Chapter 20 – Sustainable Energy

Key Terms

active solar power
biomass
energy efficiency
ethanol
geothermal energy
green pricing
hybrid vehicles
hydrogen fuel cell
methanol
net energy yield
ocean thermal electric conversion
passive solar
photovoltaic cells
tidal station

Skills

1. Review methods of energy conservation.
2. Compare the different methods of transport that conserve energy.
3. Differentiate between types of alternative energy resources.
4. Contrast active and passive solar power.
5. Classify the different types of biomass fuels.
6. Identify methods to generate electricity from tides and ocean thermal gradients.
7. Examine the characteristics of geothermal power.

Take Note: Understanding energy conservation methods is extremely important for a student preparing for the AP Environmental Science exam. It is also of paramount importance that students are able to discuss the pros and cons of each type of alternative energy resource. Essay questions on past exams have addressed biomass fuel, water diversion projects, and wind energy. Questions regarding efficiency and alternative energy also occur on the multiple-choice portion of the exam.

Net Energy Yield

The net energy yield is the total useful energy derived from a resource minus the energy required to obtain the resource and make it available. Nuclear power has low net energy because it is expensive to mine and concentrate the uranium, build nuclear power plants, and dispose of the radioactive wastes. Coal has a high net energy yield because it is relatively inexpensive to mine coal and build coal burning power plants. The electricity generating renewable resource that has the highest net energy yield is hydroelectric power. Since passive solar power does not generate electricity, it has the highest net energy yield of all of alternative energy resources.

Electrical Grids

Most electrical plants are attached to a grid. Grids connect power plants to each other and to their customers. The peak demand is the amount of electricity needed during the times of day when electricity is most needed, such as late afternoon when people are arriving home and cooking dinner. A brownout occurs when the power is not sufficiently meeting the peak demand, but the grid does

not completely fail. A blackout occurs when there is a malfunction in a power plant or in a grid. A rolling blackout occurs when areas lose power sequentially when demand is greatest. The power is then distributed over time if the power plants cannot meet the demand.

Cogeneration

Cogeneration is the simultaneous production of both electricity and steam in the same plant. Cogeneration is often used to be able to use waste heat from one process and use it in another process. For example, a steel plant using coal for heating metals could use the waste heat to heat buildings or even generate electricity. Many reverse osmosis water treatment facilities use cogeneration energy from a power plant to force the salty or brackish water through a semi-permeable membrane to produce fresh water.

Energy Conservation and Improved Efficiency

The easiest way to promote energy conservation is to promote energy efficiency. Energy efficiency is a measure of the energy produced compared to the energy consumed. The life cycle cost of an appliance or vehicle is the initial cost of the item plus its lifetime operating costs. Often energy efficient appliances cost more to purchase, but over the lifetime of the operation of the appliance will save money. For example, a new high-efficiency front loading washing machine uses far less water and electricity than a conventional top loading washing machine, saving the consumer those expenses. Additionally it spins clothing at such a rapid rate that drying time is decreased in the clothes dryer, further saving energy. The disadvantage is the initial cost, which may be significantly greater than a less efficient model. Therefore the life cycle cost of the front loader is far less than the life cycle cost of a conventional top loading machine. The biggest energy waster in most homes is the incandescent light bulb, only 5 percent efficient, thus losing 95 percent of its energy input. These bulbs can readily be replaced with a more expensive, compact fluorescent bulb that gives off four times as much light and actually lasts ten times longer than a traditional incandescent bulb.

Transportation Efficiency

Transportation can easily save energy by improving the fuel efficiency in vehicles. Automobile companies in the United States claim that it is too expensive to make automobiles more energy efficient, yet the energy efficiency standards mandated in the United States are far below those in other developed countries and even some developing countries. The use of hybrid vehicles, which have an internal combustion engine and a rechargeable battery to provide the extra energy required for speeding up and climbing hills, facilitates energy conservation. The battery in a hybrid vehicle may be charged by regenerative breaking or by plugging the battery into an electrical supply. Electric automobiles, promoted as energy efficient and nonpolluting, are only so if the source of the electricity used in the vehicles is renewable. Otherwise they simply shift a mobile point source of pollution to a stationary source, the power plant used to generate the electricity. Decreasing the number of automobiles on the roads by promoting carpooling, use of mass transit, walking, or bicycling also reduces energy expenditures and promotes conservation.

Home Conservation and Efficiency

Homes can easily be made more energy efficient. Improving building code standards in many areas would force homebuilders to improve the efficiency of homes. In addition to the change to energy-efficient appliances and lighting previously mentioned, home water heaters can be tankless, instant water heaters or changed to a more efficient natural gas water heater rather than an electrical water heater. Homes can be super-insulated, which means they have thicker insulation in their walls and attic. Homes so highly insulated do cost more to build, but the energy savings over time far outweigh the initial cost. Windows should be installed that have low emissivity (low E) to reduce energy requirements. These windows should face south to take advantage of passive solar heating. Straw bale houses, literally constructed from straw bales, are becoming more common. The houses must be covered with stucco to avoid rotting of the straw, but the houses are well insulated. Homes built into the sides of a hill, called earth-sheltered homes, use sod as their roof. The houses maintain a more constant temperature because the sod provides insulation, but require a well-reinforced roof due to the weight. Negawatt programs, where customers who increase their efficiencies receive rebates, are becoming more popular.

Sometimes simple measures can be taken to ensure that a home is more energy efficient. Homes should be kept airtight by plugging leaks around plumbing, doors, and windows to help prevent wasting energy. Keeping windows and doors shut when not in use saves energy because the outside air will not influence the inside temperature. Lights and appliances should be shut off when not in a room. Turning the thermostat up or down depending on the season will save energy. Attire can be modified to make the room temperature more tolerable. Increasing the efficiency of the air handling unit for the furnace/air conditioner will decrease energy waste, as does installing a programmable thermostat to ensure that temperatures are changed throughout the day if no one is at home. Darker roofs (lighter ones in hotter climates) will result in less energy cost as the heat from the sun is absorbed (reflected) to additionally warm (cool) a home. Operating ceiling fans in rooms (only when occupied) the rooms will feel cooler without having to increase the use of the air conditioner. Attic fans will reduce the amount of heat that builds up in the attic of a house, thus keeping the house much cooler.

When temperatures first begin to rise in the spring and wan again in the fall, opening windows on all sides of the house to allow airflow will avoid the need for central air conditioner use. Community education programs will assist the homeowner in making their home more energy efficient, as will rebates, tax write offs, or subsidies when purchasing energy-efficient appliances or increasing the amount of home insulation. The opposite could be true if individuals purchase more energy-inefficient models, by increasing the tax on these energy wasters.

> **Take Note:** It is important to separate energy efficiency from passive solar designs. A question on the 2006 AP exam involved explanation of passive solar designs, and many students focused on energy efficiency methods rather than correctly explaining passive solar energy.

Passive Solar Energy Designs

Passive solar heating designs capture the sun's energy in a building and then use the captured heat to warm the building as the heat is given off. Typically windows face south in passive solar designs

to receive sunlight all day. The heat is absorbed by brick, stone, or adobe walls, which heat up and slowly release the heat during the night. An efficient passive solar system requires little to no supplementary space heating. Again, these homes cost a bit more to construct, but the life cycle cost is much less than a standard electrically heated home. These passive solar designs are most effective in sunny climates, but may be used in other places as long as another system is used to supplement the passive solar design on cloudy days. A relatively new passive solar design is to place a greenhouse on the south side of a building, which, with appropriate vents situated throughout the house, will heat the house the entire day. The flooring must be made of heat-absorbing material such as brick or stone. Trombe walls are walls made of heat-absorbing materials that have a layer of glass situated in front of them. The air within the space created by the wall and glass is heated and circulated by convection throughout the house. Trombe walls may also contain water, which circulates through the house to heat it.

Passive solar cookers, or solar box cookers, are small-scale ovens used to cook foods. They are a box lined with a reflective material that has a clear top. Although they can be used in developed countries, they are becoming more commonplace in developing countries. It may take more time to cook food, but women and children in developing countries do not have to scavenge all day for wood, nor do they have to spend hours inhaling particulates and other pollutants as they cook the food.

Cooling houses naturally can also be done easily, particularly in hot climates. By decreasing the amount of light entering the home, with shutters, curtains, shades, awnings, or even plants outside the windows, the house accumulates less heat and thus remains cooler. To further reduce heat buildup in the attic, installing lighter colored roofs will reflect more light, thus keeping the house cooler.

Active Solar Systems

In homes, active solar heating usually employs roof mounted solar collectors to heat water, air, or antifreeze. The collectors are usually black with layers of glass filled with the material to be heated and then piped directly throughout a home for heating. These systems may also be used to heat water for bathing and washing. This type of system is also common for heating swimming pools in colder months. Some of the solar collectors are passive in design as long as they do not employ a pump.

Photovoltaic (PV) cells are wafer thin sheets of silicon imbedded with boron impurities. When photons strike the glass plate, electrons are emitted from the wafer, creating a current. The cells were expensive in the past, but the cost of the cells continues to drop. Many cells joined together are useful to generate electricity. The cells can be joined in any number and any array to generate the amount of electricity desired. Although making the PV cells pollutes water, no emissions result from the function of the PV cells. Some consider PVs aesthetic or visual pollution because they are visually unappealing, thus affecting the aesthetic value of a house or business. A new type of technology, called an amorphous silicon collector, is currently being used in calculators, watches, and toys and is being developed as a new type of PV cell.

Commercial Solar Designs

Solar thermal electricity is derived when the sun's rays are focused on a system filled with a heat absorbing liquid. The liquid then heats water, creating steam to spin a turbine. Solar power towers are systems of mirrors built around a tower. Remote-controlled sensors shift the mirrors to ensure maximum sun exposure and thus reflection onto the tower. The liquid in the tower is usually a molten salt, which then heats water to create steam to spin the turbine to create the electricity. The salt holds heat in for quite some time, and therefore the energy can even be used at night.

Pros and Cons of Solar Power

The environmental benefits to using solar energy are that the fuel is free and no pollutants are emitted as the energy is used. The active solar systems are flexible, in that a small system may be developed or a large system may be developed. Drawbacks to using solar power include that the source (the sun) is intermittent in many locations and thus this type of power is best suited to relatively sunny climates. The ability to store solar heat is limited, so using solar power to generate electricity will require more advanced technology in the future. Lead acid batteries cannot store large amounts of energy per unit mass. Acid is corrosive and the lead is a heavy metal, which must be mined and smelted. Other battery types are equally problematic. Active solar designs can be expensive at first, and commercial operations require large amounts of space. Large systems may require vast amounts of land, which may result in deforestation, erosion, and habitat disruption depending upon the location of the system. However, the sites may also be used as rangeland, so it does not have to be fully devoted to electrical generation. The energy created by solar power is direct current (DC), so unless direct current appliances are present, alternating current (AC) converters must be used.

Wind Energy

For centuries wind has been used in windmills to pump water and perform mechanical processes such as grinding grain. Present-day mechanical turbines use long propeller blades that generate large amounts of torque, which generates more electricity than a faster spinning windmill with shorter blades. Groups of wind turbines are known as wind farms. Offshore windmills are becoming a new resource of reliable energy. Frequently these structures can be placed far enough offshore that it does not disturb the aesthetics of a shoreline. A large scale offshore wind farm has been planned off the coast of Martha's Vineyard and Cape Cod, but locals are concerned about impaired boat traffic and the natural landscape.

There are numerous benefits to using wind energy. The source of the energy is free, and the windmills emit no pollutants as they function. Wind is unlimited at favorable sites. The disadvantages of using windmills include that they are unsightly and impair the aesthetic value of an area. The wind is also an intermittent source, and thus wind farms are usually strategically placed in areas where wind is relatively constant. The wind turbines are often noisy and may affect animal behavior in an area. Birds, particularly migratory birds and raptors, have difficulty seeing the propellers and are killed. These bird deaths can be avoided by adding antiperching devices, painting the blades a color the birds can see, and having the blades make noises that irritate the birds. Population density is somewhat low in areas with high wind, so power lines may need to be put into

place to convey the power to an area that needs it. Also, wind power is difficult to store and would require battery storage.

Hydroelectric Power

Hydropower functions by building dams across rivers and streams. 20 percent of the commercial energy in the world is derived from falling water. The largest hydroelectric dam in the United States is the Hoover Dam, and the largest in the world will be the Three Gorges Dam on the Yangtze River. Water is released through pipes in the dam that have turbines in them to spin a generator to make electricity. Hydroelectric power does not generate pollution as the dam functions. The net energy yield is also the highest of all of the alternative energy resources that generate electricity. The review of chapter 17 discusses the pros and cons of water diversions.

Smaller dams may also be built to generate electricity and decrease the environmental impact of the dams. These dams include low-head hydropower dams built on headwater streams and micro-hydro generators that power individual homes.

Geothermal Power

Geothermal power is derived from the energy produced as radioisotopes decay in the earth's surface. This decay heats rock or groundwater (geysers or hot springs) that can be used to generate electricity. The steam generated by the heated water then spins a turbine connected to an electrical generator to create electricity. The geothermal plants have a long lifespan and do not require land degradation for mining of materials. There are few wastes that need disposal. The water tends to have a lot of salts associated with them, so corrosion of power plant equipment may occur. When too much groundwater is used, the surrounding land may subside. Examples of areas that use geothermal power include Iceland; Boise, Idaho; and The Geysers, California.

Wave and Tide Power

Waves are used to generate electricity when they pass through a turbine causing it to spin. There are only a few commercial wave generating facilities throughout the world. The first was built in Scotland in 2001. The technology to harness wave energy is still being researched, as are the system designs that will withstand adverse weather conditions.

Tidal power is usually most efficiently generated when there is a large difference between high and low tide. An example of such a locale is Annapolis Royal in Nova Scotia. When the tide comes in, the water spins the turbine in a tidal station creating electricity. When the tide goes out, the turbines also spin, which allows continued generation of electricity. One problem with tidal power is the damage that occurs from building dams across inlets and bays. The greatest tidal energy is usually found in estuaries, and damming these areas can result in ecosystem damage including siltation and damage to breeding areas.

Ocean thermal energy conversion (OTEC) systems are designed to use the thermal gradients that are present in water columns to generate electricity. These systems run fluid through the layers of ocean water to heat and then cool it. When the fluid is heated, it spins a turbine generating

electricity. The best sites for this type of energy are along shorelines of volcanic islands, because their temperature gradients are more distinct than in other parts of the ocean.

Biomass Fuels

Biomass fuels are any organic matter that can be burned. Most biomass fuels are created via photosynthesis, including wood, charcoal, peat, and crop residues such as cornstalks, corncobs, or wheat straw. There are numerous problems associated with using wood and charcoal for energy. Wood smoke has numerous pollutants, especially particulates and carbon monoxide. The temperature of combustion may be controlled and emission control devices placed on chimneys to decrease air pollution from burning wood. Many developing countries are experiencing a wood shortage. It is estimated that 1.5 billion people lack enough wood or charcoal to heat their homes and cook their food. Women and children spend hours searching for wood. Previously densely wooded areas are now barren due to the deforestation resulting from forests being cut down to acquire the wood or charcoal necessary for life.

Methanol and ethanol can be used in internal combustion engines. Grains, sugar cane residue, or sugar beets may be used to generate ethanol. Methanol may be derived from wood, wood waste, crop residues, and sewage sludge. These biofuels typically have a high net energy yield and reduce agricultural wastes. They do require large amounts of land, and fertilizers, pesticides, and fossil fuels may be used in large amounts to generate the biomass crops.

Biogas digesters, which employ anaerobic bacteria to digest wastes, can decompose household or animal feces to create methane. In developing countries, these feces are also in demand as fertilizers, and thus may limit agricultural capability resulting in a lower food supply. The methane combustion creates far more heat than directly burning feces. Dung can also be burned directly once it is thoroughly dried. Many municipal sewage treatment plants use anaerobic digestion during their sewage treatment and use the methane produced to run their operations.

Hydrogen Power

Hydrogen burns readily and when combined with atmospheric oxygen, creates water vapor. Some NO_x and CO_x are also formed as a byproduct. Hydrogen is removed from a fossil or biomass fuel using a reformer in conjunction with a fuel cell, but researchers seek to find a renewable source of hydrogen. There are numerous types of fuel cells, but all contain a catalyst and an electrolyte solution to generate an electron stream for generation of electricity. For example, plants use sunlight to split water to form hydrogen and oxygen, and researchers would like to be able to use water in a similar fashion.

Chapter 20 Questions

Use the following for questions 1-4.

a. geothermal energy
b. passive solar power
c. active solar power
d. hydroelectric power
e. biomass power

1. uses the natural decay of radioactive isotopes in the earth's crust to heat water to spin turbines
2. exemplified by photovoltaic cells
3. examples include dung, peat, and ethanol
4. has the greatest net energy of all of the alternative energy resources

5. If your laptop computer uses 50 watts per hour and you use it for three hours per day, how much will the electricity cost to run the computer for one year if your utility charges $ 0.08 per kilowatt (kWh) hour?

a. $10.46 b. $8.52 c. $5.00 d. $4.38 e. $2.98

6. Which of the following are environmental costs associated with the generation of geothermal power?

I. land subsidence
II. groundwater depletion
III. carbon dioxide emissions

a. I only b. II only c. I and II d. I and III e. I, II and III

7. Which of the following is a passive solar design?

a. increased insulation to keep warm air in a home in the winter
b. using reflective roofing to decrease cooling costs in the summer
c. using photovoltaic cells to generate electricity
d. installing energy-efficient windows to keep hot air out in the summer to decrease air conditioning costs
e. planting a tree line of conifers to block wind from reaching a house in northern climes, which decreases winter heating costs

8. Which of the following are associated with the use of hydroelectric dams?

I. increased temperature downstream
II. decreased dissolved oxygen downstream
III. increased sediment downstream

a. I only b. II only c. III only d. I and II e. I, II, and III

9. All of the following are biomass sources of energy except

a. methanol. b. wood. c. crop residues. d. lignite. e. charcoal.

10. Which of the following are associated with commercial active solar power generation?
    I. little land use and habitat disruption
    II. mining silicates for PV cells results in erosion
    III. thermal pollution from cooling power plants

a. I only b. II only c. III only d. I and II e. I, II, and III

11. Which of the following has the greatest net energy for heating homes?

a. coal b. nuclear c. hydroelectric d. biomass e. natural gas

12. Which of the following are problems associated with wind power?
    I. bird deaths
    II. aesthetic pollution
    III. noise pollution

a. I only b. II only c. III only d. I and II e. I, II, and III

Answers Chapter 20

1. a. Geothermal energy uses the natural decay of radioactive isotopes in the earth's crust to heat water to spin turbines.
2. c. Active solar power is exemplified by photovoltaic cells.
3. e. Examples of biomass power include dung, peat, and ethanol.
4. b. Passive solar power has the greatest net energy of all of the alternative energy resources.
5. d. It would cost $4.38 for one year.
   50 w x 3 hr/day x 365 days/year x kw/1,000 w x $.08/kWh = $4.38/year
6. c. Land subsidence and groundwater depletion are some environmental costs associated with the generation of geothermal power.
7. b. A passive solar design is using reflective roofing to decrease cooling costs in the summer. Increased insulation to keep warm air in a home in the winter, installing energy-efficient windows to keep hot air out in the summer to decrease air conditioning costs, and planting a tree line of conifers to block wind from reaching a house in northern climes decreasing winter heating costs are energy-efficiency methods. Using photovoltaic cells to generate electricity is an active solar design.
8. e. All are associated with the use of hydroelectric dams.
9. d. Lignite is a type of coal.
10. b. Mining silicates does result in erosion. A lot of land is used in commercial operations but there is no thermal pollution.
11. a. Coal has the greatest net energy for heating homes.
12. e. All are problems associated with wind power.