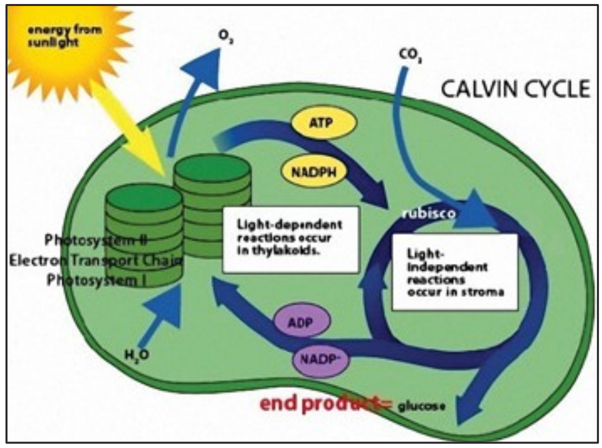
Six molecules of carbon dioxide (CO_2) and six water molecules are the **reactants**. They combine to form glucose and oxygen, which are the **products**. Sunlight provides the energy to drive the reaction from reactants to products. Note that the above chemical reaction is balanced.

reactant: the substance that changes during a chemical reaction

product: the substance resulting from a chemical reaction

Reflect

Photosynthesis is a two-step process involving light-dependent reactions followed by light-independent reactions. In light-dependent reactions, photons (a unit of light energy) are absorbed and converted to ATP. This takes place in **thylakoids**, a series of flat, stacked disks located in chloroplasts. Thylakoids are bound inside a thylakoid membrane, along with the green pigment **chlorophyll**. Chlorophyll gives plants their green color. When light energy hits the thylakoid membrane, it is used to excite electrons in the photosystems and split water. When the water molecules are split, the oxygen diffuses into the atmosphere, the electrons enter the electron transport chain, and the hydrogen ions are used as an energy source in the production of ATP. As the electrons and hydrogen ions exit the thylakoid membrane, they are picked up and transported to the Calvin cycle on NADPH, a carrier protein molecule.



In the light-independent reactions, carbon dioxide and the products of the light-dependent reaction (ATP and NADPH) undergo a series of reactions known as the Calvin cycle. The Calvin cycle produces glucose as its end product.

The combination of the light-dependent and light-independent reaction results in the overall equation for photosynthesis:

$$6CO_2 + 6H_2O + (\text{light energy}) \rightarrow C_6H_{12}O_6 + 6O_2$$

Where do the products come from that are used in the photosynthesis reaction? Water enters plants through roots, which absorb water from the soil and move it up and toward the leaves through the xylem. Water is then stored in the leaves for use in photosynthesis. Carbon dioxide enters leafy plants through *stomata*, tiny openings on the surface of leaves. Once inside the plant, CO_2 travels into chloroplasts by diffusion.

Look Out!

Photosynthesis has a number of variations in nature. Photosynthesis is not limited to plants. It also takes place in algae and some bacterial species. Not all plants are green, either. These plants, as well as red and brown algae, rely on other photosynthetic pigments for photosynthesis, giving them their distinctive colors.

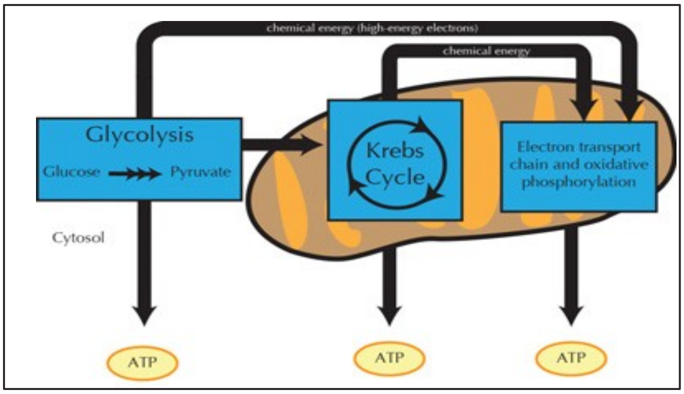
Look Out!

Cellular Respiration
Cellular respiration converts glucose into ATP. First, a process known as glycolysis occurs. Glucose enters the cell, and while in the cytoplasm, it is broken down into two 3-carbon molecules called **pyruvic acid**. Although the cell uses some ATP to begin glycolysis, the overall process produces more ATP than was used to initiate it. For each molecule of glucose that enters glycolysis, a net of two ATP molecules are generated.

In eukaryotic cells, **aerobic** respiration is a two-step process that takes place in the mitochondria following glycolysis. The two steps are:

aerobic: requiring oxygen

- **Krebs cycle**: The two pyruvic acid molecules formed during glycolysis move into the mitochondria, where they initiate a series of enzymatic reactions that release electrons and hydrogen ions and produce carbon dioxide and two molecules of ATP. The carbon dioxide diffuses out of the mitochondria. The electrons and hydrogen ions are carried to the electron transport chain on NADH (a carrier protein molecule similar to NADPH).



- **Electron transport chain**: Products from the Krebs cycle move across the inner membrane of the mitochondria. It is called the electron transport chain because electrons are shuttled back and forth across the inner mitochondrial membrane as part of this process. At the end of the electron transport chain, a process known as oxidative phosphorylation takes place. Here, the enzyme ATP synthase adds phosphate to ADP, creating approximately 32 ATP molecules per glucose in the process!

The overall reaction for aerobic respiration is:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36\ ATP$

Remember, two ATP moles are produced during glycolysis and 34 are produced during aerobic respiration (two in the Krebs Cycle and 32 in the electron transport chain).

Photosynthesis and cellular respiration are part of the same cycle. In cellular respiration, the reactants (glucose and oxygen) are the products of photosynthesis, and the products of cell respiration (carbon dioxide and water) are the reactants in photosynthesis.

What Do You Think?

Humans and other animals rely on atmospheric oxygen to survive. Without oxygen, aerobic respiration cannot occur. Many scientists worry that the destruction of rainforests and other large areas of vegetation will decrease the overall available oxygen in Earth's atmosphere. How might this affect aerobic respiration?

Anaerobic Respiration

Aerobic processes require oxygen, while *anaerobic* reactions do not require oxygen. In cellular respiration, glycolysis is an anaerobic step, as no oxygen is required. However, both the Krebs cycle and electron transport chain are aerobic processes that require oxygen.

What happens in the absence of oxygen? Glycolysis can still take place, producing pyruvic acid. In a low-oxygen environment, pyruvic acid can be turned into lactic acid as an alternate pathway for making small amounts of ATP. For example, when a person exercises strenuously and the muscles' demand for oxygen exceeds the body's ability to deliver the oxygen, lactic acid is produced in the muscles as the body tries to keep up with ATP requirements. The burning sensation often felt in muscles that are exerted is caused by lactic acid.

Some organisms, such as certain kinds of bacteria and fungi, live without oxygen under normal circumstances. They produce energy through **fermentation**, converting a carbohydrate, such as a sugar or starch, into alcohol or acid. The specific products of fermentation depend on the organism. For example, bacteria convert carbohydrates into lactic acid, and yeasts convert sugar into alcohol. Fermentation is used in the food industry to produce yeast breads and fermented alcohols such as wine and beer.

Getting Technical

Fermentation is used for more than just food. Scientists grow bacteria and yeast in large tanks called **fermenters**. The bacteria and yeast cells are genetically engineered to produce human therapeutic proteins. The proteins are then purified away from the cells. For example, bacteria are used to produce insulin, which is a treatment for diabetes. Yeasts are used to produce erythropoietin, which can stimulate red blood cell production for treating anemia. This approach allows scientists to produce large batches of therapeutic drugs to treat human diseases.

Try Now

What Do You Know?

In the spaces below, write the products and reactants for photosynthesis and cellular respiration.

Photosynthesis: 6___________ + 6_____ + light energy → _____ + 6_____

Respiration: + 6_____ → 6_____ + 6_____ + 36_____

Next, draw a line to match each term on the left with the correct description on the right.

Light-dependent reaction	Energy currency for cells
Krebs cycle	Takes place in thylakoids within the chloroplasts
ATP	Part of aerobic respiration that produces two ATP molecules
Glycolysis	Produces two pyruvate molecules
Fermentation	Includes the Calvin cycle, which produces glucose
Electron transport chain	Part of aerobic respiration that produces 32 ATP molecules
Light-independent reaction	Produces alcohol or acid and does not require oxygen

Connecting With Your Child

Observing Cellular Respiration

During photosynthesis and cellular respiration, gases are released as products of each process. Cellular respiration produces carbon dioxide. This process can be indirectly observed in the kitchen using baker's yeast. Yeast is a unicellular organism that uses fermentation to convert sugar into alcohol and carbon dioxide.

For this activity, gather together two small glass bowls or clear plastic cups, a packet of baker's yeast, and one teaspoon of white sugar. You will also need a measuring cup and a spoon. Place the two bowls next to each other. Add one cup of warm water to each bowl. The water should not be boiling or scalding hot, but it should be warmer than room temperature. To one bowl, add one teaspoon of sugar and mix with the spoon. Next, add one half of the yeast packet to each bowl and gently stir to combine. Within a few minutes, bubbles should start to rise to the top of the water. These bubbles are the carbon dioxide (CO_2), the product of cellular respiration.

More bubbles should be produced in the bowl with sugar than in the bowl without sugar. Table sugar is a disaccharide made up of glucose and fructose linked together. When added to the yeast mixture, it provides chemical energy for driving cellular respiration, resulting in greater production of carbon dioxide bubbles.

As you and your child perform this activity, you may wish to discuss the following questions:

- What are the bubbles that form after adding the yeast?
- Why was sugar added to one bowl?
- Which bowl likely produced more ATP? Explain your reasoning.
- What are some ways that you might be able to indirectly observe the products of photosynthesis?