STUDENT GUIDE

Energy Industry Fundamentals

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CENTER FOR ENERGY WORKFORCE DEVELOPMENT

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MODULE

3

ELECTRIC POWER GENERATION

STUDENT GUIDE

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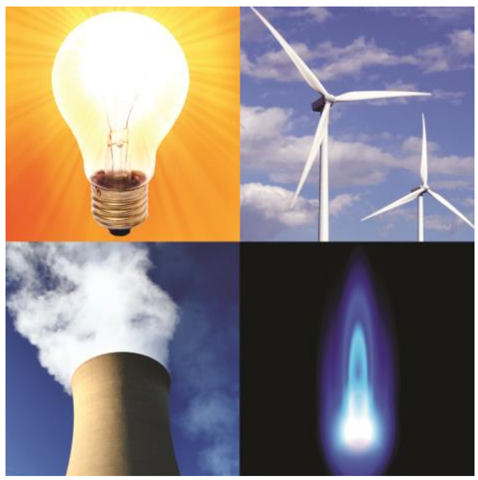

MODULE

3

ELECTRIC POWER GENERATION

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Unit A: Conventional Electric Power Generation Systems

UNIT A: CONVENTIONAL ELECTRIC POWER GENERATION SYSTEMS

Electric Power Generation

As mentioned in Module 1, most electricity is generated by electromechanical **generators** that are driven by **mechanical energy** forces. The most common electricity generation mechanical force source is what is referred to as a "steam-electric cycle." Water (in liquid form) is heated in a **furnace** to produce steam. Steam rushes past the fan blades of a **turbine** connected by a driveshaft to an electricity generator. It is the mechanical force of the steam that rotates the turbines. Recall the simplified model we discussed earlier (Figure 3A.1).

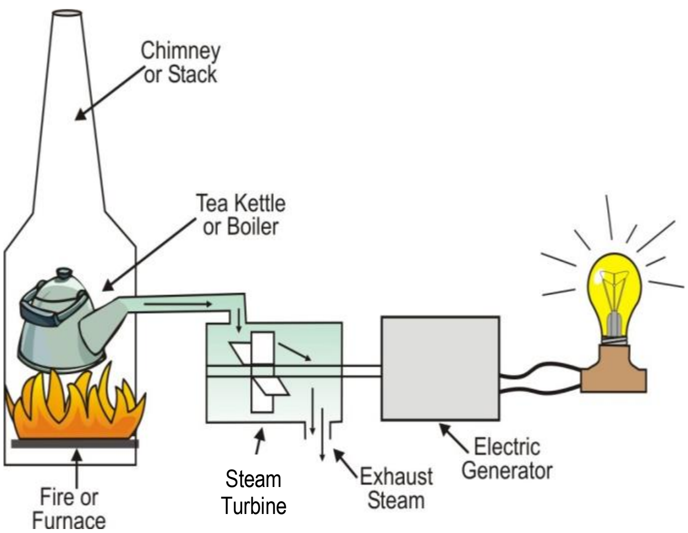


Figure 3A.1 Improved "tea kettle" power plant

While the **energy** for heating the water may be from many different sources such as **nuclear fission** or the burning of oil, gas, or coal, the electric generation systems including furnaces, **boilers**, turbines, and generators are fundamentally the same.

In addition to **fossil-fuel**, **nuclear**, and **hydroelectric** powered generation, there are also alternative and emerging **electric power generation** technologies discussed later in this module such as solar energy, **tidal energy**, **wind energy**, **geothermal energy**, and biomass energy.

How the Furnace Works

Returning to the simplified "tea kettle" plant, recall that initially it had an open fire that lost heat to the surrounding air. The next step was to enclose the fire in a steel box, called a furnace, which provided better control over the size of the fire and a way of controlling the heat flow.

Stoker Firing

What methods have been used to get the fuel into the furnace? The early furnaces, because of their small size, were hand-fired just like the first coal-burning steam boilers for home heating or steam locomotives. As the size of power plants grew, the method of supplying coal to the furnaces had to be revised. One early method used in larger furnaces was known as **stoker firing** (Figure 3A.2).

Stoker firing was accomplished in two basic ways; one consisted of using a hopper-fed conveyor system. The bunker stored the coal, fed it into the conveyor (chain gate) that moved it into the furnace to be burned, and then carried the ash out for disposal. The other consisted of a hopper-fed, rotating paddle wheel called the spreader. The spreader delivered coal to a grate where it was burned. These methods sped up the delivery of the coal but created another problem, that of getting complete **combustion**. Failing to achieve complete combustion meant not releasing all of the energy from the coal. Therefore, a more efficient way to burn coal had to be found.

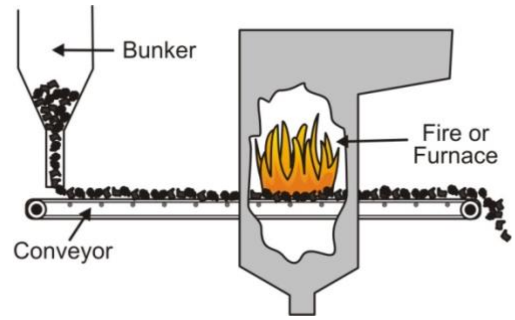


Figure 3A.2 Stoker-fired furnaces

A look at the theory of combustion shows that for coal to burn, its chemicals must combine with the oxygen in the air. When burning lump coal, the oxygen cannot reach the center of the lump rapidly enough to combine with all of the coal's chemicals to ensure complete combustion resulting in part of the coal being wasted. If the lump is broken into smaller pieces, more surface area is created, and the coal will be able to burn more efficiently.

Crushing lump coal is known as **pulverizing**. In pulverized burning, the raw coal is ground up into face-powder fineness and blown into the furnace for more rapid combustion. The actual burning takes place in mid-air instead of on the grate or conveyor as in the old stoker-fired furnaces.

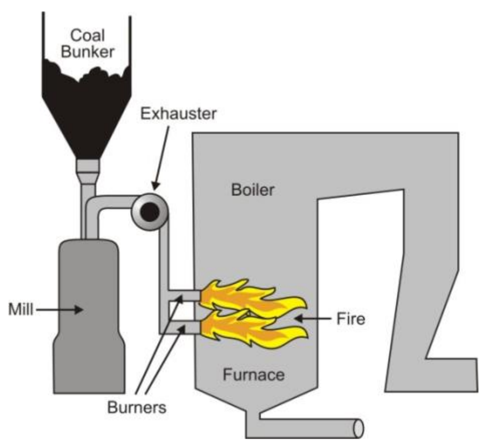


Figure 3A.3 Pulverized-fired furnace

The furnace diagram is extended in Figure 3A.3 to include the equipment necessary for pulverized coal burning. The coal is put into a storage bin called a coal bunker. The coal will slide down a chute through a feeder system and into a grinder, called a pulverizer (or mill), where it is ground up into a very fine dust. A fan, called an **exhauster**, is used to draw the dust out of the mill and blow it into the furnace. More recent **units** have eliminated the exhauster and rely instead on increased **primary air** flow to the mill to transport the pulverized coal into the furnace.

Air for Combustion

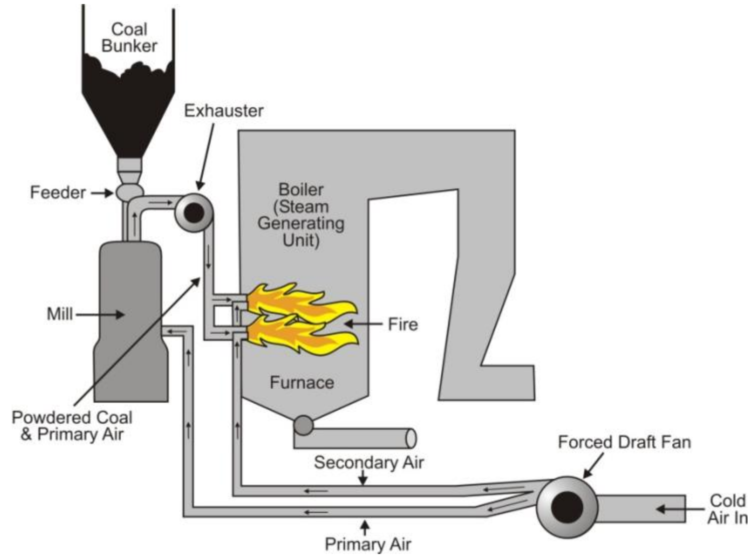


Figure 3A.4 Air for combustion

Coal requires oxygen to burn. Therefore, air must be permitted to enter the mill, so the exhauster will blow both powdered coal and air into the furnace. This air is known as primary air.

Since more air is required for complete burning (12 to 14 lbs of air to 1 lb of coal) than to transport the coal to the furnace, a **secondary air** supply must be introduced to supplement the primary source. The blower needed to produce this fourteen-to-one ratio is called the **forced-draft fan**. This fan must force the primary air through the mill and the secondary air into the furnace through controlled openings called dampers. The cold air label means that the air is at ambient outdoor temperature. In Figure 3A.4, note the inclusion of the forced-draft fan and its dual purpose of supplying the primary and secondary air to the furnace. Many furnaces have separate Primary Air and Secondary (Combustion) Air blowers.

Ignition and Combustion

In order to initiate the combustion process, the fuel must be brought to the **kindling temperature**. That is the temperature at which the fuel will ignite. Sufficient heat to raise the fuel/air temperature is supplied by the **igniters**. Igniters use natural gas or fuel oil to start the combustion. Coal dust has a much higher ignition temperature than natural gas or fuel oil; therefore, the igniter fuel must be used to raise the temperature in the furnace to prepare it for injection of coal dust. Combustion also helps raise the fuel/air temperature.

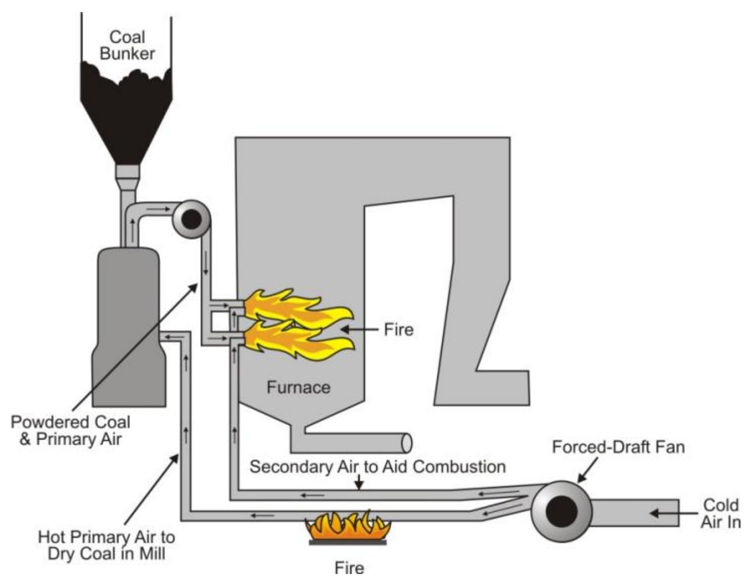


Figure 3A.5 Heated air for combustion

Everything possible is done to ensure that the ignition temperature is maintained in the furnace. Thus, it makes more sense to use hot primary and secondary air in the furnace rather than cold air that would lower the furnace temperature. Look at the second fire (shown in Figure 3A.5), which provides a way of preheating the combustion air. The furnace is more efficient due to this second fire, but an additional fuel expense has been added. It is obvious that supplying fuel for two fires will not save money, so an alternate heat source must be found.

Air Preheater, Forced-draft, and Induced-draft Fans

One possible alternate heat source is to use the heat energy going up the stack. This energy has not been used during steam generation. Putting an air **heat exchanger** in the stack to absorb the waste heat from the combustion gases and transferring it to the primary and secondary air created by the forced-draft fan would aid combustion and save money. The technical term for this heat exchanger in a stack is the **air heater** (Figure 3A.6).

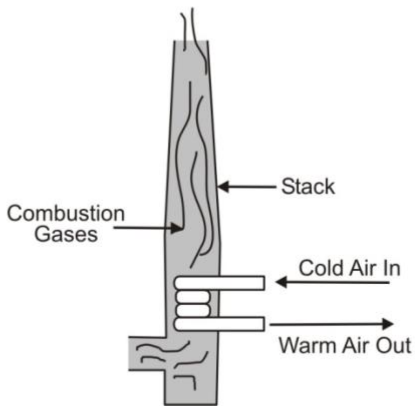


Figure 3A.6 Simple air preheater

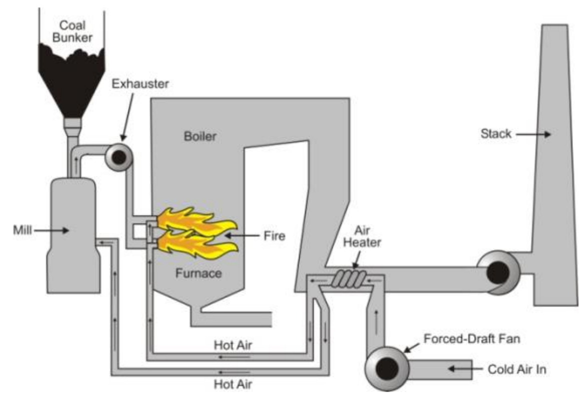


Figure 3A.7 Air heater and forced-draft fan

The redesigned diagram in Figure 3A.7 gives a more realistic picture. Now the combustion gases travel up through the boiler and are then forced downward to pass through the air heater.

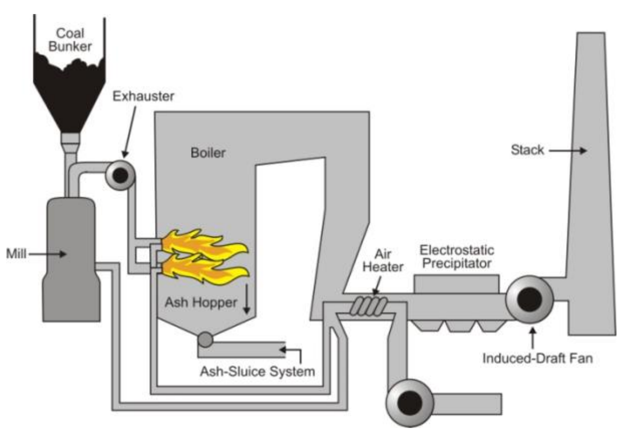


Figure 3A.8 Induced-draft fan and ash-handling systems

In addition to a fan that forces preheated air into the furnace, a second fan is often installed at the entrance to the stack to ensure that the combustion gases are drawn out of the furnace. This second fan, shown in Figure 3A.8, is called an **induced-draft fan**.

It is another means of increasing overall furnace efficiency by increasing the combustion gas pressures, thus compensating for the pressure drop resulting from flow through the steam generator.

Ash Handling Problems

This simple power plant now has almost all the elements of a modern power plant. However, there is still one more problem. Whenever coal is burned, it leaves a certain amount of residue called ash. The majority of this ash, called **fly ash**, is very fine and is carried by the exhaust gases. The remaining ash, called **slag** or **bottom ash**, is the ash that is removed from the furnace section by allowing it to fall into an **ash hopper** located at the bottom of the furnace. Once the bottom ash falls into the ash hopper, it is removed by an ash **sluice system** that carries it to a holding tank or settling pond.

The major residue problem is the fly ash, since it represents 80 to 85 percent of the total ash. This ash is so light that it is carried through the system by the combustion gases and is discharged into the atmosphere unless equipment is installed to prevent it. One method of removing this light ash from the escaping gases is to install what is known as an **electrostatic precipitator**.

The electrostatic precipitator, when located just before the induced-draft fans, removes the fly ash before the combustion gases are released into the atmosphere. Other types of pollution control equipment may be in use as well, including bag houses and scrubbers.

By adding the three pieces of equipment to the system shown in Figure 3A.8, the ash-removal system has been incorporated into the “tea kettle” power plant. The ash hopper and sluice system will remove the bottom ash from the furnace while the electrostatic precipitator and/or bag house remove(s) the fly ash from the combustion gases.

How the Boiler Works

A boiler is defined simply as a large (commonly many stories high) vessel enclosed by an assembly of metal tubing in which water is heated and steam is generated and superheated under pressure by the application of additional heat. Although this definition lends itself to a wide interpretation concerning boiler design, the primary purpose remains the same—that of converting water to steam. The boiler must be constructed and operated to separate the vapor phase (steam) in an effective manner from the liquid phase (water). The three basic functions of the boiler are pressure containment, heat transfer, and steam separation.

Equipment for Transforming Heat Energy to Steam Energy

To design a boiler, start with a simple drum (Figure 3A.9) heated from beneath just as the tea kettle was. When the water has been heated sufficiently, bubbles of steam form near the heated surface at the bottom of the drum and move up through the water. The steam then rises to the open area above the water level.

This drum in its simplest form has all three of the basic boiler functions:

1) Flow of water to the heated areas.
2) Flow of steam and heated water to the upper areas.
3) Release of steam to the collection area above the water level.

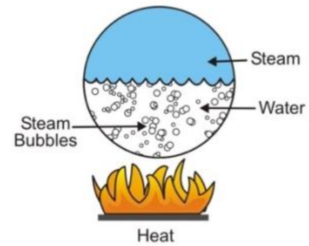


Figure 3A.9 Simple steam drum

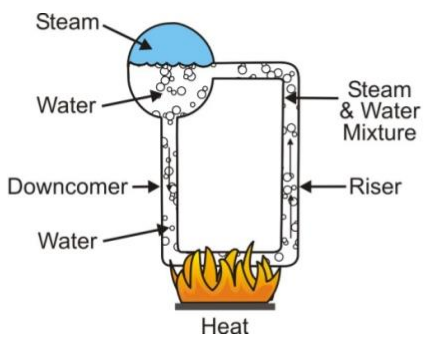


Figure 3A.10 Steam drum with tubes

Because of the small heating area, the amount of steam produced by such a drum is quite low. Increasing the steaming rate requires increasing the heating area. Such a task is accomplished by attaching tubes or pipes to the drum, as shown in Figure 3A.10 These tubes are heated and the steam/water mixture passes into the drum. The water then goes back down the tube to be heated again. This continuous cycle allows more and more steam to be built up in the drum.

The tea kettle can now be taken out of the original diagram and replaced with the steam drum system as shown in Figure 3A.11. That a steam line to the turbine has also been added should be noted.

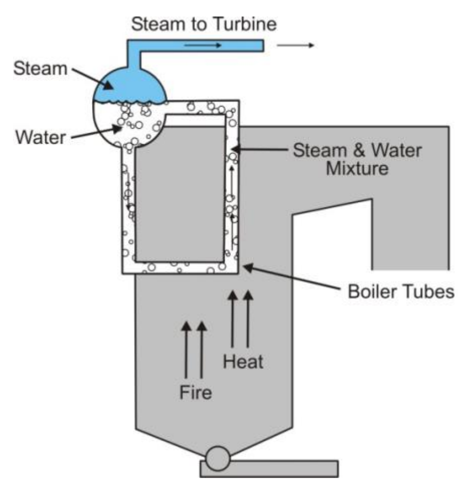


Figure 3A.11 Steam drum in furnace

Boiler

Figure 3A.12 illustrates a boiler consisting of one steel drum connected by a number of steel tubes that are arranged in the furnace walls to absorb the heat from the hot gases that pass up through the tubes on their way to the stack. These tubes serve a dual purpose: they hold water during its conversion to steam and cool the furnace walls.

To understand the theory of the drum and the tubes, it is helpful to look at each part separately, beginning with the steam drum. The steam drum serves several purposes, the first of which is to receive water and start circulation by admitting water to the tubes. The second function is to supply a water surface for steam separation and a collecting space for the steam. The third major function is to provide an outlet for the steam on its way to the turbine.

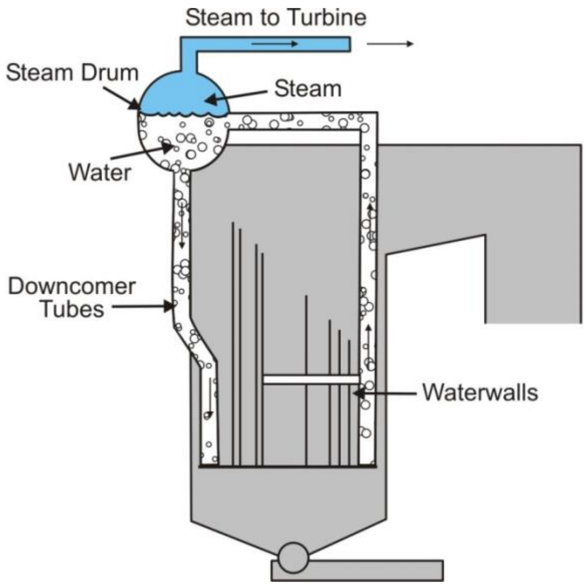


Figure 3A.12 Waterwalls

Downcomer tubes, as depicted in Figure 3A.12, carry cooler water that hasn't reached boiling temperature from the steam drum down to the bottom of the **waterwall tubes** to begin its natural convection trip back up the waterwall tubes to the steam drum. As the water inside the waterwall tubes gains heat from the furnace fireball, the warmer water naturally rises to the steam drum.

Waterwall tubes of today are closely spaced tubes lining the furnace walls that are also connected to the steam drum. The heat from the fire strikes these tubes, generating the primary steam. In modern boilers, the waterwall tubes also serve as a method of cooling the furnace walls, eliminating the need for the brick linings.

In the operation of any boiler, even a tea kettle, it is always essential to keep enough water in the boiler. If it should run dry, the metal would become red hot, soften, and rupture. At the other extreme, it should not be filled to the point where there is no room for the steam to collect. To check the water level, a gauge is attached to the steam drum that shows the approximate level at all times. Since any fluctuation in the steam flow would cause a variation in this water level, it is necessary for the operator to check it continually. If the water level drops, the operator increases the water supply; if it rises, he or she decreases it. Constant human vigilance is demanding and not very efficient, so **feedwater regulators** have been developed to control the flow automatically and to maintain the drum level almost constantly. These regulators are very helpful even in the smaller boilers, but in the case of the modern high-pressure boilers, they are imperative. For instance, a large high-pressure boiler, evaporating as much as a million pounds of water per hour, would run dry in about ninety seconds if the water supply were suddenly cut off.

Superheater

In order to put dry steam into the turbine—that is, steam that is devoid of water—the steam must be heated to a higher temperature than that which was generated in the waterwalls. The most common method of heating is using a device known as a **superheater**, shown in Figure 3A.13. The superheater is simply an arrangement of tubes located in the gas path of the furnace. These tubes receive the steam from the drum and heat it to a higher temperature before it reaches the turbine.

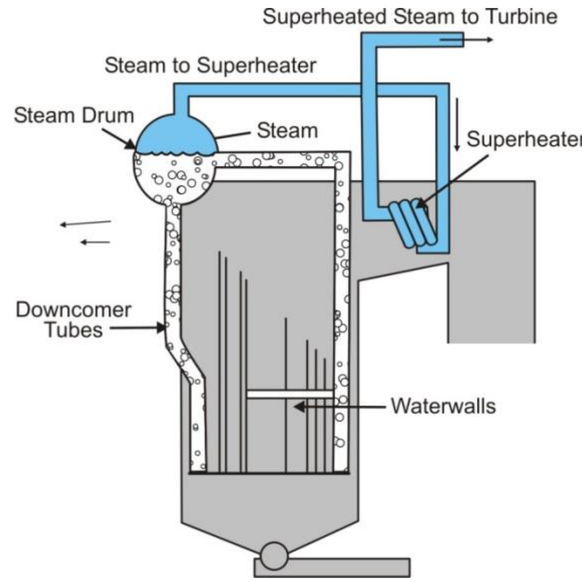


Figure 3A.13 Superheater

Superheated steam has two advantages over (saturated) steam that is not superheated: first, it increases cycle efficiency; and second, being drier, it is less likely to condense in the turbine. Heat required to superheat the steam is obtained from exhaust gases and from where it would be wasted. In the larger turbines, the formation of water droplets on the blades can be quite damaging, but this condensation can be minimized to a point where it is harmless to the machinery by using superheated steam. For these reasons, superheaters play an important part in the total operation of modern steam electric-generation stations.

How the Turbine Works

Typically, a fuel source ignites as it enters the boiler, and the heat of the combustion transfers to the water that circulates through the metal tubing. This water leaves the boiler as superheated steam, at about 1,000 degrees Fahrenheit, which passes through a turbine and rotates the turbine's **rotor** blades.

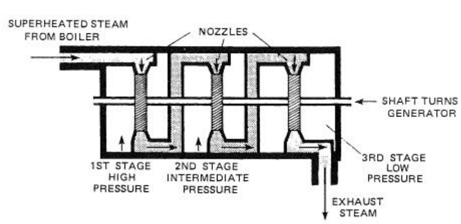


Figure 3A.14 Simple turbine

Figure 3A.14 shows the steam entering the first stage of the steam turbine from the superheater. From here, it goes through a stationary nozzle into the second stage. From the second stage, the steam goes through another stationary nozzle into the third stage. As the steam goes through the three stages, it continues to lose temperature and pressure and to expand until it is exhausted from the third stage.

The method just described provides a better method for turning the shaft and generator than the simple windmill described at first, but it is still just an example. No commercial turbine would be built in this manner, but it does illustrate the basic principles of turbine operation.

Reheater

Continuing with the plan of building a more efficient plant, the next step is to introduce the **reheater** (see Figure 3A.15). The reheater, as its name implies, is a heater that reheats the steam after it has been through part of the turbine. For instance, after the steam goes through the high-pressure state of the turbine, it goes back to the reheater. The reheater is a series of tubes located in the gas path of the furnace near the superheater. In the reheater, the steam temperature is raised by reheating before it is returned to the second stage of the turbine. The reheated steam has a temperature close to that of the primary steam, but the pressure is lower.

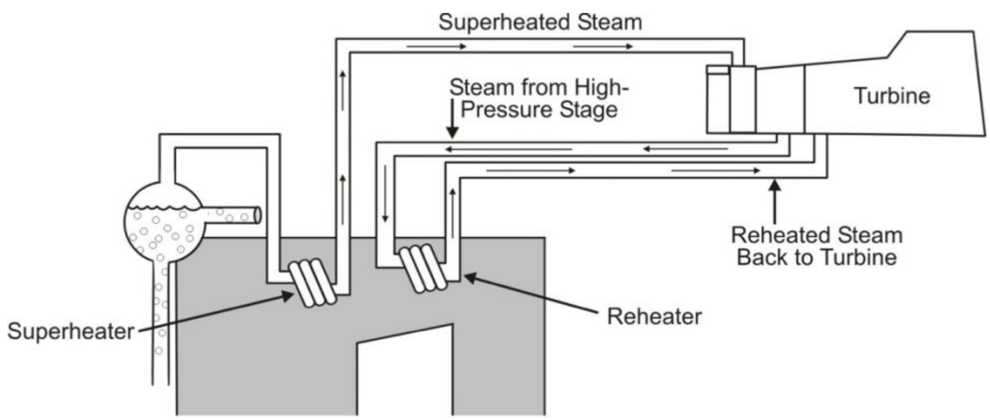


Figure 3A.15 Reheater

Condenser

Once the reheated steam completes its path through the turbine, it is discharged as exhaust. Where does it go from there? It could be released into the atmosphere, but this would be a great waste. Since time, energy, and money have already been spent to create this steam, it is reused by condensing it back into water and sending it back through the cycle. Also, condensing this steam into water can be done at a very low pressure that will allow the turbine to operate more efficiently.

How does a vacuum make a turbine more efficient? The atmospheric pressure is about 14.7 pounds per square inch. This means for the exhaust steam to get out of the turbine, it must push against the 14.7 pounds of atmospheric pressure. By creating a vacuum in the exhaust system of the turbine, the exhaust pressure is reduced; and the exhaust steam is actually pulled from the turbine. This increases the steam pressure change through the turbine, which increases the turbine efficiency by allowing it to develop more power.

To return to the topic of reusing the exhaust steam, we now attach a large hollow box to the exhaust opening of the turbine. This box, called a **condenser**, shown in Figure 3A.16, will be filled with thousands of small tubes through which relatively cool water is pumped.

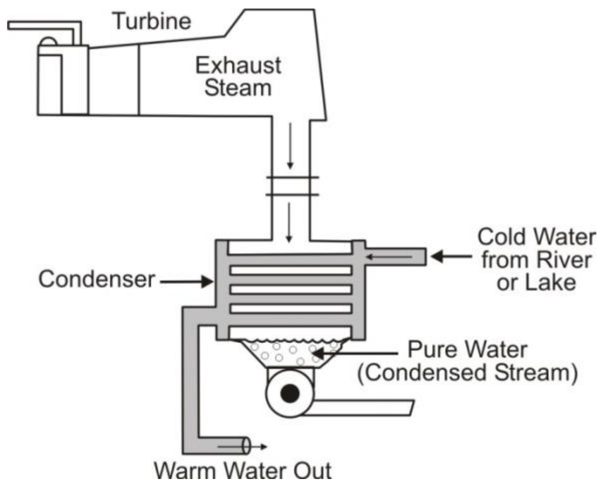


Figure 3A.16 Condenser

The cool water passing through the condenser tubes will cool the steam that passes over the outside of the tubes, and the steam will condense into water. Since the condensed water occupies less space than the original steam, a vacuum is created. These are the two functions of the condenser: to create a vacuum to enable the turbine to operate more efficiently and to transform the exhaust steam from the turbine into water for reuse in the boiler.

The condensing operation is the largest water system in the power plant. It takes 300,000 gallons or about 1,200 tons of water through the condenser tubes to condense the steam produced by just one ton of coal. Once the cooling water goes through the system, it is returned to its original source, which may be a river, lake, cooling tower, or pond, depending on the particular plant design. The water leaving the condenser **hotwell** for reuse in the boiler is known as **condensate**.

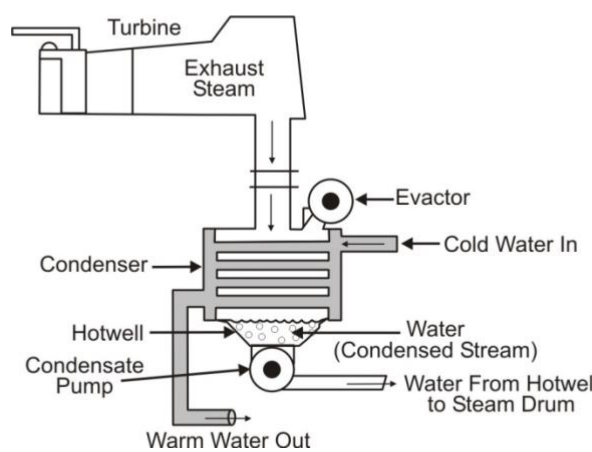


Figure 3A.17 Condensing system.

The condenser can sometimes lose the vacuum under which it operates when small quantities of air leak into it, causing it to become air bound. A loss of vacuum also causes a loss of cooling because of the air blanketing the condenser tubes. To prevent air from accumulating, a pump called an **evactor** is attached to the condenser (as shown in Figure 3A.17) to remove the air.

Boiler Feedwater Cycle

Modern boilers evaporate several million pounds of water per hour. Even with all the system's provisions for reuse of water, **makeup water** must be fed into the boiler on a regular basis. This operation of the system is known as the boiler feedwater water cycle.

Water from the Condenser

Nothing is wasted if it can be reused in any way. To reuse the condensate, which as stated earlier is the condensed turbine exhaust steam, there must be a collection chamber for it. This chamber, known as the hotwell, is located on the bottom of the condenser where it collects the condensate. To get the water from the hotwell to the feedwater water system requires another pump. This pump, called the condensate pump, is shown in Figure 3A.17 and is located directly beneath or next to the hotwell.

Makeup Water

In an operating plant, it is not possible to return all the steam to condensate due to leakage and other losses. Although the loss may be only a small amount of the total steam, it can amount to a considerable number of gallons of water over a period of time. The water that must be added to the system in order to maintain a uniform water level in the hotwell is known as makeup. As can be seen in Figure 3A.18, this makeup water is added to the system at the hotwell.

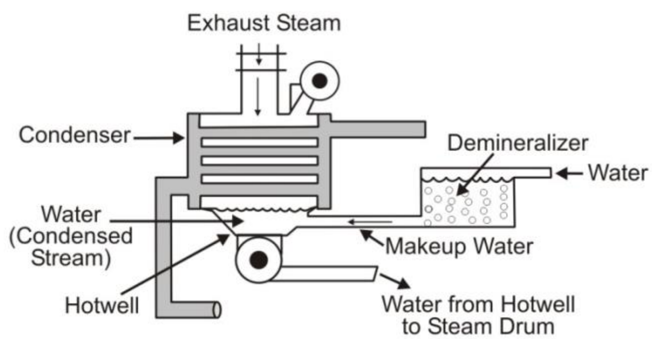


Figure 3A.18 Makeup water, hotwell, and demineralizer system

Makeup water must be pure and free from the foreign matter contained in all natural water. Just as scale forms in a tea kettle, natural water will scale the boiler tubes and cause boiler damage. Since boilers are much larger and operate at higher temperatures and pressures than tea kettles, problems other than simple scaling can be experienced. It is for this reason that all water going to the boiler must be free of solids and gases. Removing impurities from makeup water takes place in the **demineralizer system**.

Feedwater Heater

Not only must the source of the boiler water be pure, the temperature must be just right also. Cold water should not be added to the boiler for two reasons. First and most important, a severe difference in temperature between the water and the boiler could lead to damage of the boiler equipment. Second, it would lower the temperature of the water in the boiler and decrease the steam-producing rate. So, to make a boiler more efficient and to reduce the possibility of damage, it is necessary that the feedwater be heated to as high a temperature as practical before it enters the boiler.

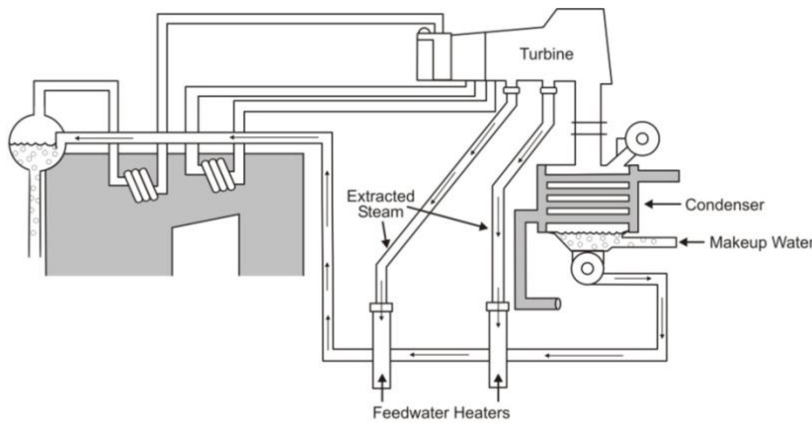


Figure 3A.19 Regenerative feedwater heating

Feedwater could be heated by a separate fuel-fired furnace, but just as with the air heater, it is more efficient to put available heat to work. To accomplish this, steam is extracted from the different turbine stages for use in a series of **feedwater heaters,** as shown in Figure 3A.19. Now the water from the hotwell can be reheated by passing it through these heaters en route to the steam drum. This method of heating the boiler feedwater is known as regenerative feedwater heating and is used in modern power plants. Some systems may have additional heaters plus heaters of different types. One type of heater different from those mentioned in the example is the **deaerating heater**. The deaerating heater, as shown in Figure 3A.20, adds heat to the feedwater and also removes the dissolved gases.

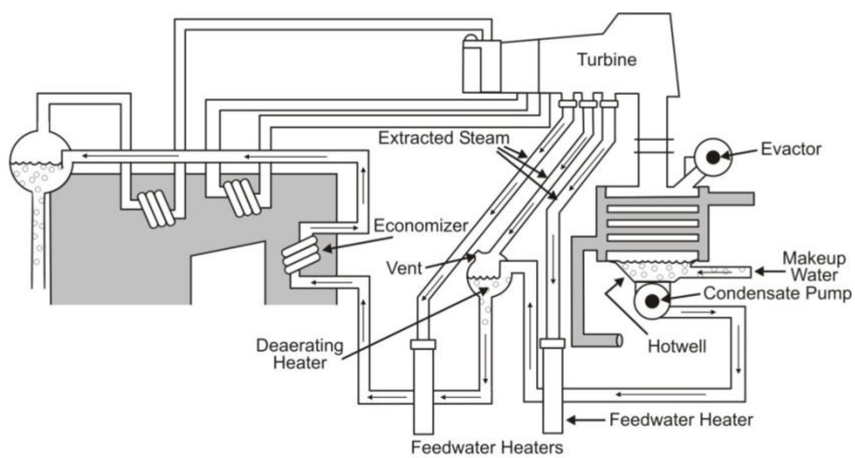


Figure 3A.20 Deaerating heater and economizer

Economizer

Referring to the furnace example for a minute, think of the air heater in which the heat in the flue gas was used to heat the air en route to the furnace. The same principle can be used with the feedwater. Placing an additional bank of tubes in the steam-generating unit area and passing the feedwater through them before it reaches the steam drum will heat the water with no additional heater. These tubes are located in the path of the combustion gases between the reheaters and the air heater as shown in Figure 3A.20. Most of the furnace heat is absorbed by the boiler tubes, superheater, and reheaters. However, some of the remaining heat that would otherwise go out the stack is left to heat the feedwater. As can be seen, the economy of the system is increased by adding this bank of tubes; consequently, it is known as the **economizer**.

Boiler Feed Pump

Since steam flows out of the boiler, it is necessary to replenish this water constantly in order to maintain the required water level in the steam drum. To maintain this level, an additional pump is added. This pump, shown in Figure 3A.21, is called the **boiler feed pump**. It must operate at a pressure high enough to overcome the pressure drop in the system and the boiler pressure.

The feedwater supply system is an essential part of power plant operation. The condensate and boiler feed pumps must constantly maintain the water supply to the boiler. If either pump or system fails, a large high-pressure boiler would run dry in about 90 seconds. This would lead, in turn, to equipment damage and a forced outage (an unscheduled shutting down of the unit)—both highly undesirable occurrences.

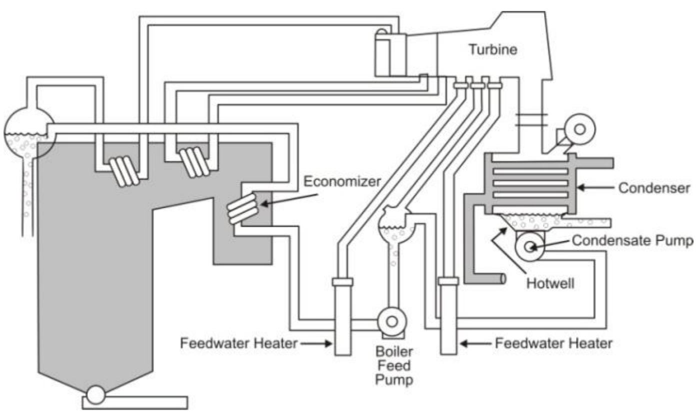


Figure 3A.21 Boiler feed pump

How a Generator Works

An electric power plant is the site of many energy conversion processes. **Chemical energy** in the form of fuel is converted to heat energy in the form of high temperature–high pressure steam. The steam turns a turbine, thereby converting the heat energy into rotating mechanical energy. The turbine rotor is connected to the rotor of the main power generator. As the turbine rotor turns, so turns the rotor of the generator. The generator rotor is made to produce a magnetic field. The action of the rotating magnetic field changes the mechanical energy into **electrical energy**, which is sent to the transmission system. Electrical energy is the end product for which the power plant is built.

The power plant main generators produce electrical power, which is conveyed to the transmission system along with electricity produced by the other main generators on the utility's system. Other smaller-sized generators perform other functions in the subsystems with the plant. These subsystems provide the support necessary to control, operate, and maintain the energy conversion processes of the plant.

The assembly of equipment required to produce electric power from one main generator is usually referred to as a unit. The major pieces of equipment that comprise a unit are the furnace, boiler (or nuclear reactor), turbine, and the main power generator. The subsystems required to operate this equipment are also part of the unit. A power plant may have more than one unit.

While the turbine is intricate in appearance, it is constructed to operate over a wide range of conditions, but its principle of operation is similar to that of a windmill and relatively easy to understand. On the other hand, the generator is very simple in appearance and standardized in construction, but its operation is more difficult to explain because it depends on magnetic and electrical principles. A working knowledge of these fundamental principles is essential to attain a thorough understanding of generator principles.

Basically, generators are nothing more than two circuits (the electric circuit and the magnetic circuit), one passing through the other. The electric circuit in the generator is stationary, made up of the **armature windings** embedded in the **stator** core and the load connected to the generator. The magnetic field is supplied and set in motion by means of the generator rotor, which is coupled to and rotated by the turbine rotor. Like the magnetic bar, the generator rotor is just a magnet with a north and south pole. Referring to Figure 3A.22, which represents a generator as viewed from one end, one can trace the magnetic circuit.

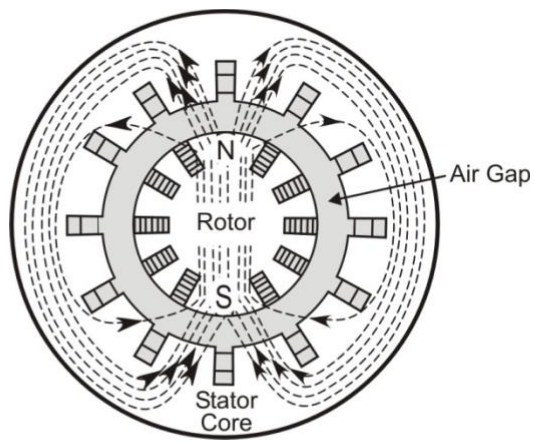


Figure 3A.22 Cross-section of a generator showing magnetic field

☼ LAB ACTIVITY: Building a Simple Generator

In this lab, you will build a simple generator using bar magnets that will be rotated around an axis and a coil of wire wrapped around a hollow core surrounding the magnets. Follow the instructions from the handout your teacher will give you. After you have completed the generator, work with your partner(s) to experiment with ways of making the generator more efficient. What would you need to add to your generator to model a power plant? If time allows, try some of your ideas. You may want to use a digital voltmeter to measure the voltage produced by your different designs.

In an electrical circuit, the number of electrons in motion is called the **amperage** or **current**, and it's measured in **amps**. The "pressure" pushing the electrons along is called the **voltage** and is measured in **volts**. For instance, a generator spinning at 1,000 rotations per minute might produce 1 amp at 6 volts. The 1 amp is the number of electrons moving (1 amp physically means that 6.24×10^{18} electrons move through a wire every second), and the voltage is the amount of pressure behind those electrons.

The generators in a modern power plant produce alternating current (AC), which is a flow of electrons that constantly changes in magnitude and periodically reverses direction. Direct current (DC) flows in the direction determined by the polarity of the applied voltage. Although the first commercial source of electricity was DC, its use for power transmission and distribution was very limited. Why? Alternating current is preferred for the following reasons:

1) AC generators produce more power than DC generators. DC generator voltage and current levels are limited to approximately 750 volts and 800 amps, while AC generators commonly generate voltages from 13 kV to 25 kV. Generating AC is more practical.
2) AC voltage and current can be stepped up or down with transformers. Transformers are relatively simple and efficient devices. Transformers don't work with DC. Changing voltage levels of direct current requires the use of more complicated switching circuits.
3) The combination of AC generators and transformers make it possible to produce electrical energy in generating stations long distances from where it will be used and then deliver it efficiently and economically, while DC generators are generally located at the site where the DC power will be used.

In a turbine generator under load, the effects can be very dramatic. To clearly understand what happens, let us review:

- Direct current is introduced into the windings of the rotor and produces a magnetic field that passes through the pole faces, across the air gap, through the stator, and back to the opposite pole face.
- The rotor is turned by action of the turbine, thereby causing the magnetic field to move relative to the armature windings of the stator.
- An electromotive force or voltage is set up across the armature windings, which results in the movement of electrons or current when these conductors in the stator are connected to an external load.

Electric Power Generation: Coal

Fossil-fueled electric generation processes and systems are fundamentally very similar. In coal-fueled electric generation power plants, heat created by burning coal converts water in a boiler into high-pressure steam. To safely contain steam pressure, the vessel must have its structural integrity assured in the construction stage and maintained by proper usage. See Figure 3A.23.

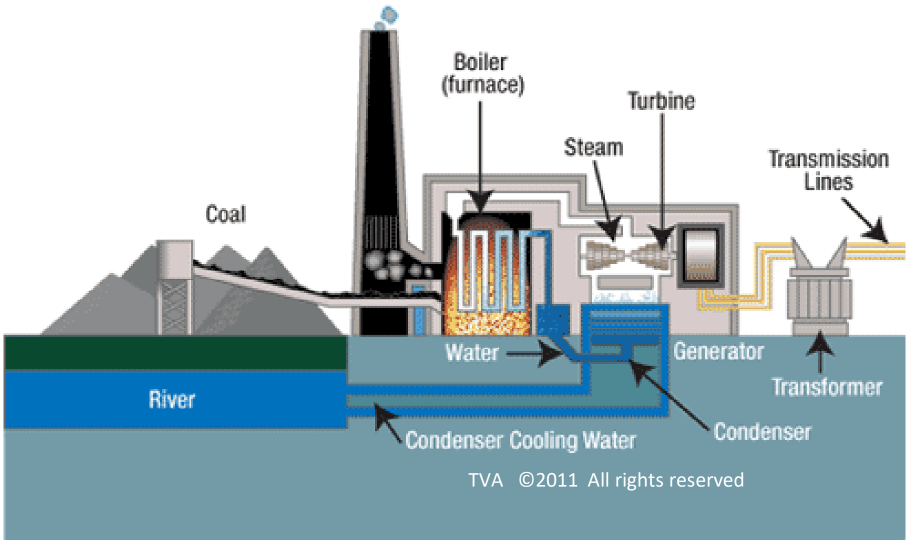


Figure 3A.23 Coal-fueled electric generation power plant

The steam rotates the turbine shaft at high speed, driving the shaft of a generator. The main function of a generator is to convert the heat energy of steam into more easily used electrical energy. It does this in two steps: first, the **thermal energy** of the steam is transformed into mechanical torque in the turbine; and second, this mechanical torque is converted into electrical energy in the generator because the turbine shaft rotation moves the magnetic field over the coils of the generator, producing electrical current.

After the steam leaves the turbine, it is usually condensed back to water and pumped back into the boiler for the process to begin again. Since the condensing is usually accomplished using makeup water**,** power generating plants are commonly located along large bodies of water or utilize cooling towers.

Electric Power Generation: Natural Gas

As mentioned earlier, fossil-fueled electric generation processes and systems are fundamentally very similar. Natural gas is typically used in two ways for electric power generation. The first method is through steam turbine generation by burning natural gas to provide heat to create steam similar to the way coal is used to create steam in coal-fired plants.

The second method of using natural gas as a fuel source is through gas turbine generation, by the use of the hot gases produced by the combustion of natural gas. In this case, natural gas is combusted and the hot combustion gases, instead of steam, turn turbines.

A third method called combined cycle technology consists of the combination of the above-mentioned processes.

A Closer Look at Gas Turbine Generation

A gas turbine is a combustion turbine, a rotary engine that gets energy from the flow of hot, compressed combustion gas. Gas turbines are normally fueled with natural gas, although low-sulfur fuel oil can also be used as needed. See Figure 3A.24.

The turbines operate like a jet engine: they draw in air at the front of the unit, compress it, mix it with fuel, and ignite it. In the combustor, fuel is mixed with air and ignited under high pressure. The high-pressure environment increases the temperature of the combustion, making it more efficient.

The products of the combustion, most importantly high velocity gases, are forced into a turbine, which spins the turbine's blades and drives their mechanical output. Similar to other power generators, the turbine rotor is connected to a generator to produce electricity.

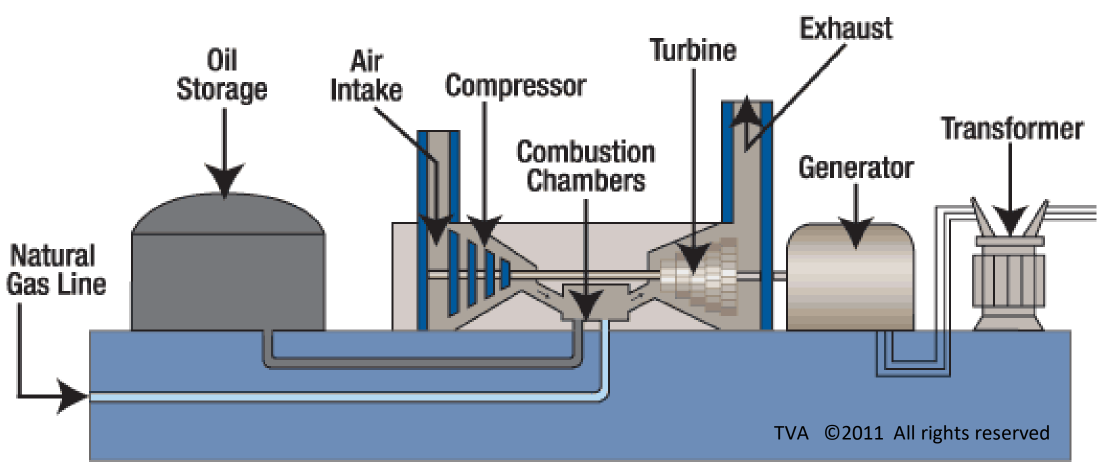
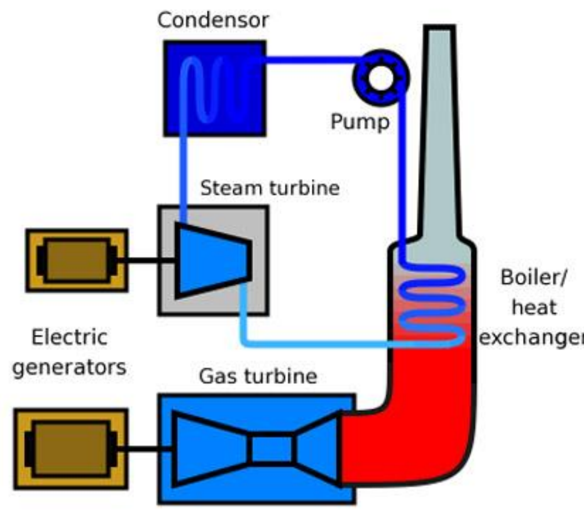


Figure 3A.24 Gas turbine generation

Combined cycle technology boosts power plant efficiency by essentially utilizing the same fuel to generate electricity twice. Natural gas power plants can reach a much higher efficiency level, around 60%, when a combined cycle configuration is used.

In combined cycle generation that utilizes gas turbines, the hot gases of combustion are used to turn the turbine as well as to provide a heat source for a boiler which produces steam for a steam generator. Electricity is produced as a result of the hot gas combustion energy and through steam energy. See Figure 3A.25.



3A.25 Combined Cycle Generation

Gas turbine plants are considered among the most expensive to operate, but they are the most flexible in the control of power output. Combustion turbines are designed to start quickly in addition to having operational flexibility in adjusting power output levels. These characteristics make gas turbine plants useful for **peak load demand** where quick start-up or short-use periods are needed. Peak load demand and other power demand concepts will be discussed further later in this module.

☼ ACTIVITY: Natural Gas Fuel Cells

Research and discuss these questions as a class.

- What is natural gas fuel cell technology?
- What are the implications (financial, environmental, other) of using natural gas as a fuel source without using combustion methods to generate electricity?

Electric Power Generation: Nuclear

Figure 3A.26 Nuclear power plant cooling tower

Nuclear energy is used as an alternative to **fossil fuels**. Nuclear power is created by controlled nuclear reactions. The **nucleus** of an atom contains energy. In a nuclear power plant, the energy contained in a **radioactive** atom such as uranium (U) is released by splitting or breaking down the nuclei. This process is called nuclear fission, and it creates large amounts of heat. See Figure 3A.26.

Nuclear fission takes place inside the reactor of a nuclear power plant. A concrete and steel enclosure called the **containment building** is constructed around a nuclear reactor to confine fission products that otherwise might be released into the atmosphere. See Figure 3A.27.

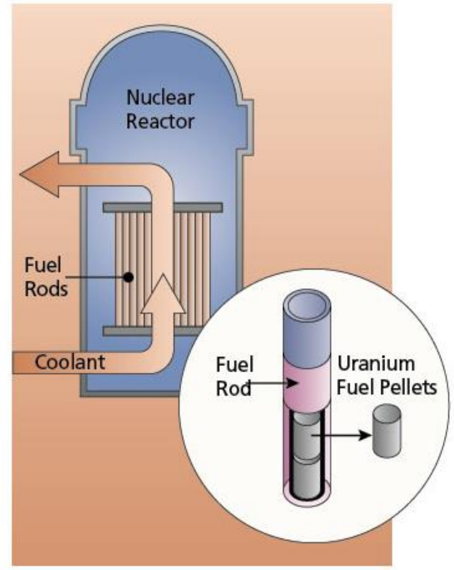


Figure 3A.27 Nuclear reactor containment building

NRC File Photo ©2011 All rights reserved

At the center of the reactor is the core which contains the uranium fuel source. The uranium fuel source within the core is composed of multiple **fuel rods**.

Typically, fuel rods are operational inside the reactor for about six years. Once the fuel rods reach the end of their usefulness, they must be stored with special procedures within special facilities such as spent fuel pools, closed storage, or **reprocessing**.

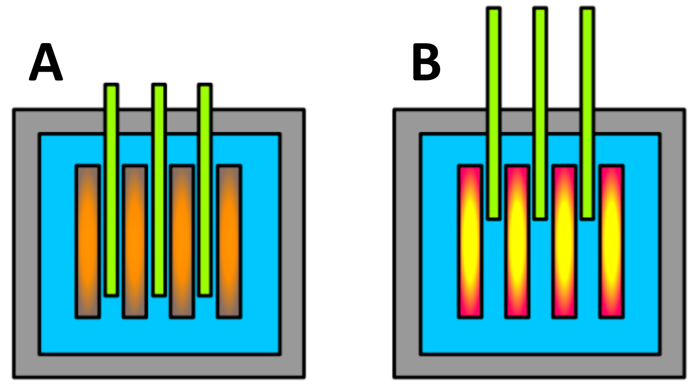
During nuclear fission of uranium, small particles called **neutrons** hit the uranium atom and split it. This splitting or "fission" releases a large amount of energy in the form of heat and radiation.

In nuclear power plants, the heat given off by the nuclear reaction is used to change water into steam. Similar to the other power generation systems covered so far, the steam passes through a turbine, rotating the turbine at high speeds, which in turn moves the magnetic field over the coils of the generator, producing electrical current. After the steam leaves the turbine, it is usually condensed back to water and pumped back into the nuclear-fueled boiler for the process to begin again.

The water that circulates through the reactor (reactor coolant system) serves two important functions. First, as mentioned above, the water is the source of steam that turns the turbines to generate electricity; and second, it controls the fission process by serving as a moderator through the change in water temperature, either slowing or speeding up the process.

An additional source of control of the fission process is the **control rods**. See Figure 3A.28. Control rods are composed of special chemical elements that can be used to control the rate of nuclear fission in the reactor. The control rod assembly position is manipulated up or down so that less or more of the assembly is exposed to the reactor core to moderate the fission reaction.

A steady rate of self-sustaining fission **chain reactions** is necessary for stable power generation output. This steady rate or “equilibrium” of self-sustaining nuclear fission reactions is known as **critical mass**.



Nuclear Reactor Control Rods

A) With the control rods down, the reaction is slowed; too many neutrons are absorbed for a chain reaction to take place.

B) Pulling up the rods speeds up the reaction, and the fuel rods start producing heat.

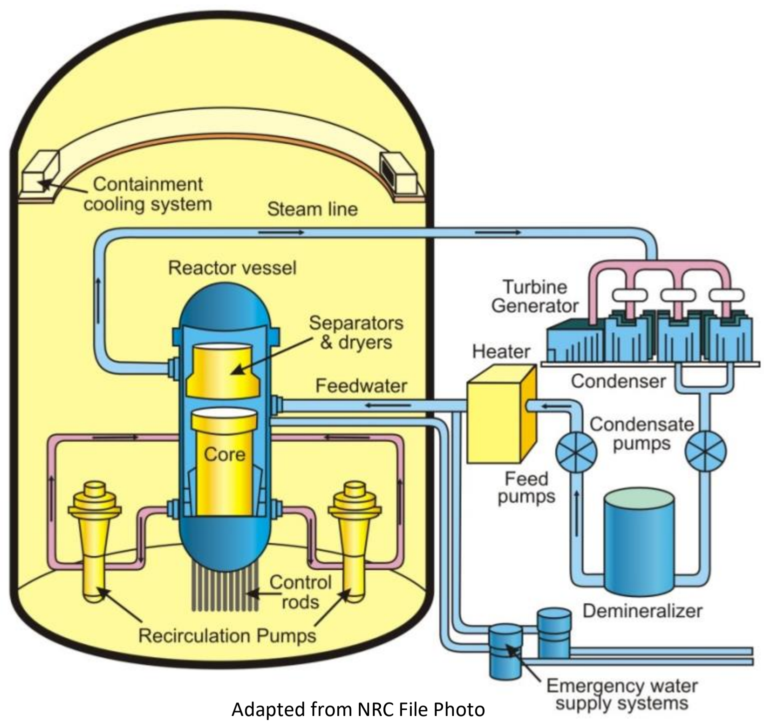
Figure 3A.28 Nuclear reactor control rods

Types of Plants

There are several types of nuclear power reactors. Only **boiling water reactors** (BWRs) and **pressurized water reactors** (PWRs) are in commercial operation in the United States.

Boiling Water Reactors

A boiling water reactor functions in the following way: The uranium core inside the **reactor vessel** creates heat. A steam-water mixture is produced when reactor coolant water moves through the core, absorbing heat. See Figure 3A.29.



Adapted from NRC File Photo

Figure 3A.29 Boiling water reactor

The steam-water mixture leaves the top of the core and enters two stages of moisture separation where water droplets are removed before steam enters the steam line. Steam is directed through a steam line to a turbine, causing it to turn the turbine generator, which produces electricity.

Unused steam is returned to the condenser where it condensed into water. That water is pumped out of the condenser, reheated, and pumped back to the reactor vessel. Boiling-water reactors contain between 370-800 **fuel assemblies**.

Pressurized Water Reactors

The majority of nuclear power plants in the United States are **pressurized water reactors**. Pressurized water reactors are different than boiling water reactors in that the steam that moves the turbine is created by a steam generator.

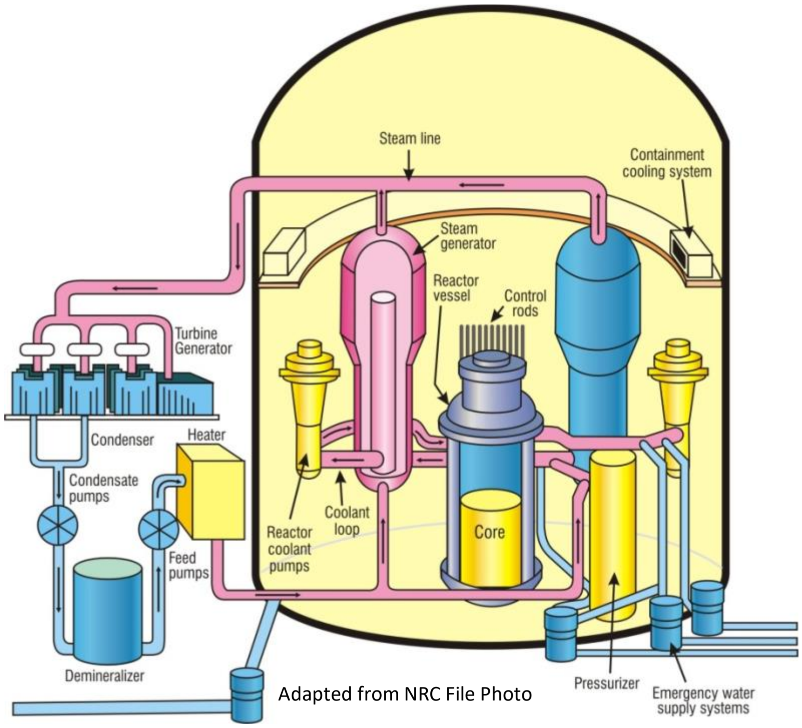


Figure 3A.30 Pressurized water reactor

A pressurized water reactor functions in the following way: The uranium core inside the reactor vessel creates heat. Pressurized water carries the heat to a steam generator. Inside the steam generator, steam is directed through a steam line to a turbine, causing it to turn the turbine generator, which produces electricity. See Figure 3A.30.

Unused steam is returned to the condenser where it is condensed into water. That water is pumped out of the condenser, reheated, and pumped back to the reactor vessel. Pressurized-water reactors contain between 150 and 200 fuel assemblies.

☼ ACTIVITY: Nuclear Reactor Design

Research and discuss these questions as a class.

- What are the differences between evolutionary and passive reactor designs?
- Discuss the advantages and disadvantages of both designs.

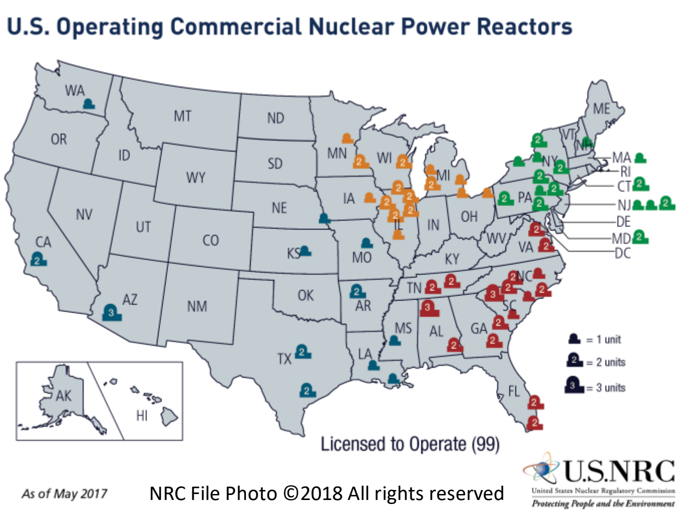
Special Safeguards and Regulations

As mentioned in Module 2, since radioactive materials can be dangerous, there are many federal entities that regulate the nuclear power industry.

The United States Office of Health, Safety and Security (HSS), in addition to the **Nuclear Regulatory Commission** (NRC), create and enforce standards and regulations for nuclear power- related processes.

The HSS is responsible for policy development and technical assistance in the areas of health, safety, environment, and physical and information security as they pertain to the initiatives of the Department of Energy. The HSS manages education and training programs; enforcement programs including nuclear safety, worker safety, and health; and information security programs.

The U.S. Nuclear Regulatory Commission has the responsibility of ensuring the peaceful and safe use of nuclear energy. The NRC is responsible for programs that promote defense and security, environmental protection, and protection of public health and safety in regard to nuclear energy. The NRC regulates programs relating to special nuclear material, radioactive wastes, and nuclear power facilities.



NRC File Photo ©2018 All rights reserved

Figure 3A.31 U.S. Operating commercial nuclear power reactors

The NRC regulates all commercial nuclear power plants that generate electricity in the United States. The NRC also regulates research and test reactors used for research, testing, and training. See Figure 3A.31.

The NRC performs regulation through regulatory requirements; licensing; safety oversight, including inspection, performance assessment, and enforcement; operational experience evaluation; and other regulatory support activities.

The NRC ensures safeguards and security specifically by regulating operations accounting systems for nuclear materials as well as security and contingency programs.

Radioactive materials, if not used properly, can damage human cells or even cause cancer over long periods of time. Nuclear power plants are required to follow special safety systems and practices to protect workers, the public, and the environment. Many of these safety standards are directed at the prevention of a catastrophic facility failure or "**meltdown**." These safety systems include shutting the reactor down quickly and stopping the fission process, systems to cool the reactor down and carry heat away from it, and barriers to contain the **radioactivity** and prevent it from escaping into the environment.

Quick Facts

Top Hydropower Producing States:

- Washington
- Oregon
- California
- New York
- Alabama

Percent of Total Electricity Generated That Comes From Hydropower:

- 80% - Idaho
- 69% - Washington
- 58% - Oregon
- 36% - Montana
- 21% - New York
- 14% - California

(Source: EIA)

Electric Power Generation: Hydroelectric

Hydroelectric power is power that is generated from water. Hydroelectric power is considered to be relatively reliable, renewable, and quickly and easily dispatched.

Hydroelectric power plants are dependent on the flow of water to generate electricity. In hydroelectric power plants, the mechanical energy to rotate the generator comes from the force of falling water pushing against the blades of a water turbine. The source of water for hydroelectric generation is usually a lake or reservoir located several hundred feet above the level of the water turbine and generator. Smaller hydroelectric plants can operate with less of a distance, as little as 20 feet. However, hydroelectric plants need a constant flow of water in order to operate efficiently. **Dams** are built to trap flowing water to be directed into a controlled flow into the turbines for better efficiency. See Figure 3A.32.

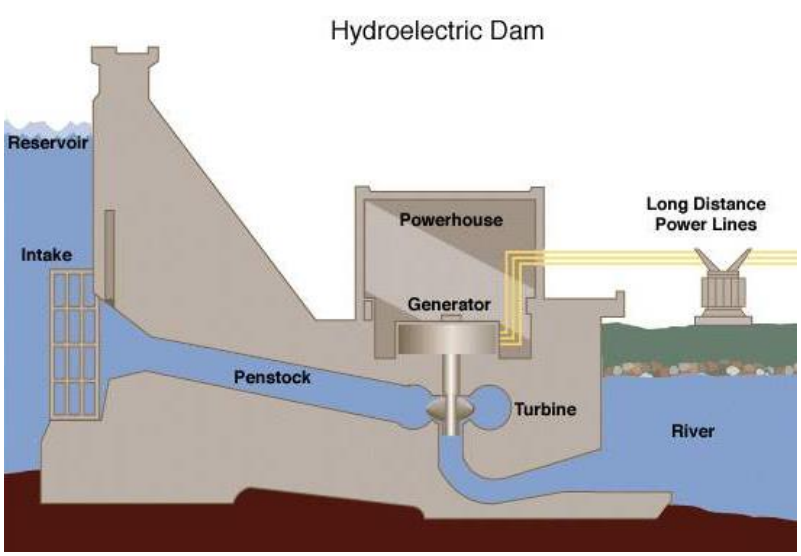
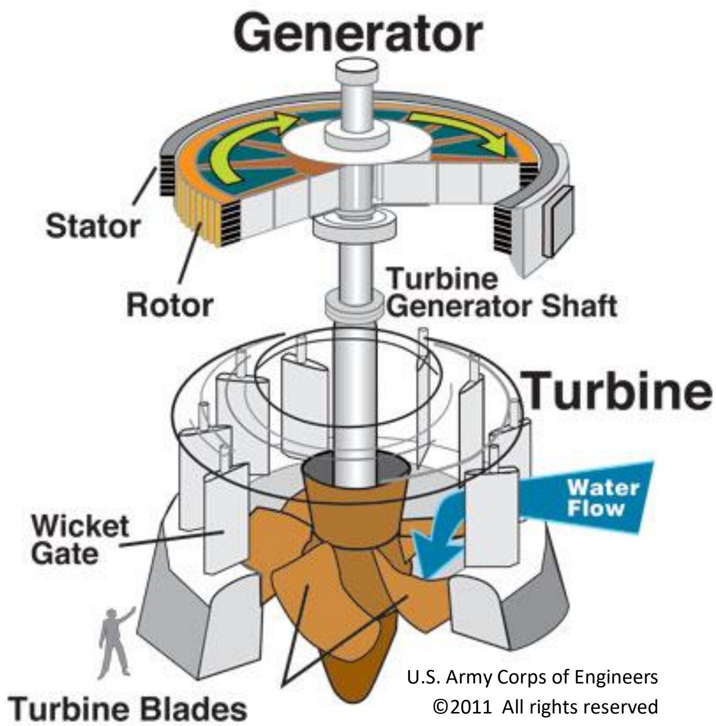


Figure 3A.32 Hydroelectric dam

Conventional hydropower plants use the water from rivers, streams, or reservoirs to produce energy. The majority of hydropower plants are conventional plants. Another type of hydropower plant is a pumped storage plant. In a pumped storage plant, water is pumped from a lower elevation reservoir to a higher elevation when off-peak low-cost electricity is available. During times of higher electricity demand, the water can be released to flow through a turbine to generate electricity and be stored in the lower reservoir.

Dams are typically built on a large river that has a significant elevation drop. The dam restricts the flow of water so that the water is contained in a reservoir behind the wall of the dam. Water intake areas located near the bottom of the dam wall direct the flow of water inside the dam to the turbines.

The force of the running water pushes the blades on the turbines and the turbine shaft turns. The turbine shaft is directly coupled to the generator, Figure 3A.33. Similar to other generator systems that have been discussed, the motion of the turbines moves the magnetic field over the coils of the generator to produce electrical current. Once the water has moved past the turbine propellers, it is released back into the river on the other side of the dam.



U.S. Army Corps of Engineers
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Figure 3A.33 Hydroelectric generator

Electric Power Generation: Supply and Demand

Electricity cannot be stored easily or efficiently; therefore, electric power must be generated on demand. Power companies must maintain and operate generation facilities to produce power when consumers demand it.

Customers' power needs are constantly changing. Consumer demand for electricity varies depending on many factors, such as time of day or the season. Different types of power plants can be categorized as to how and when they provide power in response to consumer demand.

Base Load

Base load demand is referred to as the amount of power that must be made available to meet average minimum customer demand. Therefore, a **base load power plant** is a power-generating plant that is devoted to the continuous production of a base load power supply.

Base load power plants typically include the following types of power plants:

- Nuclear
- Coal
- Fuel oil
- Hydroelectric
- Geothermal

Nuclear and coal-fired plants take a longer time to “warm-up” and reach a steady rate of power production and are therefore better suited to base load power demand. Base load plants typically operate continuously at maximum output throughout the year except when repairs or scheduled maintenance is necessary.

Peak Loading

Peak load refers to an increase in customer demand that is significantly above base load demand. Peaks in consumer power demand are covered by **peaking power plants**. A peaking power plant is typically smaller than a base load power plant and therefore is able to respond relatively quickly to increased demand for power generation.

Peaking power plants typically include the following types of power plants:

- Natural Gas
- Hydroelectric (pumped storage technology)

Load Following

A **load following power plant** operates in between base load and peaking power plants. Load following power plants have the ability to adjust their power generation in response to the change in demand throughout the day.

Load following power plants typically include the following types of power plants:

- Natural Gas
- Fuel Oil
- Hydroelectric

☼ CAREER PROFILE: Power Plant Operator

James W. has been a power plant operator for a power plant in Detroit for almost twenty years. He says that his job can be "very quiet, very routine for days or even weeks, but then—watch out! Everything happens at once in a power plant because the plant operations are interconnected. You have to stay alert for that one little reading that's off, that one event that tells you that you have a problem. Then you have to react fast. You have to know the system." What does he like the most about the job? He gives a big smile and says, "All that power."

Power plant operators have the very important job of making sure customers have enough electricity or gas to meet their daily needs. Power plant operators are in charge of operating and controlling the machines and systems that generate power.

Power plant operators fill a variety of positions. At the entry level, they may operate fuel- and ash-handling systems and move up to operating major support equipment. Finally, they may work as control-room operators. They must make periodic inspections of equipment; put equipment in and take it out of service; operate systems; clean equipment;and monitor a number of critical temperatures, oil levels, and vibration levels. Operators are generally union workers. Because power plants operate around the clock, power plant operators are required to work shifts.

Electric Power Generation: Energy Efficiency and Energy Loss Points

Energy efficiency can be described as the amount of useful energy produced by a system compared to the amount of energy input into the system. A perfectly 100% energy-efficient machine would convert all of the input energy into useful power. However, 100% efficiency is not technologically available at this time. Converting one form of energy to another involves the loss of usable energy. This loss is usually in the form of heat through **friction** and other mechanical processes.

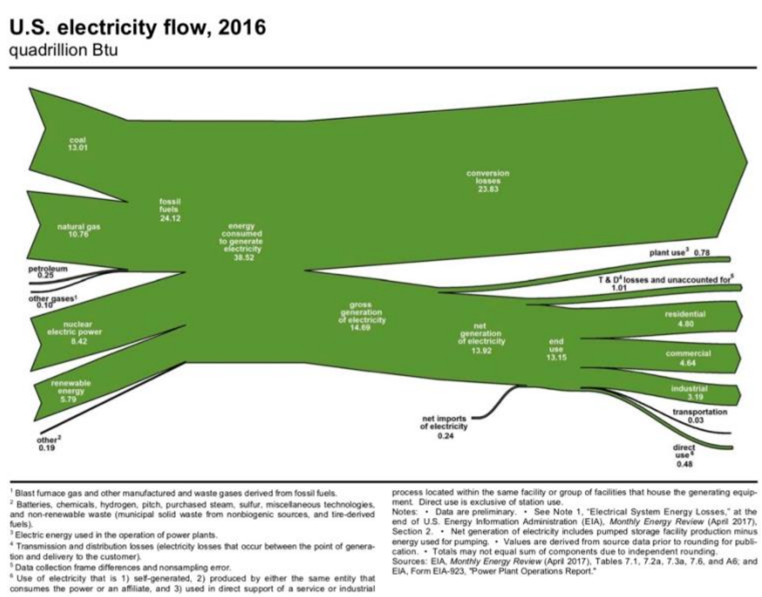

Figure 3A.34 U.S. electricity flow

Energy losses occur throughout the power generation process. But the fundamental **law of energy conservation** insists that energy is neither destroyed nor created. The sum of all energy (**potential energy**, **kinetic energy**, thermal energy, chemical energy, and electrical energy) entering a power plant must be exactly the same as the sum of all energy leaving (or lost in) a plant. For example, if one pound of coal, containing 13,500 **British Thermal units (Btu)**, is stoked into the furnace, the electrical equivalent of 13,500 Btu should be distributed from the plant. But, in fact, only about the equivalent of 4,000 Btu exit the plant as distributable electricity. The other Btu are "lost" within the plant in a variety of ways.

Furnace Losses

Hydrocarbon fuels burn with various efficiencies. Different types of coal burn with varying percentages of efficiency—the balance is ash and pollutants, which must be properly disposed of.

Steam-Cycle Losses

The steam cycle, which includes the boiler and all its associated piping, condensers, and various heat exchangers, and the cooling-water system, suffers thermal losses through radiation and absorption, and is especially susceptible to friction losses—fluid flow through miles of conduits is slowed by both turbulence and drag.

Turbine Rotation Losses

Major losses associated with this system, once it has obtained operational rotation speed, have to do with acceleration and deceleration and with auxiliary equipment operation.

Generator Losses

Generator losses consist of mechanical "drag" (friction) losses, and electrical drag losses in any generator or motor.

Unit A Glossary

air heater—heat transfer apparatus through which air is passed and vented; it makes use of a medium of higher temperature, such as the products of combustion

amperage—number of electrons moving past a fixed point in a conductor in one second; the amount of electricity flowing through a wire

amps—common abbreviation for amperes, the unit of measurement used to describe the flow of electrons (current)

armature windings—conductor windings embedded in the stator core of the generator that make up the electrical circuit of the generator; the armature windings lead to the conductors that move the electrical energy to the main power transformer

ash hopper—the portion of the furnace where the bottom ash falls and is removed by an ash sluice system that carries it to a holding tank or settling pond

base load demand—the amount of power that must be made available to meet average minimum customer demand

base load power plant—plants that operate continuously at maximum output

boilers—closed vessels in which water or other fluids are heated enough to be converted into steam

boiler feed pump—a pump that constantly replenishes the water in the steam drum; it must operate at a high enough pressure to overcome the pressure in the boiler

boiling water reactor (BWR)—a reactor in which water is used as both a coolant and a moderator; the water is allowed to boil in the core and this produces steam which is used to drive a turbine and electrical generator, and produce electricity

bottom ash—the heavy ash that is removed from the furnace section by allowing it to fall into the bottom section of the furnace; it is comprised of unburned carbon as well as impurities found in the coal that do not burn

British thermal unit (Btu)—a unit of energy in the English system, defined as the energy required to raise the temperature of one pound of water by one degree Fahrenheit

chain reaction—a fission reaction that keeps itself going due to more and more neutrons being released; depending on how fast neutrons are released, a chain reaction can be controlled or uncontrolled

chemical energy—potential energy stored in the bonds between atoms in a molecule

combustion—when a substance (fuel) combines rapidly with oxygen (usually in the presence of heat) to produce new compounds and give off heat; generally referred to as "burning"

condensate—the water leaving the condenser hotwell for reuse in the boiler; the condensing operation is the largest water system in the power plant

condenser—condenses the steam into water after it has been exhausted from the steam turbine

containment building—a concrete and steel enclosure around a nuclear reactor that confines fission products that otherwise might be released to the atmosphere

control rod—a rod, plate, or tube containing a material such as cadmium or boron which is used to control the power of a nuclear reactor. By absorbing neutrons, a control rod slows down or stops a chain reaction

critical mass—the smallest mass of nuclear material that will support a chain reaction

current—the flow of electrons

dams—barriers constructed across a waterway to control the flow or raise the level of water

deaerating heater—this heater adds heat to the feedwater and also removes the dissolved gases

demineralizer system—the system for treating makeup water to assure that the water is free of solids and gases

economizer—a heat-recovery device designed to transfer heat from the products of combustion to feedwater

electrical energy—potential energy and kinetic energy associated with the position or movement of electrical charge

electric power distribution—the transfer of high voltage electrical energy from substations to the end customer

electric power generation—process of creating electrical energy from other forms of energy

electric power transmission—the bulk transfer of high voltage electrical energy from its source at generating plants to substations

energy—the ability to do work

electrostatic precipitator—a device for removing small particles (such as smoke, dust, or oil) from a gas, such as air, by passing the gas first through an electrically charged screen that gives a charge to the particles, then between two charged plates where the particles are attracted to one surface

energy efficiency—the amount of useful energy in a system’s output compared to its input

evactor—a pump added to the condensate system that helps to ensure a vacuum and that prevents air from accumulating around the condenser tubes

exhauster—a fan used to draw the pulverized coal dust out of the mill and blow it into the furnace; recent units have eliminated the exhauster and rely instead on increased primary air flow to the mill to transport the pulverized coal into the furnace

feedwater heaters—devices that use steam extracted from the turbine to increase the temperature of the water from the hotwell before it is reintroduced to the steam drum

feedwater regulators—regulators that control the water flow automatically and maintain the drum level to a constant in the boiler

fly ash—the very fine particulates (light ash) carried through the system by the combustion gases

fossil fuels—hydrocarbons such as petroleum, coal, or natural gas, derived from prehistoric plants and animals and used for fuel

forced-draft fan—a fan supplying preheated air under pressure to the fuel-burning equipment

friction—a force that opposes relative motion of two solids or a solid and a liquid

fuel assemblies—structured collections of fuel rods within a nuclear reactor

fuel rods—long, slender tubes that hold nuclear fuel pellets for reactor use; fuel rods are bundled together in assemblies and placed into the reactor core

furnace—the portion of the generating unit containing the fire and fuel-burning equipment; the site where the chemical energy of the fuel is converted to thermal energy

generators—the portion of the generating unit where the rotating mechanical energy is converted to electrical energy. It consists of a stator containing the armature windings and a rotor (center shaft) that is turned by the turbine to produce the magnetic field

geothermal energy—energy from deep under the Earth's surface

heat exchanger—a device that moves heat from one fluid (liquid or gas) to another fluid or to the environment

hotwell—the collection system in place in the boiler to reuse the condensate water from the condenser

hydrocarbons—simple compounds containing only the elements hydrogen and carbon; fossil fuels are made of hydrocarbons

hydroelectric—power generated by using moving water to power a turbine generator to produce electricity

igniters—devices that raise the fuel/air temperature to the point of combustion

induced-draft fan—a fan exhausting combustion gases from the heat-absorbing equipment

kindling temperature—the temperature at which fuel ignites

kinetic energy—energy possessed by an object or system in motion

law of energy conservation—the total energy of an isolated system is constant; energy can be neither created nor destroyed

load following power plant—plant that has the ability to adjust its power generation in response to change in demand throughout the day

makeup water—water that is added to the hotwell to maintain the required level; it is pure and free from foreign matter

mechanical energy—energy in a mechanical system; can be potential, kinetic, or gravitational

meltdown—a severe nuclear reactor accident that happens when a nuclear power plant system fails and causes the reactor core to no longer be properly controlled and cooled; this causes the nuclear fuel to melt, and releases radiation

neutron—a fundamental subatomic particle that has nearly the same mass as the proton and no charge

nuclear energy—the energy given off by a nuclear reaction (fission or fusion) or by radioactive decay

nuclear fission—the splitting of an atom's nucleus into at least two smaller nuclei and the release of a large amount of energy (heat); two or three neutrons are usually released during this reaction

Nuclear Regulatory Commission—the U.S. regulatory agency that develops and enforces policies governing nuclear reactor and nuclear material safety

nucleus—the center of an atom

peak load demand—customer electricity demand level that is significantly above base load demand

peaking power plant—plant that is able to respond quickly to meet the needs of energy consumers in times of highest demand for and use of electricity

potential energy—energy stored in an object due to its position/location

pressurized water reactor (PWR)—a nuclear reactor in which heat is transferred from the core to an exchanger by high temperature water kept under pressure in the primary system; steam that turns turbines is generated in a secondary circuit

primary air—air that carries the pulverized coal into the furnace

pulverizing—the process of reducing coal to powder fineness for the purpose of instant combustion when it is blown into the furnace

radioactive—emitting radiation due to decaying atomic nuclei

radioactivity—a description of some elements that spontaneously give off energetic particles from their nuclei

reactor vessel—the main steel vessel containing the reactor fuel, moderator, and coolant

reheater—a heater that reheats the steam after it has been through part of the turbine

reprocessing—chemical treatment of spent reactor fuel to separate uranium and plutonium and possibly other radioactive elements from other waste products

rotor—The rotating shaft in an electrical generator that produces the moving magnetic field that induces current flow in the armature windings of the stator

secondary air—additional air flow to the furnace to ensure sufficient oxygen for complete combustion of the fuel

slag—the product resulting when molten boiler ash cools into granules

sluice system—a system that collects ash from the ash hopper and then forwards it to a holding tank or settling pond

stator—the stationary shell of an electrical generator that contains the armature windings

stoker firing—automated method of feeding coal pieces to early furnaces either by conveyer or hopper-fed rotating paddle wheel

superheater—an arrangement of tubes in the gas path of the furnace to raise the temperature of the steam above its saturation temperature

system load—the amount of electric power delivered or required at any specific point or points on a system; the requirement originates at the energy-consuming equipment of the consumers

thermal energy—the internal energy possessed by substances in the vibration and movement of their atoms or molecules

turbine—a machine for generating rotary mechanical power from a fluid flow (air, steam, water)

tidal energy—a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity

units—the assembly of equipment required to produce electric power from one main generator; the main pieces of equipment that comprise a unit are the steam generator (boiler or nuclear reactor), the turbine, and the main power generator

voltage—the difference in electrical potential between any two conductors or between a conductor and ground. It is a measure of the electric energy per electron that electrons can acquire and/or give up as they move between the two conductors

volts—the unit of measurement for voltage

waterwall tubes—closely spaced tubes lining the furnace and connected to the steam drum, where the primary steam is generated

wind energy—wind turbines convert the kinetic energy in the wind into mechanical power

Unit A References

Electric Utilities Technical Education Council and the Center for Occupational Research and Development. Fossil-Fuel Power Plant Technology Series: Power Plant Fundamentals and Systems I.

Electric Utilities Technical Education Council and the Center for Occupational Research and Development. Fossil-Fuel Power Plant Technology Series: Power Plant Fundamentals and Systems II.

Electric Utilities Technical Education Council and the Center for Occupational Research and Development. Fossil-Fuel Power Plant Technology Series: Power Plant Operator – Level II.

Energy Information Administration (EIA)
http://www.eia.doe.gov/

U.S. Electricity Flow, 2017
www.eia.gov/totalenergy/data/monthly/pdf/flow/electricity.pdf

Federal Energy Regulatory Commission (FERC)
http://www.ferc.gov

National Hydropower Association
http://www.hydro.com

Steam: What Is Steam?
http://www.tlv.com/global/TI/steam-theory/what-is-steam.html

U.S. Department of Energy (DOE)
http://www.energy.gov/

U.S. Nuclear Regulatory Commission
http://www.nrc.gov/

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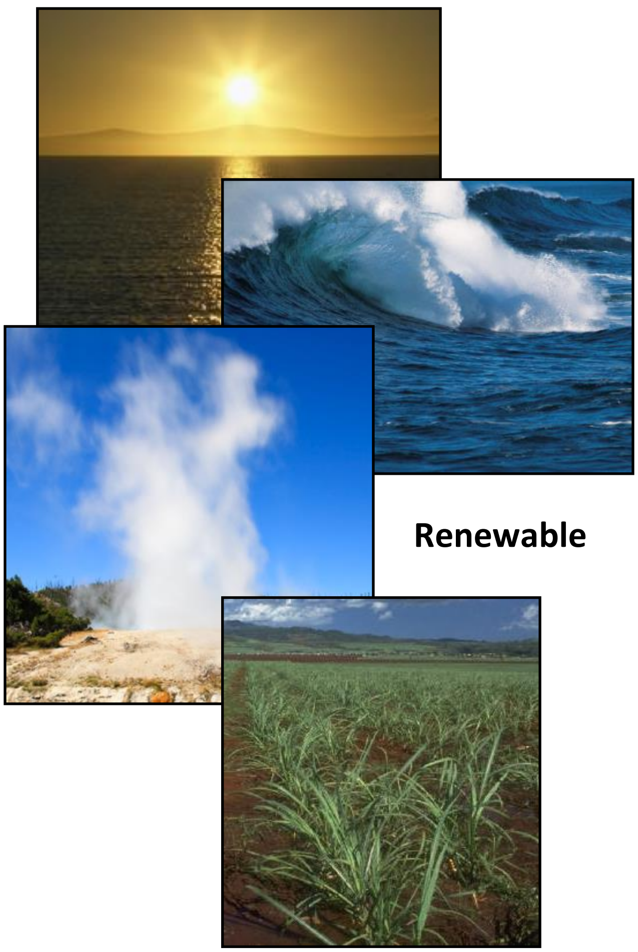
Unit B: Overview of Generation Fuel Sources

UNIT B: OVERVIEW OF GENERATION FUEL SOURCES

There are many different sources of **energy** that can be used to meet our energy needs. All of the sources have advantages and disadvantages. Various factors influence the types of fuels used as energy sources by a power plant to **generate** electricity. Price stability, resource availability, efficiency, transportation costs, and environmental concerns are all examples of factors that are considered when a particular fuel source is selected.

Fuel sources are often classified as **renewable** or **nonrenewable**. Renewable resources are those that can be replenished in a relatively short amount of time. Fuel sources such as solar, wind, geothermal, and hydropower are all considered renewable resources. Nonrenewable resources are those with limited supplies. Fuel sources such as oil, coal, and natural gas are nonrenewable resources.



Renewable

Nonrenewable

The majority of energy and utility companies utilize a variety of fuel sources to generate power at various power plants that they may operate. This variation ensures some stability during unforeseen circumstances that might affect access to fuel sources (e.g., severe price fluctuations, changes in regulations).

Energy Sources

Energy is defined as the capacity to do work. Work is defined as the action of a force moving an object through a distance. It is difficult to define the energy of a substance in a general sense, but it is easy to define it in terms of the work the substance can do. For instance, the energy of falling water is evidenced by its ability to move a waterwheel. Gas under pressure in a cylinder has energy—it is capable of moving a piston when it expands. In both cases, energy is being defined by observing work the substance does. The concept that a substance possesses a quantity of energy, which is decreased when the substance performs work and increased when work is done on the substance, is a fundamental concept of science. Therefore, the energy of water flowing over a waterwheel decreases as it does work to turn the wheel, but it would increase again if work were performed on the water by lifting it back up to an elevation above the waterwheel. Similarly, the energy of a gas under pressure in a cylinder decreases when it does work to move the piston, but it would increase again if work were performed on the gas by compressing it again.

There are many different types of energy, but they are all categorized in one of two types: **potential energy** or **kinetic energy**.

Potential energy is stored energy due to position or gravity, stresses within itself, electric charge, and other factors. Examples of potential energy include: **chemical energy**, **stored mechanical energy**, **nuclear energy**, and **gravitational energy**.

Kinetic energy is energy of motion. Examples of kinetic energy include: **electrical energy**, **radiant energy**, **thermal energy**, and **motion energy**.

Electricity is different from other energy sources because it is a secondary source of energy; it requires another energy source to make it.

Fossil Fuels as a Source of Energy

As mentioned above, energy usually is defined as the ability to do work. In today's world, most of the energy needed to do work comes from the chemical energy of **fossil fuels**. You use fossil fuels as a source of energy each time you ride in a gasoline-powered automobile. Fossil fuels power factories, airplanes, and ocean liners. They are also the fuel type most commonly used to generate electricity.

Community Connections

As a class, make a list of all jobs you can think of in your community that are directly related to fossil fuels.

Fossil fuels are found buried in Earth’s crust and the ocean floor. They are called fossil fuels because they formed from plant and animal materials that lived millions of years ago. We get each type of fossil fuel—petroleum, natural gas, and coal—from Earth by using different methods of recovery.

Fossil fuels are important natural resources. They include petroleum, natural gas, and coal. We use fossil fuels primarily in two important ways: as a source of energy and as raw materials for making other products.

Chemical Composition of Fossil Fuels

Each of the fossil fuels—petroleum, natural gas, and coal—is a mixture of hydrocarbons. Hydrocarbons are compounds made from atoms of the elements carbon and hydrogen.

Hydrocarbons are organic compounds. In organic compounds, carbon atoms form the center, or backbone, of the molecule. Each type of hydrocarbon has its own unique molecular structure.

All fossil fuels have hydrocarbons in them. Coal, however, is primarily pure carbon, with only a few hydrocarbons interspersed throughout. High grades of coal have a higher percent of pure carbon than low grades. (Elements such as sulfur also may be bound in coal. Sulfur may be found in both high- and low-grade coals.)

Community Connections

Fossil Fuels for Electricity

Find out how the electricity for your area is produced and answer these questions.

- If a fossil fuel is used, what is it?
- What is the source of the fuel?
- How does the fuel get to the power plant?
- How long is fuel from this source expected to last?

How Do We Get Energy from Fossil Fuels?

We can use fossil fuels for energy because of one very important characteristic: They burn. When they burn, they release energy in the form of heat. This burning is called **combustion**. Combustion is a **chemical reaction** in which a fuel combines rapidly with the oxygen in the air. A chemical reaction is a process in which a substance is changed into one or more new substances.

Three factors are necessary to produce combustion. These factors are: 1) fuel (a combustible material); 2) oxygen in sufficient quantity to support combustion; and 3) sufficient heat to bring the fuel to its ignition temperature and keep it there. If any one of these elements were removed, combustion could not occur.

What Happens During Hydrocarbon Combustion?

Hydrocarbon combustion is the technical term that refers to burning fossil fuels. Burning hydrocarbon fuels breaks chemical bonds in the molecules of the fuel source. Then oxygen in the air forms new bonds with the hydrogen and carbon atoms from the fuel. This combustion process produces three products: carbon dioxide, water, and heat.

What Problems and Issues Are Related to Fossil Fuels?

Fossil fuels are both limited and nonrenewable. By current estimates, Earth's total supply of fossil fuel reserves will last for several centuries. They will become increasingly expensive, though, as we use up the most available sources. Also, some fossil fuels may become totally unavailable in some areas. Since the reserves of oil, coal, and natural gas are not evenly distributed around the world, international politics also affect the availability of the fuels. As supplies decrease, it's important to look for ways of using them more efficiently while we look for other sources of energy.

Besides availability, there are other problems with fossil fuels. Petrochemicals and the chemicals used to process them sometimes find their way into our drinking water. Many plastics and other synthetic materials made from petrochemicals pollute our waterways and fill our landfills. Since their chemical composition is very stable, these materials may exist for hundreds of years before natural processes break them down into compounds that can be absorbed back into the land and water.

When we burn fossil fuels, we have more problems. As you've already learned, you get more than heat when you burn fossil fuels. You also get by-products: water vapor, CO_2, and oxides of nitrogen and sulfur. Some of these by-products create problems. They contribute to the problem known as smog. They also contribute to two less obvious problems: acid rain and global warming.

☼ ACTIVITY: Hydrocarbon Combustion

Research and discuss these questions as a class.

- What is the most useful product of hydrocarbon combustion?
- What is the least desirable product of hydrocarbon combustion?
- Where do the nitrogen and sulfur that form oxides come from?
- What gas would be formed if the amount of oxygen combined with fuel were not enough to form carbon dioxide?

Generation Fuel Source: Petroleum/Oil

As a fossil fuel, petroleum consists almost exclusively of the chemical elements hydrogen and carbon. As mentioned earlier, hydrocarbons are a diverse family of materials including natural gas, gasoline, kerosene, lubricating oils, paraffin wax, turpentine, and rubber.

Most scientists accept the organic theory of petroleum formation. According to this theory, petroleum was formed over a span of millions of years in prehistoric waters that covered most of the Earth. Tiny plants and animals lived in the shallow depth of the water and along the coastlines. As the plants and animals died, their remains settled on the muddy bottoms of the water. Sediment, in the form of fine sand and silt, drifted down over the plant and animal matter. As the amount of sediment grew into heaps and piles, the amassed weight pressed them into hard, compact beds of sedimentary rock. Throughout the rock-forming process, bacterial pressure and other natural forces worked to change the plant and animal remains into petroleum.

Oil as a Power Generation Fuel Source

Oil provides the United States with an enormous source of energy. While the majority of this oil is used for transportation, a small percentage is used to fuel electric power generation plants.

Fuel oils are the petroleum products used to generate electrical power. The oils are produced to comply with the several specifications prepared by the American Society of Testing Materials and adopted as a commercial standard by the United States Bureau of Standards. The standards have been revised several times in past years, and further alterations are expected to satisfy international changes in supply and demand.

Oil used for firing steam power plants is that portion left after distillation of crude oil to produce gasoline, hydrogen, and carbon. This oil, like coal, is a mixture of organic compounds, containing:

- Carbon
- Nitrogen
- Oxygen
- Sulfur
- Hydrogen

The two primary classes of fuel oils are distillate and residual. **Distillate fuel oils** are made up entirely of material that has been vaporized in a **refinery** distillation tower. These fuels are clean, free of sediment, comparatively low in **viscosity**, and free of inorganic ash. **Residual fuel oils** contain **fractions** that cannot be vaporized by heating. These fractions are black and heavy and retain any inorganic ash components that were in the original crude oil.

Fuel oils are graded according to gravity and viscosity, the lightest being No. 1 and the heaviest being No. 6. The latter is most widely used for steam generation because it is least expensive of the graded oils.

Drilling

Oil is found in deep underground reservoirs. Since oil is a liquid in its natural state, it can be extracted from special wells just as water is. A special "rig" is used to carry out the drilling process. Once the rig has been used to drill the well, a special pump is attached to the well to pump out the oil at a controlled rate. Oil drilling rigs can be found on land, shallow water, or offshore at sea.

Processing

The modern petroleum industry refines crude oil taken from the earth to produce useful products to meet requirements of the commercial market. Hydrocarbons give special characteristics to the parts, or fractions, of petroleum. Some of these fractions, such as gasoline and kerosene, need little change, but refineries must change other fractions before they can be used. Separating the fractions and converting them to useful products are the main functions of an oil refinery. Gasoline and diesel oil are refinery products. Both are important sources of heat energy, but neither is used normally for steam generation.

Like coal, oil cannot be burned in the delivered state. Before the oil can be burned as a fuel source, it must be atomized (broken into fine particles or a mist). Atomizing of the oil is done in the burner. Atomizing the fuel oil into fine droplets and injecting the droplet spray into a combustion chamber with a stream of combustion air ensures efficient combustion. Boilers that use fuel oil require specially-designed oil-burning equipment. In addition to atomizing the fuel, the equipment must handle large volumes of oil per hour.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Transportation

Transportation of oil for fuel usage is an important economic factor in steam power plant location decisions. In plants that use fuel oil as the main fuel for steam generation, the oil is typically delivered to the plant by pipeline, truck, rail, or barge. Another important economic factor considered in site location is fuel oil storage, with associated fire protection.

When the oil is delivered to the plant, it is stored in tanks. Like gas powered plants, oil powered plants have an intricate piping system as well. This system includes many safety features, pumps, valves, controls, gauges, instruments, regulators, alarms, and trips, and is interlocked to protect it from incorrect operation or malfunctions.

Environmental Issues

Similar to the use of coal as a fuel source, the burning of fuel oil to generate electricity causes the release of pollutants such as nitrogen oxides, sulfur dioxide, carbon dioxide, and **methane**. These pollutants can negatively affect air quality, water quality, and land quality.

In addition to the air pollutants that are released, oil-fired power plants also require a significant amount of water for cooling and other plant processes; this can negatively affect local water resources and habitats. Solid wastes are also created as by-products of the power generation process and must be handled with care as well to reduce the impact on the environment.

Focus on ...

Fuel Oil Power – Summary of Advantages and Disadvantages

Advantages

Relatively inexpensive

Easy to obtain/many sources

Disadvantages

Nonrenewable

Creation of **greenhouse gases** and other environmental pollutants

Creation of solid wastes

Large volumes of water are used.

Generation Fuel Source: Coal

Many millions of years ago, trees, plants, and other organic matter fell into the surrounding water and decayed, creating "peat bogs." Successive geological changes buried these peat bogs under many layers of sand and silt. Today, coal is mined from these prehistoric peat bogs.

An analysis of coal by chemical means shows the following components to be present:

- Carbon
- Oxygen
- Hydrogen
- Nitrogen
- Sulfur
- Ash
- Water (moisture)

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Coal as a Power Generation Fuel Source

Coal is the most abundant fossil fuel source in the United States. More than 90% of the coal that is used in the United States is used to generate electricity. In the United States, and worldwide, coal is the most common fuel source for electric power generation.

Coal Classification

Coal has many subcategories that consist of different types and characteristics. Coal is considered a primary fuel for burning in steam boilers in any of its mined types or formations. Fundamentally, coal is comprised of three components:

- Coal itself (organic matter)
- Mineral content (prehistoric plant fibers)
- Moisture (water)

When coal burns under controlled test conditions, it gives up a certain amount of heat, which is referred to as its "heating value." For U.S. coals, this figure ranges from 9,000 **British thermal units (Btu)**/lb to 15,000 Btu/lb, depending upon the source mine location. Therefore, even though it is highly desirable to have a boiler that can burn a wide range of coals, none performs equally as well with every type.

Present standards call for two classifications for coal. The first is according to rank, which is determined by the amount of alteration and compaction the coal has undergone. North American coal may be ranked as follows:

- Anthracite
- Bituminous
- Sub-bituminous
- Lignite

Difference in coal rank is measured by a progressive increase in water and in volatile matter, and by a progressive decrease in carbon and heat content. Relative amounts of water, volatile matter, carbon, and heat content determine how well the coal will withstand transportation, handling, and storage, and how well it will burn.

Anthracite is classified as a hard coal and makes up only a small part of the world's coal supply. It is very high in carbon and is low in water and volatile matter. Anthracite is jet black in color and is free of soot when burning. It requires more heat and effort to begin combustion, but, when started, it burns with a steady, clean, hot, blue-colored flame, and it burns longer than coal of lower rank. Anthracite is more expensive than bituminous coal.

Bituminous coal, classed as a soft coal, is the most plentiful rank of coal. It is the chief fuel in industrial plants that generate electricity with steam. Bituminous coal withstands transportation well, and has a slightly higher heat content than anthracite.

Sub-bituminous coal has a lower heat content than bituminous. It possesses a tendency to crumble when exposed to weather and also tends to crumble during transportation. Sub-bituminous is not mined extensively where coal of a higher rank is available.

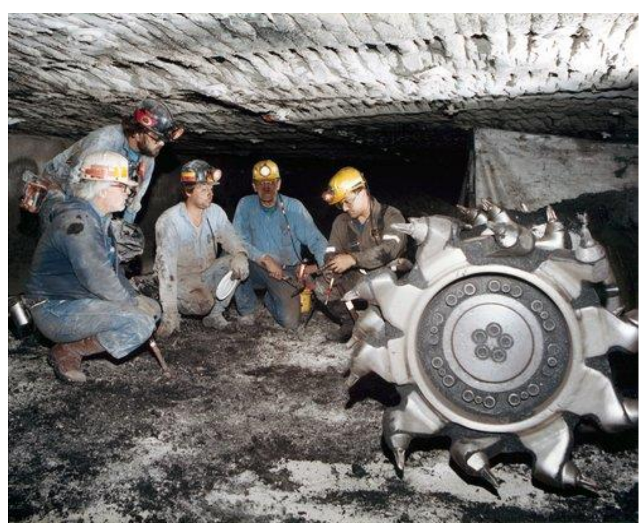
Lignite is a brown-colored coal with a distinctive woody texture. It is little changed from peat. Lignite has a high moisture content; it also crumbles when exposed to weather and during transportation, and is subject to spontaneous combustion. Lignite is the lowest rank of coal in that it has the lowest energy content.

The second method of coal classification is according to grade. Grade is determined by evaluation of ash-producing substances, sulfur, and other detrimental ingredients.

Grade is a term used to express quality. (Rank is used to express degree of coal alteration and compaction.) It is possible that a low-rank coal such as lignite may be of high grade, and a high-rank coal such as anthracite may be of low grade.

Relative amounts of sulfur- and ash-producing substances in a coal are the primary factors in determining a coal's grade. High-grade coal has less sulfur and produces less ash than low-grade coal; therefore, the high grade is more desirable and more expensive.

Sulfur is an undesirable ingredient of coal, even in small quantities. When coal is burned, most of the sulfur is discharged into the atmosphere as sulfur dioxide and sulfur trioxide—serious pollutants. When sulfur is combined with oxygen and water, it becomes sulfuric acid. This acid can corrode boilers in steam-electric power plants where coal is used as the fuel to heat boiler water.



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Coal with a high content of ash-producing substances is undesirable because ashes add useless weight that must be handled both before and after burning. Some ash contributes to air pollution, and ash components may fuse to form clinkers that could foul grates and hinder the burning process.

☼ ACTIVITY: Coal Power

Research and discuss these questions as a class.

Assume the electricity that you use at your home is produced by a lignite coal-fueled power plant. Figure out how much coal must be burned each year to supply your home electricity.

Here are two facts that you will need to solve this problem:

- One kilowatt is approximately equal to 860,000 calories of energy (a calorie is a unit of energy).
- Lignite coal has approximately 4,000 calories of energy per gram (or 4,000,000,000 calories per ton). The energy per gram of lignite is the heat content for lignite. Each fuel has its own heat content.

What other information or records do you need to research in order to solve this problem?

Mining

Coal must be mined from the ground by giant machines. There are different types of mining methods used depending on the type of coal and the location of the coal deposit.

Deep-shaft mining: Large shafts are drilled down from the surface of the ground to the coal seam, and then tunnels follow the coal seam.

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Surface mining (also called strip mining): All the rock and soil above the coal seam is removed. Then the coal is removed and the pit is filled in with the original material. This method is usually the most economical for coal seams within 200 feet of the surface.

Auger mining: A large pit is dug down beside the seam of coal. Then large drills or augers are used to bore into the coal seam. Enough space must be left between the holes in the seam to prevent cave-ins. This means that miners can’t recover all of the coal from the seam.

Transportation

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The cost of transporting coal is often higher than the cost of mining it. The majority of coal used in power plants is transported from mines by rail. An individual rail car can carry up to 120 tons of coal. Coal is also commonly transported by truck, ship, and barge.

Processing

After coal has been transported to the power plant, it is unloaded for storage and usually processed in some manner. Before use, coal may be cleaned to remove impurities such as ash, metals, and sulfur. Coal is cleaned at the storage site if it was not cleaned prior to transportation. Coal cleaning, through a variety of physical and chemical methods, reduces the size of the coal particle but increases its efficiency and reduces emissions released when burned.

In addition to cleaning, coal may be pulverized or crushed before it is fed into the plant's combustion system. By grinding the coal, the surface area is increased, which greatly increases its combustion and heating capacity, resulting in greater plant efficiency.

Environmental Issues

Coal mining can cause adverse effects on the environment. Mining debris and water quality issues are examples of common environmental concerns associated with coal mining. Since environmentalism, conservation of land, and preservation of the environment are of national concern, Federal legislation requires utility companies throughout the United States to rehabilitate or reclaim the land to minimize the adverse effects.

Coal-fired power plants are subject to federal guidelines that regulate pollution. Pollution control devices and systems such as electrostatic precipitators, filters, and particulate collectors operate with the intent of reducing the release of pollutants into the environment.

Did you know?

New Coal Technologies

Traditional methods of burning coal for electricity generation can emit pollutants that reduce air and water quality. The U.S. government supports special programs that focus on the development and implementation of new "clean coal" technologies that reduce the environmental impact of the use of coal for electricity generation.

The goal of clean coal technologies is to remove some of the coal's pollutants before, during, or after the coal is burned.

Coal Washing: Removes unwanted minerals from the coal prior to burning.

Coal Gasification: Process that converts coal into a gas before it is burned.

Scrubbers: Remove sulfur dioxide by spraying coal combustion exhaust gases with limestone and water to form synthetic gypsum.

☼ ACTIVITY: Reclamation Engineer Role Play

Assume you are a reclamation engineer with a coal-fired power company. As a reclamation engineer, you are responsible for restoring the land to a usable state after it has been mined. (Possible usable states could be grassland, wetland, forest [woodland], or cultivated farmland.)

Using the library, the Internet, and other resources, research and discuss the following questions:

- What types of information need to be collected to suggest one mining method over another for a specific site? Under what circumstances might a specific mining method be selected over another?
- How do different mining methods affect natural resources? How might reclamation activities differ for different mining methods?
- What groups of people benefit from restoration of mining land? What other populations might benefit from land restoration (animals, vegetation, other)?

Focus on ...

Coal Power – Summary of Advantages and Disadvantages

Advantages

Economical—cheapest fossil fuel source

Easy to obtain/many sources

Relatively stable fuel price

Disadvantages

Nonrenewable

Greenhouse gas emissions

Creation of environmental pollutants

Creation of solid wastes

Large volumes of water are used

Environmental impacts of mining

Generation Fuel Source: Natural Gas

As its name suggests, natural gas is not man-made. It was formed from natural materials through the action of natural forces. Scientists believe that natural gas was formed by the decay of organic matter in a source rock, such as clay or shale or limestone. The gas then passed from this source to a reservoir rock such as sand or other porous stone where the gas was held in the tiny spaces between the solid particles.

In prehistoric days, the source rocks and reservoir rocks in many areas were covered with thick layers of impermeable rock, an upper seal through which the natural gas could not pass. This cap rock held the gas in store for centuries. The bottom seal of such a reservoir frequently was water, usually salt water, or another layer of impermeable rock.

Natural gas is found in these inclined strata, in dome-like formations, or in traps that were created by great fractures in the earth, and in various combinations of these underground formations.

Pure natural gas, like solid petroleum, is made up of the chemical elements hydrogen and carbon. Although natural gas is actually a mixture of several gases, it is largely made up of a gas called methane, which is the lightest hydrocarbon. Other gaseous hydrocarbons usually present in natural gas include ethane, propane, and butane. Common types of fuel gases include natural gas and LP (liquefied petroleum) gas.

Natural Gas as a Power Generation Fuel Source

Natural gas is a familiar fuel that can be used to cook food, heat water, heat and cool homes and other buildings, and perform thousands of useful tasks in shops, plants, and factories all over this country. Natural gas can also be used as a fuel source for power generation plants.

The heating value of gas and its ease of transportation and storage, either above or below ground, and its relatively clean burning make it preferable to oil for fueling power plants.

Drilling

Natural gas generally is found wherever crude oil is found. Natural gas is often found on top of oil deposits, or dissolved in them, because the same natural forces formed both fuels. But, paradoxically, there are many natural gas wells that yield no petroleum.

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Processing

In most producing areas, natural gas is processed before it enters into long-distance pipelines. Natural gas may include two undesirable components: 1) sand, which can be removed at the wellhead, and 2) hydrogen sulfide, which may be removed before the gas is distributed. Raw gas from wells is run through several kinds of equipment to clean the gas and make it suitable for use. During processing, valuable by-products are recovered, such as light oils, natural gasoline, and other petroleum gases such as ethane, propane, and butane. As mentioned earlier in the text, since natural gas is odorless, a harmless but pungent odorizer, Mercaptan, is added to the gas during processing as a safety precaution.

Transportation

Texas, Louisiana, Oklahoma, New Mexico, and Kansas have the majority of the natural gas source reserves in the United States. To carry gas from the places where it is produced to the places where it is needed, the natural gas industry has constructed more than 225,000 miles of large-diameter pipelines.

Natural gas in a pipeline is pushed along at about 15 miles per hour. This means that on a 1,000-mile line, it takes about three days for gas to travel from the wells to the last customer. In winter, when more gas is needed for heating, the flow may be speeded by increasing the pressure in the line.

Pipeline dispatchers can control the flow of gas throughout the length of the line. They can increase or decrease the pressures as needed, spot troubles at any point by signals returned to them through automatic control systems, and can direct crews as needed to correct any problems.

Power generation plants that are fueled by natural gas are typically built in proximity to gas pipelines, or they must have gas pipelines constructed to the facility.

Environmental Issues

While the use of natural gas as a power plant fuel source causes fewer emissions than coal- or oil-fueled power plants, the combustion process does still release nitrogen oxide and carbon dioxide. Methane, another greenhouse gas, is also released by natural gas operations.

Natural gas power plants also rely on large volumes of water for plant processes. These operations may result in a variety of impacts on water resources.

Natural gas drilling can lead to other environmental concerns such as the impact on the natural habitat and wildlife.

Focus on ...

Natural Gas Power – Summary of Advantages and Disadvantages

Advantages

Relatively clean burning—less overall emissions than coal or oil

Minimal particulate matter or solid wastes

Readily available and easily transported

Relatively economical

Disadvantages

Nonrenewable

Methane and other greenhouse gas emissions

Fluctuations in fuel price

Environmental impacts of drilling

Generation Fuel Source: Hydroelectric

Water has been used as a power source since ancient times. Historically, hydropower was used to grind grains, for mining, and to perform other tasks. Most **dams** in the United States were constructed for the purpose of providing flood control and irrigation. Only a small percentage of the total dams constructed in the United States were actually constructed for the purpose of electricity generation.

Most of the larger **hydroelectric power** plants in the Unites States (Hoover, Grand Coulee) are operated by the federal government. However, there are also numerous smaller hydroelectric plants that are run by other business entities.

Water as a Power Generation Source

When the hydro **turbine** (water wheel) was invented, it introduced a new perspective on cost-efficient ways to use natural resources in the form of energy.

Hydroelectricity is electricity produced from the kinetic energy of moving water. In conventional hydroelectric power plants, the hydroelectric power comes from the potential energy of dammed water driving a water turbine and **generator**.

☼ CAREER PROFILE: Hydrologist

Christa P. is a hydrologist who works for a civil engineering firm. The firm does environmental studies for businesses and the government.

"A hydrologist has to incorporate a basic knowledge of water properties and how those properties affect the use of water in a wide variety of ways," says Christa. "I do work that relates to controlling river flooding and soil erosion. Other hydrologists might focus their careers in the areas of environmental protection, city planning, or research."

Some hydrologists spend the majority of their time outside, while others might spend most of their time in a laboratory. Christa says, "When I got my first hydrologist job out of college, I spent a lot of time in the lab testing samples. I knew that I eventually wanted to find a position that would allow me to spend more time outside doing field work."

Regardless of where hydrologists work, they must apply a knowledge of scientific and mathematical applications to help solve a variety of water-based issues.

Water Power

The amount of energy that can be derived from hydroelectric power is determined by the strength of the flow or fall. Hydroelectricity can only realistically be utilized in areas that have a moving water resource such as a river, and that are not too far from the end user, since the energy must be transferred to an electrical grid for use. When planning construction for a hydroelectric plant, there are many considerations such as elevation, water flow, water volume, precipitation levels, and high initial cost. These stipulations make hydroelectric power useful only in specific places.

Hydroelectricity Energy Losses

The power extracted from water depends on the volume and on the difference in height between the source and the water's outflow. Energy losses occur in the use of hydroelectric power similar to other fuel sources. These energy losses are **frictional** drag and turbulence.

Environmental Issues

While hydropower is considered to be a relative "clean" renewable source of electricity, hydroelectric power plants can have environmental impacts. When a dam is constructed, there are some environmental ramifications.

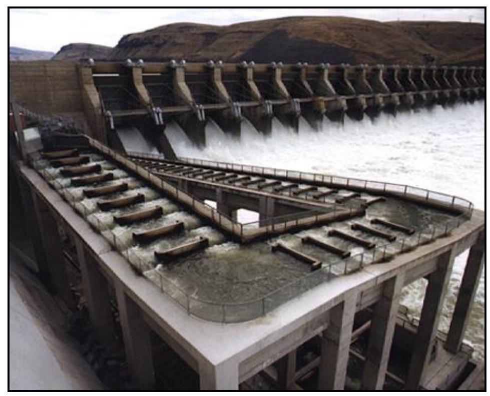
Diverting rivers or streams can cause changes in the environment in areas adjacent to the dam, reservoir, and river/stream. Fish and other wildlife may be affected by the change in the environment. Hydroelectric power plants can also have an effect on vegetation and erosion. Dams may block the natural transfer of sediment, causing silt to be deposited behind the wall of the dam.

The environmental impact of a dam varies between significant or minute depending on the location of the dam, the design of the facility, the status/health of the environment before construction, and the precautions that are taken to reduce potential issues.

The federal government plays a role in licensing hydroelectric power plants in an effort to reduce and regulate negative environmental impacts.

Did you know?

Fish ladders or "fishways" are structures that are constructed around a dam that help remedy negative impacts on fish migration that may be caused by a dam. Fish ladders enable fish to pass around a dam by swimming up a series of relatively low steps into the waters on the other side of the dam.



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Focus on ...

Hydroelectric Power – Summary of Advantages and Disadvantages

Advantages

Renewable

Limited/no direct waste

Limited greenhouse gas emissions

Economical to run and maintain once built

Efficient energy conversion

Quick start-up and response time

Disadvantages

Reliance on water levels

High initial construction cost

Possible environmental impacts

Generation Fuel Source: Nuclear/Uranium

Nuclear reactions have been happening inside the Earth since the beginning of time. Radioactive elements such as uranium constantly undergo spontaneous **fission** at a very slow rate (**radioactive decay**).

Early scientists understood that chemical chain reactions were the source of increasing rates in reactions such as chemical explosions, but harnessing the power of nuclear fission is a relatively recent occurrence.

As mentioned earlier, nuclear energy is the energy that comes from the **nucleus** of an atom. Nuclear energy is released from an atom through one of two processes: nuclear fusion or nuclear fission. In nuclear fusion, energy is released when the nuclei of atoms are combined (fused). The sun produces its energy through nuclear fusion.

In nuclear fission, energy is released when the nuclei of atoms are split apart. Nuclear fission is the process that creates energy in nuclear power plants that is converted to electricity.

Uranium as a Power Generation Fuel Source

The fuel source that is most widely used to power nuclear power plants is uranium. Uranium is selected because it is a radioactive element. It is unstable in that its atoms are easily split, which facilitates the fission chain reaction process.

Nuclear fission takes place inside the reactor of a nuclear power plant. At the center of the reactor is the core, which contains the uranium fuel source.

Did you know?

One uranium fuel pellet provides as much energy as:

149 gallons of oil

180 pounds of coal

1700 cubic feet of natural gas

Nuclear Energy Institute 2010

NRC File Photo ©2011 All rights reserved

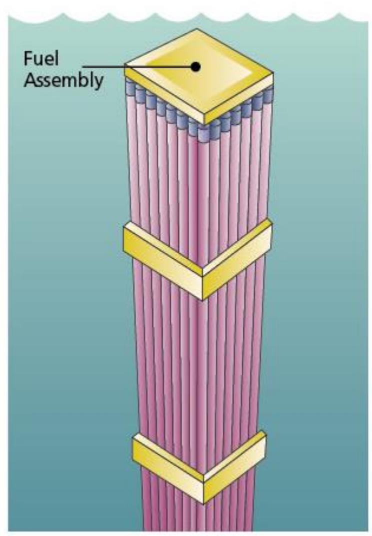
Source

Uranium is considered to be a relatively common element found in the Earth's crust, but at low concentrations, in a variety of geographical locations. Uranium **ore** is mined from the ground, through underground or **open pit mining**. Another mining method is through "solution mining," also known as **in-situ leach mining**, in which special chemicals are used to extract the uranium ore.

Processing

Once uranium ore is extracted, it is further processed by milling. Once the uranium ore has been ground up into smaller particles, the ore is chemically treated to extract the uranium. The uranium is converted into a more compact and stable form, **yellowcake**, for transport to additional processing facilities. The next step in uranium processing is enrichment. In enrichment facilities, uranium is **enriched** to be the appropriate composition to be used in nuclear reactor rods.

After enrichment, the uranium is fabricated in small pellets. These pellets are stacked into long, slender metal rods. These filled rods are called **fuel rods**. Multiple fuel rods put together are referred to as a fuel assembly. A nuclear power plant reactor usually contains multiple fuel assemblies.



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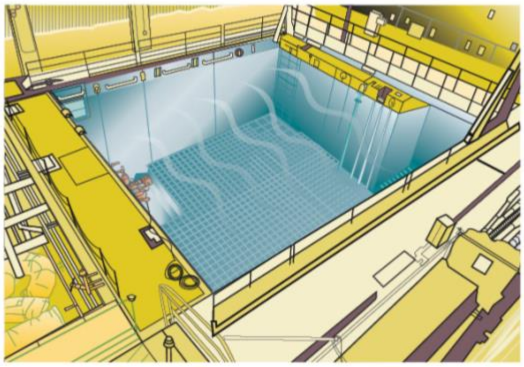
Transportation

Since nuclear materials such as uranium reactor rods are radioactive, special safety regulations and procedures have been enacted to ensure the safe transport of radioactive materials. Nuclear reactor rods are shipped by truck to the power plants to be stored until they are needed.

Storage and Disposal

Typically, fuel rods are operational inside a reactor for about six years. Once the fuel rods reach the end of their usefulness, they are referred to as **spent nuclear fuel**. Spent nuclear fuel must be stored with special procedures within special facilities.



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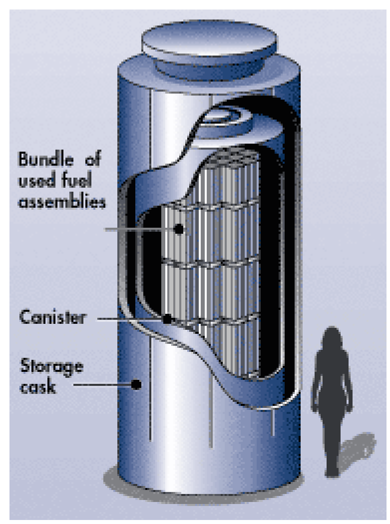
Initially, fuel rods are stored in a spent fuel pool. Even though the fission reaction has stopped, the spent fuel continues to give off a substantial amount of heat due to the continued decay of the radioactive elements. The water in the spent fuel pool cools the fuel and contains the radiation.

After the fuel rods have cooled a few years in the spent fuel pool, they are prepared for final storage/disposal.

Since radioactive materials pose a high threat to humans and the environment, nuclear wastes are stored in special steel and concrete containers called casks. High-level toxic waste is stored in high-security permanent underground repositories.



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Spent fuel can also undergo **reprocessing** prior to its final disposal or storage. Through specialized chemical procedures, nuclear reprocessing involves the separation of potentially useful components from spent nuclear fuel. Reprocessing of spent nuclear fuel helps to reduce the volume of highly radioactive nuclear waste that must be stored.

Currently, reprocessing is more expensive than making new uranium fuel. Because of this, most of the nuclear power plants in the United States do not reprocess much of their spent nuclear fuel.

☼ CAREER PROFILE: Nuclear Health Physics Technician

Mike H. is a nuclear health physics technician. Mike received his training as an engineering lab tech in the Navy. After the Navy, he worked in various technician positions until he got a job as a health physics technician at a nuclear power plant.

As a health physics tech, Mike is responsible for ensuring compliance with many standards and procedures required by regulatory agencies. Mike's duties include taking samples of exhaust air both in and from the auxiliary buildings, conducting "swipe" tests for radiation contamination in the auxiliary and turbine buildings, and going with chemical technicians and operations personnel when they take samples and make necessary inspections.

He also surveys work areas for contamination hazards and then outfits workers with proper shielding. When carrying out a worksite task where radiation exposure is a possibility, Mike works with the shift supervisor to do a "make-ready" on the area. Then he trains the workforce.

Mike's other duties include doing respirator fit tests, calibrating instruments and pocket dosimeters, monitoring radioactive waste shipments, inventorying emergency equipment, and doing whole-body radiation counts of workers.

"This job has so much versatility. I don't have to do the same thing every day. I can do something different every day if I want to. The opportunity for me to increase my knowledge is always there," says Mike.

Environmental Issues

The main environmental concern related to nuclear power production is the creation of nuclear wastes. Nuclear power plants create radioactive waste materials. Radioactive wastes are very harmful to people and the environment and must be carefully stored and safeguarded for thousands of years.

Uranium mining can also cause negative environmental impacts similar to those caused by coal mining. Nuclear power plants also use a large volume of water for cooling and other plant processes. This water use can have negative impacts on water resources and other habitats in the environment.

Did you know?

Nuclear Power Plants

As of May 2017, there were 99 operating commercial nuclear reactors at 61 nuclear power plants in the United States. The average age of U.S. nuclear reactors is about 36 years old. The oldest operating reactors, Nine Mile Point Unit 1 and Oyster Creek, began commercial operation in December 1969. Four reactors were permanently shut down in 2013, and one reactor was taken out of service in 2014. The newest reactor to enter service, Watts Bar Unit 2, came online in 2016.

Since 1990, the share of total annual U.S. electricity generation provided by nuclear power has averaged about 20%. Nuclear generation has generally increased through power plant modifications to increase capacity (known as uprates) and by shortening the length of time reactors are offline for refueling.

In February 2012, the U.S. Nuclear Regulatory Commission (NRC) voted to approve Southern Company's application to build and operate two new reactors, Units 3 and 4, at its Vogtle plant in Georgia. The Vogtle reactors are the first new reactors to receive construction approval in more than 30 years. In March 2012, the NRC voted to approve South Carolina Electric & Gas Company's application to build and operate two new reactors, Units 2 and 3, at its Virgil C. Summer plant in South Carolina.

The U.S. Energy Information Administration (EIA) projects in the *Annual Energy Outlook 2017* that new nuclear electricity generation capacity will be added in 2019 and 2020, but that capacity retirements and derates will result in less nuclear electricity generation capacity than in 2016 in every year through 2050.

The cost to build a new nuclear power plant with a capacity of 2234MW is around $13.28 billion.

The time to build a new nuclear facility is estimated to be between five and ten years.

EIA, 2016, 2018

Focus on …

Nuclear Power – Summary of Advantages and Disadvantages

Advantages

No greenhouse gas emissions

High productivity level

Low operating costs

Low cost of uranium in comparison to coal and natural gas

Long service life of plant

Disadvantages

Uranium deposits are nonrenewable

Production of hazardous waste products

High initial development cost

Unit B Glossary

auger mining—a method of mining coal in which a large pit is dug down beside the seam of coal, then large drills or augers are used to bore into the coal seam

British thermal unit (Btu)—a unit of energy in the English system, defined as the energy required to raise the temperature of one pound of water by one degree Fahrenheit

chemical energy—the energy stored in the bonds of atoms and molecules

chemical reaction—a process that leads to the change of one chemical substance to another

combustion—when a substance (fuel) combines rapidly with oxygen (usually in the presence of heat) to produce new compounds and give off heat; generally referred to as “burning”

dams—barriers constructed across a waterway to control the flow or raise the level of water

distillate fuel oils—one of the petroleum fractions produced in distillation; it is clean and free from sediment and is used primarily for space heating, diesel engine fuel, and electric power generation

electrical energy—energy from the movement of electrons

energy—the property of a system or object that enables it to do work

enriched—in this context, uranium ore (U238) that has the isotope of uranium that can be split (U235) added to it for use as nuclear reactor fuel

fission—the splitting of a nucleus into at least two smaller nuclei and the release of a large amount of energy; two or three neutrons are usually released during this reaction

fossil fuels—hydrocarbons such as petroleum, coal, or natural gas, derived from prehistoric plants and animals and used for fuel

fractions—the parts that petroleum separates into when distilled

frictional—produced by the force that opposes motion

fuel rods—sealed tubes containing pellets of nuclear fuel

generator—the portion of the generating unit where the rotating mechanical energy is converted to electrical energy; it consists of a stator containing the armature windings and a rotor (center shaft) that is turned by the turbine to produce the magnetic field

gravitational energy—the energy of position or placement

greenhouse gases—the parts of the atmosphere, both natural and manmade, that trap and hold heat within the Earth’s atmosphere

hydroelectric power—power generated by using moving water to power a turbine generator to produce electricity

in-situ leach mining—process for extracting uranium or other minerals by drilling holes into the deposit and flooding it with a chemical solution that will dissolve the deposit and then pumping that solution to the surface and extracting the minerals from the ore

kinetic energy—energy of motion

methane – the lightest of the hydrocarbons and the main ingredient of natural gas

motion energy—energy from the movement of objects from one place to another

nonrenewable—energy sources that have a limited supply

nuclear energy—the energy given off by a nuclear reaction (fission or fusion) or by radioactive decay

nucleus—the center of an atom

open pit mining—process for extracting coal or other materials by removing layers of earth

ore—rock containing the desired mineral; raw materials from which a mineral is extracted

potential energy—energy of position; stored energy

radiant energy—electromagnetic energy

radioactive decay—process by which an unstable nucleus emits radiation and becomes more stable

refinery—an industrial plant where crude oil is processed into useful products

renewable—energy sources that can be replenished in a short period of time

reprocessing—chemical treatment of spent reactor fuel to separate uranium and plutonium and possibly other radioactive elements from other waste products

residual fuel oils—residual fuel oil is used for the production of electric power, space heating, vessel bunkering, and various industrial purposes

spent nuclear fuel—fuel rods that have been depleted of useful fuel; fuel that has been used to the extent that it can no longer effectively sustain a chain reaction

stored mechanical energy—the energy stored in objects by the application of a force

thermal energy—internal energy due to vibration and movement of molecules

turbine—a machine for generating rotary mechanical power from a fluid flow (air, steam, water)

viscosity—the thickness of a fluid that determines how easily it flows; lower viscosity means that the fluid is “thin” and flows more easily

yellowcake—uranium powder mined through in-situ leaching; it is processed to produce uranium fuel used in nuclear reactors

Unit B References

Energy Information Administration (EIA)
http://www.eia.doe.gov/

Federal Energy Regulatory Commission (FERC)
http://www.ferc.gov/

Fossil-Fuel Power Plant Technology Series: Power Plant Fundamentals and Systems I.
Electric Utilities Technical Education Council and the Center for Occupational Research and Development.

Fossil-Fuel Power Plant Technology Series: Power Plant Fundamentals and Systems II.
Electric Utilities Technical Education Council and the Center for Occupational Research and Development.

Fossil-Fuel Power Plant Technology Series: Power Plant Operator—Level II.
Electric Utilities Technical Education Council and the Center for Occupational Research and Development.

National Hydropower Association
http://www.hydro.com

U.S. Department of Energy (DOE)
http://www.energy.gov/

U.S. Nuclear Regulatory Commission
http://www.nrc.gov/

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Unit C: Overview of Emerging and Alternative Generation Technologies

UNIT C: OVERVIEW OF EMERGING AND ALTERNATIVE GENERATION TECHNOLOGIES

The use of **alternative energy** and **renewable energy** technologies for the generation of electricity has become a hot topic in today's society. With growing concerns about global climate change and the use, cost, and reliability of fossil fuels, research on feasible renewable alternatives has experienced a resurgence.

While the continued development and application of alternative and renewable power generation technologies is important for the cause of reducing the environmental impact of fossil fuel use, unfortunately at this time, most "green" technologies are more expensive. This unit will review the following electric power technologies: solar, wind, geothermal, **biomass**, and ocean/tidal.

Solar Energy

Solar energy is radiant energy from the sun. Solar energy is considered a renewable energy source because the chemical reactions that power the sun are expected to keep generating sunlight for many billions of years.

People have used solar energy since ancient times. Historically, people used simple magnifying glasses to concentrate the light of the sun to catch wood on fire for warmth and cooking.

There are several ways to use the sun as a source of energy and electricity; these include **passive solar heating**, **photovoltaic energy**, and **active solar heating**.

Passive Solar Heating

The use of the sun to provide energy is not new. For years, homes have been built with most of the windows on the side providing maximum sunlight to the living areas in the winter. (In the Northern Hemisphere, where we live, the sun is always angled toward the south.) This use of sunlight is called passive solar heating. It has little impact on the environment, and it helps to decrease reliance on fossil fuels for heating. Passive solar, however, rarely completely provides enough heat to overcome the need for a secondary heat source, such as an electric or gas heater.

Critical Thinking

Passive Solar Heating
Using the library, Internet, and other resources, research why passive solar energy rarely completely provides enough heat to overcome the need for a secondary heat source.

☼ ACTIVITY: Passive Solar Heating

Obtain two white cans, two black cans, and two cans of another color. Fill the cans nearly to the top with water.

Measure and record the temperature of the water in each can. (The temperature should be the same in all of the cans at the start.)

Place one white, one black, and one colored can in direct sunlight. Place the remaining cans in a dark area.

Record the temperature of the water in each can every 10 minutes for a set period of time such as one hour. Make a data table to organize your data.

When you complete your recordings, make a graph of the temperatures. Discuss these results as a class.

Electric Power Generation through Solar Sources

Two examples of systems that generate electricity through solar energy are photovoltaic systems and solar steam systems. The production of energy from solar sources is comparatively dependable. Even though solar energy as a whole is dependable, solar electricity generation depends on a few variables. One variable is the amount of sunlight an area receives, which is affected by the time of day, weather, and the seasons. Additional conditions that affect the amount of solar energy a specific location receives depend on the latitude of the area and the topography. See Photovoltaic Solar Resource, Figure 3C.1.

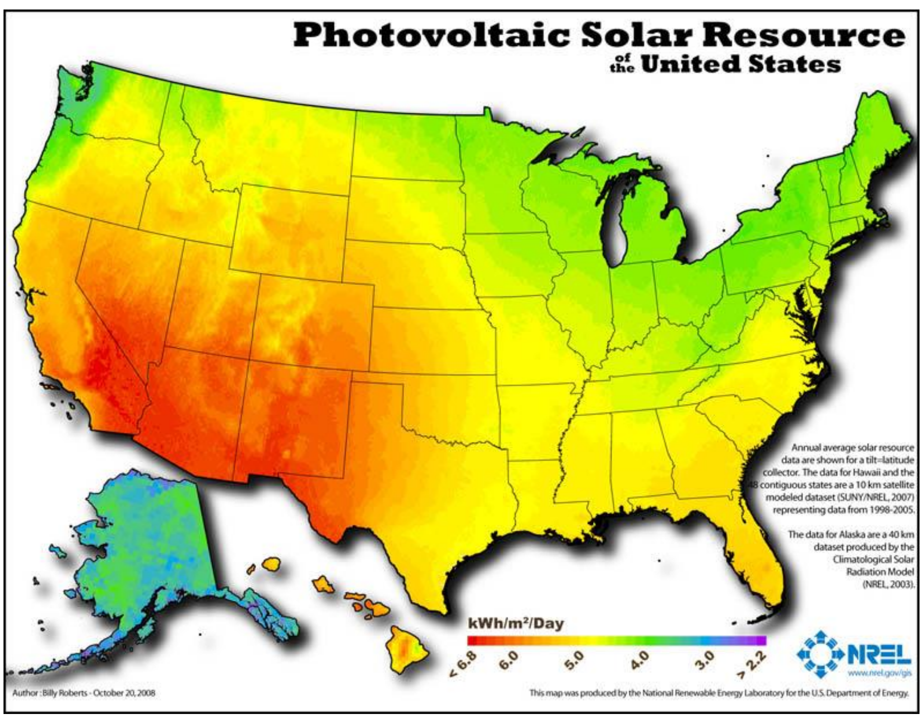

Figure 3C.1 Photovoltaic Solar Resource

Solar Energy: Photovoltaic Systems

Solar photovoltaic energy relies upon chemical reactions to generate electricity. Certain materials produce electricity when they are exposed to light. These materials are made into flat plates with electrical contacts and leads attached to them. These assemblies are called **photovoltaic cells**, or solar cells. Most solar cells used today are composed of thin sheets of purified silicon. Multiple cells are arranged together to form solar panels.

How It Works

Photovoltaic systems rely on the **photovoltaic effect** (see Figure 3C.2). The photovoltaic effect is the creation of an electric current in a material when it is exposed to light. Sunlight is composed of photons, or bundles of radiant energy. When sunlight shines on a solar cell, a chemical reaction occurs, photons give off energy, and this energy is transferred to the electrons. The electrons get excited from the energy given off from the photons and therefore conduct an electric current by moving through the material in the solar cell. Current flows up and out of the cell by way of the contacts and leads. Solar cells produce electricity in DC form, which must be converted to AC form by an inverter. Solar cells are encased behind glass plates to protect them from the environment.

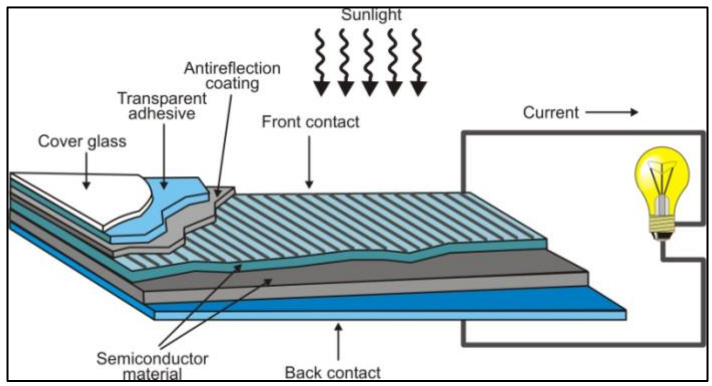

Figure 3C.2 Photovoltaic cell construction

The amount of electricity a solar cell produces depends on the size of the solar cell, its conversion efficiency, and the intensity of the light source. For electric energy applications, cells are connected to form photovoltaic modules called solar panels. An arrangement of multiple connected solar panels is called an array.

For personal or small household use, multiple arrays would be needed. The majority of private-use photovoltaic systems require the use of a battery to store energy since photovoltaic systems cannot store electricity.

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For mass electricity generation such as generation in solar power plants by utility companies, large numbers of arrays are arranged across many acres of land, hence the term “solar farm.” Most solar power plants are tied into the electrical grid and do not use batteries or other energy storage devices.

☼ CAREER PROFILE: Solar Energy Company Owner

As energy costs have risen, harnessing solar energy has become more popular and as a result, many new solar energy businesses have been created. An owner of a small solar energy company might sell solar energy systems to residential and commercial clients. When designing a solar energy system for a client, the energy needs of the client will be analyzed, and then a system will be designed and installed at the specified location.

In addition to knowledge regarding solar technologies, a small businessperson has to manage all aspects of the business, including hiring personnel, bookkeeping, maintaining inventory, and advertising. Communication skills are very important to maintaining a successful business, as a businessperson will be working with a wide variety of people.

Concentrating Solar Power Basics

Many power plants today use fossil fuels as a heat source to boil water. The steam from the boiling water spins a large **turbine**, which drives a **generator** to produce electricity. However, a new generation of power plants with concentrating solar power systems uses the sun as a heat source. The three main types of concentrating solar power systems are: *linear concentrator*, *dish/engine*, and *power tower systems*.

Linear concentrator systems collect the sun's energy using long, rectangular, curved (U-shaped) mirrors. The mirrors are tilted toward the sun, focusing sunlight on tubes (or receivers) that run the length of the mirrors. The reflected sunlight heats a fluid flowing through the tubes. The hot fluid then is used to boil water in a conventional steam-turbine generator to produce electricity. There are two major types of linear concentrator systems: parabolic trough systems, where receiver tubes are positioned along the focal line of each parabolic mirror; and linear Fresnel reflector systems, where one receiver tube is positioned above several mirrors to allow the mirrors greater mobility in tracking the sun.

Figure 3C.3 Parabolic trough

Figure 3C.4 Linear collector system

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A dish/engine system uses a mirrored dish similar to a very large satellite dish, although to minimize costs, the mirrored dish is usually composed of many smaller flat mirrors formed into a dish shape. The dish-shaped surface directs and concentrates sunlight onto a thermal receiver, which absorbs and collects the heat and transfers it to the engine generator. The most common type of heat engine used today in dish/engine systems is the Stirling engine. This system uses the fluid heated by the receiver to move pistons and create mechanical power. The mechanical power is then used to run a generator or alternator to produce electricity.

Figure 3C.5 Dish/engine system

A power tower system uses a large field of flat, sun-tracking mirrors known as heliostats to focus and concentrate sunlight onto a receiver on the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine generator to produce electricity. Some power towers use water/steam as the heat-transfer fluid. Other advanced designs are experimenting with molten nitrate salt because of its superior heat-transfer and energy-storage capabilities. The energy-storage capability, or thermal storage, allows the system to continue to dispatch electricity during cloudy weather or at night.

Figure 3C.6 Power tower system

Solar Reserves Crescent Dune CSP Project

Environmental Impacts

Even though solar energy systems operate without the production of air emissions, pollutants, or solid wastes, there are a few other environmental concerns associated with them. Certain photovoltaic systems require a large area of land for their solar panels. It is possible that the use of land may have environmental implications such as interference with habitats. The other concern some people have is that the appearance of the large groups of solar panels has a negative aesthetic impact on the environment.

Focus on ...

Solar Energy – Summary of Advantages and Disadvantages

Advantages

Renewable

No carbon dioxide or pollutants released

Minimal environmental impact depending on system installed

Low operating costs

Disadvantages

Visual impact

High initial cost

Wind Energy

Similar to hydropower, energy has been harnessed from the wind for thousands of years. Just like early water wheels, early windmills were used for pumping water and grinding grain.

Wind power is becoming an attractive alternative energy source for many people. Similar to solar power, wind is an inexhaustible renewable resource. Simply stated, wind is caused by a difference in atmospheric pressure that results from the uneven heating of the Earth's surface by the sun.

To harness the power of wind, large towers are erected to carry small, wind-powered generators called wind turbines. Most of the larger wind power plants are privately owned and the electricity they produce is sold to power companies. This lets power companies cut back on the amount of electricity that is generated using fossil fuels. Of course, on days without much wind, the wind turbines are less effective.

The energy produced by wind turbines varies from a few hundred **watts** to several **megawatts**. The amount of energy produced by a wind turbine depends on the wind speed at that specific location and the size of the wind turbine.

While wind is an inexhaustible resource, it is also a variable resource depending on the wind farm location. Typically, wind farms (large clusters of wind turbines built close together) are placed where there is a minimum average wind speed of around 13 miles per hour. If wind speed is too low, turbines cannot generate electricity. Scientists measure and record wind speed and other factors at proposed wind farm sites for many years before construction ever begins.

How It Works

There are many different designs of wind turbines with varying blade shapes that are customized for the location of the turbine to maximize electricity generation. Regardless of the design of the wind turbine, they all operate on the same principle.

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In wind turbines, the mechanical energy to rotate the generator comes from the force of the wind pushing the blades of the turbine. The force of the wind causes the turbine blades to rotate. Since the turbine blades are directly connected to the generator, rotation of the blades moves the magnetic field over the coils of the generator, producing electrical current.

The output capacity of wind turbines is limited by the size of the turbine blades and volume of wind. Usually, multiple wind turbines will be located along mountains or hilltops, so that the output can be combined in order to provide usable capacity levels.

Wind turbines have the following basic parts: blades/rotors, tower, gear box, generator, and shaft. Different styles of blades and different sizes of turbines operate most efficiently at different wind speeds and locations. See Figure 3C.7.

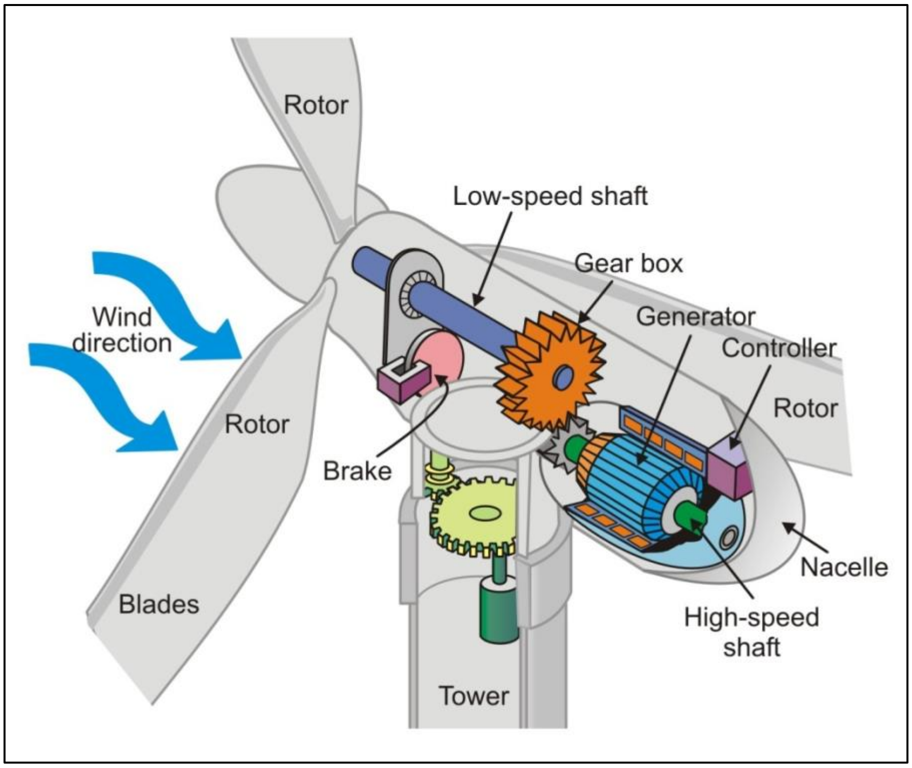

Figure 3C.7 Wind turbine components

Environmental Impacts

Wind plants do not produce any greenhouse gases or other types of air pollution. They also do not require large volumes of water for cooling. Even though wind plants are considered to be "green," there are some environmental impacts associated with wind plants. Some people feel that the appearance of the large wind towers has a negative aesthetic impact on the environment. Some wind turbines make noises that can be heard in the vicinity of the wind farm. Another environmental impact of wind turbines is the possible impact on bird populations. Many newer turbine technologies are working to resolve these negative impacts.

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Focus on ...

Wind Energy – Summary of Advantages and Disadvantages

Advantages

Renewable

No carbon dioxide or pollutants released

Does not require consumption of water

Disadvantages

Noise

Visual impact

Possible impact on local wildlife

Electromagnetic interference

Weather/seasonal dependence

High initial cost

☼ CAREER PROFILE: Wind Turbine Technician

Curtis E. is a wind turbine technician for a private energy company. Curtis travels to different wind farms in his region to maintain, troubleshoot, and fix wind turbines owned by the company he works for. "Typical tasks that I am responsible for include inspecting the entire turbine system, performing routine maintenance, and repairing any mechanical or electrical problems on the turbines," says Curtis.

Curtis says he has always had an interest in construction and technology. "Sometimes I get called to work on the installation of turbines at a new wind farm, but most of the time I work on pre-existing turbine systems collecting data and making repairs. The data I collect helps us test the health of the system and to know what adjustments or repairs might need to be made to ensure safe and efficient operation of the turbine."

The work Curtis does is essential to ensuring that the wind turbines operate reliably and at their maximum efficiency. "This job is never boring," says Curtis. "Aside from the heights that you are required to work at, technology is always changing and improving, so there is always something new or different to do."

Geothermal Energy

Water beneath the Earth's surface is sometimes superheated by the Earth's immense internal heat. The superheating of underground water reservoirs produces steam. This steam can be piped to buildings for heating or for driving machinery. The steam also can turn turbines to produce electricity. This type of energy is called **geothermal energy**. You might be familiar with geothermal energy in the context of its occurrence in nature, such as in the form of volcanoes and hot springs. Geothermal energy is relatively nonpolluting, clean, and safe.

Geothermal energy has been used historically for cooking and bathing. Modern geothermal electricity generation technologies are relatively new.

While geothermal energy is classified as naturally sustainable, there are only so many places on Earth where geothermal energy can be tapped, since it is dependent on certain geological formations. Among these are New Zealand, Iceland, and some parts of the United States. Each of these places uses geothermal energy to one degree or another.

Geothermal Power Plants

There are three main types of technology used to generate electricity from a geothermal source. Geothermal production wells are drilled to provide access to the geothermal source.

Dry Steam Plant

A **dry steam plant** (see Figure 3C.8) uses superheated steam that comes directly from the heat source. The steam travels up a well and is routed directly into a turbine. The superheated steam expands when passing through the turbine, causing the blades/shaft to rotate. The exhaust steam condenses to liquid form which drops the pressure across the turbine. Gases and wastewater are re-injected into the ground.

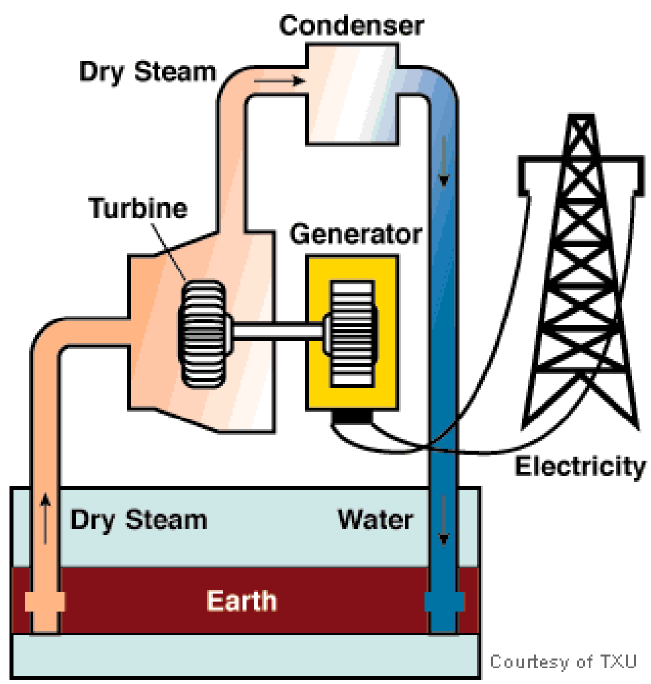

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Figure 3C.8 Dry steam plant

Flash Steam Plant

A **flash steam plant** typically uses high-pressure hot water. Pressure differences between the well and the storage device cause the water to vaporize into steam that turns a turbine and generates electricity.

Binary Cycle Plant

A **binary cycle plant** uses heat from lower-temperature geothermal resources to vaporize a secondary fluid with a lower boiling point than water. The temperature difference between the two fluids causes the creation of vapor, which drives a turbine to generate electricity.

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Environmental Impacts

Geothermal plants release a minimal amount of emissions into the atmosphere in comparison to other power generation technologies. Since geothermal source fluids are coming from deep under the Earth's crust, gases from within the Earth are released through the well. Plants designed with special technologies can capture and reduce the release of these gases into the atmosphere.

Even though geothermal plants are considered to be "green," there are some environmental impacts associated with them. Sometimes during geothermal well drilling, poisonous gases may escape into the atmosphere.

Did you know?

The country of Iceland is well-known for its geologic formations that contain extensive reservoirs of geothermal energy. It is estimated that more than 29% of Iceland's electricity is generated by geothermal sources (in comparison to only about <1% in the U.S.).

Subsidence, or gradual sinking of land, may occur in areas in proximity to geothermal plants due to the large volumes of fluids that are removed from the Earth.

Another environmental concern is the disposal of wastewater, or used geothermal fluids. These fluids must be disposed of appropriately to prevent pollution of the environment.

Focus on ...

Geothermal Energy – Summary of Advantages and Disadvantages

Advantages

Renewable

Small amount of emissions

Small amount of land needed for development

Reliable—fuel source not dependent on weather or price fluctuations

Low operating costs

Disadvantages

High initial cost

Limited are of application—site must have specific geothermal qualities

Wastewater disposal

Noise

Biomass Energy

Once a very small part of the renewable technology sector, **biomass power generation** is making great strides in becoming a more widely used source of renewable energy. Biomass is probably the oldest source of energy after the sun. Since ancient times, people have burned wood or other organic materials to heat their dwellings and cook their food.

Biomass technology involves the generation of energy from organic materials. **Bioenergy** is a term used to describe energy derived from materials such as sugar cane, straw, animal manure, or other organic materials that were living matter a relatively short time ago in comparison to fossil fuels.

Biomass Sources

The term biomass encompasses diverse fuels derived from four main types—wood and agricultural products, solid wastes, landfill gas and biogas, and alcohol fuels. Biomass fuels can be in liquid, solid, or gas form as long as they are composed of organic wastes.

Wood and Agricultural Products

Wood

Wood energy sources are derived from wood harvested for the direct purpose of serving as a biofuel, and from wood wastes from sawmills, pulping, and paper industries, such as the following.

Forestry Residues: Wood-based organic materials that remain after timber has been harvested from forests.

Milling Residues: Wood-based organic materials that remain after timber product manufacturing.

Urban Wood Waste: Wood-based organic materials that would otherwise be sent to a landfill such as construction waste and wooden pallets.

Agricultural

Agricultural energy sources are derived from crops such as switchgrass that are cultivated for the direct purpose of serving as a biofuel feedstock, and from agricultural wastes from the agricultural industry.

Agricultural residues are generated after the harvesting of an agricultural crop. These residues include materials such as stalks, straw, fruit pits, peanut hulls, and corncobs.

Solid Wastes

Waste energy sources include municipal solid waste (MSW) and manufacturing waste.

Power plants that burn garbage as their fuel source are called “waste-to-energy plants.” These plants function in a manner similar to coal-fired plants, but garbage serves as the fuel source instead of coal.

Municipal solid waste is not all biomass; perhaps half of its energy content comes from plastics, which are made from petroleum and natural gas.

Landfill Gas and Biogas

Biomass can be converted to other usable forms of energy such as methane gas. Rotting garbage and agricultural and human waste release methane gas, which is also called “landfill gas” or “biogas.”

Did you know?

One ton (2,000 pounds) of garbage contains about as much heat energy as 500 pounds of coal.

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Landfill Gas

Rotting and decay of landfill waste can result in the creation of methane gas as the waste breaks down. Most landfills are required to collect methane gas for safety and environmental reasons. Landfills can collect the methane gas, purify it, and use it as fuel.

Biogas

Methane gas can also be produced from agricultural and human wastes using special biogas digesters. Biogas anaerobic digesters are airtight containers or pits lined with steel or bricks. Waste is put into the containers where it ferments without the presence of oxygen and produces a methane-rich gas.

Alcohol Fuels

Agricultural crops such as corn and sugarcane can be fermented to produce transportation fuels. Ethanol is a common biomass alcohol fuel that can be used as a fuel source by itself or added to gasoline.

Another biomass fuel source called “biodiesel” is a fuel made from left-over vegetable oil and animal fats.

Biomass Energy Conversion Technologies

There are a variety of biomass energy conversion technologies available to convert biomass fuels into electricity. Conversion technologies may release the energy directly, in the form of heat, or the energy source may be converted to liquids or gases.

Biochemical Conversion

Biochemical conversion technologies involve the use of biochemical processes to break down the composition of biomass materials. Biochemical conversion technologies utilize enzymes, bacteria, and other micro-organisms to break down biomass materials. Examples of biochemical conversion processes include **anaerobic digestion** and fermentation.

Anaerobic Digestion

Biodigesters recover methane gas from biomass materials such as animal manure, through anaerobic digestion. The anaerobic processes require an airtight tank, “digester,” or a covered lagoon.

Methane-producing bacteria cause the decomposition process. A variety of factors affect the rate of decomposition and biogas production. The most important factor is temperature. Keeping the digester at a consistent temperature maintains consistent bacterial digestion.

Biogas produced in anaerobic digesters consists mostly of methane and carbon dioxide. The percentage of the gases in biogas depends on the feed material and management of the process.

Fermentation

Agricultural crops can be fermented to produce biomass alcohol fuels. Ethanol is the most common biomass alcohol fuel. Ethanol is created by the process of fermentation.

☼ ACTIVITY: Ethanol Production

Anaerobic fermentation of sugar cane and corn syrup has been introduced as a means of commercially producing ethanol in the United States. Additionally, methanol (used in making biodiesel) can be produced from wood pulp.

Investigate the production of ethanol from corn syrup and the production of methanol from wood pulp. Possible sources of information include the U.S. Department of Agriculture and the U.S. Department of Energy. Research and discuss the following questions:

- Where are these types of biomass alcohol fuel production taking place?
- Which microorganisms are used in the fermentation process?
- What kinds of jobs are related to ethanol and methanol production from plant feedstocks such as pulp and corn syrup?

Thermal Conversion

Thermal conversion technologies involve the use of heat to convert the biomass fuel into electrical energy. Examples of thermal conversion processes include **gasification**, pyrolysis, and combustion.

Pyrolysis and Thermal Gasification

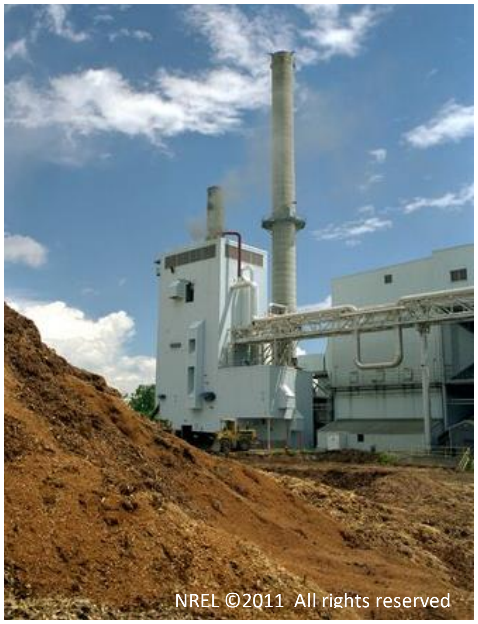
Pyrolysis and thermal gasification are related technologies. The pyrolysis process heats biomass material to high temperatures in the absence of gases such as air or oxygen. Pyrolysis creates a mixture of combustible gases, liquids, and solid residues.

Thermal gasification is different from pyrolysis in that the thermal decomposition takes place in the presence of a small amount of oxygen or air. The gases that are produced in these processes can be used to heat boilers or processed further to be used in combustion turbine/generators.

Combustion

Biomass combustion power plants include both dedicated biomass and biomass co-firing plants. Trucks bring in loads of refuse to storage bays or pits at the power plant. Heavy equipment is used to sort and mix the waste before it is combusted.

In many cases, municipal solid waste can be directly combusted with minimal processing. This process is referred to as “mass burning.” For more specialized combustion processes, waste may be subjected to more extensive processing before being combusted.



Dedicated Biomass

Dedicated biomass plants are also known as direct-fired power plants. In these systems, the fuel used to heat the system’s boiler is all biomass fuel. Similar to other steam-generated power plants, steam from the boiler is captured and rotates a turbine that generates electricity.

Biomass Co-Firing

Biomass co-firing plants combine biomass fuel materials with coal in coal-fired boilers. In co-firing plants, biomass fuels substitute for a portion of coal, which helps reduce emissions and dependence on non-renewable fossil fuel sources.

Economic Implications

Economic implications that affect biomass power plants include regional availability of biomass fuel sources, transportation costs, and available technology. Since fuel sources vary by region, biomass fuel prices are also subject to regional variations.

Biomass power plant size is often limited by the proximity of biomass fuel source availability. Transportation costs associated with the movement of bulky materials is very high. Unless the power plant is located in close proximity to rail or shipping routes, transportation costs might be a severe cost-limiting factor for a plant’s development.

Environmental Impacts

When biomass fuels are combusted, they generate air emissions such as carbon dioxide, carbon monoxide, nitrogen oxides, particulates, and other various pollutants depending on the biomass fuel used and the energy technology processes applied.

Focus on ...

Biomass Energy – Summary of Advantages and Disadvantages

Advantages

Renewable

Preserves landfill space

Disadvantages

Bulky and expensive to collect and transport long distances

Long-term storage is problematic due to degradation

Burning releases carbon and other emissions

Ocean Wave/Tidal Energy

A relatively new emerging area of renewable energy is hydrokinetics. **Hydrokinetic energy** refers to energy that is the result of water movement such as tides and currents. The constant motion of the ocean contains energy that can be used to generate electricity.

Ocean Wave Energy

Ocean waves are a form of renewable energy created by wind currents passing over the open water of the ocean. Improved methods of capturing the energy from ocean waves has been a focus of recent research in alternative energy sources.

In addition to wind currents, the strength of ocean waves is affected by tides, weather, and other natural marine occurrences. The power of ocean waves is currently collected to generate electricity in two main ways, through fixed and floating devices.

Fixed Devices

Oscillating water columns are fixed devices that are partially submerged in the water. As a wave flows in and out of the column, air within the column is forced in and out. This air movement causes the turning of a turbine that generates electricity.

TAPCHAN systems are another example of a fixed system. TAPCHAN stands for tapered channel. In a TAPCHAN system, a reservoir (or "catch basin") within a cliff has a tapered channel connected to it. Waves progressively move through the channel. As the channel narrows, the energy of the waves becomes more concentrated, causing the waves to spill over the sides of the channel. When the waves spill over the sides of the channel into the reservoir, the stored water in the reservoir is essentially pushed out and directed though a turbine to generate electricity. See Figure 3C.9.

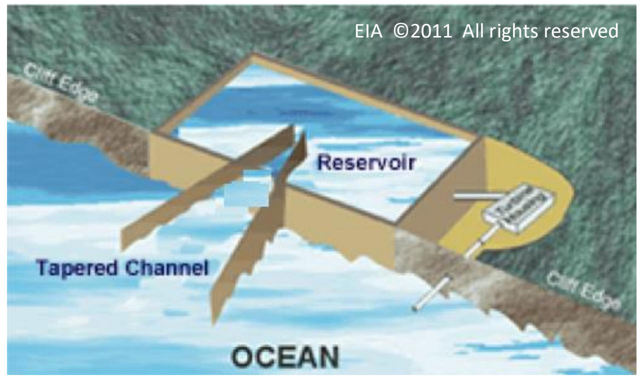


Figure 3C.9 TAPCHAN System

Floating Devices

There are a variety of floating devices that can be used to generate electricity from ocean waves. The basic premise of floating devices is that the movement or "bobbing" of the floating part of the device creates energy that can be converted into electricity.

Tidal Energy

Ocean tides are a result of the interaction of the gravitational forces of the Earth, moon, and sun. These gravitational forces cause high and low tides to occur. In areas where there is a significant difference between the tides, there is an opportunity to utilize hydrokinetic energy systems. Hydrokinetic energy conversion systems convert the energy from the movement of tides (without impeding the movement).

Tidal Barrage Power

A **tidal barrage** is essentially a tidal power station. A tidal barrage is a **dam**-type structure built across an **estuary** with gates and turbines installed to funnel and use tidal forces to generate electricity. A tidal barrage makes use of the difference in water levels (high tide/low tide) to capture the water flow, direct it to a turbine, and generate electricity.

"**Ebb generation**" in a tidal barrage allows water to enter the barrage through the gates without the turbines running. The water is trapped at high tide by closing the gates. Then the water is released at low tide to generate power.

"**Flood generation**" in a tidal barrage generates power by allowing the turbines to operate as the high tide "comes in."

"**Two-way operation**" in a tidal barrage generates power by allowing the turbines to operate as the high tide comes in and as it recedes.

Tidal Stream Power

In additional to tidal barrages that take advantage of hydrokinetics through the capture of energy from high and low tide differences, tidal power can also be captured from strong, underwater ocean currents. In tidal stream power technology, submerged turbines are driven by flowing water currents.

Environmental Considerations

Some tidal power systems can negatively affect the surrounding environment by the change in water levels caused by the use of tidal barrages. Water turbidity (cloudiness caused by suspended particles) can increase as an effect of tidal barrage construction. Increased turbidity, wildlife migration, and fish spawning may or may not be affected by tidal barrages, depending on their design and efforts to minimize environmental impacts.

Focus on ...

Ocean Wave/Tidal Energy – Summary of Advantages and Disadvantages

Advantages

Renewable

Limited/no direct waste

Limited greenhouse gas emissions

Little visual impact

Low noise generation

Disadvantages

Reliance on water levels

Output fluctuations

Integration into the power grid

Seasonal wave energy availability

High initial cost

Possible environmental impacts

Unit C Glossary

active solar heating—use of sunlight to heat liquid that is then piped to heat water or the house itself

alternative energy—energy derived from nontraditional sources as an alternative to fossil fuel use; does not necessarily mean renewable

anaerobic digestion—the process by which microorganisms break down biodegradable material in the absence of oxygen

binary cycle plant—a geothermal power plant that uses heat from lower-temperature geothermal resources to vaporize a secondary fluid with a lower boiling point than water; the temperature difference between the two fluids causes the creation of vapor which drives a turbine to generate electricity

bioenergy—energy produced from a biological resource such as biomass

biomass—biological material derived from living or recently living organisms, such as wood, waste, plant matter and other organic materials that can be used as an alternative energy source

biomass power generation—the generation of electricity from organic materials

dam—a barrier constructed across a waterway to control the flow or raise the level of water

dry steam plant—a geothermal power plant that uses superheated steam that comes directly from the geothermal heat source

ebb generation—A type of tidal generation, it allows water to enter the barrage through special gates without the turbines running; the water is trapped at high tide by closing the gates, and then generating power by releasing the water at ebb tide

estuary—the area of water where a river meets the ocean

flash steam plant—a geothermal power plant that uses high-pressure hot water; pressure differences between the well and the storage device cause the water to vaporize into steam that turns a turbine and generates electricity

flood generation—generation of power by allowing the turbines to operate as the tide comes in

gasification—process of transforming carbon-based materials into a useful fuel through high heat combustion in a controlled environment

generator—the portion of the generating unit where the rotating mechanical energy is converted to electrical energy; it consists of a stator containing the armature windings and a rotor (center shaft) that is turned by the turbine to produce the magnetic field

geothermal energy—energy derived from the natural heat resources within the Earth

hydrokinetic energy—energy that is the result of water movement such as tides and currents

megawatts—one million watts

passive solar heating—use of direct sunlight to heat water or a house

photovoltaic cells—devices that use the photovoltaic effect to convert sunlight directly into electricity

photovoltaic effect—the chemical reaction of the creation of an electric current in a material that has been exposed to solar radiation

photovoltaic energy—conversion of sunlight directly into electricity

renewable energy—energy which comes from natural resources which are renewable (naturally replenished)

subsidence—gradual settling or sinking of a land surface often associated with the following: seismic activity, underground excavation, or underground pumping

tidal barrage—a structure built across an estuary with gates and turbines installed to funnel and use the tidal forces to generate electricity

turbine—a machine for generating rotary mechanical power from a fluid flow (air, steam, water)

two-way operation—generates power by allowing the turbines to operate as the tide comes in and as it recedes

watts—the basic unit of electrical power

Unit C References

Energy Information Administration. (2016). Electric Power Annual 2015. https://www.eia.gov/electricity/annual/

National Energy Education Development Project. Exploring Hydroelectricity. http://www.need.org/content.asp?contentid=80

National Energy Education Development Project. Exploring Nuclear Energy. http://www.need.org/content.asp?contentid=76

National Energy Education Development Project. Exploring Wind Energy. http://www.need.org/wind

National Energy Education Development Project. Photovoltaics. http://www.need.org/solar

Public Service Electric and Gas (PSE&G). (2003). Introduction to the Energy Utility Industry course.

Public Utilities Reports Guide. (2008). Delivery of Service. Public Utility Reports, Inc.

U.S. Energy Information Administration. (2008). Electric Power Industry Overview 2007. http://www.eia.doe.gov/electricity/page/prim2/toc2.html

U.S. Environmental Protection Agency. (1997). EPA Office of Compliance Sector Notebook Project, Profile of the Fossil Fuel Electric Power Generation Industry.

U.S. Nuclear Regulatory Commission. (2010). Nuclear Power for Electrical Generation. Reactor Concepts Manual. http://www.nrc.gov/reading-rm/basic-ref/teachers/unit3.html

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