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1.9 GEOTHERMAL POWER

Geothermal energy is derived from heat within the earth, usually in the form of underground steam or hot water. The sources of geothermal energy are due to the molten rocks that are found beneath the surface of the earth known as *magma*. Most magma remains below the earth's crust and heats the surrounding rocks and subterranean water. Some of this water comes all the way up to the surface through faults and cracks in the earth as *hot springs* or *geysers*. When this rising hot water and steam is trapped in permeable rocks under a layer of impermeable rocks, *geothermal reservoirs* are formed. The thermal energy of these reservoirs can be taken from different depths through wells hundreds to thousands of feet deep. It can be utilized for space heating and industrial process applications, but most commonly it is used for producing base-load electric power generation. Geothermal energy is considered a renewable energy source because heat is continuously produced inside the earth. Geothermal power is cost effective, and environmentally friendly, with very low carbon emission, and, unlike solar and wind, geothermal power is immune from weather changes. However, there have been concerns that the pressurized water forced into the rock generates micro-earthquakes. It can also interact with existing deep faults, potentially causing larger temblors.

There are three types of geothermal power plants: dry-steam, flash-steam, and binary-cycle plants. The type selected depends on the temperatures and pressures of the geothermal reservoir. Typically two wells are constructed: a production well and an injection well.

Dry-Steam Power Plant — Dry-steam power plant systems were the first type of geothermal power generation plants built. They use the steam from the geothermal reservoir as it comes from the production well. The steam is piped directly to a turbine, which drives a generator that produces electricity. The steam is condensed and pumped down into the injection well to sustain production. The largest complex of geothermal power plants in the world is The Geysers north of San Francisco, California. It consists of 15 power plants with a total capacity of 727 MW. The Geysers project is located in an active seismic zone, and the increase in earthquake activity since the project began has created opposition among some area residents and environmental groups.

Flash-Steam Power Plant — Geothermal reservoirs that contain mostly hot water above 350°F (176°C) are used in flash power plants. The hot water from the production well is depressurized or "flashed" into steam which can then be used to drive the turbine. Steam exhausted from the steam turbine is condensed in a condenser cooled by cold water from a cooling tower and is used to provide make-up water for the cooling tower. Hot water not flashed into steam is returned to the geothermal reservoir through the injection well. Both dry-steam and flash-steam power plants emit minute amounts of gases such as carbon dioxide, nitric oxide, and sulfur. This type of plant is the most common type of geothermal power gen-

eration plant.

Binary-Cycle Power Plant — When the geothermal reservoir temperature is not high enough (between 250°F to 350°F) to flash steam, the hot water is passed through a heat exchanger. In this system, known as *binary-cycle* plant, the heat is recovered by a secondary fluid with a lower boiling point than water. The secondary fluid flashes to vapor, which, like steam, drives the turbines. The vapor is then condensed and circulated back to the heat exchanger. The cooled geothermal fluid is returned to the geothermal reservoir through the injection well. In a binary-cycle plant, the electricity can be generated from more common reservoirs with lower temperatures. Also, because the water from the geothermal reservoir never comes in contact with the turbine/generator unit, no gases are emitted to the atmosphere. For these reasons, binary-cycle power plants are the fastest growing geothermal power plants. A schematic of a binary-cycle power plant is depicted in Figure 1.17.

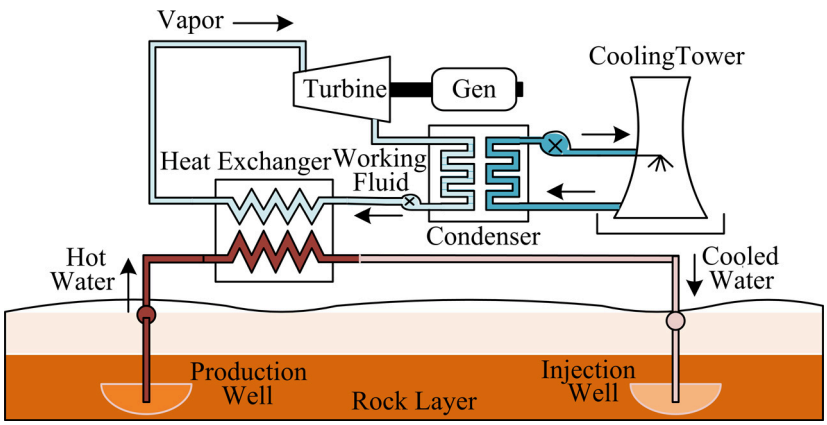

FIGURE 1.17
Schematic of a binary-cycle power plant.

The United States is the world leader in online capacity of generation of electricity from geothermal energy. In the U.S., the geothermal reservoirs of steam and hot water are mostly located in the western states, Alaska, and Hawaii. However, geothermal energy can be tapped almost anywhere. According to the Geothermal Energy Association, as of March 2009, the United States has a total installed geothermal capacity of 3,040.27 MW.

President Obama has allocated $350 million from the American Reinvestment and Recovery Act to expand and accelerate the development, deployment, and use of geothermal energy throughout the United States. However, a high-profile geothermal project in California that was launched in the fall of 2009, with millions of dollars in taxpayer funding, was permanently halted in December of 2009 in response to concerns that the project is causing an increase in regional earthquake activity.