**Chapter 12**

**Renewable Energy and Nuclear Power**

**Lecture Outline:**

1. Direct Solar Energy
   1. Solar energy is perpetually available; it varies in intensity depending on the latitude, season of the year, time of day, and cloud cover
   2. Technology exists to use solar energy directly, but initial costs associated with converting to solar power are high
   3. Heating buildings and water
      1. Visible light from the sun penetrates glass and warms the surfaces of objects inside, which in turn give off *infrared radiation* (invisible waves of heat); heat does not escape because infrared radiation cannot penetrate glass
      2. In *passive solar heating*, solar energy heats buildings without the need for pumps or fans to distribute the heat; it can save as much as 50% of heating costs
      3. In *active solar heating*, a series of collection devices mounted on a roof or in a field is used to gather solar energy; it is used primarily for heating water
   4. Solar thermal electric generation
      1. Solar thermal energy systems are more efficient than other solar technologies because they concentrate the sun’s energy
      2. Solar thermal plants do not produce air pollution or contribute to acid rain or global warming
   5. Photovoltaic solar cells
      1. *Photovoltaic solar cells* are wafers or thin films of solid state material (i.e., silicon or gallium arsenide) that are treated with certain metals so that they generate electricity when they absorb solar energy
         1. They currently provide about 5000MW of electricity worldwide (equivalent to 5 nuclear power plants) and account for about 0.15% of global electricity
         2. They generate electricity with no pollution and minimal maintenance
      2. There are a number of disadvantages to using PV solar cells
         1. They are only about 15 to 18% efficient at converting solar energy to electricity
         2. The number of solar panels for large-scale use requires a great deal of land
2. Indirect Solar Energy
   1. Combustion of *biomass*, *wind energy* and *hydropower* are examples of indirect solar energy
   2. Biomass energy
      1. Biomass consists of such materials as wood, charcoal, fast-growing plant and algal crops, crop wastes, sawdust, wood chips, and animal wastes
         1. Biomass fuel is renewable when it is used no faster than it is produced; it cannot replace fossil fuels
         2. At least half of the human population relies on biomass as their main source of energy; in the U.S. it only accounts for about 3% of total energy production
      2. Animal wastes are often converted to *biogas*; a clean fuel that can be converted into methanol and ethanol
   3. Wind energy
      1. Wind energy is an indirect form of solar energy in which the radiant energy of the sun is transformed into mechanical energy; it is the world’s fastest growing source of energy
      2. Wind power is cost-competitive with many forms of conventional energy ($.40 per kilowatt/hour in 1980 to $.04 in 2004)
      3. The use of wind power does not cause major environmental problems (although bird deaths have been of concern)
      4. Wind produces no waste and is a clean source of energy
   4. Hydropower
      1. Hydropower is the world’s main renewable source of electrical generation; it is more efficient than any other energy source in producing electricity
      2. Hydropower generates approximately 19% of the world’s electricity; with nearly 2200 plants in the U.S.
      3. About 97% of existing U.S. dams currently do not generate electricity
      4. Impacts of dams
         1. Dams change the natural flow of rivers, altering plant and animal habitats
         2. In arid regions, increases in water loss (evaporation) and salinity are problems
         3. Dams are expensive to build, but inexpensive to operate; they generally have limited life spans (50 to 200 years)
   5. Other indirect solar
      1. Ocean waves have the potential to turn turbines
      2. *Ocean temperature gradients* could produce electricity to cool buildings (through Ocean Thermal Energy Conversion - OTEC)
3. Other Renewable Energy Sources
   1. Geothermal energy
      1. *Geothermal energy* arises from the ancient heat within the Earth’s core, from friction where continental plates slide over one another, and from the decay of radioactive elements
      2. Hydrothermal reservoirs contain hot water and possibly steam; they are tapped by drilling wells and the hot fluid is brought to the surface and used to supply heat directly or to generate electricity
      3. The U.S. is the world’s largest producer of geothermal electricity; it is inexpensive and reliable
      4. Geothermal energy from hot, dry rock is an expensive way to produce energy, but could greatly expand the extent and use of geothermal resources
      5. Heating and cooling buildings with geothermal energy
         1. The Environmental Protection Agency (EPA) estimates that geothermal heat pumps (GHPs) are the most efficient heating systems available
         2. They are two to three times more efficient than other heating methods and produce the lowest CO2 emissions
   2. Tidal Energy
      1. Water at high tide contains enormous amounts of potential energy; it can be captured with a dam across a bay or a turbine and converted into electricity
      2. Total global production is only a few MWe, and is not expected to increase much in the near future
4. Introduction to Nuclear Processes
   1. *Nuclear energy* is the energy released by nuclear *fission* or *fusion*
      1. In the process of a nuclear reaction, a small amount of the mass of an atom is transformed into a large amount of energy (i.e., 1lb of uranium can release as much as energy as 7,300 metric tons of TNT)
      2. Today there are 440 commercial nuclear reactors in 31 countries around the world
      3. In nuclear bombs, the energy from many atomic fissions is release all at once, producing a tremendous surge of heat and power that destroys everything in its vicinity
   2. Atoms and Radioactivity
      1. Forms of a single element that differ in *atomic mass* are known as *isotopes*
      2. The emission of energetic particles or rays from unstable atomic nuclei is called *radioactive decay*; each *radioisotope* has its own characteristic rate of decay
   3. Nuclear Fission
      1. The steps, from mining to disposal, of the uranium fuel used in nuclear power plants are collectively called the *nuclear fuel cycle*
         1. Uranium ore contains three isotopes: U-238, U-235 (used in conventional fission reactions), U-234
         2. Uranium ore (used in the *nuclear reactors* of conventional power plants) is a nonrenewable resource; it must be refined (*enrichment*) after mining to increase the concentration of fissionable U-235
      2. The fission of U-235 releases an enormous amount of heat, used to transform water into steam – the steam, in turn, is used to generate electricity
      3. How electricity is produced from conventional nuclear fission
         1. A typical nuclear power plant has four main parts:
            1. The *reactor core* – where fission occurs; it contains the *fuel rods/fuel assemblies*
            2. The *steam generator* – uses heat produced in the reactor core is to produce steam from liquid water
            3. The *turbine* – uses steam to generate electricity
            4. The *condenser* – cools the steam, converting it back to a liquid
         2. Typically three water circuits are used to heat the water, convert the water to steam, and provide cool water to the condenser
         3. A huge, steel *reactor vessel* surrounds the reactor core; it is designed to prevent the accidental release of radiation into the environment
         4. Additionally, the reactor vessel and the steam generator are placed in a *containment building*, providing an additional line of defense against accidental radiation leaks
      4. Breeder reactors and mixed oxide fuel (MOX) for nuclear fission
         1. *Breeder nuclear fission* converts U-238 into fissionable Pu-239
            1. U-238 is not fissionable and is a waste product of conventional nuclear fission
            2. There are both safety and weapons proliferations concerns associated with breeder fission
         2. *Mixed Oxide Fuel (MOX)* is a reactor fuel that contains a combination of uranium oxide and plutonium oxide
            1. For MOX reactions, spent fuel from standard uranium-based reactors is reprocessed
            2. MOX is now used in about 30 European reactors compared with the operation of only about 3 breeder reactors worldwide
5. Pros and Cons of Nuclear Energy
   1. Nuclear energy has less of an immediate environmental impact than fossil fuels, it emits fewer pollutants into the atmosphere, and does not produce CO2
   2. Nuclear energy generates dangerous radioactive wastes (spent fuel, coolant fluids, gases) that must be carefully stored and disposed of, it is not climate neutral (requiring substantial amounts of gasoline and diesel), and it is expensive to create and run plants
   3. Electricity deregulation caused several non-competitive nuclear power plants to shut down
   4. Can nuclear energy decrease our reliance on foreign oil?
      1. Oil generates only about 3% of the electricity in the U.S.
      2. However, technological advances could change nuclear power’s potential contribution in the future (electric heat pumps, electric motor vehicles)
6. Safety Issues in Nuclear Power Plants
   1. *Meltdowns* could occur, releasing dangerous levels of radiation into the environment
   2. While the probability of a major accident is low, the public perception of the risk is high
      1. Nuclear power plants are involuntary and potentially catastrophic
      2. People are distrustful of the nuclear industry
      3. Consequences of an accident are drastic and life threatening (both short and long term)
   3. Three Mile Island (1979)
      1. Most serious nuclear reactor accident in the U.S. resulting from both human and design errors
      2. A 50% meltdown of the reactor core took place; most of the radioactivity was contained in the containment building
      3. No substantial damages or human casualties resulted; it took 12 years and 1 billion dollars to repair and reopen Three Mile Island
   4. Chernobyl (1986)
      1. The worst accident ever to occur at a nuclear power plant; one and/or two explosions ripped apart a nuclear reactor and expelled large quantities of radioactive material into the atmosphere
      2. Significant amounts of radioisotopes spread across Europe; over 170,000 people had to permanently abandon their homes
      3. Even 20 years later, much of the farmland and forests are so contaminated they cannot be used for more than a century, and local peoples still cannot drink the water or consume locally produced milk, fish, meat, fruits, or vegetables
         1. Mothers do not nurse their babies
         2. The number of attributable deaths is estimated between 10,000 and 100,000
         3. Even small doses of *ionizing radiation* can be harmful; nearly 400,000 adults and more than 1 million children currently receive government aid for health problems related to Chernobyl
   5. The link between nuclear energy and nuclear weapons
      1. U-235 and P-239 are the two fuels commonly used in atomic fission weapons
      2. 31 countries currently use nuclear energy to generate electricity; the possession of nuclear power plants gives these countries access to the fuel needed for nuclear weapons
7. Radioactive wastes
   1. *Radioactive wastes* are classified as either *low-level* or *high-level*
   2. In 2004, US Federal Courts decided that any permanent burial site must meet EPA standards for the next one million years; potential sites include
      1. Stable rock formations deep in the ground
      2. Mausoleums built in remote locations
      3. Storage in Antarctic ice sheets
      4. Burial in the seabed
   3. Radioactive wastes with relatively short half-lives
      1. U-235 may split in several ways, forming smaller radioactive atoms (i.e., krypton-85, strontium-90, cesium-137 – all with relatively short half-lives)
      2. In 300 to 600 years they will have decayed to the point where they are safe
   4. High-level radioactive liquid waste
      1. These wastes are dangerously unstable and difficult to monitor; they must be converted to solid form before they can be stored
      2. Solidifying liquid waste into solid glass or ceramic logs is known as *vitrification*
   5. Decommissioning nuclear power plants
      1. Nuclear power plants are licensed to operate for a maximum of 40 years
      2. Three options exist when a nuclear power plant is closed: storage, entombment, and decommissioning
         1. Storage – the utility company guards it for 50 to 100 years (allowing some radioactive materials to decay) until it is dismantled
         2. *Entombment* – permanently encases the entire power plant in concrete for at least 1,000 years
         3. *Decommission* – dismantles an old nuclear power plant after it closes
      3. Worldwide, 107 nuclear power plants were permanently retired as of 2004 (23 in the U.S.); 143 operational plants were 25 years or older
8. Fusion: Nuclear Energy for the Future?
   1. In fusion, two lighter atomic nuclei are brought together under conditions of high heat and pressure so that they combine, producing a larger nucleus (30mL of fusion fuel has the energy equivalent of 266,000L of gasoline)
   2. Isotopes of hydrogen are the fuel for fusion
   3. Supporters of nuclear energy view fusion as the best possible form of energy, both because its fuel (hydrogen) is available in virtually limitless supply and because it produces no high-level radioactive waste
9. The Future of Nuclear Power
   1. Standardizing a “new generation” of nuclear reactors designed to be 10 times safer than current reactors could lower costs for nuclear power
   2. Creating new fission reactors (i.e., PBMR – pebble-bed modular reactors) are potentially much safer than the ones in current operation
   3. More research and training is needed for nuclear engineers to safely design, build, and operate nuclear power plants