Chapter 5

Energy Resources and Consumption

A variety of sources provide the energy necessary to power developing and industrialized societies. Fossil fuels, which included coal, oil, and natural gas, are the result of millions of years of decay of organic material deep within the Earth. Humans now extract these resources in order to harness the stored energy through combustion processes. Alternative fuel sources, such as hydroelectric power and nuclear power, have been used for many generations. New advancements in energy production have led to new types of energy sources, such as solar, wind, biomass, hydrogen, geothermal, tidal, and wave energy. Now more than ever, the importance of addressing both energy production and consumption on a global scale is at the forefront of modern society. Conservation initiatives and sustainable sources are becoming the focus of the energy industry and societies as a whole.

Energy Concepts

Energy comes in many forms, both natural and man-made. Forms of energy include mechanical, thermal, chemical, nuclear, electrical, and electromagnetic. Energy measures the ability of an object to perform work and to move objects. Energy can be transferred or converted from one form to another. There are two forms of mechanical energy: potential energy and kinetic energy. Energy possessed by a moving object is called **kinetic energy.** A stationary object has **potential energy** if its position can be converted into movement. If you suspend a coin from your fingers as if you are going to drop it, but you don't let it fall, the coin has potential energy, or energy stored in a system or an object. If you drop the coin, as it falls through the air it has kinetic energy, or energy due to its motion.

Forms of Potential and Kinetic Energy

Potential Energy	Kinetic Energy
Chemical energy is the most practical form of energy. It is a chemical reaction between bonds of atoms to form molecules. Chemical energy is converted to thermal energy when we burn wood in a fireplace. There are two types of chemical reactions: endothermic and exothermic. Endothermic reactions take in heat energy; thus, providing no usable energy. Exothermic reactions release energy during the reaction. For example, when we burn coal in the presence of oxygen, we get carbon dioxide, water, pollutants, and energy. The chemical reaction is $\text{coal} + O_2 \xrightarrow{\text{burn}} CO_2 + H_2O + \text{pollutants} + \text{energy}$	**Thermal energy,** or heat energy, is the energy created by the movement of molecules within a substance. As a substance gets warmer, the vibrations of the molecules within that substance increase. When boiling water, for example, thermal energy is added to the bottom of a pot. This thermal energy is transferred across the pot, into the water, and the water molecules move faster. Eventually, enough heat is added to boil the water, and as the water boils, it quickly turns to steam.

(continued)

Potential Energy	Kinetic Energy
Mechanical potential energy is energy stored in objects by tension or position. A stretched rubber band is an example of stored mechanical energy, as are objects held above the ground. Gravitational energy is also classified as a type of mechanical energy.	**Kinetic (electromagnetic) energy** is energy of motion, which can be transformed into electrical energy. One way to generate electrical energy is to turn a generator, which consists of coiled copper wire and magnets. As the wire coil spins, it cuts through the magnetic field, resulting in a flow of electrons through the wire. (Moving electrical charges possess both an electric and a magnetic field.) This process generates an alternating current that passes into electrical transmission lines. This is the form of electrical energy we use in our houses. Anything that turns the copper coil through the magnetic field possesses kinetic energy that can create electromagnetic energy, including wind or water turning a turbine, or coal or nuclear fusion boiling water, whose steam powers similar turbines.
Nuclear energy is stored in the nuclei (core) of an atom and is released when an atom splits apart or two atoms join together. The process of splitting an atom is called **fission,** and the process of joining atoms is called **fusion.** For example, fission occurs in nuclear power plants when huge amounts of heat are created by splitting the nuclei of uranium atoms. The process of fusion occurs when the sun combines the nuclei of hydrogen atoms.	
Gravitational energy is energy stored in an object's height. The higher and heavier the object, the more gravitational energy is stored. When you ride a bicycle down a steep hill and pick up speed, your gravitational energy is converted to motion, or kinetic energy. Hydropower generation converts the gravitational energy of water in reservoirs to kinetic energy of moving water, which drives turbines that create electricity.	
Electrical energy is created from the motion of electrons. Electrical energy is transferred by tiny charged particles called **electrons,** typically moving through a wire. Just as gravitational energy is stored in stationary water in reservoirs, electrical energy is stored in batteries. When electrical energy is allowed to convert itself into the kinetic energy of electrical current, it can be used to power a cellphone or start a car. During a storm, electrical energy may be generated and released as lightning. Walk across the carpet on a dry day and you store electrical energy in your body, which you release with a small zap when you touch a conductive object. This is static electricity.	

The following table contains some of the most common energy terms used in AP Environmental Science.

Common Terms Used in AP Environmental Science

Term	Definition
British Thermal Unit (BTU or Btu)	The amount of heat it takes to raise the temperature of 1 pound of water by 1°F
Calorie (c)	The amount of heat it takes to raise the temperature of 1 gram of water by 1°C (1.8°F)
Kilocalorie (C)	The amount of heat it takes to raise the temperature of 1 kilogram of water by 1°C (1.8°F)
Horsepower (hp)	Primarily used in the combustion engine market, such as in autos, trucks, boats, and backup generators; 1 horsepower = 746 watts
Joule (J)	The force of 1 Newton applied through 1 meter of displacement
Watt (electrical) (W)	Measures the rate of energy conversion and is defined as 1 joule per second; commonly used in terms of kilowatt-hour (kWh) energy consumption; used by power plants to describe how much energy they generate (megawatt-hours) and on home energy bills (kWh)
Watt (thermal)	Used in nuclear power plants to measure the amount of thermal energy generated

Common SI (International System of Units) Prefixes Used in Energy

Term	Definition
Kilo– (k)	1,000 or 10^3; common metric term that is used in the power industry
Mega– (M)	1,000,000 or 10^6; common metric term that is used in the power industry
Giga– (G)	1,000,000,000 or 10^9; commonly used in the computer industry and in talking about energy needs and energy produced in regions and smaller countries.
Tera– (T)	1,000,000,000,000 or 10^{12}; new term used in the computer industry and is becoming more common in talking about the total energy needs and energy produced in a country

Following is a table of conversion factors useful in environmental science. On the AP Environmental Science exam, the conversion factors are provided, and conversions are rounded. For example, 1 kWh is equal to 3,413 BTU, but the AP Environmental Science exam rounds this number to 3,400 BTU, which makes multiplication easier. Despite the fact that conversions are given on the exam, it is useful to familiarize yourself with the conversions below to build intuitive understanding of relationships between units.

Conversions		
Symbol	**Unit**	**Conversion**
1 c	Calorie	3.968 BTU or 4,186 J
1 BTU	British Thermal Unit	0.254 c or 1,055 J
1 W	Watt	1 W for 1 hour is 3.413 BTU
1 kWh	Kilowatt hour	1 kW for 1 hour is 3,413 BTU ***Note:*** 3,400 BTU is commonly used on the AP exam to simplify calculations.
1 MW	Megawatt	1,000,000 W or 1,000 kW
1 GW	Gigawatt	1,000,000,000 W, 1,000,000 kW, or 1,000 MW
1 hp	Horsepower	0.7457 kW or 2,545 BTU
1 gallon gas	Gallon of gasoline	125,000 BTU
1 barrel oil	Barrel of crude oil	25,000,000 BTU or 42 gallons of crude oil
1 CF natural gas	Cubic foot of natural gas	1,031 BTU

APES Math Problems

Every set of free-response questions on the AP Environmental Science exam includes at least one math-based problem. Recently, including more than one math problem has become the norm. For the most part, the math consists of algebraic word problems, including determining a percentage change to using dimensional analysis for unit conversion problems, and problems of straightforward arithmetic.

Math Problems on Prior AP Environmental Science Exams

The following is a review of the math problems for previous AP Environmental Science exams, with energy calculation problems in bold:

- 1998: **Energy calculation (BTU) of a dishwasher,** dimensional analysis
- 1999: Percentage change, air pollutants
- 2000: **Energy calculation (BTU) of a power plant,** pollutant calculation (pounds of sulfur), dimensional analysis
- 2001: **Energy calculation (BTU) of a house,** dimensional analysis
- 2002: **Gasoline consumption vs. electric vehicles,** dimensional analysis; Graphing of LD_{50}
- 2003: Graphing, population growth rate calculation
- 2004: **Energy calculation in kWh of wind power, conversion between kilo and mega,** comparison, dimensional analysis
- 2005: Percentage change, meat consumption; **Usage calculation of barrels of crude oil,** ANWR, simple dimensional analysis
- 2006: Net change, ratio, CO_2 and temperature; Change over time, graph provided, decline of fish population
- 2007: Water usage and cost, dimensional analysis
- 2008: Cross-multiplication, how many acres; Calculation of volume for a landfill, dimensional analysis; Graph total fertility, no grid lines provided
- 2009: **Energy calculation for methane digesters** (number was a decimal but had to round to the whole number; number was not nice and neat, dimensional analysis); Percentage of land use change, graph provided, GM crops
- 2010: Cost to capture CO_2 emissions, simple dimensional analysis; methane emissions from termites, dimensional analysis; rising sea level, simple dimensional analysis

Dimensional Analysis

A dimensional analysis uses conversion factors to transform data represented in one type of units to data represented in other units.

Here's how to solve a math problem using dimensional analysis:

1. **Read the question to determine the final units.**
2. **Set the final units at the end of a dimensional analysis equation.**
   These desired final units are the only units that will not "cancel." All other units will be used to convert from starting units toward the desired ending units.
3. **Check that the problem is set up so that starting units are converted into ending units.**
   To cancel units, you need the unit on one top numerator and one bottom denominator of the dimensional analysis equation. Units should cancel the same way numbers would cancel.
4. **Simplify the math, cancel out zeros, and simplify the numbers.**
5. **Solve the math.**
6. **Rewrite the answer including the units.**
   Indicate that this is the final answer.

EXAMPLE:

> Several AP Environmental Science teachers were sitting around a table discussing the full coal cars heading east to several big cities and the empty coal cars returning to the mines in the west. The teachers were wondering how much energy was in each coal car and how long the coal would last. In addition, they discussed the environmental impact of mining and transporting the coal across these distances.
>
> A large, coal-fired power plant produces 48 million kWh of electricity each day. Assume the following: 10,000 BTUs are required to produce 1 kWh of electricity; 1 pound of coal produces 5,000 BTUs of heat; each coal car can hold 120 tons; 1 ton is 2,000 pounds.
>
> **A.** How much heat in BTUs is needed to operate the coal plant for one day?
> **B.** How many coal cars will be needed to operate the power plant for the day?
> **C.** How many trains will be needed to power the plant for a day if the train pulls 100 coal cars?

Follow the steps listed earlier:

1. **Read the question to determine the final units.**
   The first question asks how much heat in *BTUs* is needed to produce the power for one day.
2. **Set the final units at the end of a dimensional analysis equation.**
   Using the information provided, days should be on the bottom and BTUs on the top (BTUs/day). kWh/day, is included in the statement "48 million kWh are produced in one day." Write this first. Next, it states that 10,000 BTUs are used to produce 1 kWh of electricity, so place BTUs/kWh second in the analysis. Now, with kWh on the top and kWh on the bottom, the units cancel.

$$\frac{48 \text{ million kWh}}{\text{day}} \left| \frac{10{,}000 \text{ BTUs}}{1 \text{ kWh}} \right. =$$

3. **Check that the problem is set up so that starting units are converted into ending units.**

4. **Simplify the math, cancel out zeros, and simplify the numbers.**

$$\frac{48\text{ million }\cancel{\text{kWh}}}{\text{day}}\;\Bigg|\;\frac{10{,}000\text{ BTUs}}{1\;\cancel{\text{kWh}}} =$$

In this problem, the numbers are already in their simplest form.

5. **Solve the math.**

$$\frac{48\text{ million}}{\text{day}}\;\Bigg|\;\frac{10{,}000\text{ BTUs}}{1} = \frac{480{,}000\text{ million BTUs}}{\text{day}}$$

6. **Rewrite the answer including the units.**

$$\frac{480{,}000\text{ million BTUs}}{\text{day}}\text{ or simplified: }\frac{480\text{ billion BTUs}}{\text{day}}$$

Helpful Hints

- ❑ In the 13 years of the AP Environmental Science exam, no one has ever lost points for failing to include the units. However, it is *highly recommended* that units are included at every step to ensure that you're solving the problem correctly.
- ❑ When solving the problem, be sure to fully document all of your work, including the dimensional analysis in the book that will be scored. If the problem is solved in the test pages for making notes and the only answer is in the scored booklet, you won't receive any points, even if the answer is correct. In addition, often in the data-based question, partial points are given for showing the setup of the equation.
- ❑ Scientific notation can be used.

Now answer the second question in the example:

1. **Read the question to determine the final units.**
   The final units are coal cars per day.
2. **Set the final units at the end of a dimensional analysis equation.**
3. **Check that the problem is set up so that starting units are converted into ending units.**
4. **Simplify the math, cancel out zeros, and simplify the numbers.**

$$\frac{480{,}00\cancel{0}\;\overset{\cancel{000{,}000}}{\cancel{\text{million BTU}}}}{\text{day}}\;\Bigg|\;\frac{1\;\cancel{\text{lb}}\text{ coal}}{5{,}\cancel{000}\;\cancel{\text{BTU}}}\;\Bigg|\;\frac{1\;\cancel{\text{ton}}}{2{,}\cancel{000}\;\cancel{\text{lb coal}}}\;\Bigg|\;\frac{1\text{ coal car}}{12\cancel{0}\;\cancel{\text{tons}}}$$

5. **Solve the math.**

$$\frac{48{,}000}{\text{day}}\;\Bigg|\;\frac{1}{5}\;\Bigg|\;\frac{1}{2}\;\Bigg|\;\frac{1\text{ coal car}}{12} = \frac{48{,}000\text{ coal cars}}{120\text{ day}} = \frac{400\text{ coal cars}}{\text{day}}$$

6. **Rewrite the answer including the units.**

$$\frac{\text{400 coal cars}}{\text{day}}$$

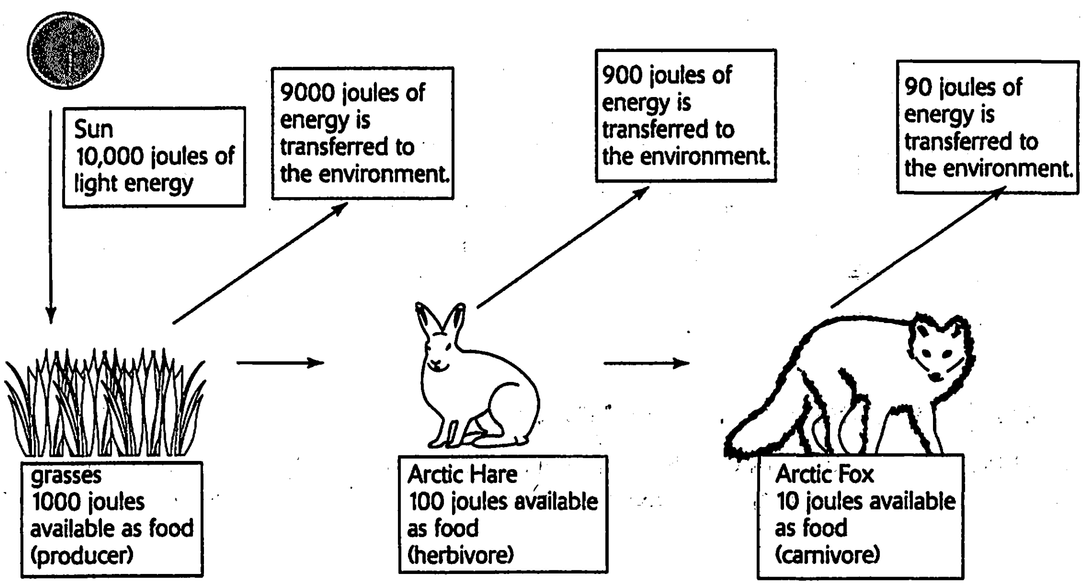
Now try the final question in the example.

1. **Read the question to determine the final units.**
   The final units are trains per day.
2. **Set the final units at the end of a dimensional analysis equation.**
3. **Check that the problem is set up so that starting units are converted into ending units.**
4. **Simplify the math, cancel out zeros, and simplify the numbers.**
5. **Solve the math.**
6. **Rewrite your answer including the units.**

$$\frac{400\ \cancel{\text{coal cars}}}{\text{day}} \Bigg| \frac{\text{trains}}{100\ \cancel{\text{coal cars}}} = \frac{\text{4 trains}}{\text{day}}$$

Laws of Thermodynamics

There are four laws of thermodynamics, two of which are especially applicable in natural systems. The **first law of thermodynamics** states that energy can be changed from one form to another, but it cannot be created or destroyed. Energy input is equal to energy output. The **second law of thermodynamics** (see the following figure) deals with order and has many implications including the fact that systems naturally flow from states of high energy (low entropy), to states of low energy (high entropy). Systems do not naturally move toward higher states of order, and when energy flows through the components of a system, some energy is made unavailable at each transfer. Think of a food chain: the sun's energy is photosynthesized in plant material, which may then be eaten by (for example) a deer. However, the deer uses much of this energy for heat and movement, rather than growth, so when the deer is eaten by a mountain lion, the lion receives only a fraction of the initial energy provided by the sun.



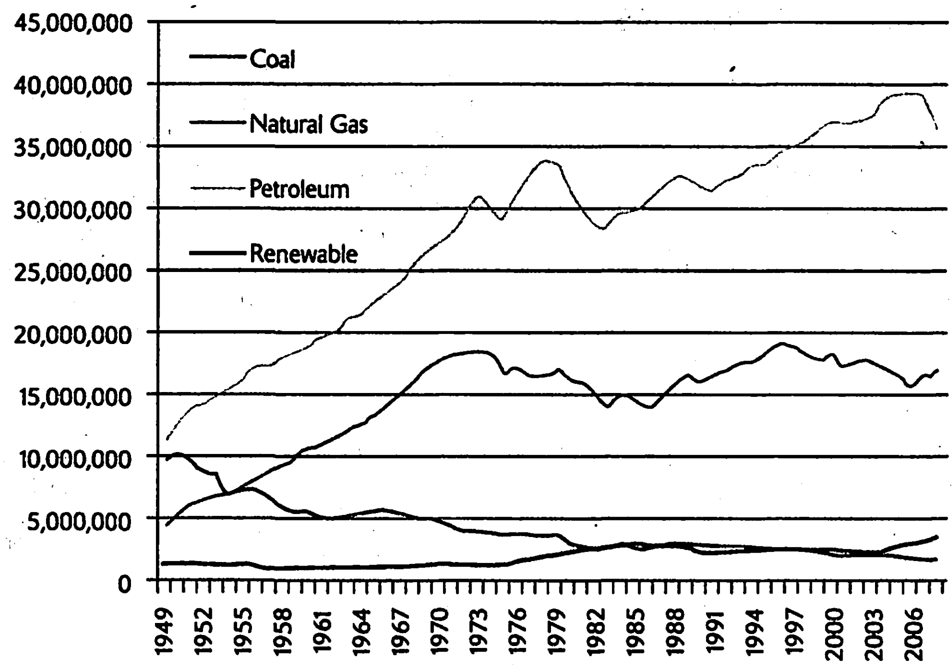
Progressive loss energy in the food chain due to the Second Law of Thermodynamics

Energy Consumption

Biomass, usually in the form of wood, was humanity's fuel for thousands of years, until the Industrial Revolution. Although wood is considered a renewable resource, the need for wood grew along with the human population, and as the Industrial Revolution put more demands on wood consumption, forests could no longer regrow as fast as they were being cut, leading to overall depletion. This depletion meant that humans had to go farther and farther to reach forests to satisfy their energy needs, but the energy cost of transporting wood from faraway forests was great compared to the amount of energy derived from the wood. These two factors prompted a switch from wood to coal as the energy source of choice.

At the beginning of the Industrial Revolution, coal was abundant and cheap. It has a higher energy yield per pound than wood. Around 1885, as the Industrial Revolution became widespread not only in the United Kingdom and the United States but also in much of Europe and Japan, the worldwide energy produced by burning coal exceeded the energy produced by burning wood. In turn, coal was replaced by petroleum in the middle of the 20th century. Petroleum remains the dominant source of energy worldwide (see U.S. Energy Consumption Graph below). However, during the latter half of the 20th century and the first decade of the 21st century, coal and natural gas have seen rapid expansions in use, due in part to the increase in the cost of petroleum and the decline in petroleum reserves.

U.S. Energy Consumption by Source



Source: Kenneth R. Szulczyk, Ph.D.

The History of Energy Consumption

Until the late 1950s, the United States was able to meet its energy needs with domestic production. At the end of that decade, however, energy consumption exceeded domestic production, and the United States began to import energy, generally in the form of petroleum. Why was there a change in energy consumption? Because prior to World War II, the United States was just coming out of the Great Depression and energy consumption was comparably low. During the early stages of war, the United States increased the manufacturing of ships, planes, and vehicles built to fight and transport American troops and ammunition for war. After the war, only limited manufacturing remained during the Cold War, and other manufacturing was converted to peace time activities. The shift from agricultural to industrial professions also continued during this time. In the 1930s, approximately 21 percent of the work force worked on farms. By the 1950s, that number had decreased to just over 12 percent; it had decreased to 3.4 percent of the work force by the 1980s.

The average home size also began to get larger, from 938 square feet of floor space in 1950 to 2,266 square feet in 2000, a 141.6 percent increase over 50 years. Larger homes require more energy for heating and cooling. Additionally, the population began to shift toward warmer climates, requiring increased use of air conditioning to cool homes, business, and public buildings. Even in temperate climates, people started using air conditioners more often. Other energy-using appliances were developed, modified to become more automated requiring more energy, or increased in size and, thus, energy consumption. For example, refrigerators were developed, became ubiquitous, and then became larger. TVs first appeared in the late 1940s, and by the late 1950s became common household products, and then became larger. Washing machines, dryers, and dishwashers replaced hand washing and wringing, automating the cleaning of clothes and dishes. All these changes required more energy.

Square Footage Increase in Average Home Size (1950s to 2000s)

	1950s	1960s	1970s	1980s	1990s	2000s
Square Feet	938	1,225	1,500	1,740	2,080	2,266
Change in Square Feet		287	275	240	340	186
Percent Increase		30.6	22.4	16	19.5	8.9

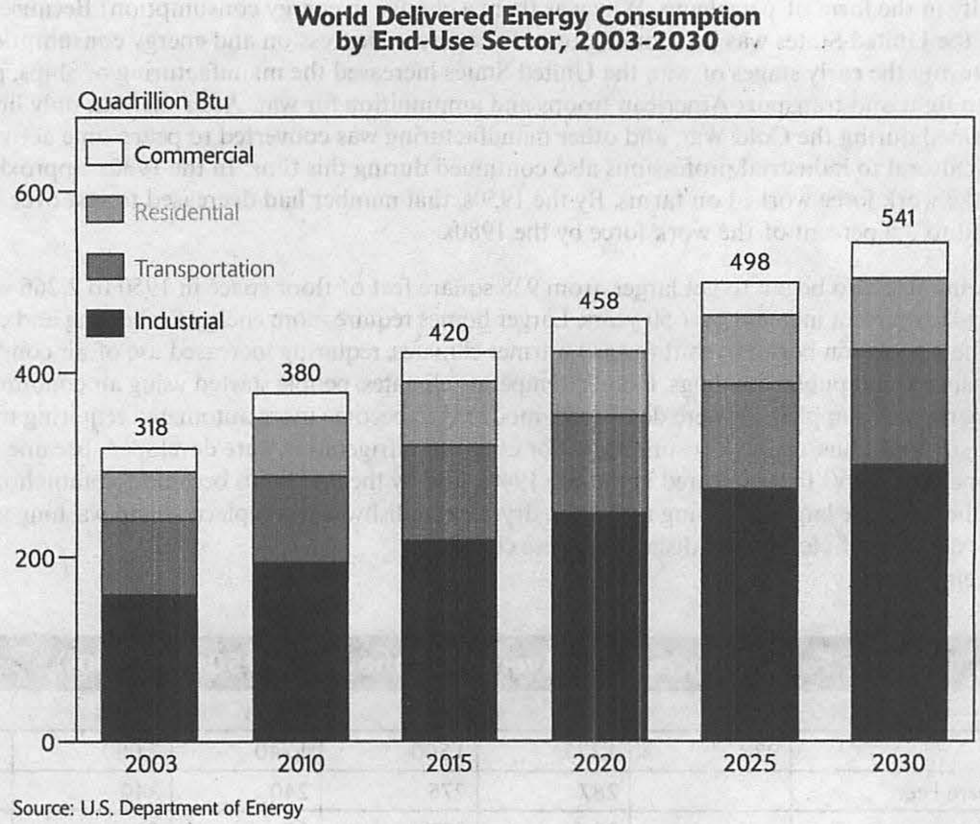
Energy consumption is typically divided into four end users: industry, transportation, residential, and commercial. Since 1950, industry has been the largest end-user of energy. Industry is defined as the production of economic goods and services. This includes mining and refining; farming; construction; manufacturing; services such as law and medicine; the distribution of manufactured goods; and, most recently, research, design, and the development of technology.

The transportation of people and goods is the second largest consumer of energy. Types of transportation include air, rail, road, water, and pipeline. Transportation can be divided into three broad categories: infrastructure, vehicles, and operations. Infrastructure needed for transportation: roads, railways, airways, waterways, pipelines, airports, rail, bus, warehouses, trucking terminals, and refueling depots. Vehicles include automobiles, bicycles, motorcycles, buses, trucks, trains, and aircraft. Operations include the financing, legalities, and policies related to operating vehicles.

Residential energy use takes place in single-family homes, multifamily residences, and mobile homes. Multifamily homes include apartments, condominiums, and town houses. Residential areas may include schools, hospitals, and parks that are used by the residents.

Commercial end users of energy include the places where goods and services are exchanged for money.

The following graph shows the energy delivered to each sector starting in 2003 and projected delivery past 2010.



Present Global Energy Use

Worldwide, most energy comes from nonrenewable sources, primarily the consumption of fossil fuels (petroleum, coal, and natural gas) and the use of nuclear power. Fossil fuels are described as *nonrenewable* because their supply is finite. Their current high rate of use means that eventually we will run out of these energy sources. Renewable energy sources are replenished in a short period of time and include biomass (peat, trees, and other plant material), geothermal, hydroelectric, solar, and wind.

Future Energy Use

The energy needs of the United States and the world are increasing, primarily due to population growth, industrialization, and technology. The world population is increasing, and as the population increases, the need for additional energy increases. Approximately 38 nations are developed, and the remaining countries are in various stages of development. As they develop, their energy needs increase to meet the increase in production of goods and services. Technology usually leads to an increase in energy needs as well. The current technological revolution, with more powered items including computers and cellphones, has brought about great changes in society with a resulting increase in energy consumption, even with the development of low-energy technology.

The four fuel sources of clean coal, methane hydrates, oil shale, and tar sands may help meet future global energy needs.

Fossil Fuel Resources and Use

Fossil fuels including coal, oil, and natural gas are nonrenewable. The journal *International Energy Outlook* (2004) predicts that by the year 2025 about 87 percent of human energy needs will be provided by fossil fuels. Formed from plants and animals, fossil fuels are buried beneath the Earth's surface.

Societies around the world are dependent upon fossil fuels. Therefore, it is extremely useful to know how long these resources are likely to last. Scientists are trying to answer just that question. Just as important is the question of how much longer recovering fossil fuels will be technologically and economically viable. Many of the Earth's most accessible fossil fuel deposits are already being depleted, forcing energy companies to go farther, dig deeper, and work harder to recover remaining reserves, which adds to the remaining costs.

Coal, Oil, and Natural Gas

Coal, oil, and natural gas are the most commonly used fossil fuels. Although supplies are diminishing, consumption is still increasing due to a growing worldwide population and increasing industrialization in developing countries.

Clean Coal

Coal is the dirtiest and most abundant of the fossil fuels. Clean coal refers to the process of removing the pollutants that have a harmful effect on the environment. Technologies include washing coal to remove minerals and impurities and removing the sulfur dioxide and carbon dioxide from the flue gases. Cleaner-combustion technologies are being developed to make the burning of coal more efficient and help reduce contaminants during the combustion process. For example, coal can be converted into synthetic gas (syngas) in a process called **gasification.** Or the impurities in coal can be removed and used in other products. Treating coal-produced flue gases with steam can remove SO_2 and CO_2. Finally, researchers are developing carbon capture and storage (CCS) technologies to capture and store CO_2 emissions from coal.

The world's first "clean coal" power plant began generating energy in September 2008 in Germany. Due to the high cost of the technology, the German government owns the plant. The power plant captures CO_2 and acid-rain-producing sulfides. The CO_2 is compressed into liquid and stored. Future plans may inject liquid CO_2 into depleted natural gas fields.

Formation of Coal

Coal is formed in an **anaerobic environment,** one in which there is no oxygen. A swampy, heavily vegetative environment is ideal for forming coal. As plant matter falls into the swamp, it is quickly covered in mud. Over time it becomes deeply buried, and the plant matter becomes compressed as more and more mud is deposited on top of it. The pressure from the weight squeezes the liquid out of the dead plant material, leaving behind the carbon matter to form the complex chains found in coal. Some 300 million to 360 million years ago, such environments were widespread throughout the world, and much of the coal we use today was formed then.

To form coal, plant matter must first become peat. Peat is a low-energy fuel that is still used today in some parts of the world, generally when coal is unavailable. Peat varies from compressed matter to semihard substances that still look vegetative. It is cut from open pits, usually still wet, and must be dried to be used. The less compressed the peat, the higher the water content.

After millions of years under high pressure and temperatures, the peat turns into **lignite,** often called brown coal. This coal is drier and has a higher energy content than peat. Brown coal can still contain up to 70 percent moisture. Of the three types of coal, it has the lowest heat content. Lignite is used in power generators in locations where it is found in large quantities.

A denser, drier fuel with a higher energy content than lignite is formed with further compression and time. This black coal, called **bituminous** coal, is valuable as a fuel source for generating electricity and to manufacture coke for use in the steel industry. Rarer than lignite, bituminous coal is soft with a higher sulfur content and represents approximately 50 percent of the U.S. coal reserves.

After more compression, time, and exposure to extreme heat, black coal can be transformed into **anthracite.** Anthracite is a glossy, almost metallic-looking substance. With the highest energy content of the three types of coal, it has a low sulfur content and makes up approximately 2 percent of the U.S. reserves. Anthracite is the rarest of the three types of coal.

Graphite is the final stage of the carbon compression and heating process but is not considered a fossil fuel since it is difficult to ignite. Graphite is commonly used as the "lead" in pencils and as a dry lubricant.

Extraction and Purification of Coal

Two primary methods of mining coal are underground mining and surface mining. Most coal seams are too deep for surface mining, so underground mines must be dug. Approximately 60 percent of the world's coal production is from underground mining. Seams of coal, are found in long strands. When the seams of coal are near the Earth's surface, it may be more economical to extract the coal through open cuts in the surface of the Earth's crust. This method recovers a greater proportion of the coal deposit compared to underground mining. Globally, about 40 percent of coal production involves surface mining, but in the United States and Australia the technique is more prevalent, with 67 percent in the United States and around 80 percent in Australia. Mined coal may go through a variety of processes to remove sulfur and contaminants.

Oil

Oil Shale

Oil shale is a sedimentary rock that is rich in kerogen, an organic compound from which liquid hydrocarbons are extracted when heated. For use as an energy source, kerogen requires more processing than crude oil. It is, thus, more costly than oil, and the processing increases the negative environmental impacts, including damage to the surrounding environment due to surface mining and the disposal of waste material. The net-energy yield is considered moderate because energy is needed to mine the deposits, to heat the mined material, and to restore the mined area. There are major deposits of oil shale around the world, with several in the United States. These large deposits are found in Colorado, Utah, and Wyoming, but the world's largest reserves are in Australia, Estonia, Germany, Israel, and Jordan. China and Estonia have well-established oil-shale industries, while Brazil, Germany, Israel, and Russia have smaller oil-shale industries.

Tar Sands

Tar sands (also known as oil sands, extra-heavy oil, and bituminous sands) are a type of unconventional petroleum deposit. Note that the word *petroleum* means "rock oil" or "oil from the Earth." Tar sands contain naturally occurring mixtures of sand, clay, water, and an extremely dense and viscous form of petroleum. Technically, tar sands are referred to as bitumen and are found in large quantities in many countries, including Canada and Venezuela. Bitumen is an extremely viscous form of petroleum that can be extracted by heating tar sands. The resulting hydrocarbon requires more processing for use than crude oil, increasing both cost and environmental impact. Additional environmental impacts include damage to the surrounding environment due to surface *mining* and the disposal of waste material.

Like oil shale, tar sands yield moderate energy. Liquefying the crude oil from the sands requires injecting steam into the sand, which takes energy. The oil is then refined much like crude oil is refined. The process of generating useable oil from tar sand creates two to four times the amount of greenhouse gases as the production of conventional oil. The sulfur content is also higher, so larger amounts of sulfur dioxide are produced when the oil from tar sands is burned, resulting in an increase in acid rain.

Only since 2003 has oil shale been considered part of the world's oil reserves. The higher price of crude oil and the new technologies developed to obtain the oil from the oil sands has made it profitable to extract this unconventional oil. There are major deposits of oil shale in many places around the world, including deposits in the United States (Colorado, Utah, and Wyoming). The world's largest reserves are in Canada and Venezuela, each of which has oil sand reserves approximately equal to the world's total reserves of conventional crude oil supplies. Oil sands may represent as much as two-thirds of the world's total petroleum reserves.

Extraction and Purification of Crude Oil

Crude oil is a naturally occurring, complex mixture of hydrocarbons (with a variety of molecular weights) and other organic compounds found in geological formations at varying depths beneath the Earth's surface. Crude oil is obtained by drilling through the Earth's surface into deposits. Often, natural gas is found with these deposits but is usually not recovered.

Crude oil is refined into a large number of products, including gasoline and motor-vehicle fuels, kerosene, asphalt, and a variety of chemical reagents that can be used to make plastics, pharmaceuticals, and other chemical by-products. This is accomplished mostly by heating the crude oil and separating the different components by their boiling points.

Natural Gas

Formation of Natural Gas

Natural gas formation is similar to that of crude oil, from the remains of tiny aquatic plants and animals. When huge amounts of these organisms die over many years, they sink to the ocean floor and then are covered with silt and mud, decaying anaerobically (without oxygen). Over time, mud accumulates, and the pressure and heat on the organic materials increases. Eventually, the pressure squeezes out most of the liquid, leaving behind the dry carbons to form the long carbon chains in crude oil. The shorter chains, such as those in methane, ethane, propane, and butane, also form and become natural gas. Usually, natural gas and crude oil are found together. In some areas, natural gas is more abundant, and in other areas crude oil is found in larger amounts. Thus, in any given field, a company usually drills for either natural gas or crude oil, but not both.

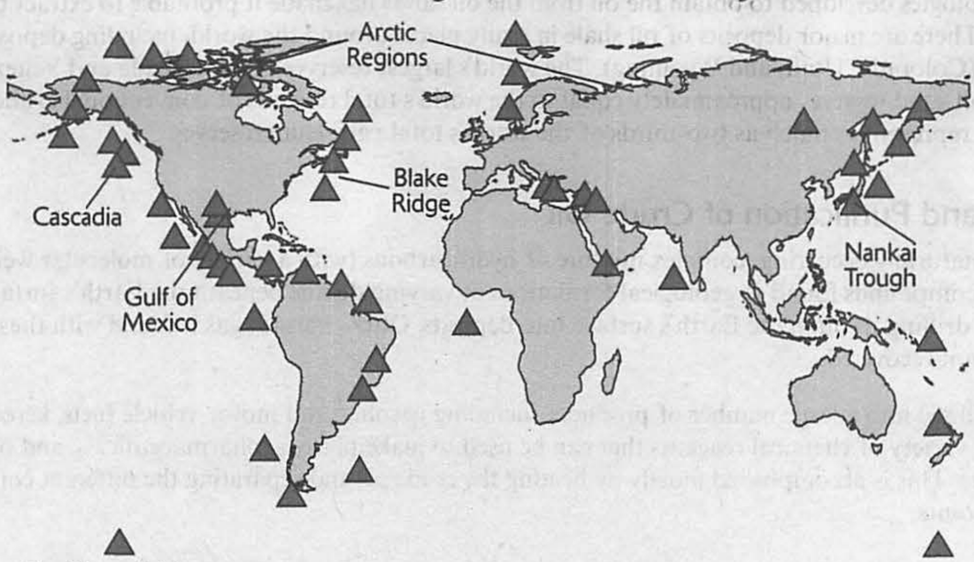
Methane Hydrates

Methane hydrates are a recently discovered source of natural gas locked in ice formed at low temperatures and high pressures (often called "burning ice") and found in unique settings on Earth. On land, methane hydrates are found in the tundra, where cold temperatures persist in the shallow regions of the permafrost. The tundra's methane comes from decomposing plants and animals trapped in the permafrost. Methane hydrates also are found deep in the ocean, where the pressures are high and the temperatures are low, forming at depths greater than 500 meters and, in some parts of the deep oceans, may be very thick. The following figure shows the locations of known methane hydrate deposits. If used at their current rate, there may be a 350- to 3,500-year supply. Although not recognized as a fossil fuel at this time, another source of methane gas is that which escapes from pockets of fossil fuels in the deep oceans.

Two major issues are associated with the use of methane hydrates as a source of energy:

- The cost of locating and "mining" the methane hydrates
- The concern that methane, a greenhouse gas, will be released while obtaining and processing the methane, thus speeding up global warming

Locations of Large Amounts of Methane Hydrates



Source: Naval Research Laboratory

Methane hydrates made the news during the attempts to contain the *Deepwater Horizon* oil spill in the Gulf of Mexico in 2010. As the crude oil poured out of the broken well, methane also leaked out, and at the low-temperature depth of the broken oil well, methane hydrates formed. The methane hydrates made it difficult to install a containment system to help control the flow of crude oil and blocked the openings to the containment system.

Extraction and Purification of Natural Gas

Once a hole is punctured into a natural gas reservoir, the gas usually flows from wells under its own pressure. Natural gas is collected by small gas lines that are then connected to larger gas lines. These transmission pipelines move the natural gas great distances to areas where natural gas is present in low quantities or does not exist at all, or where the population and demand exceed the natural supply. Natural gas requires processing that includes the removal of water or water vapor, acid gas, and mercury. Natural gas also can be processed to obtain methane, ethane, propane, butane, and pentane. A small amount of odorant is added to give the gas a smell reminiscent of rotten eggs. Since natural gas is odorless, an odorant is added to help detect leaks that could otherwise create fires and explosions or be harmful if inhaled.

Synfuels

Synthetic fuels, or **Synfuels**, are liquefied fuels obtained from nonpetroleum sources such as coal, natural gas or biomass feedstocks through chemical conversion. For example, diesel and jet fuel that is made from coal are synfuels. Some synfuels are derived from waste, such as plastic or rubber. Daily production of synfuels is over 240,000 barrels with additional projects in development.

Advantages and Disadvantages of Synfuels	
Advantages	**Disadvantages**
Once converted, synfuels can be transported	Synfuels are not efficient, with minimal net energy yield.
Synfuels cause less air pollution than conventional coal when combusted.	Expensive production facilities.
Synfuels are uneconomical.	Synfuels would diminish coal reserves.
	There is an increased environmental impact due to mining of coal, processing into synfuels, and the burning of synfuels.

World Reserves and Global Demand

Fossil fuels (coal, crude oil, and natural gas) are nonrenewable resources, and eventually their reserves will run out. There has been much discussion and debate about how much of each fossil fuel remains. Adding to the difficulty in predicting a date at which fossil fuel reserves will run out is the difficulty in predicting demand as the world's need for energy increases with population growth and the industrialization of more countries. The world reserves and global demand for three fossil fuels are:

- **Coal:** By far the largest reserves of natural fuels are the various types of coal. The known reserves of coal are estimated to last about 200 years at the current rate of consumption. However, if consumption increases at the conservative rate of 5 percent per year, that figure drops to 86 years. Unknown reserves are estimated to last another 1,000 years. The largest reserves of coal are in Australia, China, Russia, and the United States.
- **Crude oil:** Of the three fossil fuels, the known reserves of crude oil are estimated to last about 45 years at current consumption and will dramatically decrease if consumption increases. The largest reserves are in the Middle East, which increases the potential for disruption in the world oil supply due to unstable governments, friction between the countries in the Middle East, and the recent wars in Iraq.
- **Natural gas:** At current consumption rates, the known reserves of natural gas are estimated to last 60 years. Europe has approximately 42 percent of the known reserves, while the Middle East has about 34 percent and the United States has about 3 percent.

Environmental Advantages and Disadvantages of Fossil Fuels

Following are the advantages and disadvantages of using coal, oil, and natural gas as sources of energy.

Advantages and Disadvantages of Coal	
Advantages	**Disadvantages**
Coal produces a relatively high amount of energy per pound.	Surface mining scars the Earth and destroys habitat.
Prices are relatively inexpensive and stable.	Subsurface mining can cause respiratory problems for workers.
Technologies to generate electricity are readily available.	Sixty percent of mining operations are done deep beneath the Earth's surface, increasing risks for mine collapses.
There is a large supply of undiscovered coal.	The estimated CO_2 (greenhouse gas) produced by an uncontrolled natural fire burning in coal beds around the world is greater than all of the CO_2 produced from automobiles in the United States.
Emissions can be reduced with the use of current technological advancements.	Coal is a non-renewable energy source.
	Delivery methods and pollution technologies can be costly.
	Runoff pollutes the rivers, lakes and oceans.
	Coal releases sulfur which can contribute to acid deposition and industrial smog.

Advantages and Disadvantages of Crude Oil	
Advantages	**Disadvantages**
There is established infrastructure for transport and use as a fuel.	Combustion of crude oil releases CO, CO_2, and other emissions.
Crude oil can produce fairly high net-energy compared to other products.	Crude oil is diminishing. Estimations are from 40 to 90 years.
Crude oil has a proven processing system.	Drilling, storing, processing, and transporting crude oil can cause a disruption to ecosystems.
Products have many uses.	Used oil is difficult to recycle.
	Spills can be devastating to ecosystems and the economy.

Advantages and Disadvantages of Natural Gas	
Advantages	**Disadvantages**
Natural gas is in a relative abundance.	Natural gas is a non-renewable energy source.
Delivery transport systems already exist.	Combustion of natural gas releases CO_2.
Natural gas has high net-energy per volume.	When pressurized, liquefied natural gas is extremely dangerous and can result in extreme explosions (BLEVE).
Natural gas emissions are cleaner burning than coal and oil.	Environmental damage can occur from extraction and pipelines, including releasing contaminated wastewater.
Natural gas has a variety of uses including home heating, cooking, and transportation.	Leaks can cause fires and explosions.
Natural gas cannot spill and contaminate soil, groundwater, or surface waters.	Liquefying the gas into liquefied natural gas can be costly.

Nuclear Energy

Nuclear Power

Currently, 31 countries produce electricity using nuclear power. Another ten countries have announced plans to build nuclear-generating power plants. The United States is the single largest producer of electricity from nuclear power, at 101,111 MW of capacity, which in 2008 accounted for approximately 19.7 percent of the United States production of electricity. France is the second largest producer of electricity generated by nuclear power plants, accounting for 76.2 percent of its total electrical power. Following are the top five countries in capacity and the top five countries in percentage of electrical production. Only France makes both lists. The dates for the data are 2007 and 2008.

Top Five Countries in Capacity and Percentage of Electrical Production

Country	Megawatt Capacity	Country	Percentage of Electricity from Nuclear Power
United States	101,119	France	76.2%
France	63,473	Slovakia	56.4%
Japan	46,239	Belgium	53.8%
Russia	21,743	Ukraine	47.4%
Germany	20,339	Armenia	43.5%
World	**371,348**	**World**	**14.0%**

The use of nuclear-generated electrical power grew rapidly in the United States from the early 1960s until the late 1980s. However, since the late 1980s, the use of nuclear power in the United States has declined. Reasons for the decline include huge cost overruns, higher-than-expected operating costs, safety concerns, issues with the disposal of nuclear waste, shorter-than-expected life of nuclear power plants, and a perception that nuclear power is a risky financial investment. Two historical nuclear incidents that played a role in the decrease in nuclear power in the United States were the accident at Three Mile Island in Pennsylvania on March 28, 1979, and the accident at Chernobyl, in what was then the Soviet Union and is now the Ukraine on April 26, 1986. The 2011 nuclear accident at the Fukushima Daiichi plant in Japan, resulting from an earthquake and subsequent tsunami, may change the face of nuclear energy. This event will most likely alter the public's perception of nuclear energy, as well as the safety controls and procedures of nuclear power plants near coastlines and major fault lines.

There was a renewed interest in building additional or replacement nuclear power plants in the United States until the incident at the Fukushima Daiichi power plant in Japan. This interest was due to the increased need for electrical power, which outstrips the current capacity of traditional power plants, an increase in fossil-fuel prices, and a concern about the release of carbon dioxide by fossil-fuel plants and the subsequent link to global warming.

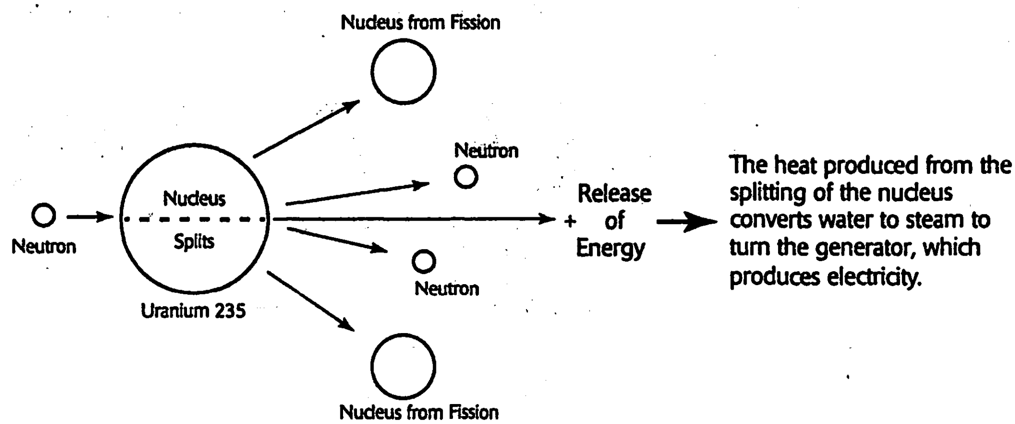
Advocates of nuclear power claim that it is sustainable, reduces carbon dioxide emissions, and increases national energy security by decreasing the reliance on foreign crude oil. Supporters also argue that the risk of storing nuclear radioactive waste is small and can be further reduced by advances in nuclear power plant technology. In addition, the overall safety record for nuclear power plants is better than that for traditional fossil-fuel power plants.

Critics of new nuclear power plants believe that nuclear power is dangerous and not worth the cost or the risk. These critics are generally skeptical that new technology can decrease the hazards of nuclear radioactive waste. Critics also point out the problems of storing the nuclear waste, the lack of a national policy on nuclear storage, the potential radioactive contamination by accidents or terrorism, and the long-term storage of the nuclear waste before it is safe to be disposed of.

Nuclear Fission Process

Nuclear-power-generated electricity is usually produced by a process called nuclear fission. During the nuclear fission reaction, shown below, an atom is split into two smaller elements along with by-products (neutrons, photons, gamma rays, and beta and alpha particles). The fission reaction is exothermic, giving off great quantities of heat. The heat is used to convert water into steam that turns a generator, which produces electricity. This reaction must be carefully controlled to ensure that it does not critically overheat.

Converting Nuclear Fission into Electrical Energy



The potential energy per pound of nuclear fuel is exponentially greater than that of most established fuels (coal, petroleum, and natural gas). However, it is impossible to create a nuclear fission reaction without producing radioactive waste, which remains highly radioactive for thousands or even millions of years. Currently, most nuclear waste is stored on-site because there is no national program in the United States to dispose of nuclear waste. By traditional standards, nuclear waste must be stored for the length of time it takes for the material to go through ten half-lives. U-235, one of the most common nuclear fuels, has a half-life of 704 million years, and U-238 has a half-life of about 4.47 billion years. In other words, nuclear waste must be stored forever in a secure location.

Nuclear Fuel

There are two primary forms of fuel used in nuclear power plants: uranium and plutonium.

Uranium

Uranium has an atomic number of 92 and its chemical symbol is U. It has between 141 and 146 neutrons, meaning there are six isotopes, the most common being U-238 (146 neutrons), which makes up 99.284 percent of the uranium found in nature. U-235 (143 neutrons) and U-234 (142 neutrons) also occur naturally, at 0.711 percent and 0.0058 percent of natural reserves, respectively. All six forms of uranium are at least weakly radioactive, meaning that they shed particles. Uranium is commercially extracted from uranium-containing minerals such as uraninite. Uranium decays slowly by emitting an alpha particle.

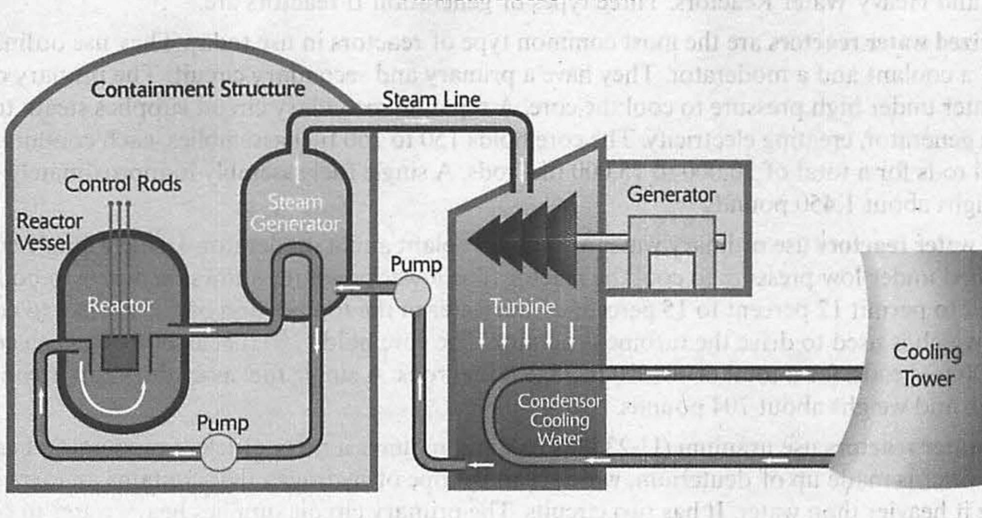
U-235 is the only naturally occurring isotope capable of nuclear fission. Only 3 percent of U-235 is used in power plants to generate electricity, while 85 percent is used for weapons. Power plants convert U-238, which is not fissile, into plutonium-239 (Pu-239), which is fissile.

Plutonium

Plutonium, whose chemical symbol is Pu, is the heaviest naturally occurring element and has an atomic number of 94. As fission occurs in a nuclear reactor, Uranium (U-238) is said to be *fertile* and is able to capture one of the free neutrons flying around in the core of the reactor. This indirectly becomes plutonium (Pu-239). It is estimated that one-third of nuclear energy produced comes from his process, known as burning Pu-239.

International inspectors regularly inspect nuclear power plants to limit the production of Pu-239 and other radioactive isotopes that could be used to build nuclear weapons. One of the greatest fears is that if Iran and North Korea develop nuclear power plants (see an example in the following figure), they will not participate in these inspections and, thus, could build a supply of Pu-239 to be used in nuclear weapons.

Nuclear Power Plant



Nuclear Reactors

Reactors have several common components:

- **Fuel:** Uranium is the basic fuel used in all reactors. The uranium is enriched and processed into uranium oxide (UO_2). The UO_2 is formed into ceramic pellets and loaded into long tubes, usually zirconium alloy. When grouped together in a bundle, the tubes form a fuel assembly that is located in the core of the reactor.
- **Moderator:** It is usually water, occasionally heavy water, and rarely graphite. The moderator will slow down the release of neutrons in the core.
- **Control rods:** The rods are made of cadmium, hafnium, or boron. They are inserted and withdrawn from the core to control the rate of fission by absorbing neutrons.
- **Coolant:** The coolant is a liquid or gas that is circulated through the core to transmit heat away.
- **Containment:** Modern reactors have a containment structure that encapsulates the core. It is designed to prevent external intrusion and to protect everything surrounding it from the effects of radiation caused from a malfunction inside. It is usually constructed of steel and at least three feet of steel reinforced concrete.
- **Core:** The core may contain up to 75,000 fuel rods. The core is where fuel assemblies are located and where nuclear fission takes place.

Nuclear reactor types

Nuclear reactors have several common features in construction and operation, and are grouped into four generations. Each generation is grouped by age, and within each generation there are several reactor types.

- **Generation I** reactors were designed and built during the 1950s and 1960s. Very few of these early designs are still running. Generation I reactors are only expected to last about 40 years. The safety devices are primitive by today's standards and some do not have containment domes. For example, a Graphite-Moderated Reactor is a generation I type of reactor that uses water for cooling and steam and uses graphite as the moderator. Used in the former Soviet Union (USSR), these reactors were very unstable and are no longer being used. (see Chernobyl case study).
- **Generation II** reactors are in use today and are known as Pressurized Water Reactors, Boiling Water Reactors, and Heavy Water Reactors. Three types of generation II reactors are:
  - **Pressurized water reactors** are the most common type of reactors in use today. They use ordinary water as both a coolant and a moderator. They have a primary and secondary circuit. The primary circuit supplies water under high pressure to cool the core. A separate secondary circuit supplies steam to drive a turbine generator, creating electricity. The core holds 150 to 250 fuel assemblies, each containing 200 to 300 fuel rods for a total of 30,000 to 75,000 fuel rods. A single fuel assembly is approximately 13 feet high and weighs about 1,450 pounds.
  - **Boiling water reactors** use ordinary water as both a coolant and a moderator. Using a single circuit, water is supplied under low pressure to cool the reactor. The lower pressures allows the water to boil and is designed to permit 12 percent to 15 percent of the water in the top portion of the reactor to convert to steam, which is used to drive the turbine generator. The core holds 750 fuel assemblies, each containing 90 to 100 fuel rods, for a total of 67,500 to 75,000 fuel rods. A single fuel assembly is approximately 14.5 feet high and weighs about 704 pounds.
  - **Heavy water reactors** use uranium (U-235) as fuel and requires a more efficient moderator, heavy water. Heavy water is made up of deuterium, which is an isotope of hydrogen that contains an extra neutron, making it heavier than water. It has two circuits. The primary circuit supplies heavy water to cool the reactor. A separate secondary circuit transports steam to turn the turbine generator. The core holds 12 fuel assemblies, each containing 37 (2-foot) fuel rods for a total of 444 fuel rods.
- **Generation III reactors** incorporate the most current technologies but very few have gone online. These reactors are similar to generation II reactor designs but incorporate improved fuel technology, thermal efficiency, passive supply systems, and a standardized design. The standard design is meant to reduce construction and maintenance costs. The designers expect an operational life of 60 years.
- **Generation IV** reactors are mostly theoretical in nature at this time and are not expected to be feasible before the year 2030. Among the many types of experimental nuclear reactors are fast-breeder reactors. Fast-breeder reactors allow fission to propagate, meaning that as one radioactive atom decays, it is allowed to create other radioactive atoms. Left unchecked, these newly created atoms would themselves decay, creating heat and more radioactive atoms (and eventually a large explosion). The trick of fast-breeder reactors is to allow the production of additional radioactive atoms, but to disallow their decay. Thus, fast-breeder reactors create more fissionable material than they consume. Again, this is but one of many types of experimental nuclear reactors.

Advantages and Disadvantages of Nuclear Power	
Advantages	**Disadvantages**
Low emissions.	The waste from nuclear energy is radioactive and decomposes very slowly (over thousands and millions of years).
Usable technology is readily available.	Potential catastrophic consequences could befall nature and humans if a failure or serious accident should occur, including death.
It is possible to generate large amounts of energy from one plant.	There is an increased target risk for terrorism.
	Plants are licensed for 40 years and then can renew their licenses or shut down (decommission). It takes 20 years to build a nuclear power plant. Decommissioning of older plants is very expensive.
	Uranium is a scare resource and its supply is projected to last between 100 to 200 years.
	Special facilities are required for radioactive waste disposal.

Safety Issues

Safety is a major issue with nuclear power. Safety is evaluated in terms of both equipment and operator. For equipment there are three major areas of concern:

- Control of the radioactivity using control rods
- Maintenance of the core cooling system
- Maintenance of the barriers that prevent the release of radiation

The control rods can be adjusted to control the availability of released neutrons that drive the energy reaction used to create heat and, thus, electricity. The cooling system removes heat from the power plant, ensuring that it does not build to the point at which it can cause an explosion. Radiation barriers are constructed to hold radioactive material if it is released in an accident.

There are several precautions taken to prevent exposure to radioactive materials at a nuclear power plant:

- The equipment inside the core of the reactor is handled remotely. Employees are kept behind a physical shield.
- The time that an employee is in areas where exposure might be an issue is limited.
- The individual dose exposure is monitored, and limits are very strict.

Radiation and Human Health

The potential exists for a large-scale disaster at nuclear power plants, like that at Chernobyl. High, short-term exposure to radiation from a nuclear power plant accident leads to a very painful death. This was the case in Chernobyl, where several employees and many technicians brought in to control the accident were exposed to high levels of radiation and most of them died as a result. Most recently, the nuclear accident in Japan has not yielded major health problems from immediate radiation exposure, but there may be long-term effects that are not yet seen.

Scientists, policy makers, and the public also debate the safety of working in conditions of low-level radiation in nuclear power plants over a long period of time. Employees at nuclear power plants (like employees who may be exposed to radioactive material on the job, such as X-ray technicians, dentists, or scientists) wear dose exposure badges that monitor and display radiation doses received by the employees. These dose exposures are logged and there are limits on the dose that a person is allowed to receive in a year and in a lifetime. Reaching dose limits is more likely to occur working near radioactive material outside a nuclear power plant than it is working inside the plant itself.

Understanding Half-Life

If an isotope of an element is unstable, it experiences radioactive decay, or the process of losing energy from an unstable nucleus. The isotope's half-life is the amount of time that it takes for half of the isotope to decay. To be considered safe, a radioactive isotope must complete ten half-lives. Using an isotope's half-life, questions can be answered about quantities that remain after a given period of time, and also questions of how much time it takes to decay certain amounts of an isotope.

Calculating Using Half-Life Information

On the AP Environmental Science exam, there may be questions about half-life in both the multiple choice and free response sections.

EXAMPLES:

1. How long must an isotope be stored to be considered safe for disposal?

This type of question requires simple calculation. If given the isotope's half-life (in years), multiply it by 10 to find the number of years (or other unit) when the material will be considered safe. Below is a table of common isotopes, their half-lives, and the number of years it will take to be considered safe.

Isotope	Half-Life	Years to Be Considered Safe	Comment
C-14	5,730 years	57,300 years	Used in carbon dating to determine the age of organic material
P-32	14.29 days	142.9 days	Used in genetic and cellular research
Pu-239	24,100 years	241,000 years	Used in nuclear power plants and weapons
U-238	4.47 billion years	44.7 billion years	Used in nuclear power plants
U-235	700 million years	7 billion years	Used in nuclear power plants

2. How much carbon-14 would be left after a set number of half-lives?

This type of question asks how much quantity would be left after a set number of half-lives.

Half-Life of Carbon-14		
Half-Life Spent	**Quantity (g)**	**Years**
0	10,240	0
1	5,120	5,730
2	2,560	11,460
3	1,280	17,190
4	640	22,920
5	320	28,650
6	160	34,380
7	80	40,110
8	40	45,840
9	20	51,570
10	10	57,300

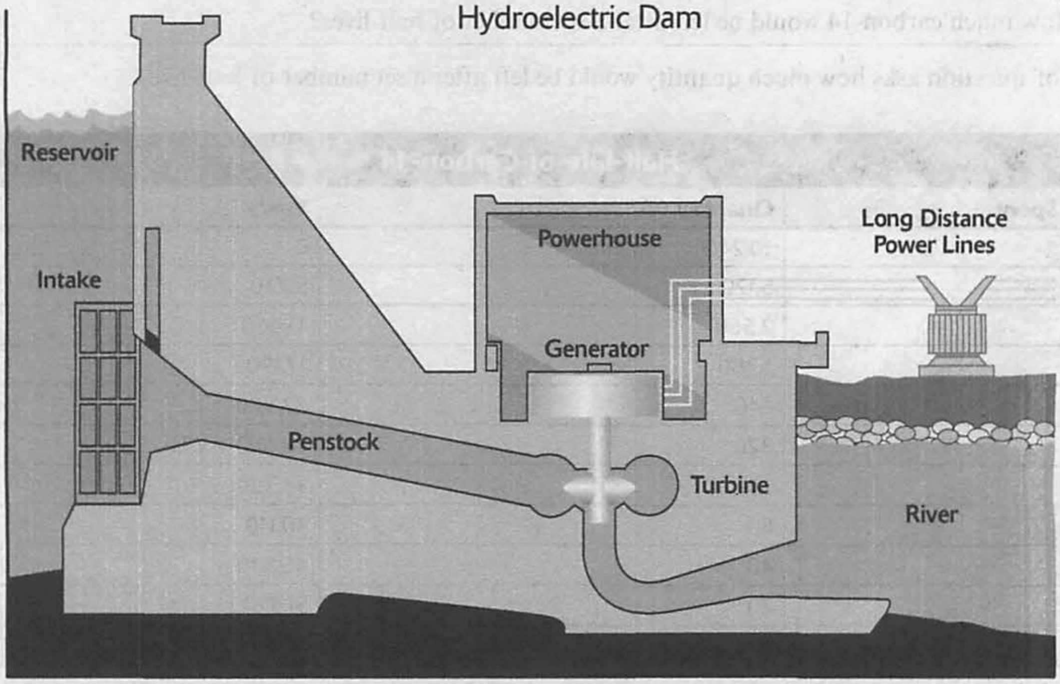
Hydroelectric Power

Dams are built to create reservoirs that capture water, which is then released at a controlled flow, producing electricity as it flows over turbines. Hydroelectric power supplies approximately 12 percent of the power in the United States.

One major advantage of dams is the controlling of downstream flooding by containing the water produced by spring thaws and heavy storms. This is important because a population lives along rivers and streams that flood. Controlling flooding prevents deaths, property destruction, and damage to crops used for human food or animal feed. One disadvantage is the buildup of silt behind the dam. As silt builds up behind the dam, the dam holds less water, making the dam less reliable as a reservoir for water. This could increase water shortages and decrease the potential to produce hydroelectric power.

Hydroelectric power plants are similar to coal-fired power plants in that both turn a turbine, which then turns the shaft of an electric generator, producing electricity. Coal-fired plants use steam to turn the blades of the turbine, while hydroelectric plants use water to turn the turbine. The result is the production of electricity.

For hydroelectric power generation, a dam is built across a river that has a large change in elevation (which creates more water energy). The dam stores water behind it in the form of a lake or reservoir. The water intake is near the bottom of the dam (see the figure below). Gravity pulls the water through the penstock. Lower in the penstock is a turbine propeller, which is turned by the moving water. The shaft of the turbine is connected to the generator. The shaft turns the generator, and the generator produces the electrical power. Power lines carry the electricity to the power grid. The water continues past the propeller and into the river on the downstream side of the dam.



Source: Tennessee Valley Authority

Advantages and Disadvantages of Hydroelectric Power (Dams)	
Advantages	**Disadvantages**
No fossil fuel is needed.	There is flooding of land behind dams, sometimes including towns.
Dam reservoirs can store rainwater for use in the case of drought.	Dams disrupt natural seasonal changes in rivers, and ecosystems can be destroyed.
Hydroelectric plants are relatively inexpensive to maintain.	Impacts downstream water flow, often diminishing available water.
Hydroelectric is a renewable energy source because the Earth's water cycle replenishes upstream flow.	Silt accumulates and prevents mineral-enriched sediment to reach farmlands.
Dams can be shut down immediately if needed.	Water evaporation increases due to an increase in water surface area of the reservoir behind the dam.
Dams create lakes for recreation (fishing and boating).	The mating cycle of fish, such as salmon and steelhead trout, can be altered.
Dams control downstream flooding and provide a uniform source of water year round.	Sediment is altered downstream, impacting water flow and silt deposition.
There are no CO_2 emissions during operations.	
Provides electricity for a large number of people.	

Case Study: The Colorado River

The Colorado River starts in the Rocky Mountains and passes through seven states and two Mexican states, covering approximately 1,450 miles before emptying into the Gulf of California. There are six dams along the river and much of the water is taken out for agricultural and domestic uses along the way. Some of the water is moved hundreds of miles from the original river to distant cities. At the end of the river, the once large volume is often a trickle, and the water return is frequently contaminated with pesticides, fertilizers, drugs, and other contaminants.

Case Study: Salmon

Salmon are migrating fish, returning from the ocean to spawn in the stream where they were hatched. When they hatch, salmon slowly make their way downstream toward the ocean. Later, they return to the river, swim upstream to find the place they hatched, spawn, and die. Salmon usually return three years after they hatch to spawn and die. Steelhead trout usually return in two or three years and may head back out to the oceans and make several trips over their lifetime. Damming a river makes this migration difficult or impossible.

Almost every river system in the West has been blocked by a dam, often with more than one dam along the length of a single river. These dams have destroyed important habitat for fish spawning, along with areas important for salmon's growth. For example, the Columbia River has less than 110 km (70 miles) of remaining free-flowing water, which is not enough to sustain wild salmon. Of the estimated 130 West Coast salmon runs, 81 percent are extinct, and the remaining 19 percent are endangered. California has severely limited fishing on several of its salmon runs and has even eliminated fishing altogether in some years.

To help mitigate this loss, fish passage facilities and fish ladders have been built to bypass dams. While juvenile fish are moving downstream toward the ocean, dams may allow water to pass over the spillway to encourage the fish to swim over the tops of dams instead of through the turbines. Juvenile fish also may be collected and transported downstream.

Some salmon is farm raised. Fish farms often consist of holding pens in the ocean where the fish are kept and fed for upwards of three years. There is concern that these farm-raised fish may escape and mate with the wild salmon and contaminate the gene pool. Another issue with farm-raised salmon is the amount of waste produced by the fish, which is concentrated below the pens in the ocean. There is concern that this waste may be harming the environment in the area.

In 2010, scientists announced that eggs of Atlantic salmon had been genetically modified by the insertion of the gene from an ocean pout and a growth gene from the Pacific Chinook salmon, allowing the fish to grow year-round. Commonly, native salmon do not grow in the winter months. With gene insertion, the fish can grow to market size in approximately two years instead of three. There are claims that the modified eggs are reproductively sterile because they are **triploidic** (having three sets of haploid genetic information), eliminating the interbreeding amongst themselves and with native, wild stocks. The company plans to sell only female eggs and raise fish in inland systems away from the oceans. FDA studies claim that up to 5 percent of the eggs may be fertile and the resulting fish may, in fact, be able to breed with wild-type salmon. The FDA must approve the fish for sale in the marketplace because the genes have been altered. There is some concern that these larger genetically modified salmon could eventually displace the natural salmon.

Energy Conservation

Strategies to conserve energy are an important aspect of the AP Environmental Science exam. In the free-response questions asking for suggestions on different ways to save energy at home, in an office building, or in transportation. There are many energy conservation methods, which may vary in effectiveness across states and regions of the United States, due in part to climate and cultural differences. Here is a common list of energy-saving ideas with brief explanations:

- Add **insulation** to help hold in warm air in the winter and cool air in the summer, while blocking the unwanted heating and cooling effects of outside air.
- Add **weather stripping** to reduce drafts around door frames.

- Lower the **thermostat** in the winter and raise it in the summer to use less energy. Instead, compensate by wearing warmer clothing in the winter and cooler clothing in the summer. Also, install thermostats on each floor to more efficiently regulate temperature.
- Replace single-pane windows with **double- or triple-pane windows** filled with noble gases, which cut down heat exchange through windows.
- Replace older equipment with more **energy-efficient appliances.** This may include water heaters, washers and dryers, dishwashers, heaters, air conditioners, stoves, and refrigerators.
- Cut down on energy loss through items that are plugged in but not turned on. **Unplug electrical equipment** when not in use.
- Add **ceiling fans.** A reversible ceiling fan can change the direction of the circulating air, and any ceiling fan can redistribute the hot air during the winter or the cool air during the summer.
- Use **electronic switches** to turn on and off the heater and air conditioner.
- Buy a more **fuel-efficient vehicle.**
- **Maintain vehicles** with proper tire inflation and tune-ups.

Energy Efficiency

The U.S. Department of Energy recently established the **Office of Energy Efficiency and Renewable Energy (EERE),** with the goal of reducing U.S. dependence on foreign crude oil and developing technologies that promote energy efficiency for buildings, homes, transportation, power generation, and industry.

The EERE's role is to promote the research, development, and implementation of energy-efficient technologies through investing in speculative research and development that may provide for the future energy needs of the United States. Private investment in this sector is limited because of the high cost of research and the high risk of the investments. The EERE works with state and local governments, national laboratories, universities, and the private sector.

Energy Star

The U.S. Environmental Protection Agency created the Energy Star program in 1992 in an attempt to reduce energy consumption and, thus, greenhouse gases emitted by power plants. Starting as a voluntary labeling program to identify and promote energy-efficient products, Energy Star first labeled computer products and expanded in 1995 to include residential heating and cooling systems. More than 40,000 Energy Star products are available today, including major appliances (refrigerators, washers, dryers), heating and cooling systems, office equipment, electronics, lighting, and more. In addition, the label can be found on new homes as well as on commercial and industrial buildings. In 2006, 12 percent of new homes were labeled Energy Star compliant. The Energy Star program is credited with the spread of LED traffic lights, compact fluorescent lighting, and power management systems for office equipment.

Energy Star has become an international standard for energy-efficient consumer products originating in the United States. Other countries, including Australia, Canada, Japan, New Zealand, and the European Union, have developed similar programs. Products carrying the U.S. Energy Star logo generally use 20 percent to 30 percent less energy than required by federal standards.

Many programs are available to help homeowners take advantage of converting to Energy Star appliances and other energy-saving devices. These include state and federal tax rebates for installing new refrigerators, washers and dryers, heating and cooling systems, and multi-paned windows; also, there are programs to help mitigate the cost of installing solar panels on homes.

However, even with rebates and assistance programs, solar panels can be expensive, and the payback in reduced energy costs may take many years. To create similar energy conservation, homeowners may well be advised to start by determining ways to reduce energy usage. Can insulation be added to reduce energy for heating and cooling? Are windows single-paned? How old is their heating and cooling system? How old are the appliances? It might be more cost-effective and energy wise to make these changes before installing solar panels.

Corporate Average Fuel Economy

The Corporate Average Fuel Economy (CAFE) regulations were first enacted by the U.S. Congress in 1975, partly in response to the 1973 Arab oil embargo, and with the goal of improving the fuel economy of cars and light trucks. The "light trucks" group includes trucks, vans, and sport utility vehicles (SUVs) sold in the United States. Fuel economy is expressed in miles per gallon (mpg) and the CAFE is based on the manufacturer's fleet of current-year-model passenger cars or light trucks under 8,500 pounds (3.856 kg) manufactured for sale in the United States.

The United States and Canada have the least strict CAFE standards among developed nations. The U.S. standard is 25 mpg, while the European Union standard is 45 mpg, and the Japanese standard is even higher. However, the United States and Canada have the strictest emissions standards in terms of parts per million (ppm) of pollutants. Some high-mileage vehicles in Europe would not meet the U.S. emissions standards; California has even tighter emissions standards. There may be a tradeoff between improved gas mileage and pollution control.

The National Highway Traffic Safety Administration (NHTSA) regulates the CAFE standards, while the Environmental Protection Agency (EPA) measures the vehicle fuel efficiency for the fleets. Congress has specified that the CAFE regulations must be set at a "maximum feasible level" and consider the following criteria:

- Technological feasibility
- Economic practicality
- Effect of other standards on fuel economy
- Need of the nation to conserve energy

The EPA and NHTSA are often at odds with each other over the intent of the CAFE regulations. The EPA encourages consumers to purchase more fuel-efficient vehicles, while the NHTSA is concerned that smaller, more fuel-efficient vehicles may lead to more traffic deaths.

For CAFE purposes, cars and light trucks are considered separate and have different standards. As of 2004, cars must exceed 27.5 mpg, and light trucks must average 20.7 mpg. The standard for trucks under 8,500 pounds was 22.5 mpg in 2008, 23.1 mpg in 2009, and 23.5 mpg in 2010. Starting in 2011, new standards will take effect, and the targets will be based on the truck size footprint.

How to Calculate Percent Change

A vehicle's change in weight can be used as an example demonstrating how to calculate percent change.

Percent Change = $\frac{V_2 - V_1}{V_1} \cdot 100$, where V_1 is the initial value, and V_2 is the second value.

If vehicles' average weight went from 3,220 pounds to 4,066 pounds, you would calculate the percent change as follows:

$$\begin{aligned}\text{Percent Change} &= \frac{4{,}066 - 3{,}220}{3{,}220} \cdot 100 \\ &= \frac{846}{3{,}220} \cdot 100 \\ &= 0.263 \cdot 100 \\ &= 26.3\%\end{aligned}$$

CAFE Standards in Miles per Gallon for Passenger Cars until 2011			
Model Year	**Passenger Car (mpg)**	**Model Year**	**Passenger Car (mpg)**
1978	18	1995	27.5
1979	19	1996	27.5
1980	20	1997	27.5
1981	22	1998	27.5
1982	24	1999	27.5
1983	26	2000	27.5
1984	27	2001	27.5
1985	27.5	2002	27.5
1986	26	2003	27.5
1987	26	2004	27.5
1988	26	2005	27.5
1989	26.5	2006	27.5
1990	27.5	2007	27.5
1991	27.5	2008	27.5
1992	27.5	2009	27.5
1993	27.5	2010	27.5
1994	27.5	2011	30.2

Hybrid Electric Vehicles

Hybrid cars were invented by Porsche in 1900 and were subsequently dropped in favor of gasoline-only vehicles. Today's hybrid cars were first developed by the Japanese companies Honda and Toyota. Hybrid vehicles contain smaller gasoline engines, which are supplemented as needed by electric motors. When you apply the brake in a hybrid car, the energy from braking is captured and the car's kinetic energy is converted into electrical energy that charges the battery. If the battery is low, the electric motor will also convert energy from the gasoline engine to charge the batteries.

Honda's technology uses an electric motor to provide assistance to a constantly running gasoline engine as needed, commonly when the car is accelerating or climbing hills. Toyota's technology allows the car to run completely on the battery at low speeds and to assist the gasoline engine during accelerations and hill climbing. The Honda Civic gets better gas mileage on the highway than surface streets, while the Toyota Prius gets better gas mileage driving city streets than the highway. Both technologies produce about 65 percent less CO_2.

In 2010, Toyota had a limited number of plug-in Prius vehicles that were being used as test cars, and the company planned to release consumer versions soon thereafter. The plug-in hybrid has a larger battery and allows the owner to plug the car into a 110-volt outlet at home, work, or another location to completely charge the battery. The plug-in hybrid will allow the owner to drive up to 13 miles on a charge at a maximum speed of 62 mph.

Several companies and individuals have modified Prius cars to get 100 mpg. These changes have usually involved converting the car to be a plug-in vehicle and adding lithium-ion batteries. Conversion kits are available, and specialists can be found to install the high-voltage lithium-ion batteries. However, the cost for such a conversion is approximately $10,000, which is likely more than the savings in gasoline costs across the life of the vehicle.

These savings in gas costs are also counterbalanced by maintenance costs, which are generally higher for hybrid engines than for gasoline-only engines. The hybrid battery is under warranty for 100,000 miles in some states and 150,000 miles in others, with some owners reporting battery life over 200,000 miles. However, new batteries cost approximately $5,000 to replace, including installation. Many people believe that these batteries are hazardous. Toyota has a program to completely recycle its batteries.

Electric Cars

Electric cars in one form or another have been a part of car culture since the vehicle's inception. In fact, the first cars were electric, developed before the internal combustion engine was constructed. The development and subsequent improvements of the combustion engine ultimately pushed electric cars from the market. Then, as now, electric cars faced the problems of limited mileage on a single battery charge and the lengthy time needed to charge the battery.

Other attempts at reviving the electric car include the EV1, released on a lease-only basis by General Motors in 1996. The last of these vehicles were leased in 1998, with lease terms and extensions expiring in 2003. Subsequently all returned EV1s were crushed, though a few remain in museums. To learn more about the EV1 program and its death, watch the movie *Who Killed the Electric Car?* (2006).

With the recent increase in gasoline prices, interest in electric cars is once again on the rise. Despite technological advancements, these cars still face the same problems: battery technology that limits the total miles a car can drive on a single charge and the long time it takes to recharge. Several companies are developing electric car technology. For example, Chevrolet has recently released its all-electric car, the Volt. The Volt gets about 40 miles per charge and is emissions free (not taking into account the method used to generate the electricity the car uses to charge its battery). Currently, electric cars work well for owners who plan to use them only for short commutes.

Tesla is a car company devoted only to electric cars. Tesla was started in 2003 and released its first car in 2008, the Roadster. The Roadster gets about 275 miles per charge with zero tailpipe emissions. A second model, the Model S, will be released in 2012 and get about 300 miles per charge. Charging the Tesla roadster with a 110-volt plug takes about 32 hours. However, plugging the car into a 220-volt outlet allows the car to charge its batteries in only 3.4 hours.

Detractors point out that electric car technology trades one form of CO_2 and other gas emissions for another, as the electricity to charge these cars still must be generated. Traditional gasoline cars are **mobile-source** forms of pollution, meaning that emissions can be moved from one location to another as the vehicle drives. However, the emissions of electric cars are considered **point-source** emissions, localized at the electric power plant where the car's electricity originates, which may burn coal, natural gas, or petroleum (or may depend on renewable technologies including wind, solar, or geothermal).

Other Vehicle Options

Traditional gasoline is no longer the only option for powering cars. The new energy-efficient diesel cars that account for approximately 45 percent of new car sales in Europe are 30 percent more fuel efficient and emit 20 percent less CO_2 than conventional gasoline-powered cars. Besides making diesel from crude oil, diesel can be made from coal (synfuels). Diesel cars also can be converted to run on biodiesel. Biodiesel can be made from either plant material or from vegetable oil. Brazil runs 45 percent of its cars on ethanol. Other countries are experimenting with E85, which is 85 percent gasoline mixed with 15 percent ethanol. Ethanol can be made from corn, soy, or plant waste material.

Advantages and Disadvantages of Biodiesel	
Advantages	**Disadvantages**
Reduced CO and CO_2 emissions.	Increased NO_x emissions and increased photochemical smog.
Reduced hydrocarbon emissions.	Higher cost than regular diesel.
Better gas mileage.	Low net-energy yield for soybean crops.
Has the potential to be renewable if the source for the biodiesel is renewable.	Loss and degradation of biodiversity due to land being used for increased crop production.
Sources such as algae and oil palms offer high net-energy yield.	May compete with growing food for land use and raise food prices.
Sources from other crops offer moderate net-energy yield.	

Advantages and Disadvantages of Ethanol	
Advantages	**Disadvantages**
Reduced CO emissions.	Low net-energy yield with some crops.
Some reduction in CO_2 emissions if sugarcane is used.	Increased NO_x emissions and increased photochemical smog.
Can be mixed with gasoline and sold as E85 or as pure ethanol.	May compete with growing food for land use and raise food prices.
Potentially renewable.	Higher cost than regular diesel.
High net-energy yield for bagasse and switchgrass.	Higher CO_2 emissions using corn.

Another new fuel used to power vehicles is the hydrogen fuel cell, which coverts hydrogen into energy. There are various ways to access the hydrogen and convert it into useable form. One such way is electrolysis, where electricity is passed through water, separating the hydrogen and oxygen. The by-product of hydrogen fuels cells is water.

Mass Transit

The goal of public transportation is to move large numbers of people in one vehicle. When asked about mass transit, most people think of buses, subways, and light rail. Other forms include air, trains, and ships. People in Japan, Europe, and a few places in the United States, including the San Francisco Bay area and New York City, frequently take into account the accessibility of mass transit when evaluating where to live and work. Ridership in Japan is close to 50 percent, with the percentage of riders even higher in Tokyo. In a 2006 survey, 5 percent of the U.S. population used mass transit, while 20 percent had easy access to mass transit. Public transportation is more likely to be used by people living in cities with a population greater than 100,000. For example, ridership in New York City is over 50 percent; Washington, D.C., at 39 percent; Chicago at 25 percent; and Los Angeles at 11 percent. In the five years of 2006 to 2010, the use of mass transit increased in the United States partly in response to increases in gasoline prices, incentives of employers to increase the use of mass transit, expansion of some mass transit systems, and the idea of being more "green."

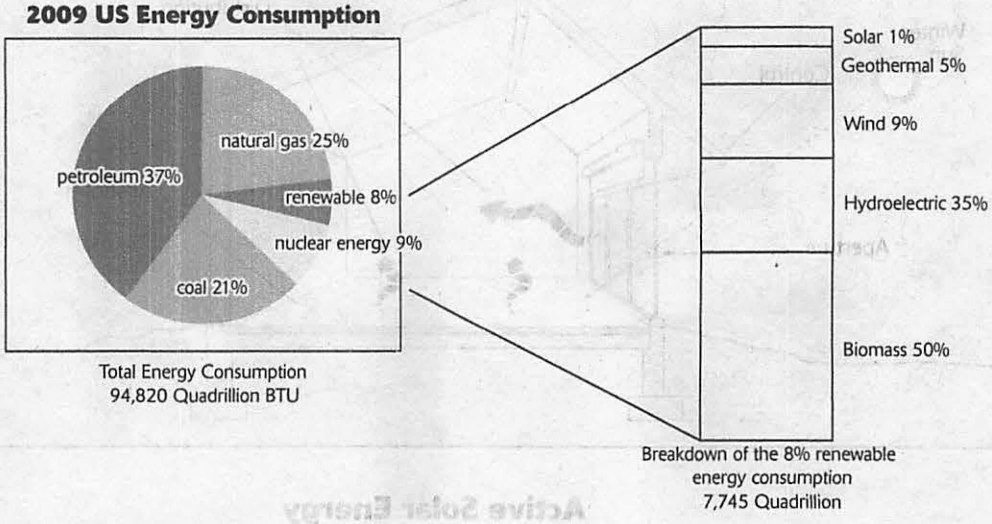
Buses are the most commonly used form of mass transit, partly because they can easily adjust their routes and time schedules to meet the needs of the population they serve. As transit systems have replaced their aging buses, they often choose buses that run on compressed natural gas (CNG). CNG burns cleaner than diesel, reducing CO_2 and particulates emissions. Bus systems offer low fares to attract riders, often operating at a loss and, thus, must rely on governments to subsidize their expenses.

Some cities have subway systems, most of which are underground electric light-rail systems. Chicago and a few other cities have elevated systems. One distinction between buses and subways is that subway systems are removed from the flow of traffic and, thus, can provide a faster form of transportation when city streets are clogged. Subways use less energy and generate less pollution than cars, require less land for tracks and parking, cause fewer accidents and deaths than cars, and reduce congestion in the cities. Disadvantages include a fixed track system that cannot be adjusted to meet changes in society, the cost of building and maintenance, and the noise and vibrations can impact nearby residents and businesses.

Light-rail systems are usually powered by electricity but can also use diesel. Like subways, their tracks are fixed, making it difficult to adjust routes. Light-rail systems can be mixed with traffic in systems where cars and buses share the road with the light-rail system. They also can have designated lanes and stops to allow passengers to get on and off the system easily. Light-rail systems are more expensive to build than bus systems, but cheaper than subway systems. Their schedules are easier to adjust than those of a subway system but not as flexible as a bus system.

Renewable Energy

Renewable energy can be replenished without depleting supplies. There are several forms of renewable energy, each with pros and cons. As shown below, approximately 6 percent of the total energy usage in the United States is generated by renewable energy, which includes biomass, geothermal, hydroelectric, solar, and wind. Other forms of renewable energy are being investigated.



Solar

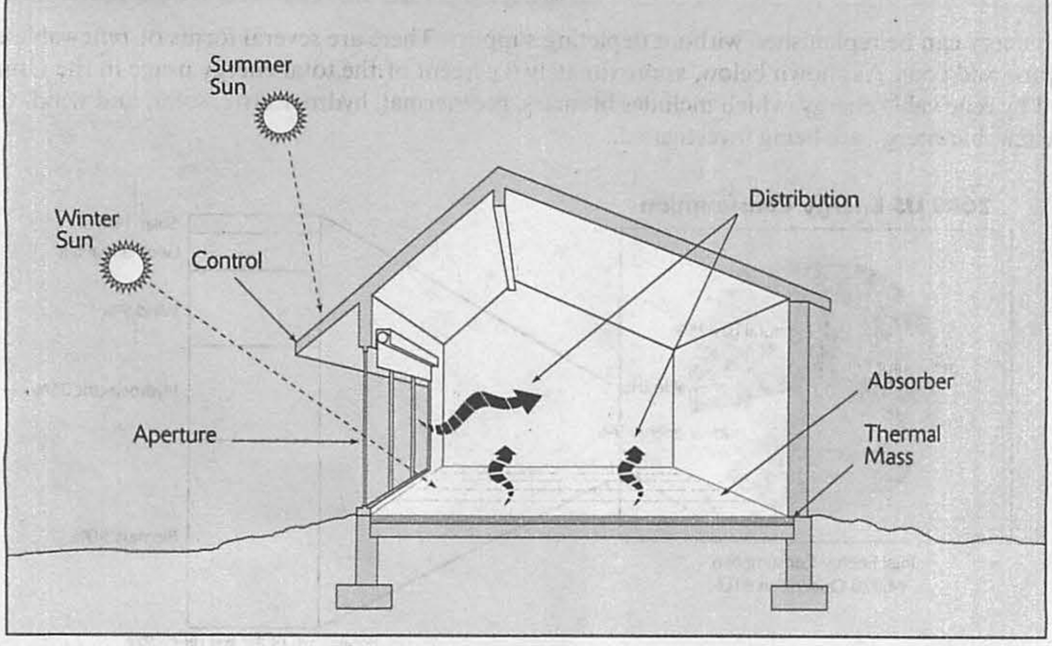
The sun's radiant energy is used both to create heat directly and for conversion into electrical energy. There are two types of systems:

- **Passive solar energy systems** require no moving parts and, thus, no input of electrical activity. These include both gravity-fed heating systems and photovoltaic cells, which capture the sun's energy to generate electricity. In a solar electricity system, sunlight hits the transparent solar cells causing them to emit electrons, and many cells wired together produce electricity. The electricity can be used immediately, cells can be connected to batteries to store the energy for later use, or cells can be connected to the power grid to share electricity with other users. Detractors point to the inefficiency of solar cells, but newer photovoltaic cells have increased this efficiency.

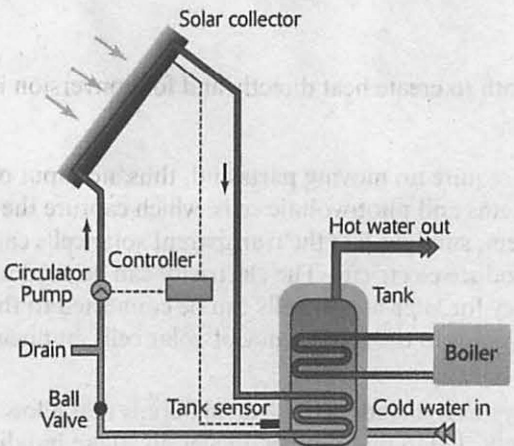
  Additional passive heating systems include the use of materials that allow the heat from the sun to be captured in the winter and reflected in the summer. Generally, these buildings are constructed to face the primary direction of the sun, maximizing the potential to trap heat in the winter.
- **Active solar energy systems** use pumps and fans to move water heated by the sun throughout buildings, requiring some input of electrical energy. This hot water can be used to heat the house and can be used as hot water for cleaning and bathing.

See the following figures for illustrations of passive and active solar energy.

Five Elements of Passive Solar Design



Active Solar Energy



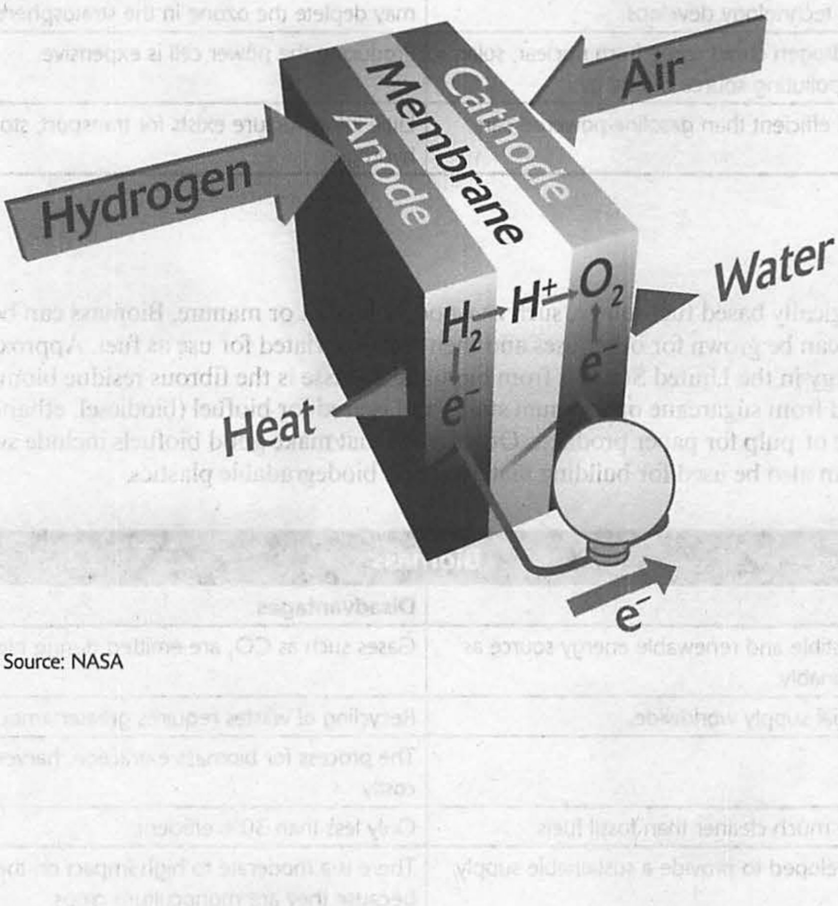
Solar	
Advantages	**Disadvantages**
There is an infinite, free supply of solar energy.	Solar energy is most efficient where sunlight is most consistent.
Solar energy is clean, renewable, and sustainable.	Initial costs for installation and building are high.
The energy collected can be stored in batteries.	Solar panels require a large area for efficiency.
There is limited or no maintenance.	Sunlight can be blocked by trees and buildings.
	Some people consider the solar panels to be unsightly.

Hydrogen Fuel Cells

The basic concept of a hydrogen fuel cell is to use hydrogen and oxygen in a chemical reaction to produce energy and water. Like a typical battery, a hydrogen fuel cell uses an anode and a cathode that are separated by an electrolyte. Hydrogen reacts with a catalyst on the anode electrode, splitting into negatively charged electrons and positively charged hydrogen ions. The electrons flow out of the cell and are used as electrical energy. The positively charged hydrogen ions move through the membrane to the cathode, where they combine with oxygen to produce water. Unlike in a typical battery, as long as the fuel cell is fed with hydrogen and oxygen, it will never run down or run out. Hydrogen fuel cell technology is being developed for cars and other forms of transportation. These fuel cells are being used to generate small amounts of electricity to supplement larger power systems. They are also being used in isolated areas where running transmission lines may be difficult or expensive.

Basic Fuel Cell Reaction

$$2\,H_2 + O_2 \rightarrow 2\,H_2O + \text{energy}$$



Source: NASA

Hydrogen Fuel Cells	
Advantages	**Disadvantages**
Hydrogen has three times the energy (pre-mass) of natural gas.	Hydrogen production is very energy-intensive in order to separate it from a water molecule.
Hydrogen can be obtained from splitting water. Hydrogen is the most abundant element in the universe.	Hydrogen gas is highly flammable and burns extremely hot.
The use of hydrogen as a fuel has minimal environmental impact. The only emissions from hydrogen combustion are water and heat.	An efficient method to store hydrogen has not yet been developed.
Hydrogen can be produced domestically, reducing dependence on foreign energy supplies.	Production may indirectly produce harmful emissions, depending on what energy source provides the electricity to split the water molecule.
They are highly efficient (45% to 65%), and the number may be likely to increase as technology develops.	There is concern that if hydrogen leaks in the atmosphere, it may deplete the ozone in the stratosphere.
Energy to produce hydrogen could come from nuclear, solar, wind, or another less polluting source of energy.	Producing the power cell is expensive.
Hydrogen is more fuel efficient than gasoline-powered cars.	Little infrastructure exists for transport, storage, and retrieval of hydrogen.

Biomass

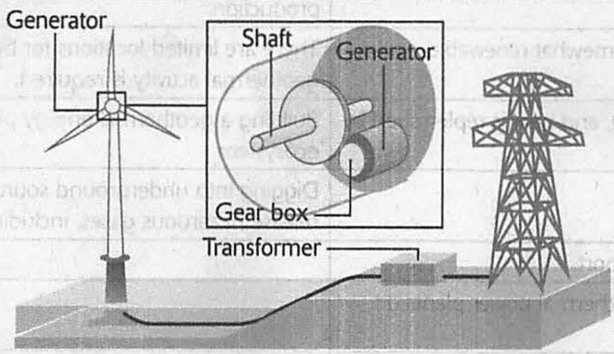
Biomass is any biologically based fuel source, such as wood, charcoal, or manure. Biomass can be grown specifically for use as a fuel or it can be grown for other uses and then reappropriated for use as fuel. Approximately 50 percent of the renewable energy in the United States is from biomass. Bagasse is the fibrous residue biomass that remains after juice is extracted from sugarcane or sorghum stalks and is used for biofuel (biodiesel, ethanol, or methanol) or as a renewable source of pulp for paper products. Other crops that make good biofuels include switchgrass, hemp, and corn. Biomass can also be used for building materials and biodegradable plastics.

Biomass	
Advantages	**Disadvantages**
Biomass is an inexhaustible and renewable energy source as long as it is used sustainably.	Gases such as CO_2 are emitted during biomass burning.
There is a large potential supply worldwide.	Recycling of wastes requires greater amounts of water.
It is cost effective.	The process for biomass extraction, harvesting, and storage is costly.
Biomass briquettes are much cleaner than fossil fuels.	Only less than 30% efficient.
Plantations can be developed to provide a sustainable supply.	There is a moderate to high impact on the environment because they are monoculture crops.
	It can lead to soil erosion, water pollution, loss of habitat, and loss of biodiversity.
	Growth of biomass requires large amounts of land and other inputs, such as water, fertilizers, and pesticides.
	Growth of the crops may utilize land and other resources needed for food production.

Wind

Historically, windmills were used to pump water for farms and ranches. For example, the many windmills in Holland were built to help remove water from low-lying areas reclaimed by the dikes. Today's windmills are giant wind-powered turbines that generate electricity as they turn. More specifically, wind turns blades that are attached to a generator, which converts the mechanical energy (wind) into electricity. Cables carry the electricity to the transmission line. Wind turbines clustered together are called wind farms.

WIND POWER



- Wind causes blades to rotate.
- A shaft turns a generator to produce electrical energy.
- A transformer converts electrical energy to high voltage.
- Electricity is transmitted via the power grid.

Wind	
Advantages	**Disadvantages**
No harmful pollutants.	Turbines can be damaged in storms.
Easily constructed.	Wind does not always flow at the same speed. Backup systems need to be in place to compensate for periods of decreased production.
Wind farms can be located placed off of coastlines, where there are large amounts of steady winds.	Rotating blades of turbines have killed birds and bats.
Land beneath turbines can be used for other uses.	The appearance of wind turbines has been criticized.
Highly efficient.	Plastic components are produced from crude oil sources.
Wind farms can produce energy for several homes simultaneously.	Large amounts of space are necessary for wind farms.
No waste disposal.	Farms located in the ocean may have negative unintended impacts on the ecosystem.

Geothermal

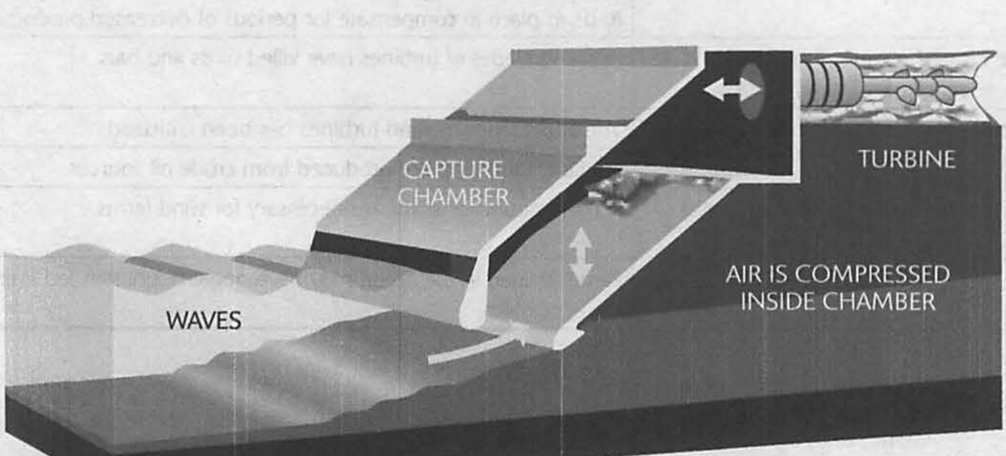
Geo means "of the Earth," and *thermal* means "heat"; therefore, geothermal energy is using the Earth's heat to generate electricity. Geothermal heat in the form of hot underground rock formations, molten rock, and hot subterranean water is used to turn a water source into steam, which drives electrical turbines. The top three countries in geothermal energy production are the United States, the Philippines, and Mexico. The system can be used to heat a house in the winter and to cool the house in the summer. Currently less than 1 percent of human energy use is generated by geothermal. Scientists estimate that using 1 percent of the energy stored in the top 5 kilometers of the Earth's crust would provide 250 times more energy than all the Earth's crude oil and natural gas reserves combined.

Geothermal	
Advantages	**Disadvantages**
Lower CO_2 emissions than fossil fuels.	Water and heat can be depleted, diminishing energy production.
Geothermal energy is clean and somewhat renewable.	There are limited locations for building plants since access to geothermal activity is required.
Water supply is replenished by rain, and heat is replenished by the Earth's interior.	Building a geothermal energy plant can diminish a fragile local ecosystem.
It is relatively inexpensive.	Digging into underground sources of geothermal energy can release hazardous gases, including hydrogen sulfide.
There is no waste disposal or transport.	
There is low land disturbance. Geothermal power plants do not have to be large.	
Energy source (fuel) does not require transport.	

Ocean and Tidal Waves

Although the concept is not new, the collection of energy from ocean and tidal waves is not widely used at this time. As shown in the figure below, this type of energy generation starts when the wave hits a platform, which in turn pushes on air in a chamber, pushing on the turbine. This turns a generator to convert the energy into electromagnetic energy. There are also other methods that capture ocean and tidal waves to generate electricity.

Ocean and Tidal Wave



Only a few places are currently using waves to generate electricity: off the northern coast of France, in the Bay of Fundy, on the northeast end of the Bay of Maine between the United States and Canada, and in Strangford Lough off the coast of Northern Ireland. A wave farm is being installed off the coast of Reedsport, Oregon. Other ocean-wave or tidal-wave projects are being planned throughout the world.

Ocean and Tidal Waves	
Advantages	**Disadvantages**
Wave technology is clean and renewable.	Dependent upon proximity to oceans.
Wave technology is reliable.	Subject to corrosion from saltwater.
No harmful environmental pollutants.	The environmental effect on species and habitats is unknown.
No waste disposal.	Visual or noise effects may occur.
Low land disturbance.	There may be conflicts between the needs of commercial shipping and recreational boaters.

Practice

Questions 1–3 refer to the following answer choices.

A. Potential energy
B. Kinetic energy
C. Electrical energy
D. Electromagnetic energy
E. Nuclear energy

1. The gasoline stored in tanks at the gas station contains which type of energy?

2. Which type of energy involves both fusion and fission?

3. Which type of energy comes to our homes through wires?

4. The loss of energy in subsequent levels of a food web is due to which of the following?

   A. First Law of Thermodynamics
   B. Second Law of Thermodynamics
   C. Law of Conservation
   D. Law of Conservation of Mass
   E. Law of Conservation of Momentum

5. Energy consumption is divided into four categories: industry, transportation, residential, and commercial. Which of the following is NOT part of the transportation sector?

   A. Air, rail, roads, and waterways
   B. Services such as law and medical
   C. Personal vehicles such as automobiles, bicycles, and motorcycles
   D. Operations including the financing, legalities, and policies for vehicles
   E. The infrastructure of roads and railways

6. Which fuel source is NOT being considered for future energy use?

   A. Clean coal
   B. Methane hydrates
   C. Oil shale
   D. Petroleum
   E. Tar sands

7. Which of the following is NOT considered a fossil fuel?

   A. Graphite
   B. Coal
   C. Petroleum
   D. Natural gas
   E. Methane hydrates

8. Which of the following is NOT an advantage of coal production?

   A. High net-energy yield
   B. Subsidies to keep the prices low
   C. Non-explosiveness
   D. Estimated large supply of undiscovered reserves
   E. Decreased biodiversity

9. Which of the following is NOT an advantage of nuclear power?

   A. No air pollutants are produced.
   B. Decommissioning is expensive.
   C. Water pollution is low.
   D. Little carbon dioxide is released during processing.
   E. Disruption of the land is moderate.

10. Dams have both advantages and disadvantages. Which of the following is an advantage of building a dam across a river?

- **A.** Large flooded area behind the dam
- **B.** Controlled downstream flooding
- **C.** Sediments building up behind the dam
- **D.** Increased water evaporation
- **E.** Building expenses

11. If you live in the Southwest and you want to make your house more energy-efficient, which of the following would NOT be a way to do so?

- **A.** Replacing your 25-year-old air conditioner
- **B.** Replacing your single-paned windows with double-paned windows
- **C.** Removing ceiling fans because you replaced your air conditioner
- **D.** Adding weather stripping
- **E.** Adding insulation

12. What is the percentage change in average passenger car fuel mileage from 1978 at 18 mpg to 2010 at 27.5 mpg? (You may NOT use a calculator.)

- **A.** 18
- **B.** 26.2
- **C.** 27.0
- **D.** 37.5
- **E.** 52.8

13. Which of the following is NOT a disadvantage of solar energy?

- **A.** It is inefficient where sunlight is seasonal.
- **B.** Battery technology is limited.
- **C.** It is great for remote locations.
- **D.** Efficiency is low.
- **E.** Systems get old and need to be replaced.

14. Which of the following is NOT produced by the combustion of fossil fuels?

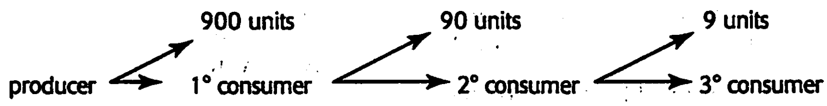
- **A.** Carbon dioxide
- **B.** Water
- **C.** Pollutants
- **D.** Energy
- **E.** Glucose

15. Historic energy consumption changed dramatically in the 1800s. Which is NOT a reason for this change?

- **A.** Industrial Revolution
- **B.** Population growth
- **C.** Development of the combustion engine
- **D.** Switching from wood to coal as a primary energy source
- **E.** Building of cross-country railroads

Answers

1. **A** Potential energy is stored energy; gasoline in the tank is stored, so it is potential energy.
2. **E** Only nuclear energy can include both fusion and fission.
3. **C** Electrical energy is the alternating current that is transmitted to homes, businesses, and other locations by power lines.
4. **B** As energy flows up a food chain, approximately 10 percent of the energy moves to the next level, while the other 90 percent is heat transferred to the environment. See the following illustration.



5. **B** Services such as law and medicine are part of the industry sector.
6. **D** Petroleum is currently being used as a fuel source. The other four choices are in development or expansion to fulfill a bigger part of our energy needs.
7. **A** Although graphite's basic source is the same compacted carbon that creates coal, it is the final stage *beyond* the three types of coal. Because it does not combust, it is not considered a fossil fuel.
8. **E** This question asks which is *not* an advantage or, put differently, "Which is a *disadvantage?*" Mining coal can destroy habitats and, thus, decrease biodiversity. It also produces air pollutants, especially sulfur dioxide, which combines with water to form sulfuric acid, a major component of acid rain, which can lower the pH of soil and lakes (among other consequences).
9. **B** This question also asks for a *disadvantage.* Decommissioning is a very expensive process, which makes it a disadvantage. The others are all advantages of nuclear power.
10. **B** Controlling downstream flooding prevents property damage and may save lives; thus, it is an *advantage* of building a dam across a river. (However, some areas historically have depended on seasonal flooding to distribute the rich topsoil used for growing crops.)
11. **C** Although ceiling fans use energy to operate, they help keep the house cool in the summer by improving air circulation, and they help lower energy costs.
12. **E** $V_1 = 18$ mpg and $V_2 = 27.5$ mpg and use the following formula:

$$\begin{aligned}\text{percent change} &= \frac{V_2 - V_1}{V_1} \cdot 100\\ &= \frac{27.5 - 18}{18} \cdot 100\\ &= \frac{9.5}{18} \cdot 100\\ &= 0.528 \cdot 100\\ &= 52.8\%\end{aligned}$$

13. **C** Solar panels work well in remote locations where it may be difficult or too expensive to run power lines to transport electricity. Santa Cruz Island in the Channel Islands off the coast of California runs one of its facilities using solar panels, storing electricity collected during the day in batteries to be used at night when solar energy cannot be collected.

14. **E** The following equation is the combustion reaction for fossil fuels (coal, natural gas, crude oil). Only glucose is not produced in this reaction; the other four choices are produced in the reaction.

$$\text{Fossil Fuel} + O_2 \xrightarrow{\text{burns}} CO_2 + H_2O + \text{Pollutants} + \text{Energy}$$

15. **D** The shift from wood to coal as the world's primary energy source is the change that occurred, not a *cause* of the change.