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1.3 ENERGY RESOURCES FOR ELECTRICITY GENERATION

Sources of energy to generate electricity are fossil fuels, uranium, water, wind, solar, geothermal, biomass, fuel cell, and, occasionally, oil. Each system has advantages and disadvantages, but many of the systems pose environmental concerns. With today's emphasis on environmental consideration and conservation of fossil fuels, many alternative sources are being considered for employing the untapped energy sources of the sun and the earth for generation of power. These energy sources are inexhaustible and are known as *renewable energy sources*. These include energy from water, wind, the sun, geothermal sources, and biomass sources such as energy crops. Renewable energy sources have the potential to provide electricity to homes and businesses without causing air pollution or depleting nonrenewable resources. Due to extensive efforts to reduce the greenhouse gas emissions in recent years, the production of electric energy from renewable sources has become the fastest-growing source of electricity generation, and several utilities have abandoned plans for coal plants. Undoubtedly, if this trend continues, it will leave a good portion of dirty coals in the mines within two decades. With the advent of electric utility deregulation, renewable energy sources are being utilized in the development of small power stations, which are directly connected to the consumers, as well as large scale utility power plants.

According to the U.S. Energy Information Administration Existing Generating Capacity, the total installed electric generating capacity in 2008 was about 1,010,171 MW. The estimated United States population in 2008 was 304,060,000. That is,

$$\text{Installed capacity per capita} = \frac{1,010,171 \times 10^6}{304.06 \times 10^6} = 3,322 \ \text{W}$$

Assuming uniform distribution, this is equivalent to 4.45 horsepower (HP) per person. In 2008, the annual kWh consumption in the United States was about $4,119 \times 10^9$ kWh. The latest figures for the total generation shares by energy source for the United States, published by the U.S. Energy Information Administration (EIA) and released in February of 2010 in its "Electric Monthly Report," are presented in Figure 1.1. This shows that the nonrenewable fossil fuels, namely coal, natural gas, nuclear, and oil, accounts for about 89.2 percent of the United States' requirements for electricity generation in 2009. Approximately 44.4 percent is generated from coal, 20.2 percent from nuclear, 23.6 percent from natural gas, and 1 percent from oil.

The combustion of coal produces carbon dioxide, sulfur dioxide, nitrogen oxide, and ozone as well as fine particles which are then released into the atmosphere. An increase in the earth's levels of atmospheric carbon dioxide increases the greenhouse effect and contributes to global climate change. Sulfur dioxide and nitrogen oxides contribute to smog and acid rain. Coal also contains traces of toxic heavy elements such as mercury, arsenic, and dilute radioactive material. Burning them in very large quantities releases this material into the environment and leads to low

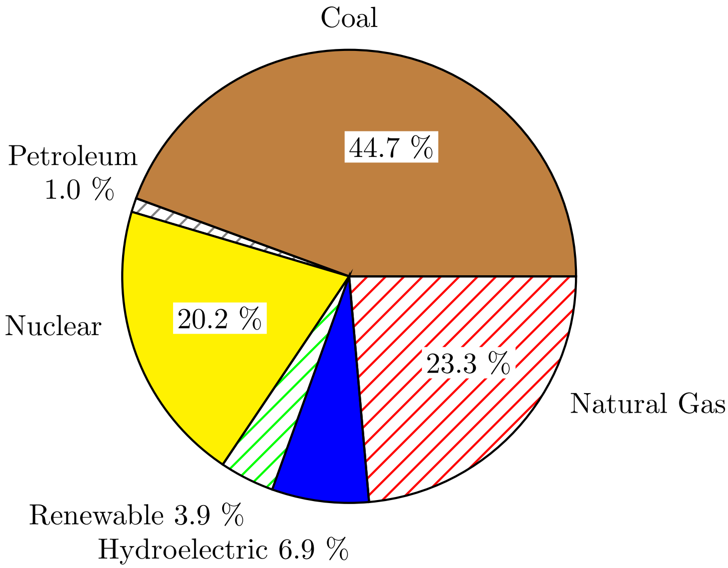

FIGURE 1.1
Net generation shares by energy source, year-to-date through November, 2009.

levels of radioactive contamination, the levels of which are, ironically, higher than that of a nuclear power station. Coal has the highest carbon intensity among fossil fuels, resulting in coal-fired plants having the highest output rate of CO_2 per kWh. In 2007, the national average output rate for coal-fired electricity generation was 2.16 pounds CO_2 per kWh. Natural gas is the least carbon-intensive fossil fuel, and the output rate for CO_2 from natural gas-fired plants in 2007 was 1.01 pounds CO_2 per kWh.

Renewed interest in environmental issues has raised concerns about electric power plants burning coal, resulting in the application of cleaner coal technologies to reduce the emission of mono-nitrogen oxides, sulfur dioxide, and carbon dioxide. Buildup of human-related greenhouse gases has become an issue of concern because of its negative effects on the environment, human health, and economic well-being of all the people of the world. The Intergovernmental Panel on Climate Change (IPCC) has set the goal of reducing carbon dioxide to 350 ppm (parts per million) by 2025. Nations and the international community as a whole are trying to bring the rate of increase in emissions of greenhouse gases under control, or to mitigate the effects of such emissions through carbon capture and storage (sequestration) technologies. Renewable Portfolio Standard (RPS) and Renewable Fuel Standard (RFS) policies adopted by many states are efforts to mitigate carbon dioxide emissions (USDOE/EIA 2008). RPS requires electric power facilities to use a minimum percentage of their fuel from renewable sources, and RFS requires blending of renewable fuels (ethanol) with gasoline at specified minimum levels. The efficiency of some of these systems can be improved by cogeneration (combined heat and power) methods. Process steam can be extracted from steam turbines. Waste heat produced by thermal generating stations can be used for space heating of nearby buildings. By combining electric power production and heating, less fuel is consumed, thereby reducing the environmental effects compared with separate heat and power systems.

Multiple technologies for carbon dioxide capture are available; most of them can be classified into three main groups:

- Post-combustion: CO_2 capture from the flue gas after combustion of the fossil fuel.
- Pre-combustion: Removal of CO_2 from the fossil fuel prior to combustion.
- Oxy-fuel: Combustion of fossil fuel with pure oxygen rather than air.

Post-combustion involves capturing the carbon dioxide produced by the combustion of coal immediately before it enters the stack and storing it underground. Post-combustion capture technology can be added to existing coal or gas power plants without modifying the original power plant.

Pre-combustion is a process where carbon in the fuel is separated or removed before the combustion process. Instead of coal or natural gas being burned in a combustion plant, the fuel can be converted to hydrogen and CO_2 prior to combustion. The CO_2 can then be captured and stored, while the hydrogen is combusted to produce power. Pre-combustion capture technology is applicable only to new fossil fuel power plants because the capture process requires strong integration with the combustion process.

Oxy-fuel combustion with CO_2 capture is very similar to post-combustion CO_2 capture. The main difference is that the combustion is carried out with pure oxygen instead of air. As a result the flue gas contains mainly CO_2 and water vapor, which can be easily separated. The challenge is that it is expensive to produce pure oxygen.

Nuclear and most renewable energy sources do not have direct CO_2 emissions. Biomass fuels do emit CO_2 upon combustion; however, the carbon is reabsorbed by growing plants over the lifecycle of biofuel production. To reduce greenhouse gas emissions, many states have adopted a Renewable Portfolio Standard policy, requiring electric power facilities to reach a specified minimum percentage of their fuels from renewable resources by a certain date (USDOE/EIA 2007). Presently, 30 states (including the District of Columbia) have adopted a mandatory Renewable Portfolio Standard (RPS), and four states have voluntary goals. The mandated goals for renewable resource use ranges from 4 percent in 2009 in Massachusetts to 25 percent in 2025 in Illinois, Minnesota, and Oregon (USDOE/EIA 2007). It is assumed that the use of renewable energy resources will reduce greenhouse gas emissions. Renewable Portfolio Standards may bring economic and health benefits such as job creation and cleaner air, in addition to reducing greenhouse gas emissions (PEW Center 2008).