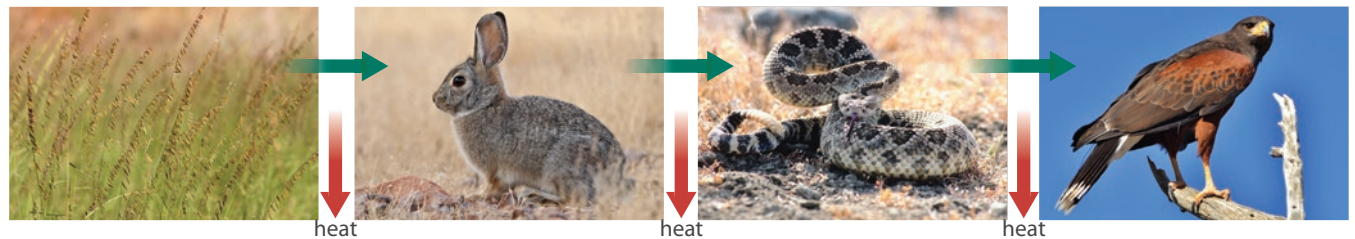


# Energy and Matter Distribution in Ecosystems

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.

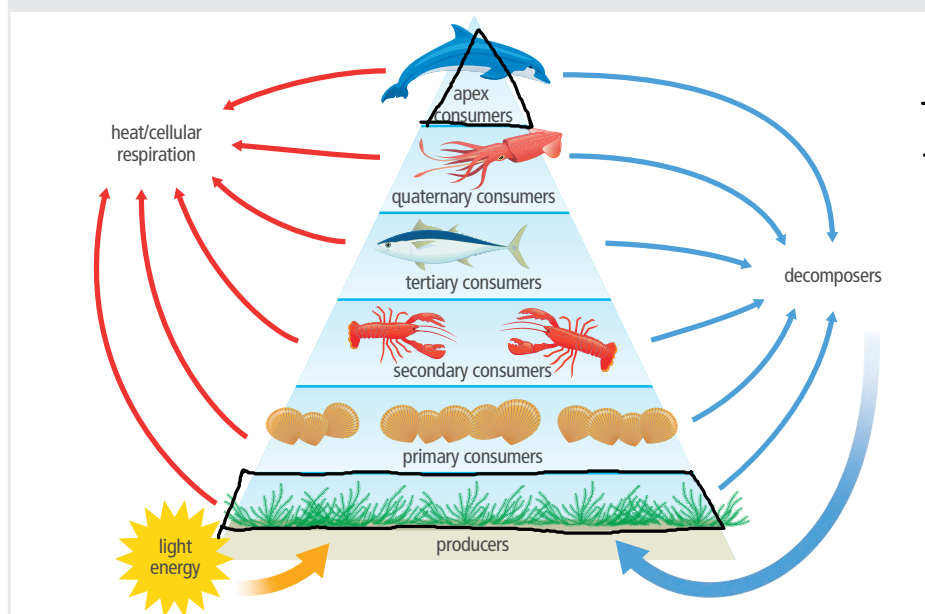
**FIGURE 14:** Energy and matter transfer between trophic levels, but some energy is lost as heat.



## 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.

Increase in trophic level means decrease in energy / biomass

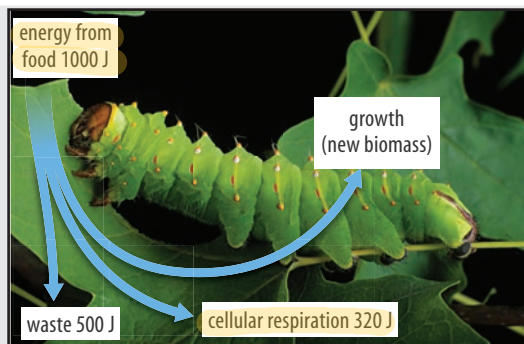


# Energy Calculations

## 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

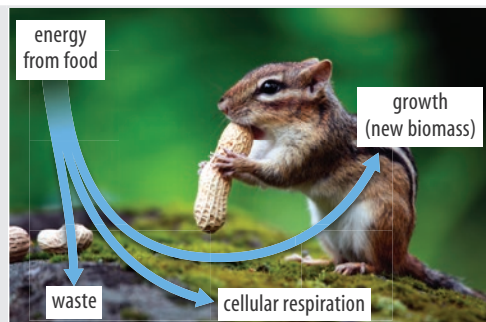
To determine the percentage of energy that is usable, divide the amount of available energy by the total amount of energy and multiply by 100 percent:

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

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.

- How many joules of energy are available to convert into new biomass?
- What percentage of the total energy was available to become new growth?
- What percentage of the total energy consumed was converted to unusable forms via cellular respiration, heat, and waste? **96.1**
- Make a model that supports the idea that energy is conserved. Use evidence from this example to support your claim.

Handwritten calculations:

$$1000 \text{ J} - 177 \text{ J} - 784 \text{ J} = 39 \text{ J}$$

$$\frac{39 \text{ J}}{1000 \text{ J}} = 3.9\%$$

$$100\% - 3.9\% = 96.1\%$$

## 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.

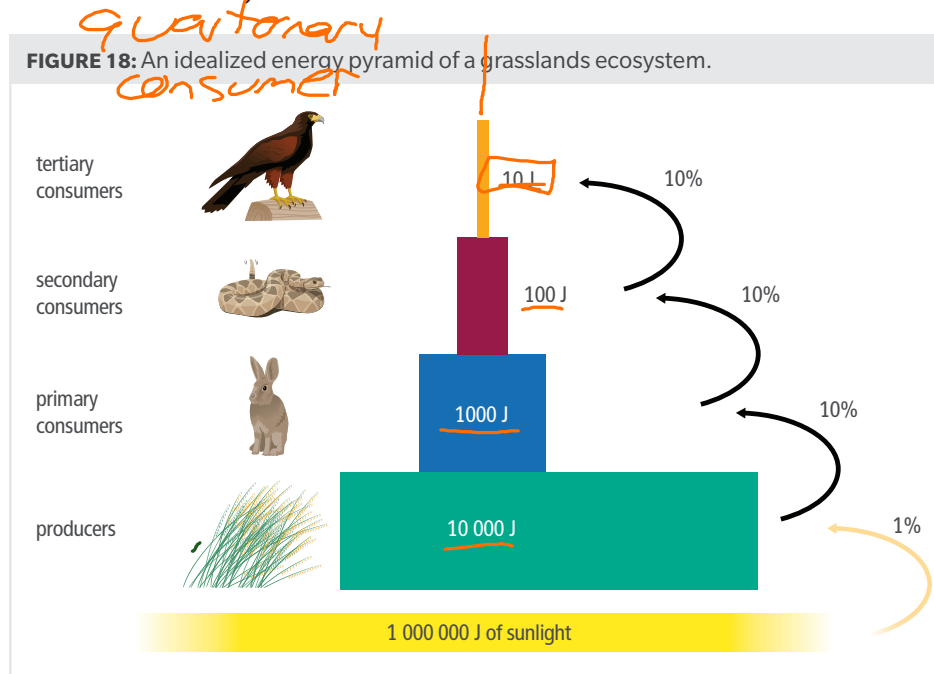
Pyramid models are useful for showing the productivity of an ecosystem and can illustrate the distribution of energy, biomass, and number of organisms. Productivity is the percentage of energy entering the ecosystem that is incorporated into biomass at a particular trophic level. Modeling ecosystem productivity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

### 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.



#### Gather Evidence

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



#### 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.

There is not enough energy for a quaternary consumer

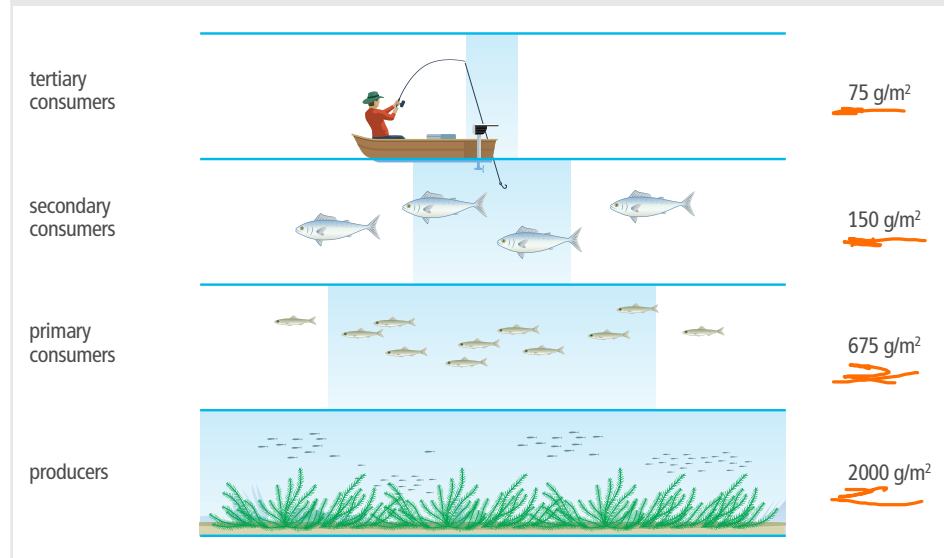


**Gather Evidence** Why is there a limit to the number of trophic levels in an ecosystem? Is energy conserved in an ecosystem?

## 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  $\text{g}/\text{m}^2$ .



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.