5.4 Efficiency, Energy Sources, and Energy Conservation

Electric light bulbs were invented over 150 years ago. Today, billions of light bulbs (lamps) illuminate vast areas of Earth at night (**Figure 1**). Light bulbs transform electrical energy into radiant energy and thermal energy.

Figure 1 Large areas of Earth are illuminated by incandescent light bulbs at night.

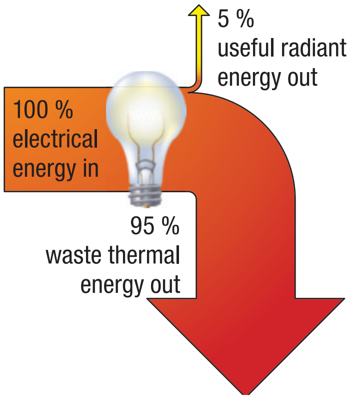

Figure 2 Incandescent light bulbs transform a very small percentage of the electrical energy supplied into radiant energy. Therefore, incandescent bulbs produce a lot of thermal energy waste.

Have you ever noticed how hot incandescent light bulbs get? Typical incandescent bulbs transform only about 5 % of the electrical energy delivered to the bulbs into radiant energy. The other 95 % of the electrical energy is transformed into thermal energy (**Figure 2**). We say that incandescent light bulbs are 5 % efficient at converting electrical energy (the supplied energy) into radiant energy (the desired energy). Since we use light bulbs for illumination, not heating, the thermal energy produced is considered to be waste energy or lost energy.

Efficiency

efficiency the amount of useful energy produced in an energy transformation expressed as a percentage of the total amount of energy used

Efficiency is the ratio of the amount of useful energy produced (energy output, or E_{out}) to the amount of energy used (energy input, or E_{in}), expressed as a percentage. Efficiency is calculated as follows:

$$\text{efficiency} = \frac{E_{out}}{E_{in}} \times 100\ \%$$

Tutorial 1 Using the Efficiency Equation

The efficiency equation may be used to calculate the efficiency of transforming one form of energy into another, or the efficiency with which work changes an object's gravitational potential energy or kinetic energy. In the first Sample Problem of this Tutorial, you will calculate the efficiency of transforming one form of energy into another. In the second Sample Problem, you will calculate the efficiency with which a machine transforms mechanical work into gravitational potential energy.

Sample Problem 1

A firefly's body transforms chemical energy in food into radiant energy that appears as a greenish glow in its abdomen (**Figure 3** on the next page). Fireflies use this glow to attract mates or prey. What is a firefly's efficiency if its body transforms 4.13 J of chemical energy into 3.63 J of radiant energy?

Since we are given the amounts of energy used and produced, we may use the efficiency equation to calculate the efficiency with which the firefly's body transforms chemical energy into radiant energy.

Figure 3 A firefly can transform chemical energy into radiant energy.

Given: $E_{in} = 4.13$ J (chemical); $E_{out} = 3.63$ J (radiant)

Required: efficiency

Analysis: $\text{efficiency} = \frac{E_{out}}{E_{in}} \times 100\ \%$

Solution:
$$\text{efficiency} = \frac{E_{out}}{E_{in}} \times 100\ \%$$
$$= \frac{3.63\ \cancel{\text{kJ}}}{4.13\ \cancel{\text{kJ}}} \times 100\ \%$$
$$\text{efficiency} = 88\ \%$$

Statement: The firefly's body transforms chemical energy into radiant energy with 88 % efficiency.

Sample Problem 2

What is the efficiency of a rope-and-pulley system if a painter uses 1.93 kJ of mechanical energy to pull on the rope and lift a 20.0 kg paint barrel at constant speed to a height of 7.5 m above the ground (**Figure 4**)?

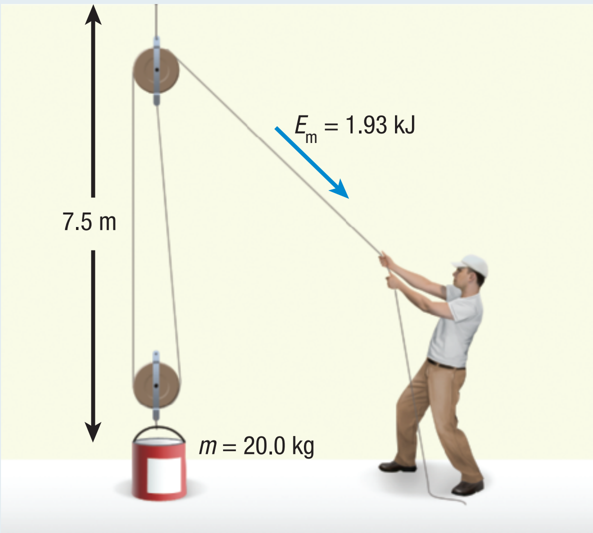

Figure 4 What is the efficiency of this rope-and-pulley system?

In this question, the input energy is the energy the painter uses to pull on the rope. You are not given the output energy, so you cannot use the efficiency equation right away. As the painter pulls on the rope, the paint barrel moves higher and gains gravitational potential energy. The painter's mechanical energy is transformed into gravitational potential energy. Therefore, E_g is the output energy, E_{out}. We may calculate the barrel's gravitational potential energy when it is 7.5 m above the ground by using the equation $E_g = mgh$.

Given: $E_{in} = 1.93$ kJ or 1.93×10^3 J; $m = 20.0$ kg; $h = 7.5$ m; $g = 9.8$ N/kg

Required: E_g, E_{out}, efficiency

Analysis: $E_g = mgh$ and $\text{efficiency} = \frac{E_{out}}{E_{in}} \times 100\ \%$

Solution:
$$E_g = mgh$$
$$= (20.0\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(7.5\ \text{m})$$
$$= 1.470 \times 10^3\ \text{J (two extra digits carried)}$$
$$E_{out} = 1.470\ \text{kJ (two extra digits carried)}$$
$$\text{efficiency} = \frac{E_{out}}{E_{in}} \times 100\ \%$$
$$= \frac{1.470\ \cancel{\text{kJ}}}{1.93\ \cancel{\text{kJ}}} \times 100\ \%$$
$$\text{efficiency} = 76\ \%$$

Statement: The efficiency of the rope-and-pulley system is 76 %.

Practice

1. A forklift uses 5200 J of energy to lift a 50.0 kg mass to a height of 4.0 m at a constant speed. What is the efficiency of the forklift? T/I [ans: 38 %]
2. A tow truck attaches a cable to a car stuck in a muddy ditch. The 1250 kg car is pulled up an embankment to a height of 1.8 m at a constant speed. The cable exerts a force of 5500 N over a distance of 12.6 m to pull the car out of the ditch. K/U T/I
   (a) What is the amount of useful energy produced? [ans: 22 kJ]
   (b) What amount of energy is used to pull the car from the ditch? [ans: 69 kJ]
   (c) Calculate the percent efficiency. Why is the efficiency less than 100 %? [ans: 32 %]

Improving the Efficiency of Energy Transformations

Figure 5 Fluorescent lamps are more efficient at producing radiant energy than are incandescent lamps.

Incandescent light bulbs are wasteful because they produce more thermal energy than radiant energy. Light bulbs are more efficient when they transform a greater amount of electrical energy into radiant energy. This is achieved, for example, in fluorescent lamps and compact fluorescent lamps (CFLs).

A CFL is a more compact version of the long fluorescent tube lamps commonly used in large spaces such as office buildings and schools (**Figure 5**). Fluorescent lamps may transform up to 25 % of the supplied electrical energy into radiant energy. This is a significant improvement in efficiency over incandescent light bulbs. Although fluorescent lamps typically cost more than incandescent bulbs to purchase, they may provide the same amount of illumination at a lower overall cost because they use less electrical energy to produce the same amount of radiant energy. However, fluorescent lamps contain mercury, a poisonous element, which may pollute the environment when the lamps are not disposed of properly. **Table 1** describes the energy transformation efficiency of a number of different devices and processes.

Table 1 Energy Transformation Efficiencies of Various Devices and Processes

Device or process	Energy transformation	Major waste output energy	Transformation efficiency	Considerations
gasoline-powered vehicle	chemical (in gasoline) → kinetic (vehicle motion)	thermal	8–15 %	• produces carbon dioxide, which contributes to climate change • creates air pollution
electric vehicle	electrical → kinetic (vehicle motion)	thermal	24–45 %	• currently more expensive to purchase than gasoline-powered vehicles • more efficient than a gasoline vehicle but uses heavy batteries that must be constructed and discarded in special ways to help limit environmental contamination
bicycle	kinetic (pedal) → kinetic (bicycle motion)	thermal	90 %	• most efficient self-powered vehicle • limited to transporting one or two individuals • use is weather dependent • road safety issues
loudspeakers	electrical → sound	thermal	1 %	• efficiency appears to be low, but useful output energy is more than enough to produce audible sound • most of the electrical input is transformed into thermal energy
electric heater	electrical → thermal	radiant	98 %	• very efficient transformer of electrical energy into thermal energy
hydroelectric power plant	kinetic (moving water) → electrical	thermal	80 %	• efficient method of generating electricity • damming rivers may flood land and disrupt ecosystems
nuclear power plant	nuclear → electrical	thermal	30–40 %	• relatively efficient for generating electricity • produces radioactive waste
solar cell	radiant → electrical	thermal	20–40 %	• relatively efficient for generating electricity
photosynthesis	radiant → chemical	thermal	5 %	• although it appears inefficient, it is the only process that transforms radiant energy into chemical energy in organisms • directly or indirectly responsible for maintaining virtually all life on Earth
animal muscles (including human muscles)	chemical (in food) → kinetic (muscle movement)	thermal	20 %	• although it appears to be relatively inefficient, this energy-transforming process provides all the energy animals use to perform work

All the devices and processes in Table 1 transform energy with less than 100 % efficiency. This is a general result: no device or process is 100 % efficient. Another general result is that thermal energy is the most common form of waste energy. Of course, when thermal energy is the desired form of energy output (as in a heater), it is not considered to be waste energy. A primary goal of scientists and engineers is to improve the efficiency of devices and processes that transform energy.

Sources of Energy

We obtain energy from a variety of sources. For example, animals obtain chemical energy from food. This energy originates as radiant energy from the Sun (solar energy), which is captured and transformed into chemical energy by plants in the process of photosynthesis.

Energy-rich substances such as crude oil and natural gas are commonly called **energy resources**. Some energy resources are considered non-renewable, while others are renewable. A **non-renewable energy resource** is an energy-rich substance that cannot be replenished as it is used in energy-transforming processes. Fuels such as coal, oil, and natural gas are common non-renewable energy resources. A **renewable energy resource** is an energy-rich substance with an unlimited supply or a supply that can be replenished as the substance is used in energy-transforming processes. Radiant energy from the Sun is an example of a renewable energy resource.

energy resource energy-rich substance

non-renewable energy resource a substance that cannot be replenished as it is used in energy-transforming processes

renewable energy resource a substance with an unlimited supply or a supply that can be replenished as the substance is used in energy-transforming processes

Non-renewable Energy Resources

Non-renewable energy resources are the most widely used sources of energy. Most automobiles, trains, motorized boats, and airplanes use non-renewable sources of energy. The most common are fossil fuels.

FOSSIL FUELS

Today, most automobile engines use the chemical energy in fuels such as gasoline and diesel. These fuels are called **fossil fuels** because they are the decayed and compressed remains of prehistoric plants and animals that lived between 100 million and 600 million years ago. Like today's plants, ancient plants transformed solar energy into chemical energy through photosynthesis. After the plants died, their bodies decomposed to form chemical mixtures such as crude oil. Today, we pump crude oil from underground deposits and separate, or refine, it into a variety of useful substances, including gasoline and diesel fuels.

fossil fuel fuel produced by the decayed and compressed remains of plants that lived hundreds of millions of years ago

Other commonly used fossil fuels are coal and natural gas. Unlike gasoline and diesel, which are liquids at room temperature, natural gas is a gas that is mainly composed of a compound called methane. Natural gas is used as a fuel in furnaces (for heating), stoves (for cooking), and automobiles (for transportation) (**Figure 6**).

Figure 6 The burner of a natural gas stove

Fossil fuels are non-renewable energy resources because it takes millions of years for them to form. Once we use up the limited supply of these fuels, we will no longer have them as a source of energy. Of course, we will run out of fossil fuels and other non-renewable energy resources faster if we waste them or if we use devices that transform their energy inefficiently.

NUCLEAR ENERGY

Nuclear energy is a form of potential energy produced by interactions in the nucleus of atoms (atomic nuclei). Nuclear energy is released and transformed into other forms of energy when the nuclei of large, unstable atoms such as uranium decompose into smaller, more stable nuclei. Nuclear energy is also released when the nuclei of small atoms such as hydrogen combine to form larger nuclei. The decomposition of large, unstable nuclei is called **nuclear fission**, which takes place in power plants and radioactive elements. The combination of smaller nuclei to form larger nuclei is called **nuclear fusion**, which is the power source of the Sun.

nuclear fission the decomposition of large, unstable nuclei into smaller, more stable nuclei

nuclear fusion a nuclear reaction in which the nuclei of two atoms fuse together to form a larger nucleus

Figure 7 The Pickering Nuclear power plant in Pickering, Ontario

In Canada, nuclear energy is produced mostly by the fission of uranium in large nuclear power plants (**Figure 7**). In this process, nuclear energy is transformed into thermal energy, which heats water and turns it into steam. The high-pressure steam passes through pipes and turns the blades of a turbine, which is connected to an electricity generator (**Figure 8**). The electricity generator produces current electricity that is distributed through a large network of wires called the power grid. Currently, nuclear power plants produce approximately 52 % of Ontario's supply of electrical energy. You will learn more about nuclear energy in Chapter 7.

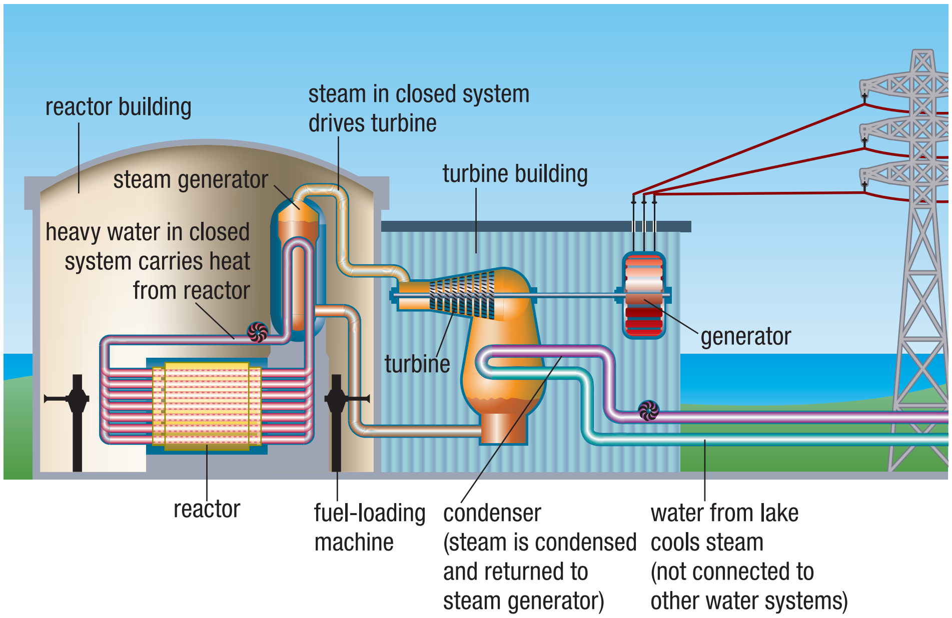

Figure 8 Basic operations of a nuclear power plant

Renewable Energy Resources

Renewable energy resources are virtually inexhaustible. Some renewable energy resources have been used as sources of energy for a long time, while others have been discovered more recently. The radiant energy of the Sun, the kinetic energy of moving water (waves and waterfalls), and the kinetic energy of moving air (wind) are some of the renewable energy resources that humans have used over time.

SOLAR ENERGY

solar energy radiant energy from the Sun

A common renewable energy resource is radiant energy from the Sun, or **solar energy**. Scientists have estimated that the Sun will continue to emit radiant energy for the next 5 billion years. This is such a long time that we consider the supply of radiant energy to be unlimited and, therefore, renewable.

passive solar design building design that uses the Sun's radiant energy directly for heating

photovoltaic cell a device that transforms radiant energy into electrical energy

Solar energy may be transformed into thermal energy for heating or into electrical energy to run electrical devices and appliances. **Passive solar design** is designing homes and buildings to take direct advantage of the Sun's radiant energy for heating. Alternatively, the Sun's radiant energy may be transformed into electrical energy using a device called a **photovoltaic cell**. The electrical energy produced by photovoltaic cells may be used immediately to run electrical appliances or may be stored in batteries for future use.

Passive Solar Design

In the northern hemisphere, the Sun appears to move from east to west in the southern part of the sky. However, the Sun appears to reach a much higher altitude in the middle of the day during the warmer summer months than it does during the colder winter months. Architects and designers may take advantage of the seasonal changes in the Sun's apparent position in the sky when they design buildings.

For example, they may place windows and eaves on the south-facing side of a building so that the rays of the Sun shine directly through the windows in the winter but not in the summer (**Figure 9**). This design will help the building's interior spaces warm up in the winter and remain cooler in the summer.

Additional passive solar design elements that architects may use include

- orienting buildings so that they have one wall facing the Sun
- placing more windows or larger windows on the sunny side of a building
- placing tall deciduous trees on the sunny side of a building so the Sun's rays are blocked in the summer when the trees are covered in leaves but not in the winter when the leaves have fallen off the trees

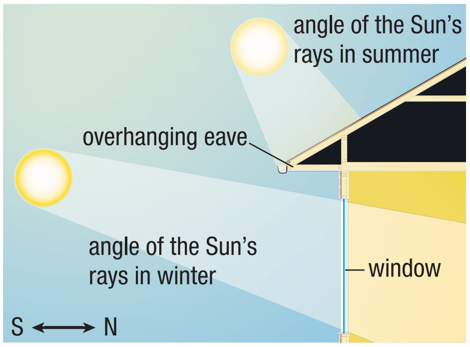

Figure 9 Passive solar design helps reduce the need for furnaces and air conditioners.

Photovoltaic Cells

When solar energy interacts with certain solids, such as modified forms of silicon, the radiant energy may be transformed into electrical energy in the form of an electric current. This is the energy transformation that occurs in a photovoltaic cell. When the source of radiant energy is the Sun, the photovoltaic cell is sometimes called a solar cell (**Figure 10**).

Photovoltaic cells may be placed on the roofs of houses and other buildings or on the surfaces of devices such as outdoor light fixtures and parking meters (**Figure 11**). Since photovoltaic cells rely on a constant supply of solar energy to operate, they are usually connected to batteries, which store excess electrical energy produced on bright, sunny days for use at night or on cloudy days.

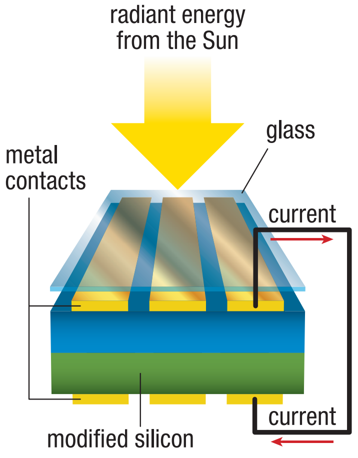

Figure 10 Radiant energy is transformed into electrical energy (electric current) in a photovoltaic cell.

Figure 11 A parking meter uses electrical energy produced by a solar cell.

hydroelectricity electricity produced by transforming the kinetic energy of rushing water into electrical energy

HYDROELECTRICITY

The kinetic energy of rushing water is transformed into electrical energy (electric current) in a hydroelectric power plant. Electrical energy produced in this way is called **hydroelectricity** or, simply, hydro. Hydroelectricity is considered a renewable energy resource because the water cycle ensures that there is always a supply of water with high potential energy in the power plant's reservoir (**Figure 12**). In the water cycle, solar energy causes water in lakes and rivers to evaporate and rise into the upper atmosphere, where the vapour cools, condenses, and falls as precipitation. As water in the reservoir falls through the penstock, it gains kinetic energy and strikes the blades of a fan-like turbine at the lower end. The turbine is connected to an electricity generator, which produces electric current. Hydroelectric power plants produce more electrical energy than any other renewable energy resource in the world.

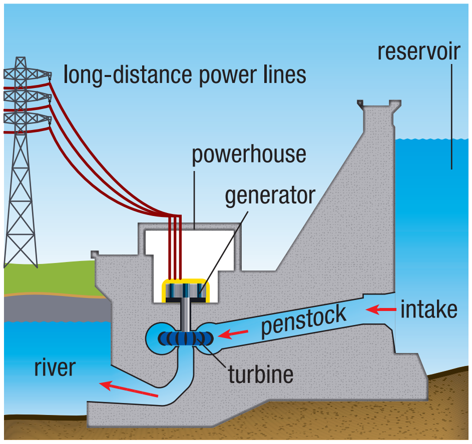

Figure 12 Operations of a typical hydroelectric power plant

A number of other renewable energy resources, in addition to solar energy and hydroelectricity, may help us reduce pollution and meet our energy needs. **Table 2** describes additional renewable energy resources.

LEARNING TIP

"Conserving Energy" and "The Law of Conservation of Energy"
When we say "conserve energy" or "energy conservation," we are referring to ways in which people may avoid wasting energy. However, the law of conservation of energy refers to the idea that the total amount of energy is conserved when one form of energy is transformed into another form of energy.

Table 2 Additional Renewable Energy Resources

Renewable energy resource	Description	Considerations
geothermal	• Earth possesses a virtually unlimited supply of thermal energy deep underground. • Geothermal energy may be used directly for heating and cooling or be transformed into electrical energy.	• accessible only in certain areas • in some locations, deep holes need to be drilled into the ground to reach pockets of thermal energy
wind	• Wind strikes the blades of a fan-like turbine, which turns an electricity generator that generates electrical energy.	• can be used only in windy locations • turbines generate electricity only when wind is blowing • turbines are noisy, and the blades may strike birds and other wildlife
tidal	• As tides rise and fall, the moving water strikes the blades of a turbine, which turns a generator. The generator generates electrical energy. • Tidal turbines are similar to wind turbines and are placed in bodies of water where significant tidal movements occur.	• turbines only work during tidal movements • may disrupt aquatic ecosystems
biofuels	• Biofuels are solid, liquid, and gaseous fuels derived from the bodies of living or dead plants and animals. • Biofuels can include wood, biological waste, and gases such as methane produced during the decomposition of plant matter. • Solid biofuel may be called biomass and gaseous biofuel may be called biogas.	• burning the fuels may produce air pollutants, including carbon dioxide, which is linked to climate change

Although renewable energy resources are replaceable or unlimited in supply, non-renewable energy resources such as coal, oil, and natural gas continue to be the most widely used sources of energy in the world today. Much of this is because most of today's electric power plants, engines, heating systems, and appliances are designed to transform the chemical energy in fossil fuels into other forms of energy. The large-scale, global use of fossil fuels and fossil fuel–using devices keeps prices relatively low.

CAREER LINK

To learn more about becoming an energy operations manager or power systems engineer,

GO TO NELSON SCIENCE

Conserving Energy

Energy may be conserved by designing, producing, and using machines, appliances, and devices that transform energy more efficiently. Energy may also be conserved by

- turning lights off when not required
- switching off electrical devices instead of leaving them on standby mode
- taking short showers instead of baths if possible
- running dishwashers and clothes washers only when they are full
- hanging clothes to dry
- using fans to reduce the need for air conditioning
- using public transit and carpooling when possible

WEB LINK

To learn more about ways you can conserve energy,

GO TO NELSON SCIENCE

5.4 Summary

- The equation to calculate the efficiency of an energy transformation is $\text{efficiency} = \frac{E_{out}}{E_{in}} \times 100\ \%$, where E_{out} is the useful energy output and E_{in} is the energy input.
- No energy-transforming device is 100 % efficient. Typically the waste energy is in the form of thermal energy.
- Non-renewable energy resources are energy-rich substances that cannot be replenished when they are used up in the energy transformation process.
- Renewable energy resources are energy-rich substances with an unlimited supply or a supply that can be replenished.
- There are many ways to conserve energy.

UNIT TASK BOOKMARK

You can apply what you have learned about efficiency and energy resources to the Unit Task on p. 360.

5.4 Questions

1. In a race, a 54 kg athlete runs from rest to a speed of 11 m/s on a flat surface. The athlete's body has an efficiency of 85 % during the run. How much input energy did the athlete provide? T/I
2. Athletes who compete in downhill skiing try to lose as little energy as possible. A skier starts from rest at the top of a 65 m hill and skis to the bottom as fast as possible. When she arrives at the bottom, she has a speed of 23 m/s. T/I
   (a) Calculate the efficiency of the skier.
   (b) Explain why the mass of the skier is not required when calculating the efficiency.
3. A golf club with 65 J of kinetic energy strikes a stationary golf ball with a mass of 46 g. The energy transfer is only 20 % efficient. Calculate the initial speed of the golf ball. T/I
4. Describe one advantage and one disadvantage in using
   (a) non-renewable energy resources
   (b) renewable energy resources K/U A
5. Compare nuclear power plants with hydroelectric power plants in terms of efficiency, method of generating electricity, energy transformations, and environmental impact. K/U C A
6. An article on the Internet claims, "Fossil fuels are actually a renewable energy resource since decaying plant and animal matter is making new oil, natural gas, and coal all the time." Discuss the validity of this statement. C A
7. In this section, two different methods of using solar energy were described: passive solar design and photovoltaic cells. Explain the difference between passive solar design and photovoltaic cells. K/U