Solar Education for NY
SchoolPower ...Naturally

Biomass Energy

SPN LESSON #41

TEACHER INFORMATION

LEARNING OUTCOME

After a biomass demonstration, students are able to relate how food chains and food webs route matter and energy through an ecosystem and represent the feeding levels of a food chain or food web through a pyramid of energy. The concept that energy cannot be recycled but that some is lost to the biological community at each feeding level is developed.

LESSON OVERVIEW

This lesson provides students with an overview of how energy and matter move through an ecosystem. The primary focus is on the loss of energy at each feeding level in a food chain and the significance of this loss. Students construct three energy pyramids. One is generic and is used to emphasize that only 10% of the energy captured by autotrophs is transferred in a usable form to primary consumers. The continued loss of energy is illustrated up through the tertiary consumer level. In order to relate this concept to energy used in home heating and cooking, energy pyramids for a coniferous forest and a temperate deciduous forest are also constructed. Students must employ some of their mathematical skills to successfully construct the pyramids.

GRADE-LEVEL APPROPRIATENESS

This Level III lesson is intended for use with students taking a Living Environment course in grades 9–10.

MATERIALS

1 metric ruler
1 roll of clear tape or glue
1 pair of scissors
1 copy of the activity
2 "Pyramid of Energy: Feeding Levels" sheets
1 or 2 sheets of plain paper

SAFETY

- Caution students to use scissors carefully.
- There are no other special precautions students need to be aware of while doing this activity.

TEACHING THE LESSON

This lesson can be taught as part of a discussion of food chains and food webs and energy transfer. These concepts are important parts of Key Ideas 6 and 1. Teaching this lesson is also appropriate when dealing with Key Idea 7 of the *Living Environment Core Curriculum*.

A biomass demonstration provides students with a conceptual basis for this activity.

- Collect some plant material, and weigh it in front of the class. Leaves, grass, and yard clippings, as well as leftover lettuce and other leafy salad fixings from the school cafeteria, work well. Ask students to predict what the mass of the vegetation will be after drying. Record their predictions and post them somewhere in the room.
- Spread the plant material out on several pages of newspaper and allow it to dry. Drying will likely take several days.
- Weigh the dried plant material and compare the new mass to student predictions. Even though it seems obvious, ask students why the mass has changed so dramatically. They should realize that the evaporation of water out of the tissues is the reason for the weight loss.
- Point out that what is left is the biomass of the plants. *Biomass* is the term applied to tissues that the plants synthesized from the products of photosynthesis. This is also what is available as a source of energy to an organism that consumes the plant. Consumers will use both the organic compounds and the energy present in the molecular bonds of these compounds.
- Place some of the dried plant material in a crucible or other appropriate container and burn it. Ask students where the energy that can be "observed" in the form of light and heat is coming from. They should respond that the energy was located in the bonds of the molecules composing the plant mass. Since there should be only a little ash left in the crucible, ask students where the solid plant matter went. They should eventually state that the plant matter has been chemically changed from its original form into carbon dioxide and water vapor. These gases can be recycled and made available to living organisms. The energy, in the form of heat, will leave Earth and enter space. The heat is an energy form that can no longer be utilized by living organisms.
- Point out to students that an analogous chain of events is involved in the transfer of matter and energy in food chains and food webs in ecosystems.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

Activity Analysis

Pyramids of Energy			
Pyramid One	Energy present (kilogram calories)	Length of strip (mm)	Energy lost as heat (kilogram calories)
Plants	240	240	
Herbivores	24	24	216.0
1^{st}-Level Carnivores	2.4	2.4	21.6
Top-Level Carnivores	.24	.24	2.16

Temperate Forest Energy Pyramid	Energy present (kilogram calories)	Length of strip (mm)	Energy lost as heat (kilogram calories)
Plants	8,000	200	
Herbivores	800	20.0	7200
1st-Level Carnivores	80	2.0	720
Top-Level Carnivores	8	0.2	72
Coniferous Forest Energy Pyramid	Energy present (kilogram calories)	Length of strip (mm)	Energy lost as heat (kilogram calories)
Plants	3,000	75.0	
Herbivores	300	7.50	2700
1st-Level Carnivores	30	0.75	270
Top-Level Carnivores	3	.075	27

Each strip is 240 mm long. The first energy pyramid merely has students conserve 10% of the strip at each energy transfer and set 90% of the strip aside. The temperate forest and coniferous forest pyramids use a different scale. Students will be able to compare these two since the same scale (10 mm = 400 kcal) is used. Other than in terms of general shape, these last two pyramids will not be comparable to the first.

1. (a) Explain what has become of the energy that is not transferred at each feeding level.

   The energy that is not transferred is lost as heat.

   (b) Explain why the energy that is not transferred at each level cannot be picked up by plants and cycled back through the system in the same way that atoms and molecules can be cycled.

   Once energy has been transformed into heat, it is no longer usable by organisms and ultimately leaves the biosphere. This isn't true of atoms and molecules. Atoms and molecules repeatedly cycle through food chains and food webs and biochemical cycles such as the carbon and water cycles.

2. The first law of thermodynamics states that energy can neither be created nor destroyed but can be transferred and transformed. The second law of thermodynamics states that in every energy conversion, some energy is lost as heat. Explain how these laws relate to the functioning of an ecosystem.

   First law of thermodynamics: Once the energy in a substance has been used, it cannot be reused. Therefore, an ecosystem must have a constant input of energy.
   Second law of thermodynamics: There is more energy at the lower levels of an energy pyramid (producers) and so higher level consumers (carnivores) need to eat more producers or lower level consumers in order to compensate for the energy lost as heat at each level.

3. If 1,000 kilograms of plant material are consumed by the rabbits in an area, explain why a few days later the rabbit population does not weigh 1,000 kilograms more than it did.

   Much of the plant material is metabolized. The rabbits break the plant material down into carbon dioxide and water during the process of respiration. The energy released is used to fuel rabbit life processes and much of the energy is lost as heat. Also, not all of the plant material is digested by the rabbits. Some passes unchanged through the digestive system and is excreted.

Extended Activities

Food Chain Activity

- Have students monitor the amount of sunlight incident on the solar panels and explain how daily fluctuations in solar energy reaching producers impact on the energy available to living organisms.
- Provide students with pictures of a number of different organisms. Show them a variety of plants, herbivores, and carnivores. Have student teams arrange the pictures into several different food chains. They should write out the food chains, using appropriate food chain notation. For groups finding the activity too easy, introduce a picture of a decomposer such as a fungus, or one of the protists that is a producer.

Producer—>Herbivore (first-order consumer)—>Carnivore (second-order consumer)—>Carnivore (third-order consumer)

- Next, have them draw an energy pyramid that represents one of the food chains they put together. They should then write an explanation of why there is much energy at the plant level of the pyramid and so little energy at the top level. See if they can relate this to the fact that there are few top-order consumers such as mountain lions, hawks, and polar bears.
- How might the amount of energy available in a given ecosystem be different if the transfer of energy from one level of the energy pyramid to the next had the same efficiency as the utilization of sunlight by the solar panels?

Ecological Problem Letter

- Have students read the passage that follows:

  Many New York State residents think that the New York State Department of Transportation should follow an example set by Texas highway officials. Fifty years ago, the Lone Star state began sowing wildflower seeds along its nearly 71,000 miles of highway. This amounted to 800,000 acres of roadside. The highway department supported the germination, growth, and blooming of some 5,000 different types of wildflowers native to the state.

  In New York and many other states, roadside maintenance involves planting grasses, regular mowing, irrigation, fertilization, and spraying with chemicals to discourage insect pests and unwanted plants. With the wildflower program well established, Texas road crews mow only a few times a year and that is the extent of their roadside maintenance program. The mowing is necessary only to spread the wildflower seeds.

  Other New York residents are suggesting that some sections of roadside be planted with trees that have a long life span. In addition to beautifying the roads, the wildflowers and trees would provide a habitat for native animals and help to reduce erosion and entrap carbon. The wildflowers and trees are resistant to drought, insects, and freezing weather.

  (Adapted from McCommon, M. (1983). "A Blooming Boom in Texas." *National Wildlife* 21 (5): pp.4–5.)

- After reading the passage, have students consider the environmental and economic impact of planting wildflowers and/or trees along New York State highways. Encourage students to find the potential amount of biomass and energy that could be stored in a square meter of roadside if wildflowers or trees were planted rather than grasses. Ask students how this plan would impact Earth's energy budget. Also ask them how this might have an impact on the global supply of renewable and nonrenewable energy resources and on atmospheric gases such as carbon dioxide, oxygen, and hydrocarbons. Guide students to consider not just the plants but the machinery and fuel that typical roadside maintenance requires. After giving them an opportunity to research the topic, encourage them to share their findings and offer their opinions. Make a chart listing both positive and negative outcomes associated with planting roadside flowers and trees.

- Once students have organized their data, have them work in pairs to draft a letter to the editor of a local newspaper stating their point of view on this topic and substantiating it with facts.

ADDITIONAL SUPPORT FOR TEACHERS

BACKGROUND INFORMATION

Energy is measured in several units. When large quantities of energy are involved, ecologists prefer to use the kilogram calorie, which is the amount of heat needed to raise the temperature of 1 kilogram of water $1^{o}C$ at $15^{o}C$. Because ecologists are interested in energy flow in a specific area, they measure the energy per unit of area. The area could be a square centimeter or a square meter. Earth receives energy from the Sun. Only part of this energy is absorbed.

Energy flow through an ecosystem can be explained by the first two laws of thermodynamics. The first law states that energy is neither created nor destroyed. Energy may change forms, pass from one place to another, or act upon matter. Regardless of what transfers or transformations take place, there is no gain or loss in the total amount of energy. The energy is transferred from one form or one place to another. When wood is burned, the potential energy present in the molecules of wood equals the kinetic energy released in the form of heat and light. During this reaction, energy is released to the environment. Sometimes energy from the environment enters into a reaction. In photosynthesis, for example, the molecules of the products (sugar, water, oxygen) store more energy than the reactants (water, carbon dioxide) had. The extra energy comes from the Sun. Again, there is no gain or loss in total energy. It has merely been transferred and transformed.

Even though the total amount of energy involved in a chemical reaction such as the burning of wood does not increase or decrease, much of the energy stored in the wood is degraded into a form incapable of doing any further work or being used by a living organism. The energy ends up as heat that disorganizes or randomly disperses the molecules involved. Entropy is the measure of this disorder.

The second law of thermodynamics states that when energy is transferred or transformed, part of the energy assumes a form that cannot be passed on. When wood is burned in a boiler to produce steam, some of the energy creates the steam that performs work, but much of the energy is dispersed into the air as heat. The same thing happens in an ecosystem. As energy is transferred from one organism to another, a large part of the energy is degraded as heat. The remainder is stored in living tissue.

Energy enters the biosphere in the form of visible light that is stored in chemical bonds during photosynthesis. All of the Sun's energy that is stored through photosynthetic processes is referred to as gross primary production. Like animals, plants require energy for maintenance and reproduction. The energy for these needs is provided through cellular respiration. The energy available to consumers is what is left after plants fulfill their own energy requirements. In terms of satisfying the energy needs of other organisms in an ecosystem, it must be noted that much of the living material in plants is physically unavailable to herbivores. They cannot reach it. Once plant material is consumed by an herbivore, some of it may pass through the animal's body undigested. A grasshopper assimilates about 30% of the grass it consumes, while a mouse assimilates 85%–90%. Once consumed, the energy is used for maintenance, growth, or reproduction, or it is passed from the body in the urine or feces. This leaves approximately 10% of the original energy the animal took in available for storing in living tissue. The mouse, even though it assimilates a much higher proportion of the energy initially taken in than the grasshopper, loses much of it due to the high cost of maintaining a constant body temperature and a high level of activity. The same is true at each feeding level. On average, only 10% of the energy taken in is assimilated into living tissue. The remainder is lost primarily in the form of heat.

The laws of thermodynamics and the efficiency of energy transfer can also be examined in relation to photovoltaic systems used to generate electricity. Solar cells are approximately 20% efficient when it comes to converting sunlight into electricity. A system display provides the actual "System Efficiency Sunlight to AC" along with "Solar Input Power" (sunlight incident on the solar array) and "AC Output Power."

REFERENCES FOR BACKGROUND INFORMATION

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Produced by the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)
www.nyserda.ny.gov

(STUDENT HANDOUT SECTION FOLLOWS)

Name________________________________

Date ________________________________

Biomass Energy

What is biomass?

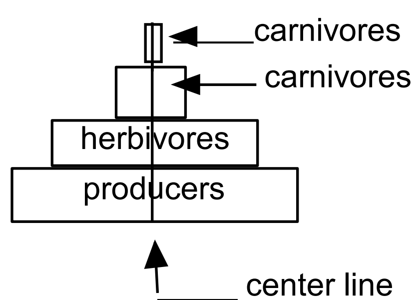
It is through the process of photosynthesis that plants generate organic matter called biomass. If you were to measure the plant biomass in a yard or a field, you would dig up a given area of vegetation (a square meter would be enough), separate the soil from the plant roots, dry all of the plant material collected, and then weigh it. The dried plant material is the biomass of the plants collected. A general way to think about plant biomass is to consider it a measurement of the amount of carbon dioxide converted into organic plant matter through the process of photosynthesis. If you were to measure the *total* biomass for an ecological community (all of the living organisms in an area), you would need to collect not only the plants but the animals, protists, and all of the other living organisms. You would then need to determine the total mass of all these organisms.

Food chains and food webs represent the route that both matter and energy take through an ecosystem. Humans and other organisms use most of the energy they take in to fuel their own life processes. Much of the energy is converted into heat and lost as a source of energy. Only a small portion of the energy taken in is stored in an organism's tissues. This energy is stored in the chemical bonds of each organism's biomass. If a particular population of organisms has a large biomass, it is an indication that that population has a large amount of stored energy.

In almost all ecosystems, autotrophs (green plants and other producers) possess a large biomass. This biomass represents a large amount of stored chemical energy. When the plants are consumed by herbivores, not all of the stored energy is converted into animal biomass. In other words, not all of the plant matter consumed becomes animal matter. There are several reasons for this. Much of the plant material eaten by animals is not digested. It passes through the digestive system unchanged and is excreted. Most of what is digested is converted into carbon dioxide and water through the process of respiration during energy release. The energy is used by animals to support life activities such as movement, breathing, responding to stimuli, and maintaining an appropriate body temperature. The heat radiated by organisms is lost to the environment. In a way, body heat represents biomass from the plant level of a food chain that is not converted into biomass at the herbivore level. The same is true when herbivores are consumed by carnivores. Much of the energy is lost to the environment and ultimately to space in the form of heat.

Plants are able to capture about 1% of the solar radiation reaching Earth. If 1 million kilocalories of solar energy strike Earth, plants would be able to use this energy to carry out photosynthesis and form organic molecules containing about 10,000 kilocalories. Herbivores are about 10% efficient at converting plant material into animal material; therefore, of the plant material consumed, only about 1,000 kilocalories would be converted into animal biomass. The same is true at the next feeding level. The 1,000 kilocalories of herbivore consumed would be converted into about 100 kilocalories of carnivore biomass. The rest would be converted into heat and lost to the environment.

Graphically represented, biomass at the different feeding levels of a food chain or food web forms a pyramid—a pyramid of biomass. Because energy is stored in the chemical bonds of the organic molecules that constitute the biomass, the energy stored at each feeding level in a food chain also is represented by a pyramid—a pyramid of energy.



Materials
1 metric ruler
1 roll of clear tape or glue
1 pair of scissors
2 "Pyramid of Energy: Feeding Levels" sheets
1 or 2 sheets of plain paper

Develop your understanding

Steps for Energy Pyramid One

1. Cut out each of the strips on your "Pyramid of Energy: Feeding Levels" sheet. All of the strips are the same size and have a line indicating the center. You will be constructing several energy pyramids by cutting the strips the appropriate length and lining them up at their centers. See the sample energy pyramid to the right.
2. (a) Label one of the strips "Producers."

   (b) Measure the length of the strip in millimeters and record this number in the Pyramid of Energy data table. This will represent the hypothetical number of kilocalories present at this feeding level.
3. (a) Label a second strip "Herbivores."

   (b) Only 10% of the energy present in the biomass of the producers is converted into animal biomass. Therefore, the length of the herbivore strip will be only 10% of the length of the producer strip. Determine how many millimeters long it should be and record the number in the appropriate place on the data table. Cut the herbivore strip the correct length. *Be careful to keep the center line in the middle of your strip.*
4. (a) Label a second strip "1st-Level Carnivores."

   (b) Only 10% of the energy present in the biomass of the herbivores is converted into carnivore biomass. Therefore, the length of the carnivore strip will be only 10% of the length of the herbivore strip. Determine how many millimeters long it should be and record the number in the appropriate place on the data table. Cut the 1st-level carnivore strip the correct length. *Be careful to keep the center line in the middle of your strip.*
5. (a) Arrange the three strips (producer, herbivore, and 1st-level carnivore) to form an energy pyramid with three levels. Be sure to align the center line of each strip with the center line on the others.

   (b) Tape the pyramid to a blank sheet of paper and label it "Energy Pyramid One."
6. (a) Determine how long the line should be for the top-level carnivores. Record the measurement in the appropriate place on the data table.

   (b) Add this strip to your energy pyramid by drawing it. Be sure it is the correct width, and center it.

Steps for Coniferous Forest and Temperate Deciduous Forest Energy Pyramids

Burning firewood for heat is one of the oldest forms of energy used by humans. Burning firewood can be thought of as the utilization of biomass energy or "bioconversion." It uses energy from present-day photosynthesis. In the United States about 5 million homes rely entirely on wood for heating. About 20 million homes use wood for some heating. The most recent development in woodstoves is the *pellet stove*. It burns compressed pellets made from wood wastes.

In developing countries, firewood is the only fuel source for cooking for over one billion people. Ninety percent of Earth's fuelwood is produced and used in developing countries. A temperate deciduous forest populated by trees such as maple, beech, birch, and oak, which lose their leaves in the winter, produces approximately 8,000 kilogram calories per square meter per year (kcal/M^2 year). A coniferous forest populated by evergreen trees such as pine, spruce, and hemlock, which keep their leaves (needles) in the winter, produces about 3,000 kcal/M^2 year.

7. (a) Using a scale of 10 millimeters equals 400 kcal, make an energy pyramid that represents the amount of energy captured by one square meter of deciduous forest in a year and another that represents the amount of energy captured in a year by one square meter of coniferous forest.

   (b) First, record the length of the strips (in millimeters) and the kilogram calories each represents in the appropriate place on the data table. Also calculate and record the amount of energy lost at each feeding level.

   (c) Except for the scale, follow steps 2–6 above. Tape or glue each completed energy pyramid to your paper and label it with the correct title. Note: If some of the strips are too small to cut, use a pencil to draw that section of the pyramid.

Pyramids of Energy			
Pyramid One	Energy present (kilogram calories)	Length of strip (mm)	Energy lost as heat (kilogram calories)
Plants			
Herbivores			
1st-Level Carnivores			
Top-Level Carnivores			
Temperate Forest Energy Pyramid	Energy present (kilogram calories)	Length of strip (mm)	Energy lost as heat (kilogram calories)
Plants			
Herbivores			
1st-Level Carnivores			
Top-Level Carnivores			
Coniferous Forest Energy Pyramid	Energy present (kilogram calories)	Length of strip (mm)	Energy lost as heat (kilogram calories)
Plants			
Herbivores			
1st-Level Carnivores			
Top-Level Carnivores			

Analysis

1. (a) Explain what has become of the energy that is not transferred at each feeding level.

   (b) Explain why the energy that is not transferred at each level cannot be picked up by plants and cycled back through the system in the same way that atoms and molecules are cycled.

2. The first law of thermodynamics states that energy can neither be created nor destroyed. The second law of thermodynamics states that in every energy conversion, some energy is lost as heat. Explain how these laws relate to the functioning of an ecosystem.

3. If 1,000 kilograms of plant material are consumed by the rabbit population in an area, explain why a few days later the rabbit population does not weigh 1,000 kilograms more than it did.

Pyramid of Energy: Feeding Levels