CHAPTER 18

ENERGY EFFICIENCY AND RENEWABLE ENERGY

Summary

1. The advantages of improving energy efficiency include benefits to the environment, people, and the economy through prolonging the availability of fossil fuel supplies, reducing oil imports, achieving very high net energy yields at lower cost, reducing pollution, and improving local economies. Ways to increase energy efficiency include the use of cogeneration and more efficient motors in industry, fuel efficient vehicles, better building design, modifications of existing buildings to reduce heat loss, and a greater use of renewable energy to provide heat and electricity.

2. The advantages of solar energy include reduction of air pollution, reduction of dependence on oil, and low land use. Disadvantages include release of toxic chemicals during production of photocells, the short life of solar systems, damage done to deserts, the need for backup systems, and high cost.

3. The advantages of hydropower include a high net energy yield, a low cost of electricity generated, a long lifespan, no carbon dioxide emissions during operation, flood control below the dam, provision of water for irrigation, and an increase in reservoir development. Disadvantages include high construction costs, high environmental impact, high carbon dioxide emissions from biomass decay, flooding of natural areas, conversion of land habitats to lake habitats, danger of the dam collapsing, people relocation, limits to the fish populations below the dam, and decreases in the flow of silt.

4. The advantages of wind power include a high net energy yield and efficiency, a low cost and low environmental impact, no carbon dioxide emissions, and quick construction. Disadvantages include a need for winds and backup systems, high land use, visual and noise pollution, interference with bird migrations, and causing the death of birds of prey. Many parts of Canada have a good potential for wind energy development.

5. The advantages of biomass include large potential supplies, moderate costs, no net carbon increase, and the fact that it uses agricultural, timber, and urban wastes. Disadvantages include being a nonrenewable resource; having a moderate to high environmental impact; having low photosynthetic efficiency; and causing soil erosion, water pollution, and loss of wildlife.

6. The advantages of geothermal energy include a very high efficiency, low carbon dioxide emissions, low cost and land use, low land disturbance, and moderate environmental impact. Disadvantages include scarce suitable sites, potential depletion, moderate-to-high air pollution, noise, odour, and high cost.

7. The advantages of hydrogen gas include the fact that it can be produced from water, the low environmental impact, no carbon dioxide emissions, a competitive price, ease of storage, safety, and high efficiency. Disadvantages include the amount of energy needed to produce

the fuel, a negative energy yield, high cost, and the fact that it is nonrenewable and no fuel-distribution systems exist.

8. The advantages of using smaller, decentralized micropower sources include size, fast production and installation, high energy efficiency, low or no CO_2 emissions, low air pollution, easy repair, reliability, increased national security, and being easily financed.

9. We can improve energy efficiency by increasing fuel efficiency standards; providing large tax credits for purchasing energy efficient cars, houses, and appliances; encouraging independent energy production; and increasing research and development.

Key Concepts and Learning Outcomes

After completing this chapter, students should be able to answer the following key questions.

18-1 What Is Energy Efficiency, and How Much Energy Do We Waste? Saving Money by Not Wasting Energy

A. Energy efficiency is a measure of the useful energy produced compared to the energy that is converted to low-quality heat energy.
   1. Energy efficiency can be achieved by using more efficient technologies that are available and are being developed. An example is the use of fluorescent bulbs (20% efficient) in place of incandescent bulbs (5% efficient).
   2. About 84% of all commercial energy used in North America is wasted. About 41% is wasted because of the degradation of energy quality imposed by the second law of thermodynamics.
   3. About 43% of the energy used is unnecessarily wasted by such things as motor vehicles, furnaces, and living and working in leaky, poorly designed buildings.
   4. When buying energy-consuming items, the life-cycle cost (initial cost plus lifetime operating costs) is an important factor in making a decision.
   5. Four commonly used energy devices waste large amounts of energy: the incandescent light bulb (95% waste), a nuclear power plant (66% waste), an internal combustion engine (75–80% waste), and a coal-burning power plant (66% waste).

18-2 What Is Net Energy Efficiency? Honest Energy Accounting

A. Net energy efficiency is a measure of the useful energy obtained from a resource after subtracting the energy used and wasted to make the energy available.
   1. Net energy efficiency includes the efficiency of each step in the process of making energy available for use.
   2. A comparison of electricity produced by a nuclear power plant and passive solar heating indicates that only about 14% of the initial energy produced is useful, compared to 90% for passive solar heat.
   3. Two general principles for saving energy are as follows:
      a. Keep the number of steps in an energy conversion process as low as possible.
      b. Strive to have the highest possible energy efficiency for each step in an energy conversion process.

18-3 How Can We Save Energy in Industry? Cogenerate, Buy New Motors, and Use Efficient Lighting

A. There are many ways to save energy in industry.
   1. Some industries save energy and money by using cogeneration, a combination of heat and power systems that has been used for many years in western Europe.
   2. Another energy-saving method is to replace energy-wasting electric motors. Most are inefficient because they run at full speed with output throttled to match the task. The cost of replacing such motors with adjustable speed drive motors would be paid back in about one year and save enormous amounts of energy.
   3. Switch from low-efficiency incandescent lighting to higher-efficiency fluorescent lighting.

18-4 How Can We Save Energy in Industry? Cogenerate, Buy New Motors, and Use Efficient Lighting

A. The best way to save energy in transportation is to increase the fuel efficiency of motor vehicles.
   1. Between 1973 and 1985, fuel efficiency rose sharply for new cars sold in Canada and the United States. This occurred because of government-mandated standards.
   2. Between 1985 and 2004, the average fuel efficiency for new cars sold in the United States levelled off, or declined slightly.
   3. Fuel economy has been increasing recently as the public pays more attention to environmental considerations and fuel costs and car companies compete to market more fuel-efficient cars
   4. Also, governments consider the greenhouse gas savings that can be achieved through efficiencies in the transportation sector.
   5. Gasoline consumption would be cut in half if Canadian and U.S. governments required the average motor vehicle to get 17 kilometres per litre within 10 years.
   6. China announced plans to impose stricter rules than those suggested above.

18-5 Are Hybrid-Electric Vehicles the Answer? A Current Option

A. Hybrid-electric vehicles have a battery and a small internal combustion engine to recharge the battery.
   1. This vehicle runs on gasoline, diesel fuel, or natural gas PLUS a small battery.
   2. Such cars have been available from Toyota since 1997, and Ford since 2004.
   3. Latest choices are “plug-in” electric hybrids, such as the Chevy Volt. This car has an extra-large battery that can be charged overnight by plugging it into an ordinary household circuit.
   4. The next step is an all-electric car, and there are already several such models on the market, such as the Tesla Model S.
   5. A big issue that has worked against completely electric cars is the distance that can be driven on a single battery charge.

18-6 Are Fuel-Cell Cars the Answer? Possible Star of the Future

A. Fuel-cell vehicles burn hydrogen fuel. The hydrogen fuel combines with oxygen in the air to produce electricity and water vapour.
   1. Fuel cells are at least twice as efficient as internal combustion engines.
   2. They have no moving parts and require little maintenance.
   3. They produce little or no pollution, depending on how the hydrogen fuel is produced.

4. Affordable fuel-cell vehicles should be on the market by 2020.
5. Hydrogen gas stations will need to be built, or possibly a fuel-cell system will be available for home use.

18-7 How Can We Design Buildings to Save Energy? Work with Nature

A. To save energy in buildings, we can get heat from the sun, superinsulate buildings, and use plant-covered ecoroofs.
   1. Designing energy efficient buildings is a growth industry.
      a. The Biology Building at the University of Ottawa is the most energy-efficient building of its kind in Canada. Its features include the following:
         1) a system that recovers heat from exhaust air, known as insulated curtainwall construction
         2) a system that collects heat from the building's growth chambers
         3) a circulation system that vents dry air into rooms for heating purposes
         4) an efficient lighting system
         5) a 73% reduction in energy consumption, compared to standard building designs
   2. A superinsulated house is an energy-efficient design.
      a. They generally cost 5% more to build, but savings within five years cover this extra cost.
      b. In Sweden, these homes use 90% less energy than a typical North American home.
   3. Strawbale houses use walls made of compacted straw covered with plaster or adobe.
      a. There is a problem in convincing financial institutions of the value of these unconventional types of housing.
   4. Ecoroofs or green roofs are covered with plants.
      a. They provide good insulation and absorb storm water.
      b. They outlast conventional roofs, and make a building more energy efficient.

18-8 How Can We Save Energy in Existing Buildings? Stop Leaks, and Use Energy-Efficient Devices

A. We can save energy in existing buildings by insulating them, plugging leaks, and using energy-efficient heating and cooling systems, appliances, and lighting.
   1. It is important to insulate and plug leaks, as about one-third of the heated air escapes through closed windows, holes, and cracks.
   2. Use energy-efficient, low-E (low-emissivity), windows to cut heat losses by two-thirds and reduce CO_2 emissions.
   3. Stop other heating and cooling losses by wrapping ducts in attics and basements.
   4. In decreasing order, the most energy-efficient methods to heat space are as follows:
      a. superinsulation
      b. a geothermal heat pump
      c. passive solar heating
      d. a conventional heat pump (in warmer parts of Canada only)
      e. a high-efficiency natural gas furnace
   5. Microturbines are cogeneration units, about the size of a refrigerator, that run on natural gas or liquefied petroleum gas (LPG) to produce heat and electricity. They pay for themselves in six to eight years in saved fuel and electricity.

6. Heat water more efficiently by using a tankless instant water heater fired by natural gas or LPG, not electricity. They last three to four times longer and cost less to operate than conventional tank heaters.
7. Use energy-efficient appliances. Most appliances are now rated in terms of energy efficiency.
8. Use energy-efficient lighting; using fluorescent bulbs could cut electricity cost by 30 to 60%.
9. Turn off electrical devices when not using them, and turn off the instant-on features in TVs, cable boxes, DVDs, computers, etc.
10. Set strict energy-efficiency standards for new buildings. This could reduce energy usage per home by about two-thirds.

18-9 Why Are We Still Wasting So Much Energy? We Get What We Reward

A. A glut of low-cost oil and gasoline has been part of the reason for energy wastage. The price does not include the harmful costs.
   1. Government tax breaks and other economic incentives for consumers and businesses would help promote improvements in energy efficiency.
   2. By investing in improving the energy efficiency of their home, homeowners will have their investment repaid within a few years, and about 20% more money available for use.

18-10 What Are the Main Types of Renewable Energy? Solar Capital

A. Six types of renewable energy are solar, flowing water, wind, biomass, geothermal, and hydrogen.
   1. Each of the renewable energy alternatives has advantages and disadvantages.
   2. Renewable energy is not being developed because there is no financial incentive to migrate to this type of energy.
   3. The prices we pay for our current energy do not include their harm to the environment and to human health.
   4. A key advantage of renewable energy, aside from low environmental impact, is that it allows energy problems to be solved in so many versatile ways depending on the combination of renewable energy sources that are available locally.

18-11 How Can We Use Direct Solar Energy to Heat Houses and Water? Face the Sun and Store Its Heat

A. We can use direct solar energy to heat our houses and our water.
   1. Passive solar heating systems have been used for thousands of years. The sun's heat could be absorbed and stored within a structure by
      a. orienting buildings toward the sun,
      b. using adobe and thick stone walls to collect and store heat during the day and release it gradually at night
   2. Buildings that are heated passively add about 5 to 10% to the construction cost of a house, but the life-cycle cost of operation is 30 to 40% lower. New buildings may include the following:
      a. energy-efficient windows and attached greenhouses that face the sun to collect solar energy by direct gain
      b. walls and floors (made of concrete, adobe, brick, stone, and water in containers) that store collected solar energy as heat and release it slowly

   c. a small backup heating system, as needed
3. Active solar heating systems absorb energy from the sun in a fluid (air, water, or antifreeze solution). The fluid is pumped through special collectors on the roof or on racks facing the sun.
   a. Some heat can be used directly.
   b. The rest of the heat is stored in a large, insulated container filled with gravel, water, clay or a heat-absorbing chemical to be released as needed.
4. Most analysts do not expect widespread use of active solar collectors for home use because of high costs, maintenance requirements, and an unappealing appearance.
5. The advantages and disadvantages of passive or active solar heating are given in Figure 18-16.

18-12 How Can We Cool Houses Naturally? Insulate and Work with Nature

A. To cool houses naturally, superinsulate them and work with nature.
   1. Open windows for breezes, and use fans to move air.
   2. Block sunlight with deciduous trees, window overhangs, or awnings.
   3. Use a light-coloured roof, and hang reflecting foil in the attic.
   4. Suspend reflective insulating foil in an attic to block heat from radiating down into the house.
   5. Place plastic earth tubes underground where the earth is cool year-round; a tiny fan can pipe cool and dehumidified air into an energy-efficient house.
   6. Use high-efficiency heat pumps for air conditioning in warm climates.

18-13 How Can We Use Solar Energy to Generate High-Temperature Heat and Electricity? Desert Power

A. Solar thermal systems can collect and transform radiant energy to high-temperature thermal energy (heat), which can be used directly, or converted to electricity.
   1. One type of system uses a central receiver system (a power tower).
      a. Heliostats (computer-controlled mirrors) track and focus the sunlight on a central heat collection tower.
   2. A solar thermal plant collects sunlight and focuses it on oil-filled pipes running through the middle of a large area with curved solar collectors.
      a. The sunlight produces temperatures high enough to produce steam to run turbines and produce electricity.
   3. Inexpensive solar cookers can be used by individuals to concentrate sunlight and cook food.
      a. This is especially true in sunny, developing countries.
      b. They reduce indoor air pollution and deforestation, and save labour and time needed to collect wood.

18-14 How Can We Produce Electricity with Solar Cells? Use Your Roof or Windows as a Power Plant

   1. Photovoltaic (PV) cells (solar cells) convert solar energy directly into electrical energy.
      a. The solar cell is a transparent wafer that contains a semiconductor.
      b. Sunlight energizes electrons in the semiconductor and causes them to flow, creating an electrical current.

2. Solar cells can be incorporated into roof and glass walls and windows. British Petroleum is building the world's largest factory to produce windows, cladding and roofing materials with power-producing solar cells.
3. Banks of solar cells or arrays of solar cells can be used to generate electricity.
4. Less-developed countries, such as India and Zimbabwe, are installing solar-cell systems in thousands of villages.
5. Organic solar cells, incorporated into carbon-based polymers, could enter the marketplace within a few years. They could be printed on a sheet of paper and placed anywhere, such as on a house, a car, or even clothing.
6. Nano solar cells are being developed that can be embedded in plastic materials and manufactured in large volumes for a very low cost.
7. Solar cells currently supply about 2.7% of the world's electricity, but by 2040, they could supply 11% of the world's supply.
8. One advantage of solar energy is that people can get power from rooftop technology.

18-15 How Can We Produce Electricity from Flowing Water? Renewable Hydropower

A. Flowing water trapped behind dams, and released as needed, can spin turbines and produce electricity.
   1. Hydropower is an indirect form of renewable solar energy.
   2. Three methods are used to produce such electricity.
      a. Large-scale hydropower uses a high dam across a large river to create a reservoir. The advantages and disadvantages of this method are given in Figure 18-21.
      b. Small-scale hydropower uses a low dam, with little or no reservoir, across a small stream with the turbines turned by the stream's flow. A micro-hydrogenerator (a small turbine) can even be used to provide electricity for a single home.
      c. Pumped-storage hydropower uses surplus electricity from a conventional power plant to pump water from a lower reservoir to a reservoir at higher elevation. Water in the upper reservoir is released through a turbine when electricity is needed.
   3. Hydropower supplied 19% of the world's electricity in 2012.
   4. There is pressure on the World Bank to stop funding large-scale dams because of their environmental and social consequences. Small-scale projects eliminate most of the harmful environmental effects of large-scale projects.
   5. Electricity can also be produced by tapping into energy from tides and waves. The costs are high, and there are few favourable locations for this technology.

18-16 What Is the Status of Wind Power? Expanding Rapidly

A. Wind power is the world's most rapidly growing form of indirect solar energy.
   1. Since 1990, the installed capacity of global wind power has increased more than 100-fold and is currently the second-fastest-growing source of energy, after solar energy.
   2. As of 2014, China had 31% of the total installed capacity for wind power.
   3. Windmills are found in almost all of the provinces in Canada.
      a. Wind potential in Canada is greatest on the East and West Coasts.
      b. Wind potential is also good around the Great Lakes.
   4. The advantages and disadvantages of using wind power are shown in Figure 18-27.
   5. Wind power has more advantages and fewer serious disadvantages than any other energy resource.

6. Mass production of wind turbines would cut costs of production, making wind the cheapest way to produce electricity.

18-17 How Is Biomass Used to Provide Energy? Burning Carbon Compounds

A. Plant materials and animal materials can be burned to provide heat or electricity, or they can be converted into gaseous or liquid biofuels.
   1. Most biomass is burned directly for heating, cooking, and industrial processes.
      a. This comprises up to 90% of the energy used in the poorest developing countries.
   2. In biomass plantations, large amounts of fast-growing trees, shrubs, perennial grasses, and water hyacinths are grown to produce biomass fuel.
   3. Crop residues and animal manure can be collected and burned, or converted into biofuels.
   4. Ecologists argue that it makes more sense to use animal manure as a fertilizer and crop residues to feed livestock, retard soil erosion, and fertilize the soil.
   5. The general advantages and disadvantages of burning solid biomass are listed in Figure 18-29.

18-18 What Is Biodiesel? An Unusual Version of a Common Fuel

A. Biodiesel is a liquid fuel—made from biomass—that can be used in diesel engines.
   1. It has properties similar to conventional diesel fuel, and it can be used in normal or modified diesel engines, either by itself or mixed with conventional diesel fuel. It can also be used as heating oil.
   2. Advantages of biodiesel are as follows:
      a. It has low carbon emissions and contains no sulphur.
      b. It has excellent lubricating properties.
      c. It provides a use for waste, such as chicken fat, and can be a local source of fuel.
   3. Its disadvantages are as follows:
      a. It has lower caloric value than conventional diesel fuel.
      b. It can gel at cold temperatures.
      c. It can damage rubber seals in engines that aren't designed for high concentrations of biodiesel.

18-19 How Can Gaseous Fuels Be Produced from Biomass? Bacteria and Chemistry to the Rescue

A. Some forms of biomass can be converted into gaseous and liquid biofuels by bacteria and various chemical processes.
   1. Biogas is a mixture of 60% methane and 40% CO_2.
      a. In rural China, 500 000 biogas digesters are in use.
      b. They convert plant and animal wastes to methane gas used for heating and cooking.
      c. The remaining solid residue is used as fertilizer.
      d. Biogas potential is high in Canada and the United States because there are large quantities of livestock wastes.
      e. About 300 large landfills in the United States have wells drilled in them to recover methane produced by the decomposition of organic wastes. BMW's auto plant in Spartanburg, South Carolina, obtains more than 25% of its electricity and 10% of its heat by burning methane gas from a nearby landfill.

18-20 What Are the Advantages and Disadvantages of Using Liquid Ethanol and Methanol Produced from Biomass as a Fuel? Mixed Signals

1. Industrialized farming uses more energy to produce crops than can be obtained in the conversion of grain crops to biomass, so there is a net energy loss.
2. Gasahol is made of gasoline mixed with pure ethanol and can be used in gasoline engines.
3. Methanol is generally made from natural gas, but it can be produced from carbon dioxide, coal, and biomass.
   a. Chemist George A. Olah advocates producing a methanol economy by producing methanol chemically from carbon dioxide in the atmosphere.
   b. He maintains that this will slow global warming.

18-21 What Is Geothermal Energy? Tapping the Earth's Internal Heat

A. It is possible to tap into the geothermal energy stored in the Earth's mantle.
   1. Geothermal heat pumps use a system of pipes and ducts to make use of heat stored in underground rocks and fluids. The Earth is used as a heat source in winter and a heat sink in summer.
   2. Geothermal exchange, or geoexchange, uses buried pipes filled with fluid to move heat in or out of the ground for heating or cooling needs. Many energy experts say that geothermal exchange is the most-energy-efficient, cost-effective, and environmentally clean way to heat or cool a building.
   3. In deeper and more concentrated underground reservoirs of geothermal energy, we find dry steam (with no water droplets) and wet steam (steam and water droplets).
   4. There is also hot water trapped in porous or fractured rock.
   5. Wells can be used to withdraw wet steam, dry steam, or hot water to produce heat or electricity.
   6. Three other nearly nondepletable sources of geothermal energy are molten rock (magma), hot dry-rock zones, and warm-rock reservoir deposits.
   7. About 85% of Iceland's buildings, and 45% of its energy, is provided by geothermal energy.
   8. The potential for geothermal energy in the Western Canadian Sedimentary Basin is being examined.
      a. There are many sources of hot water here.
      b. The amount of geothermal energy available is much greater than that stored in Alberta's oil and gas reserves.
   9. The advantages and disadvantages of geothermal energy are listed in Figure 18-32.
   10. There are two problems with geothermal energy.
      a. It is too expensive to tap, except for the most concentrated and accessible sources.
      b. It may be depleted if heat is removed faster than it is renewed.

18-22 Can Hydrogen Replace Oil? Goodbye Oil, Smog, and CO_2 Emissions; Hello Hydrogen

A. Hydrogen gas can be produced from water and organic molecules and produces nonpolluting water vapour when burned.
   1. Some energy analysts view hydrogen gas as the best fuel to replace oil during the last half of this century.
   2. There are three problems with the widespread use of hydrogen as fuel.
      a. Hydrogen is chemically locked up in water and organic compounds.

   b. It takes energy and money to produce hydrogen from water and organic compounds.
      1) It is not a source of energy.
      2) It is a fuel produced by using energy.
   c. Current versions of fuel cells are expensive, but are the best way to use hydrogen to produce electricity.
3. The advantages and disadvantages of using hydrogen as fuel are given in Figure 18-33.
4. Difficulties with using hydrogen include lack of free hydrogen and a need to use other energy sources to produce hydrogen.
5. It may be possible to produce hydrogen by growing bacteria and algae that will produce hydrogen gas rather than oxygen as a by-product.
6. Possible ways to store hydrogen once it is produced include the following:
   a. storing it in compressed gas tanks either above or below ground
   b. storing it as more dense liquid hydrogen, but then keeping it very cold, which is costly
   c. storing it in solid metal hydride compounds; for example, DaimlerChrysler's use of sodium borohydride as a way to store hydrogen in a nontoxic and nonflammable solution that can be safely pumped in and out of vehicles without hydrogen gas leakage
   d. absorbing hydrogen gas on activated charcoal or graphite nanofibres
   e. trapping and storing hydrogen gas in a framework of water molecules called clathrate hydrates
7. Hydrogen may be safer than gasoline.
   a. It disperses into the atmosphere quickly.
   b. It does not pose a fire hazard. Metal hydrides, charcoal powders, and graphite carriers will not explode or burn if a vehicle's tank ruptures.

18-23 What Is Micropower? Think Small and Dispersed

A. Small-scale dispersed energy-generating units may replace centralized, large-scale plants over the next few decades.
   1. The era of large, centralized power plants is coming to a close. Energy analysts believe that micropower systems (decentralized systems that generate 1 to 10 000 kilowatts of power) will provide much of our electricity in the coming decades.
   2. Advantages of the decentralized micropower systems over traditional systems are given in Figure 18-36.

18-24 What Roles Will Economics and Politics Play in Our Energy Future? Rewards Pay Off

A. Governments can use a combination of subsidies, tax breaks, and taxes to promote or discourage use of various energy alternatives.
B. Implementing policies such as those shown in Figure 18-37 over the next several decades could save money, create a net gain in jobs, reduce greenhouse gas emissions, and sharply reduce air pollution and water pollution.

18-25 How Can We Develop a More Sustainable Energy Future? Stop the Waste, Use the Sun, and Cut Pollution

A. Canada is a huge country with great distances between cities and major sources of energy.

1. Transferring energy over vast distances is expensive, inefficient, and vulnerable to disruptions.
2. Using diverse local sources of energy to supply our communities would solve these problems and create local jobs.
3. Upgrading to new decentralized technologies and strategies would provide Canada with a more efficient, more renewable, more secure, less polluting, and more sustainable energy future.

