Chapter 10

Energy Resources

Understanding Energy

Energy Sources

Fusion: Our Original Source of Energy

Much of the energy that reaches Earth originates from **fusion** reactions in the sun. Fusion reactions combine lighter elements to form heavier elements. In the combination of these elements, some mass is converted into light energy that is carried through space by photons.

Energy that we use from coal and oil also comes from solar energy. **Photosynthesis** converts atmospheric carbon dioxide into an organic molecule, glucose. Dead organic material is compressed over time and either produces carbon alone (coal) or a mixture of hydrocarbon compounds (oil). When we burn fossil fuels, such as coal and oil, we are using solar energy that was captured by photosynthesis millions of years ago.

Solar energy can also be captured by water during the **hydrologic cycle.** When water evaporates upon being heated, then precipitates and falls into a reservoir, it can turn a turbine in a hydroelectric power station.

The energy we derive from nuclear sources came from a star, but not our own sun. During a previous generation of planets, a star exploded and created large, unstable elements, such as uranium and plutonium. These elements give back the energy of the star's explosion as they undergo radioactive decay.

Some energy is made available to us as tidal energy, which originates by the gravitational potential energy of the moon as it pulls against the seas.

Photons and Light Absorption

When photons reach the Earth, they are either reflected back into space or they are absorbed. Photons are absorbed because they are intercepted by a molecule that has a bond in it that vibrates when struck by the photon. In this way, light energy is converted into **kinetic energy** in the molecule. The increased motion within the molecule gives it heat.

For example, sunlight carries energy through the atmosphere and strikes the ocean. The bonds in ocean water molecules absorb the light energy and convert it into kinetic energy. If the water molecule has sufficient kinetic energy, liquid water will evaporate. The movement of the atmosphere carries the water vapor up a mountain. As the altitude increases, the pressure drops and the air releases the water as rain. As the water moves downhill in a river and through a power plant, some of its potential energy converts to kinetic energy and pushes the turbine to make electricity. This electrical energy is available because the water molecule originally absorbed light energy from the sun.

In the formation of coal, light was originally absorbed by the **chlorophyll** molecules in a plant. The chlorophyll initiates photosynthesis in the plant's cells, which convert carbon dioxide and water into glucose and oxygen gas. The glucose and other biological molecules in the plant fall off, decay, and become compressed under great heat and pressure over many years to become coal. The coal can then be burned to warm a building or create steam that turns a turbine that generates electricity. The coal provides energy because the chlorophyll molecules originally absorbed light energy from the sun. In both these examples, different mechanisms stored solar energy, which was used in the form of electricity some time later.

How Electric Power Is Made

Much of the energy humans currently use in daily life is in the form of electricity, which ultimately comes from the above-mentioned sources. Electricity is made by using some mechanical force to turn a turbine, which turns a generator to make electricity. The needed force can come from flowing water (hydroelectric) or high pressure steam that comes from water that has been boiled by the heat produced from either a chemical or nuclear reaction. The turning generator moves a set of magnets relative to a conducting wire. Through electromagnetic induction, the moving magnetic field exerts a force on the mobile electrons in the wire and causes the electrons to flow. Flowing electrons represent electrical current, which contains voltage.

The Second Law of Thermodynamics states that some energy will be lost as heat when energy is transformed from one type of energy into another, such as with the generation of electrical energy. Figure 10.1 shows a sequence of the forms energy takes as it is transformed from sunlight to electrical energy via hydroelectric power generation. In each transition, some energy will be lost as heat. The percent of energy available to do useful work after each step is called the *efficiency* of that energy transfer. The total energy efficiency for a number of steps equals the product of the efficiencies of each step.

For example, the series of energy transformations in Figure 10.1 represents six steps. If each step allows 80% of the energy to move to the next step (20% would then be lost as heat in each step), then the total efficiency for the process would be

$$0.8 \times 0.8 \times 0.8 \times 0.8 \times 0.8 \times 0.8 = 0.8^6 = 0.26, \text{ or } 26\% \text{ efficient.}$$

Figure 10.1 Energy Transformations Needed to Make Electricity

Sun
⇓
Evaporated water
⇓
Precipitated water
⇓
Falling water
⇓
Water pushing turbine
⇓
Turning generator magnets relative to conductor
⇓
Electrical energy

Energy Units and Calculations

Units of Energy

The fundamental metric units of energy are: kg • meter^2/seconds^2. The derived metric unit for all of these forms of energy is the **joule**. Therefore,

$$1 \text{ joule} = 1 \text{ kg} \cdot \text{m}^2/\text{sec}^2$$

Power is the amount of energy exerted in a given time and is expressed in units called **watts**; therefore,

$$1 \text{ watt} = 1 \text{ joule/sec}$$

Electrical energy is often expressed in terms of watts instead of joules by multiplying both sides by seconds; so the following relationship becomes important:

$$1 \text{ joule} = 1 \text{ watt} \cdot \text{sec}$$

Example 10.1

Question: How many joules are in a kW-hr?

Answer:

$$3.6 \times 10^6 \text{ J} = 1 \text{ kW-hr} \times \frac{1 \text{ J}}{\text{W-sec}} \times \frac{1{,}000 \text{ W}}{1 \text{ kW}} \times \frac{3{,}600 \text{ sec}}{1 \text{ hour}}$$

Sometimes energy is expressed in terms of nonmetric units, such as **British Thermal Units** (BTU) where 1.0 BTU = the amount of heat needed to raise 1.0 pound of water by 1°F; or calories, where 1.0 cal = the amount of heat needed to raise 1.0 grams of water by 1°C. Therefore:

$$1 \text{ kW-hr} = 3{,}400 \text{ BTUs} = 3.6 \times 10^6 \text{ J} = 1.5 \times 10^7 \text{ cal}$$

Unit Conversions

Many problems simply involve converting one set of units to another. The following steps help solve unit conversion problems:

1. Write down the units of the answer.
2. On the other side of the equals sign, write the given information.
3. Use conversion factors to cancel the units of the given information so that only the units of the answer remain.

Example 10.2

Question: How many BTUs are in 14.0 kW-hr?

Answer:

$$4.76 \times \mathbf{10^4}\ \text{BTU} = 14.0\ \text{kW-hr} \times \frac{3,400\ \text{BTUs}}{1\ \text{kW-hr}}$$

Example 10.3

Question: Assuming one pound of coal used by a power plant yields 5,000 BTUs of heat energy, how many BTUs are produced by 2,500 pounds of coal?

Answer:

$$1.25 \times \mathbf{10^7}\ \text{BTU} = 2,500\ \text{lbs. coal} \times \frac{\overset{5,000}{\cancel{3,400}}\ \text{BTUs}}{1.0\ \text{lb. coal}}$$

Example 10.4

Question: How many joules of heat are produced from 2,000 lbs. coal? (There are 1,059 J per BTU; 1.0 lb. coal produces 5,000 BTUs.)

Answer:

$$1.1 \times \mathbf{10^{10}}\ \text{J} = 2,000\ \text{lbs. coal} \times \frac{5,000\ \text{BTUs}}{1.0\ \text{lb. coal}} \times \frac{1,059\ \text{J}}{1\ \text{BTU}}$$

Specific Heat Calculations

Specific heat capacity refers to a material's ability to absorb heat. For example, it takes more heat to raise the temperature of water by 1.0°C than it does to increase the temperature of sand by the same amount. Each unit of heat energy is connected to a different definition of specific heat, each of which carries meaning about units that can be used to solve problems.

Table 10.1 Units of Energy and Specific Heat Definitions

Unit of Energy	Amount of Unit Needed to Heat Water
Joule	Heat needed to raise temperature of 1.0 gram water by 4.2°C
Calorie	Heat needed to raise temperature of 1.0 gram water by 1.0°C
BTU	Heat needed to raise temperature of 1.0 pound water by 1.0°F

Each different material has a different specific heat capacity, or the amount of heat contained in the material per degree. In general,

Heat needed = mass of material × specific heat × ΔTemp

Or $q = mC\Delta T$

where q = amount of heat absorbed by the material
m = mass of the material
C = specific heat capacity of the material
ΔT = change in temperature of the material (final temperature – initial temperature)

Example 10.5

Question: How many joules of heat are needed to heat 5.0 g water by 10.0°C? ($C_{\text{water}} = 4.2\ \text{J/g} \cdot {}^\circ\text{C}$)

Answer: Using $q = mC\Delta T$,

$$210\ \text{J} = 5.0\ \text{g water} \times \frac{4.2\ \text{J}}{\text{g water} \times {}^\circ\text{C}} \times 10.0^\circ\text{C}$$

Example 10.6

Question: How many BTUs of heat are needed to heat 10.0 lbs. water by 10.0°F? ($C_{\text{water}} = 1.0\ \text{BTU/lb.} \cdot {}^\circ\text{F}$)

Answer: Using $q = mC\Delta T$,

$$100\ \text{BTUs} = 10.0\ \text{lbs. water} \times \frac{1.0\ \text{BTU}}{\text{lb. water} \times {}^\circ\text{F}} \times 10.0^\circ\text{F}$$

Example 10.7

Question: How many calories of heat are needed to heat 25.0 g of water by 10.0°C? ($C_{water} = 1.0\ J/g \cdot °C$)

Answer: Using $q = mC\Delta T$,

$$\mathbf{250\ cal} = 25.0\ \text{g water} \times \frac{1.0\ \text{cal}}{\text{g water} \times °\text{C}} \times 10.0°\text{C}$$

Electrical Energy Calculations

Some calculations take advantage of the time component in the common electrical units of energy, kW-hr. Don't forget that when you divide by units, you turn them upside-down and multiply. For example, to divide by miles-per-hour, you simply multiply by hours-per-mile. Also, even though you might cancel the units of kW in kW-hr, the time unit (hr) remains.

Example 10.8

Question: How long will a 100 W bulb shine with an energy input of 1.0 kW-hr?

Answer:

$$10\ \text{hr} = 1.0\ \text{kW-hr} \times \frac{1{,}000\ \text{W}}{1.0\ \text{kW}} \times \frac{1}{100\ \text{W}}$$

Example 10.9

Question: How many kW-hrs of energy are needed to light a 75 W bulb for 100 hours?

Answer:

$$\mathbf{7.5\ kW\text{-}hr} = 100\ \text{hr} \times 75\ \text{W} \times \frac{1.0\ \text{kW}}{1{,}000\ \text{W}}$$

Non-Renewable Energy Sources

Formation and Use of Fossil Fuels

Coal

During the carboniferous period about 300 million years ago, conditions on earth favored freshwater swamp ecosystems, which in turn produced a significant amount of plant material. Upon dying, the plants decayed underwater, became compacted, and formed peat—which is about 5% carbon. As peat was covered by sediments, it became further compressed and formed lignite coal—which is about 60% carbon. Further compression yielded bituminous coal (about 75% carbon), which is the type of coal most often used in electric power generation. The most compressed form of coal is called anthracite—which is over 90% carbon. As a general rule, older coal has a higher carbon content, which provides more heat when burned.

Oil and Gas

In the same manner that coal was formed from plants, crude oil and natural gas were formed by the decomposition of microorganisms. Oil typically exists within the pores of sandstone. The sediment that compresses the decaying organisms is itself compressed and forms shale, which absorbs the oil into its pores.

Crude oil is a heterogeneous mixture of many hydrocarbon molecules, which are separated from each other during the refining process. The greater the number of carbon atoms in an organic molecule, the higher will be that molecule's boiling point and viscosity. Organic molecules with less than five carbon atoms are gaseous. Molecules with 6–9 carbon atoms are liquid and used for light fuels, such as kerosene and gasoline. Molecules with the largest number of carbon atoms are solids and semi-solids, such as waxes and tars.

Use of Fossil Fuels

Coal is the most abundant non-renewable energy source and is used for about 27% of the world's energy needs. It is mined in either a surface mine or a shaft mine. Coal is bulky to transport, and combustion of it yields oxides of sulfur (remaining in the coal as a result of decomposed proteins) that, when combined with water, produces acid rain. Also, rain runoff flowing through open mines produces acidic mine drainage.

Nuclear Power

Radioactivity

Radioactivity is caused when unstable nuclei undergo a nuclear reaction and give off high-energy electromagnetic radiation. Unstable nuclei are created when the ratio of neutrons to protons is not appropriate. At this point the nuclear forces between nuclear particles cannot overcome the electrical repulsion between protons, a nuclear reaction occurs, and energy is emitted.

Energy is produced during a nuclear reaction because an extremely small portion of the mass of the nuclear particles is converted directly into energy ($E = mc^2$). The resulting energy is usually of very short wavelength and high frequency—far outside the visible electromagnetic spectrum. High-energy electromagnetic radiation can cause severe damage to biological tissue.

Nuclear Reactions

In Chapter Two, chemical reactions were described as a change in the way atoms were arranged together. For example, one atom of carbon combines with two atoms of oxygen to form one molecule of carbon dioxide. Both reactants and products have one atom of carbon and two atoms of oxygen, just rearranged.

Nuclear reactions are similar to chemical reactions because matter is conserved at a superficial level. They are different in that nuclear reactions do not rearrange matter like a chemical reaction; a nuclear reaction actually changes the identity of matter from one type of element to another by adjusting the number of either neutrons or protons in the nucleus. Five types of nuclear reactions are important in AP Environmental Science.

1. **Neutron capture**: In this reaction, a nucleus absorbs free neutrons to become an isotope—often unstable and radioactive—of the original nucleus. This is the type of nuclear reaction whereby free neutrons from the Chernobyl explosion converted non-radioactive nuclei into unstable, radioactive nuclei.

   e.g., $4\ {}^{1}n + {}^{127}I \qquad {}^{131}I$

2. **Alpha decay**: This naturally occurring type of decay emits an alpha particle (helium nucleus) as the unstable parent atom attempts to become more stable. As a result, the atomic number of the element decreases by two, and the total mass number decreases by four.

   e.g., ${}^{238}U \qquad {}^{234}Th + {}^{4}He$ (alpha particle)

3. **Beta (β) decay**: This naturally occurring decay emits an antineutrino from the nucleus, which later decomposes into an electron. The result is that a neutron in the nucleus turns into a proton and the atomic number of the element increases by one.

   e.g., ${}^{234}Th \qquad {}^{234}Pr + {}^{0}e$

4. **Fission**: Fission is the breakup of large, unstable nuclei into many smaller nuclei. It is usually catalyzed by bombarding the large nuclei with neutrons. This is the reaction that takes place in nuclear power plants and in atomic weapons—such as those dropped on Japan to end World War II. The neutrons that are given off in a fission reaction, in turn, catalyze other large nuclei to split, which can result in an explosive chain reaction unless the neutrons are absorbed. Fission reactions in nuclear power plants are moderated by control rods, which slow the fission reactions by absorbing neutrons.

   e.g., ${}^{1}n + {}^{235}U \qquad {}^{97}Kr + {}^{141}Ba + 3\ {}^{1}n$

5. **Fusion**: Fusion is the combination of two small nuclei into one larger nuclei. This type of nuclear reaction only occurs at very high temperatures, such as those that occur on stars—including our sun—and with thermonuclear weapons. To date, we have not figured out how to control this reaction well enough to generate electricity.

   e.g., ${}^{2}H + {}^{2}H \rightarrow {}^{4}He$

Nuclear Reactors

1. Anatomy of a Reactor

   While nuclear reactors differ in size and levels of containment, all nuclear reactors are similar in that they:

   - use fuel packed together in a fuel assembly
   - use control rods—or moderators—to absorb neutrons and control the rate of fission inside the reactor core
   - heat a material that is in contact with the fuel, which also cools the reactor core
   - use a heat-exchanging material to carry the kinetic energy of the originally heated material to the turbine
   - use a coolant to prepare the heat-exchanging medium for reheating

2. Types of Nuclear Reactors

   - Boiling water reactors (BWRs) allow water to come in direct contact with the fuel assembly. This radioactive water then leaves the containment structure and drives the turbine directly. This is probably the dirtiest type of nuclear reactor and carries the highest chance of accident.
   - Pressurized water reactors (PWRs) allow water to circulate through the core of the reactor to absorb heat and cool the fuel rods. When this water reaches a high enough pressure, it heats a secondary circuit of water, which evaporates to steam and drives the turbine. This is the type of reactor that is most often used in commercial nuclear power plants.
   - Heavy water reactors (HWRs) use heavy water—water whose hydrogen has an extra neutron—as both a cooling agent and a moderator.
   - Graphite reactors use graphite—or carbon—as both a moderator and cooling agent. Then they blow gas through the reactor to carry the heat to steam generators, which in turn drives the turbines. Chernobyl was a graphite reactor.

- High temperature, gas-cooled reactors (HTGCRs) coat the fuel pellets with a ceramic, then blow helium through the pellets as a coolant. A melt-down is not possible unless operators put too many pellets together. While this seemed to be a promising design because fuel could be added and removed while the reactor was operating, no such reactors have successfully remained operational.

Health Risks Due to Radioactivity

Radioactivity is energy emitted from nuclear reactions. Like any other types of energy, if it is high enough, radiation can damage humans. Our bodies are constantly subjected to background radioactivity due to cosmic rays, the sun, building materials, and other sources. For the most part, our cellular machinery has evolved to be able to handle doses of radioactivity at these levels. However, irresponsible use of nuclear power or explosives in the world can expose humans to much higher levels of radiation. To better understand the risk of biological damage due to radiation, one must understand how doses of radioactivity are measured.

1. Dose Measurements

   The metric units of energy are **joules**. The units of energy measurement for radiation are **rads** (radiation absorbed dose). One rad equals 10^{-2} joules. The amount of biological damage is related to both energy, measured in rads, and the type of subatomic particle colliding with the body. Therefore, **rems** (roentgen equivalent for man) are a more accurate unit when considering biological risk. One rem equals the number of rads multiplied by a constant that is related to the type of particle causing the radiation. The biological effects of a radioactive dose depend on

   a. the type of particle involved,

   b. the overall energy of the radiation,

   c. the length of time of exposure,

   d. the tissues that have been exposed, and

   e. the chemical properties of the radioactive element.

2. Biological Damage

   Biological damage can occur in two general ways: there can be damage to somatic cells, or there can be damage to the genetic machinery inside the cell.

   Somatic, or general body cells, can be physically damaged due to the energy of an acute exposure (burns, for example). Even if the somatic cell damage has not caused immediate death or is not visible, less evident body cells may be damaged enough to cause death in a few days or weeks.

   With lower level chronic exposure, there may be **genetic** changes within the cell that cause some form of cancer, or have teratogenic effects. Below is a list of various doses, causes for the doses, and possible effects. This chart represents an approximation because every body responds differently to radiation.

Table 10.2 Cause and effects of various radioactive doses. The highest doses would occur through nuclear accidents, war, or chronic exposure to nuclear waste. Mrem = millirem = 1/1,000 rem

Dose (mrem)	Cause	Effect
3 mrem	5-hour flight	None
7 mrem/yr	Building materials	None
50 mrem/yr	Cosmic radiation	None
50 mrem	Diagnostic x-ray	None
200 mrem/yr	Typical annual dose	None
700 mrem	Brain scan	None
1,000 mrem/yr	Safety threshold	None
10,000 mrem/yr		Cancer risk
25,000–50,000 mrem		Decrease in white blood cells
350,000–500,000 mrem		Risk immediate death, half die in 30 days

Pollution Risks of Nuclear Power

Unlike power plants that use fossil fuels, producing electricity from nuclear-generated steam does not produce air pollution. However, every step of the mining, refining, processing, use, and storage of nuclear fuel contains the possibility of introducing radioactivity into the environment.

Ideally, once nuclear fuel is used up in the environment, it can be re-processed and used again. Practically, this only happens in a few countries. In the United States, nuclear fuel is not re-used, but stored for many years at the site of use. We are still trying to figure out how to store nuclear fuel over many years so that future generations are protected.

Again, while nuclear power plants do not generate air pollution, they do need vast amounts of water to cool the nuclear core and/or the steam that the core produces. For this reason, nuclear power plants tend to be located near rivers, and much of the river is diverted through the plant to provide the necessary cooling. In some locations, local authorities allow the temperature of rivers to be increased by 5°C, which is enough to decrease the amount of dissolved oxygen in the river and can put the temperature of the river outside the tolerance range of key organisms. Consequently, this type of thermal pollution has the ability to be just as devastating to the environment as the emission of more toxic forms of pollution.

Renewable Energy Sources

Renewable energy sources can be regenerated within our life time at a rate that exceeds its use. Energy sources that are considered renewable include solar, wind, biomass, geothermal, hydro, and tidal sources.

Solar Heating

Passive solar heating uses design of orientation, special materials, and space to maximize the retention and flow of solar energy. Passive solar heating does not involve moving parts or an input of energy.

Some passive designs include the following:

1. A Trombe wall: a massive wall built behind a window exposed to the sun that will retain and re-emit solar heat
2. Extended eves that block the summer sun
3. A greenhouse with vents into a living space

Active Solar Heating

"Active" refers to the input of energy in order to gain full benefit from the solar heating design. For example, water that is heated by the sun on the roof of a house may be considered passive, but if an electrical pump is used to circulate water through the system, it would be considered active solar heating. Adding a pump or fan to a passive system makes it an active system. For example, a fan that circulates air past a Trombe wall creates an active solar heating system.

Photovoltaic Cells

Photovoltaic cells convert solar radiation directly into electricity. Photovoltaic cells are composed of layers of semiconductor wafers that give off electrons via the photoelectric effect when photons strike the wafers. As a result, the moving electrons flow along a conductor and provide a current of electricity.

Photovoltaic cells were initially used during the space program to provide ongoing power for satellites. With improved semiconductor designs, photovoltaic efficiency has also improved.

Fuel cells are actually a method for energy storage, rather than generation. Photovoltaic cells collect solar energy and convert it directly to electricity, which is directed to a membrane that separates hydrogen and oxygen from water molecules. At a later time when the energy is needed, the membrane can be changed to combine the hydrogen and oxygen back together to form water, and the electricity initially put into the process is returned with a high level of efficiency (very little energy is lost to heat) and no pollution is created.

Wind

About 2% of the solar energy that strikes the Earth heats the air and creates wind, which carries the ability to do mechanical work. Windmills are from 35–60% efficient in converting mechanical energy into electrical energy.

Wind energy had a large impact on the American westward expansion. Windmills provided a critical source of self-sufficient energy to pump water out of aquifers for cattle, crops, and towns. Today, giant wind farms use large aerodynamically designed rotors to produce electricity but thousands of the small windmills are still used in ranches and rural areas.

Pros:

1. Wind energy is pollution-free.
2. Wind is renewable indefinitely.
3. The land under wind farms is more easily used for other purposes—grazing cattle, for example—than the land under solar collectors or reclaimed coal mines.

Cons:

1. Like solar power, energy obtained from wind must be stored using batteries or fuel cells.
2. Wind is unreliable in most areas. There are only a few locations where the wind is constant enough to be a dependable source of energy.
3. Windmills and rotors take up space and can be unsightly. Windfarms are often in remote areas and might not be noticed, but they hinder the sense of open space or wilderness.

Biomass

Plants convert the energy of solar photons into chemical energy stored inside the bonds of organic molecules. About half the energy that plants absorb undergoes this conversion. When those chemical bonds are broken—such as when wood is burned on a fire—most of the energy is released.

Besides burning plant matter or animal waste, another way to capture solar energy is to ferment organic material. Yeasts can metabolize sugars to produce alcohol, which can then be stored or burned to regain the chemical energy stored in the bonds.

Bacterial digestion of carbon wastes—such as animal dung—can produce methane, or natural gas, which can be burned to provide heat or run a generator. However, in the Third World countries that are inclined to use this process, the dung may be better used as a source of nutrients for crops.

Geothermal

Geothermal energy from mantle heating is possible in a few places in the world. Steam or hot water that is warmed by the Earth's mantle is drawn out of deep wells and used to drive turbines to generate electricity, or pumped directly through buildings to provide heat. Once the kinetic energy of the steam or hot water has been used, the water is further cooled and returned to the ground to be re-heated.

Geothermal steam can be depleted without warning, which effectively makes it a nonrenewable source of energy. Geothermal steam usually contains dissolved salts that corrode and encrust pipes and generating equipment; some of the chemicals used to clean the pipes and turbines are very toxic. Because of its lack of availability, potential for depletion, and the dissolved ions, obtaining energy from geothermal steam is only practical in those very few areas where "clean" steam—very nearly distilled water—is available.

Geothermal energy from heat pumps, unlike geothermal steam heat, can be used anywhere in the world. Geothermal heat pumps use the same principles that operate a refrigerator to pump heat into or out of the Earth using a series of pipes and a heat-carrying fluid. The Earth provides a nearly limitless heat sink that absorbs heat during hot days and provides heat during cold days. Geothermal heat pumps are being used increasingly in homes and large city buildings; the larger the building, the greater must be the exposed surface of pipe underground. Geothermal energy using heat pumps is a renewable energy source, and is very promising.

Hydroelectric

Pros:

1. Producing electricity from falling water is a highly efficient, nearly pollution-free method of producing electricity. About 85% of the gravitational potential energy contained in water by virtue of its high position can be converted into electricity when the water passes through a turbine at the end of its fall.
2. Because no chemical or nuclear reaction is used to heat steam to drive the turbine, no toxic by-products are produced that could potentially spoil the environment.

3. Hydroelectric power is a renewable resource. After the water passes through a dam, solar energy evaporates the water and moves it uphill so that it may go through the cycle again.

Cons:

1. The water impounded behind a dam devastates the previously existing habitat.
2. Silt flowing into the impounded water piles up behind a dam to reduce its effectiveness.
3. The river is blocked so that species of fish and other organisms may not pass through.
4. The slow flow of water behind the dam can create oxygen-depleted or pathogenic aquatic systems. For example, schistosomiasis is a disease that is caused by parasitic flatworms that live within snails, which live in the waters behind dams in tropical areas.
5. The impounded water can also displace people who lived along the former river bank. For example, the Three Gorges project in China will displace about one million people, who will need to compete for resources with existing residents in some new place.
6. When a large body of water is impounded behind a dam in a warm climate, a considerable amount of water is lost to evaporation. In some countries, this water might be more useful for drinking or producing crops, rather than being stored so that a fraction of it may pass through a turbine to provide electricity.

Tidal

Tidal movement is a unique source of hydroelectric power and shares the same pros and cons of that source. It is the only type of power that ultimately comes from a non-stellar source—in this case, the movement of the moon. Like wind and solar power, the electricity generated from tidal movement is intermittent; energy must be stored in order to serve a constant need. An additional drawback for capturing tidal energy is that saltwater must flood normally brackish estuaries, which alters that biome considerably. Also, retention of saltwater for too long in inland estuaries may promote saltwater intrusion of freshwater aquifers. Finally, because retaining water from tides only gives the water a few feet of gravitational potential energy, there must be a very large area that is flooded in order to obtain a small amount of energy. For example, water that falls 700 feet at Hoover Dam provides 40 times more power than the water that falls 17 feet in the Bay of Fundy—and most tidal drops are much less than this.

Patterns of Human Energy Use

A Brief History of Human Energy Use

Hunters-Gatherers

Bands of people from prehistoric times have used fire from wood fuel as a primary source of energy. Using this type of energy required bands of people to move from place to place and allow the land to replenish itself before the band returned. However, increased population growth placed too many people on the land and risked depleting this style of energy use.

The Neolithic Revolution

With the advent of farming and animal domestication about 10,000 years ago, energy derived from a wood-burning fire was supplemented with muscle energy from animals (to pull carts and plows). Farming allowed a population of people to concentrate its sources of food and grow crops to fuel domesticated animals, but the source of energy was still limited to the energy captured by crops and trees.

The Industrial Revolution

Four major advances caused the Industrial Revolution: improved agricultural practices, the invention of the steam engine, the ability to make steel, and the increased use of coal as an energy source. Each of these advances played off each other to allow for greater population densities in cities, improved manufacturing and technology, and stimulated economic growth.

Improved agricultural methods allowed for increased population densities, which was supported by the use of coal instead of wood for heat in more populated areas. The availability of coal facilitated the discovery of how to make steel from iron, and the invention of the steam engine helped to mechanize modern production and pump water from deep coal mines—further improving the supplies of coal. Major businesses grew up around each of these developments, which allowed people to support their families with salaries from factories rather than raise crops and livestock. Greater wealth allowed each member of society to use a greater amount of energy; per capita energy use increased by a factor of eight.

The Automobile Society

The use of a new energy source—refined crude oil—allowed automobile owners to live farther from work and market, but consume ever greater amounts of energy per capita in the course of daily life. Owning cars allowed families to live in suburbs and commute longer to work. The advent of the suburbs corresponded with an increase in labor-saving devices—such as a garage-door opener, and luxuries—such as air conditioning. For example, some metropolitan areas nearly double summer energy production simply to cool air. Few people owned cars or cooled air 100 years ago, but it is difficult to function in a highly developed society today without a car—and without using the energy needed to operate a car. Likewise, few people in developed countries expect to live and work in a warm climate without the luxury of cooled air.

Developed vs. Undeveloped Countries

Different countries in the world are at different stages of development. With each stage of development, per capital energy use increases dramatically. The hunter-gatherer only uses fire to cook food and stay warm in the winter. The farmer uses that amount of energy, and also the energy needed to plow fields. The industrialized worker needs energy to spin cotton, manufacture goods, and build bridges. The automobile owner needs all those types of energy, plus energy to operate a car.

Currently one-fifth of the world's population lives in a developed country, but that 20% of the population uses more than 80% of the world's energy supply. An American uses more energy in a day than a person in an undeveloped country uses in a year.

Current Residential and Commercial Energy Use

In a developed country today, energy comes from many sources in the following approximate proportions.

Table 10.3 Sources of Energy

Source	Percentage of Energy Provided
Oil	36%
Coal	26%
Gas	23%
Nuclear, solar, wind, hydro	9%
Biomass, including wood	6%

Of these energy sources, natural gas is the most efficient. Less than 10% of its energy is lost in processing and transport, and it needs very little refining. Also, because it contains more hydrogen per carbon atom, it produces less carbon dioxide—and therefore contributes less to global warming—than other carbon-based fossil fuels.

Table 10.4 Uses of Energy

Use	Precentage of Energy Used
Residential and light commercial	35%
Industrial	35%
Transportation	25%
Other	5%

Energy Conservation

The following represent a few recommendations that the average consumer can follow to conserve our energy resources, and reduce the environmental impact of obtaining the energy needed to operate our society.

1. Live closer to markets and work
2. Use vehicles that use less energy for construction and for daily operation
3. Use products and eat foods that require less energy to manufacture
4. Reduce, reuse, recycle
5. Live in homes and work in buildings that require less energy to operate. Such buildings would be engineered to take advantage of the sun for heating, use geothermal resources for heating and cooling, and minimize the use of fossil fuels.
6. Engage in recreational activities that require less energy

Case Summaries

Ohio River System

Principle mentioned in this case:

- **Environmental damage related to power production**

In the 1930s, a series of locks and dams allowed tug-driven barges to navigate far up the Ohio River. Because of the easy access to coal transported by barges, and cooling water from the river, electric utilities built nearly 50 coal-fired power plants to provide power for Chicago and much of the Eastern Seaboard. Additionally, the river navigation system allowed for easy transport for chemical, cement, crude oil, and grain industries also near the river. Inexpensive power and transportation provided the essential infrastructure to fuel population and economic growth in the area. However, the acid rain and heavy metal pollution from the high density of coal-fired power plants is a severe environmental health liability for the area. Considerable pressure is exerted on industries—particularly the power industry—to reduce emissions.

Dam-Breaching: A Post-Hydroelectric Era?

Principles mentioned in this case:

- **Reduction in hydroelectric power facilities**
- **Restoration of rivers**

Since the early 1900s, the Army Corps of Engineers and some major engineering firms have been building dams to produce inexpensive hydroelectric power. However, states are beginning to feel that the benefits of a free-flowing river outweigh the convenience and cost-savings of hydroelectric power, plentiful local water supply, and lake-style recreation. For years, the U.S. Fish and Wildlife Service recommended removal of the Edwards Dam on the Kennebec River in Maine. Finally, the Federal Energy Regulatory Commission allowed the dam to be opened and permit migration of key fish species upstream. Removal of other dams in the northwest on the Elwa and Snake Rivers are also being considered.

Oil Transport from Alaska

Principles mentioned in this case:

- **Environmental damage related to energy production**
- **Bioremediation**
- **Effect of oil production on wildlife**

Large oil reserves were discovered on the northern coast of Alaska in 1967. Locked in by ice for the majority of the year, some method other than oil tanker had to be devised to transport the oil to warmer ports and on to refineries. In the early 1970s, a 1,300-kilometer-long pipeline was constructed between Prudhoe Bay to Valdez. The 1.2 meter diameter pipeline had to be elevated above the tundra so that the oil—super-heated to facilitate rapid flow—would not melt the permafrost, and would not be a barrier for animal migration.

In 1989, a supertanker named *Exxon Valdez* ran aground in Prince William Sound, releasing many millions of gallons of oil and devastating the marine ecosystem for thousands of miles of coastline. Although Exxon poured large sums of money into the attempted remediation, the most successful cleanup was performed by naturally occurring bacteria that digested the oil.

Persian Gulf Wars: Oil and Foreign Policy

Principle mentioned in this case:

- **Political instability as a result of reliance on fossil fuels for an energy source**

Iraq, led by Saddam Hussein, invaded Kuwait in August 1990 and laid claim to the rich oil fields of this small country. The United States immediately protected next-door Saudi Arabia from the same fate, and then attacked Iraqi troops to regain Kuwait.

The conditions of surrender in the conflict demanded that Iraq not build up a long-range missile arsenal—which had been used against troops and Israel during the conflict, and to not build or stockpile weapons of mass destruction (Iraq had already used chemical weapons on Kurdish towns in northern Iraq). United Nations inspectors were to make sure that such an arsenal was not developed. Intermittent non-compliance from Iraq eventually led to the second Gulf War, which began in the spring of 2003.

The Arctic National Wildlife Refuge: Oil and Biodiversity

Principle mentioned in this case:

- **Biodiversity**

Two different legislative acts in 1960 and 1980 set aside about 40 million acres on the northern coast of Alaska for wilderness protection, called the Arctic National Wildlife Refuge (ANWR). This area is a sensitive tundra biome that is rich with wildlife and provides rangeland for the second largest caribou herd in the world. However, increased energy demand and depleted domestic oil reserves (and subsequent increased reliance on foreign oil) puts pressure on Congress to authorize drilling for oil in the refuge.

The James Bay Power Project: Return to Hydroelectric Power

Principles mentioned in this case:

- **Hydroelectric power from the tides**
- **Estuary ecosystem**
- **External cost paid by indigenous peoples**

The James Bay Power Project is a plan for hydroelectric power that would impound vast amounts of water in northeastern Quebec. The plan would impede all of the free-flowing rivers in about one-fifth of this large province, thereby destroying the habitat for animals that depend on those rivers—and threatening the indigenous cultures that depend on those animals for food. Possible environmental damage includes siltation, nutrient pollution, habitat destruction, thermal pollution, and salinization. Each of these consequences would eliminate many critical species, as well as destroy the way of life for local Inuit and Cree populations. After the effects of the first phase of the project were observed, the possibility of further environmental damage has halted the project, but the need for power in Canada and the northeastern United States—which would be the largest user of James Bay power—continues to grow.

Three-Mile Island: A Hint of Nuclear Catastrophe

Principle mentioned in this case:

- **Nuclear accident**

Three Mile Island is a nuclear power plant located outside of Harrisburg, Pennsylvania, on the Susquehanna River. In March 1979, a faulty pump and gauge led to a decision to override the emergency cooling system at an electricity-producing nuclear reactor, and the temperature of the reactor increased and caused a partial core meltdown. Some radioactive steam was released, and many people evacuated local neighborhoods. The reactor was never restarted after the accident, and its fuel was removed entirely in 1990. This incident eroded American confidence in the safety of operating nuclear-powered electrical generation plants—let alone the controversy in finding a place for nuclear waste, and very few new nuclear power plants were built in the United States after this.

Yucca Mountain: An Attempt to Complete the Nuclear Fuel Cycle

Principles mentioned in this case:

- **Nuclear fuel cycle**
- **Storage of nuclear waste**

The nuclear fuel "cycle" is not really a completed cycle because much of the radioactive waste created is not reprocessed and, in fact, has no final resting place. High- and medium-level waste is often stored on-site where it was used, or shipped by rail to sites such as the Idaho National Engineering and Environmental Laboratory, near Idaho Falls, Idaho. Other similar sites exist in South Carolina, New York, and Washington.

While some other countries reprocess spent nuclear fuel rather than store it in temporary locations, no country has yet developed a permanent storage facility for high-level radioactive waste.

One proposal is to put the waste in borosilicate glass containers, which would then be encased in steel canisters and stored above ground until it could be safely buried.

One possible permanent storage site is Yucca Mountain, which was chosen because it is geologically stable and located in an isolated area of Nevada, near a nuclear test site. It is also very dry; the water table is about 2,000 feet below the mountain and, therefore, unlikely to be polluted. Although some exploratory tunneling has occurred, actual construction of the site has not in the face of local protests. Construction is scheduled to begin in 2005.

Chernobyl Nuclear Catastrophe

Principles mentioned in this case:

- **Severe nuclear disaster**
- **How countries respond to nuclear disaster**

On April 25, 1986, at Power Station Four in the small city of Chernobyl in Ukraine, technicians began a test to see how much power would be produced from a turbine that was still spinning after the steam had been turned off. This test initiated a sequence of events that led to the rapid overheating of the reactor, which deformed the core so that the control rods could not be further inserted. As a result, the core melted and caused an explosion.

The explosion released vast amounts of neutrons that, through neutron bombardment, caused nonradioactive elements to become radioactive. In addition to the immediate fatalities of workers and severe radiation exposure to nearby populations, air currents carried radioactive particles high into the atmosphere where normal convective downdrafts created "hotspots" in various locations in Europe.

Wherever radioactivity increased in communities around Europe, officials responded by giving children large doses of nonradioactive iodine. Neutron bombardment of iodine in the environment had created radioactive iodine (I-131), which would be metabolized and imbedded in young thyroid glands, where it could cause thyroid cancer. Flooding the body with nonradioactive iodine decreased the chance of the thyroid assimilating the radioactive isotope, and therefore decreased the chances of thyroid cancer.

Overall there were about 30 immediate fatalities, and hundreds of people were to die over the subsequent months due to radiation-related complications. Over 100,000 people were evacuated from nearby towns and villages, some of which have since become ghost towns and have never been re-inhabited.

It took ten days and heroic sacrifices to flood the core with neutron-absorbing boron and decrease the outpouring of radioactive material. By November 1986, the Ukrainian government had covered the reactor core with cement, but further containment is planned for the future.

Soviet Nuclear Legacy

Principle mentioned in this case:

- **Ongoing effects of irresponsible use of nuclear power**

While the Chernobyl accident was an immediate embarrassment to the struggling Soviet leadership, four decades of the Cold War arms buildup and economic shortcuts left environmental calamities that eventually became known after the Soviet Union fell.

More than 100 nuclear bombs had been detonated to move earth for mining or construction. Over 400 nuclear explosions occurred in weapons testing. Radioactive waste dumps are found throughout the region, including over 600 dump sites near Moscow. A now-infamous example is the dumping of waste into the Techa River, causing widespread, unmonitored contamination near Chelybinsk. The health of the environment and the people of the former Soviet Union will be affected for many years to come because of irresponsible use of nuclear devices.

Environment and Society