Box 5.1 Electricity Technology Box

To produce electricity, a generator shaft is turned by an external force, such as water, steam, or wind. The water could be from a dam or hydroelectric source or from pumped storage. The steam could be in created in a boiler by burning fossil fuels or biomass, from nuclear fission or from geothermal energy. As the generator shaft turns, wires rotate in a magnetic field inducing a current. As the shaft passes the positive and negative poles of the magnet, the current reverses causing alternating current. The number of times the current reverses per second is called Hertz. Current in the US is typically 60 Hertz, whereas current in Europe is 50 Hertz.

The current represents the amount of electrons that flow through a medium and is measured in Amps. The medium resists the flow and this resistance is measured in Ohms. Materials such as rubber with tightly packed atoms that do not allow a current of electrons to pass through are insulators. Materials that allow the passage of electricity easily, such as aluminum and copper, are called conductors. The force pushing the electrons is measured in volts. It is a measure of electric potential. Volts = Ohms*Amps. The watt is a measure of power per unit of time and is equal to Volts times Amps. Since electricity was discovered and developed by scientists after the metric system was developed, you do not typically have the archaic units of measurement that exist for the other energy products.

Electricity is usually generated at 13,000 volts =13 kv. Voltage is increased using transformers to 115 kv or more for long distance transmission. Lines as high as 1000 kv are used in Russia. Raising the voltage lowers the current and reduces transmission losses. After transmission electricity is lowered to 440 volts at a substation and decreased to 120 volts for residential customers in the U.S. and Canada but more often to 220 volts worldwide. For voltages worldwide, see http://kropla.com/electric2.htm.

The majority of steam electric generation is from fossil fuels that are burned to heat a boiler for steam. Coal is typically unloaded by using cranes to overturn rail cars. The coal is then ground to a fine powder and blown into a furnace with preheated air. Oil is a bit easier to use usually coming in by pipeline or tanker and is stored in large tanks until used. It is usually heated and sprayed into the furnace. Gas typically is not stored but comes directly from a pressurized pipeline to the combustion section of either the boiler or the turbine. Burning the fossil fuel heats water to steam, which comes out of nozzles, hits the turbine blades, and turns them. The small blades are closest to the boiler. As the steam loses energy, larger blades are needed to catch the remaining energy in the steam. The temperature drop from the turbine to the condenser is typically 1000 degrees F to 100 degrees F. Then condenser water is sent to a lake, river, or cooling pond.

The share of capital cost in the US are typically

44% for electricity production;

22% for transmission; and

34% local distribution.

The share of operating cost are typically

89% production and fuel,

3% transmission, and

8% local distribution.

Gas can also be used to run a turbine with the heated air running the turbine rather than heating water. Although this takes less capital, it is typically less fuel-efficient. The efficiency of the process is typically 25% for a gas turbine instead of the 35% efficiency of steam. However, combined cycle, which takes the exhaust from the gas turbine and uses it to generate steam, can raise efficiencies to over 50%.

Thermodynamics tells us that the theoretical maximum efficiency for electricity generation is $1 – T_2/T_1$ where T_2 is the temperature of the cooling water outputted and T_1 is the temperature of the steam inputted into the turbine both measured in degrees Kelvin (K°). (0 K° is absolute zero and means the material has no more heat to lose. O K° equals –273 degrees Celsius (C°) or –459 degrees Fahrenheit (F°). Each degree Kelvin is one degree Celsius. The following formulas show you how to convert from Celsius to Kelvin and Fahrenheit to Celsius. $K = C + 273$, $C = 5/9(F - 32)$.

To create electricity from nuclear energy, atoms of uranium 235 (U235) or plutonium 239 (Pu239) are split by being bombarded by neutrons releasing heat and more free neutrons that keep the reaction going. For a simulated chain reaction go to http://lectureonline.cl.msu.edu/~mmp/applist/chain/chain.htm. In boiling water reactors, the heat is collected in ordinary water that turns to steam and turns the turbine. In a pressurized water reactor, super heated water passes through a primary cooling loop transferring the heat to a secondary loop to create steam to run the turbine. Both these types of reactors are called light water reactors, since they use ordinary water, rather than heavy water, gas or other materials to transfer heat to the turbines.

Uranium ore is mined much like other metals and is milled to turn the ore into a yellow powder (U_3O_8) called yellow cake. The yellow cake contains the two natural uranium isotopes - the scarce U235 (0.71%), which is fissionable, and the abundant heavier U238 (99.29%), which has more neutrons and is not fissionable. When using uranium for nuclear power in light water reactors, it must be enriched to increase the U235 concentration to about 4%. The Canadians have developed a heavy water reactor called the Candu. Since the heavy water slows down the neutrons, natural uranium does not have to be enriched to maintain a chain reaction.

To enrich uranium, the U_3O_8 is usually converted to uranium hexafluoride UF_6. Gas centrifuge or gas diffusion processes are used to enrich the UF_6. The enriched UF_6 is then fabricated into uranium dioxide UO_2 pellets, which are put into fuel rods. These fuel rods are put into fuel assemblies for insertion into the reactor core. If there is a problem or the operators want to slow or stop the reaction, they lower cadmium or boron carbide control rods into the fuel assembly to absorb neutrons.

With the chain reaction, U235 is used up and some of the U238 is converted to plutonium Pu239. A fraction of the fuel rods are replaced at a time - usually 1/4 for a boiling water and 1/3 for a pressurized reactor. Spent fuel is high-level nuclear waste and is placed in cooling ponds. Spent fuel is reprocessed in Japan and Europe to recover U235, U238, and Pu239. With reprocessing about 3% of the original quantity of fuel is nuclear waste. It is illegal to reprocess spent fuel in the U.S. for fear of the proliferation of plutonium to make nuclear weapons.