What you will learn:

- What electricity is
- What an electrical current is
- How electricity is created
- How electricity is used to perform useful tasks
- The physical delivery system
- Key physical properties of electricity
- The four key physical sectors of the electric business

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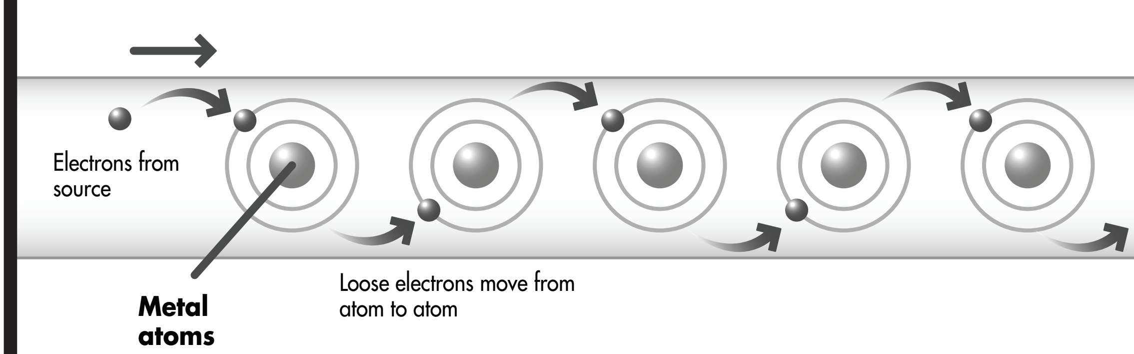
SECTION TWO: WHAT IS ELECTRICITY?

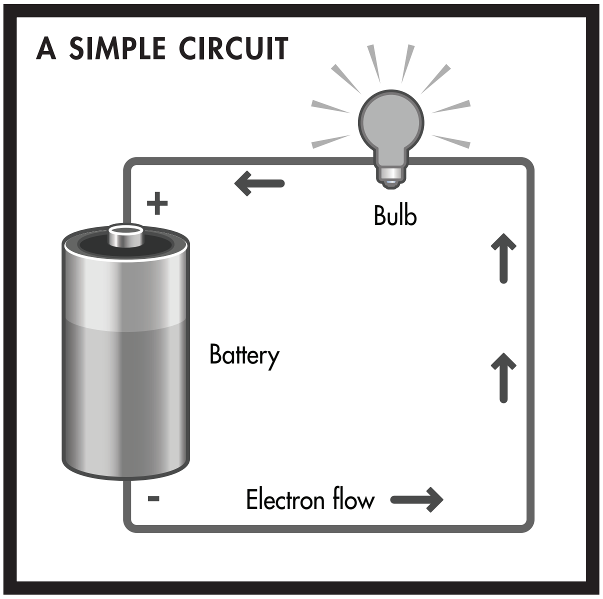
Electricity is simply the flow of electrons through a conductor[1]. Electrons are the tiny negatively charged particles that are found in all atoms. Electricity is transmitted as loose electrons move from one atom to the next within a conductor. A conductor is any material that facilitates this transmittal of electricity.



Most practical applications of electricity require electrons to flow through a circuit. A circuit includes a source of electrons (a battery or generator), an energy consuming device (such as a light bulb), and conductors (wire) that transmit the electrons to and from the bulb. In the simple circuit illustrated on page 10, the battery causes electrons to flow through the wire to the light bulb where light is created. The electrons then return to the battery via the wire and the electric circuit is complete. Note that the bulb does not "consume" the electrons, but rather the electrons flow through a material in the bulb causing it to glow.

Before we continue, there are several quantitative terms associated with the flow of electrons you will need to understand. The rate at which electrons flow through a conductor is called current and is measured by amperes or amps (A). If we were to compare the flow of electrons through a conductor to the flow of water through a hose,

[1]Throughout this book we will use the term electricity to mean the flow of electrons through a conductor, which is also known as current electricity. There is a second type of electricity known as static electricity. Static electricity is the transfer of electrons from one material to another and is not discussed in this book.



this rate would be the equivalent of gallons per second. There are two factors that affect this rate – the force applied to the electrons and the resistance to flow within the conductor. The force that moves electrons is called voltage, and is measured in volts (V). The higher the voltage, the faster the rate of flow (the higher the current). Voltage, then, is the equivalent of pressure in our hose. Resistance, which is measured in ohms (R), impedes the flow of electrons. As you might imagine, the higher the resistance in the conductor, the slower the rate of flow (the lower the current). Returning to our water analogy, ohms are equivalent to any friction or blockage that might slow down the flow of water through the hose. Current is always directly proportional to voltage and resistance as shown in a relationship known as Ohm's law:

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$$\text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms)}}$$

SIX TYPES OF ENERGY

Electrical energy is one of six major types of energy:

Chemical energy — Stored energy released as the result of two or more atoms and/or molecules combining to form a chemical compound.

Electrical energy — Energy associated with the flow of electrons.

Electromagnetic energy — Energy associated with electromagnetic radiation including visible light, infra-red light, ultraviolet light, x-rays, microwaves, radio waves, and gamma rays.

Mechanical energy — Energy that can be used to raise a weight.

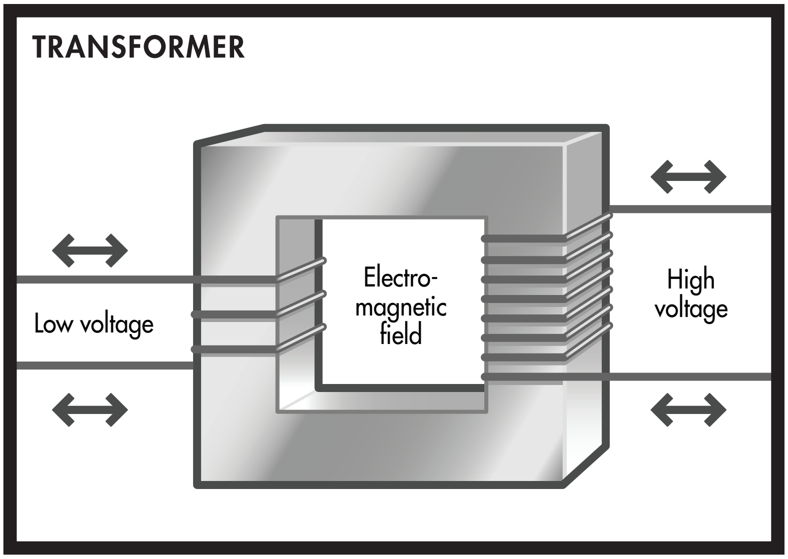
Nuclear energy — Stored energy released as the result of particles interacting with or within an atomic nucleus.

Thermal energy — Energy associated with atomic and molecular vibrations that results in heat.

Electrical energy stands alone in value among the six because it can be easily transported and readily transformed into other useful energy forms: to mechanical energy via an electric motor; to electromagnetic energy via light bulbs, microwave ovens, etc.; and to thermal radiation via radiant heaters.

This means that you would maintain the same current in a circuit if you increased both the volts and the ohms by the same ratio. You would increase the current if you increased the voltage but did not change the ohms. Conversely, you would decrease the current if you left the voltage unchanged, but increased the ohms.

Different voltages are used in a circuit depending on what is being done with the electricity. High voltages are used to transmit electricity long distances while lower voltages are used to power home appliances and office equipment. Voltages can be changed through the use of transformers. Transformers are able to change voltages because applying electricity to two different sized coils of wire in near proximity results in a voltage transformation. By adjusting the coil size, engineers can adjust voltage as required.



Most home appliances in the U.S. are operated on 110 V. Large appliances such as electric dryers and some electric ovens operate on a higher voltage of 220 V. We commonly refer to home electric services from the utility as 120/240 V services. Notice that while voltage may be supplied to a home at 120 V, the appliances use 110 V. The difference in voltage is due to resistance in home wiring. Commercial and industrial buildings often operate a number of their devices at higher voltages such 480 V. The size of an electrical service is determined in amps. A typical home built today in the U.S. would have a service of 200 amps.

How Electricity is Created

To begin the flow of electrons through a conductor, a source of energy is required. This can be either chemical or electromagnetic energy. Batteries and fuel cells operate by using chemical energy to free electrons from one material and transfer them to another via a conductor. Batteries and fuel cells contain three components – two electrodes and an electrolyte. The electrolyte reacts with the electrodes to create oxides that result in excess negative charge in one electrode (creating the negative terminal) and excess positive charge on the other (creating the positive terminal). The imbalance in charge creates an electric current when the terminals are connected to form a circuit.

Electromagnetic energy is used in two primary ways to create electricity. Solar or photovoltaic (PV) cells are made of materials that cause electrons to flow when light strikes the cell. As with a battery, the flow is directed through a circuit. The most common way of creating electricity – the electric generator – uses electromagnetic energy in a very different way. An electric generator creates electricity by what is called electromagnetic induction. Electromagnetic induction uses magnetism to make electrons flow. A source of mechanical energy (a steam turbine, gas turbine, wind turbine, or water turbine) is used to spin a shaft connected to a coil. This coil is suspended between the poles of a magnet and is connected to wires in a circuit by metallic brushes. As the coil spins through the magnetic field, electrons flow through the coil and brushes and then into the electric circuit.

ELECTRICAL TERMINOLOGY

Current — The rate of flow of electrons.

Amps — The unit used to measure current.

Voltage — The force that moves electrons.

Volts — The unit used to measure voltage.

Kilovolts — Another unit used to measure voltage, equal to 1000 volts.

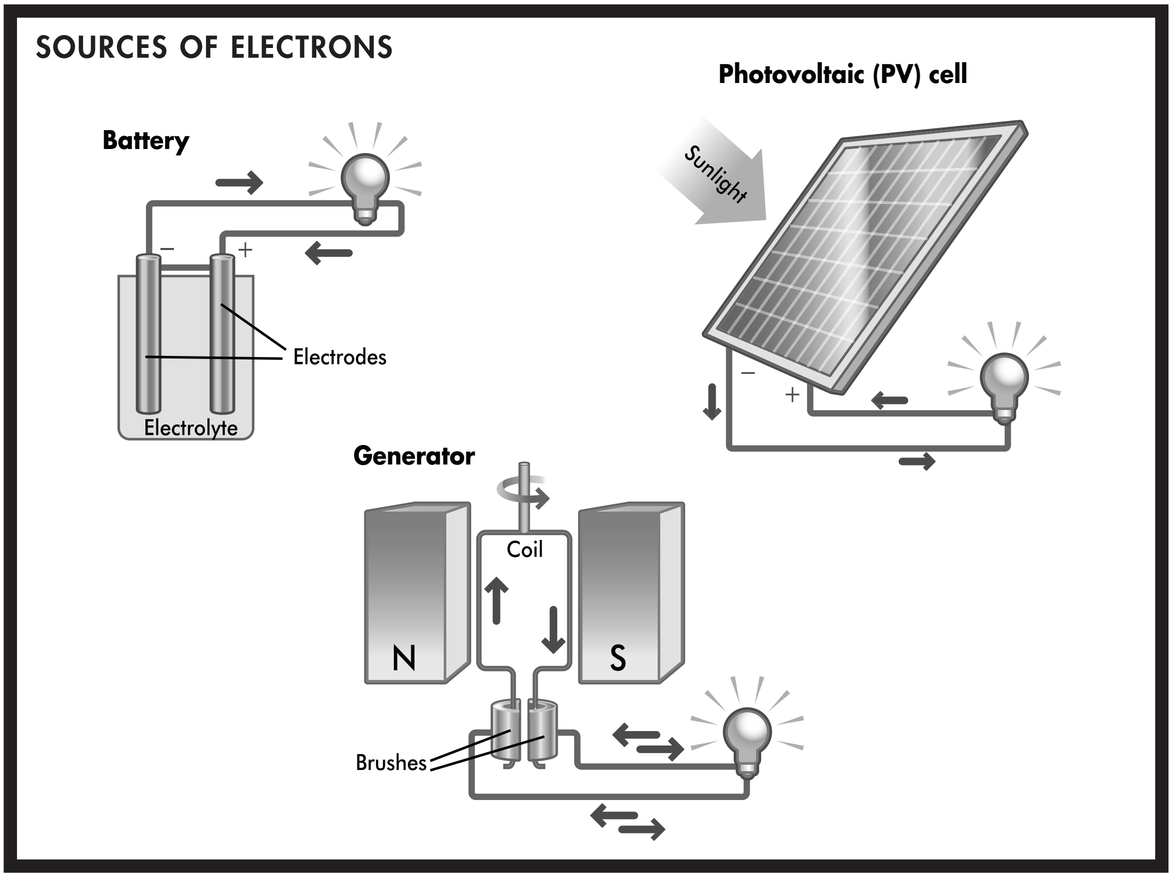
Resistance — A measure of the strength of impedance, which is the physical property that slows down electrons.

Ohms — The unit used to measure resistance.

Transformer — A device used to change voltages in a circuit.

How Electricity is Used to Perform Useful Tasks

You now know that electricity is the flow of electrons through a conductor. You also know that it flows through a conductor in a circuit under variable rates of flow. If that was all electricity did, however, it's unlikely you'd be reading about it in this book! What we've yet to discuss is that moving electrons create specific effects that can be harnessed to perform useful tasks. These effects include magnetism, heat and light. To understand electricity it is important to remember that unlike, say natural gas, electrons are not consumed while creating value. They can, however, be directed through specific materials resulting in all kinds of useful by-products. For example, light can be created by moving electrons through a filament of tungsten wire that is wound in a tight coil. The electrical flow causes the coil to heat up so that it becomes white hot and glows. This is the principle behind the incandescent light bulb, which is used commonly in our homes. The fluorescent light bulb works on a different principle. When an electrical current moves through certain gasses, they emit ultraviolet light.



The ultraviolet light (which is invisible) strikes a phosphor coating on the inside of the fluorescent tube, causing the phosphor atoms to glow. Electric motors are made possible by the fact that moving electrons create magnetic fields. When properly harnessed, these magnetic fields can be used to spin a shaft creating mechanical energy which can then be used in a variety of ways.

One additional way that electricity is used to create value involves the principle of control. By controlling the flow of electrons, electronic devices can be used to transfer information. This is the principle behind transistors and microchips, the two devices that have made modern technology possible[2]. For example, by controlling the flow in a specific way, we can represent the number 1 or 0, allowing us to digitize information.

The amount of electricity necessary to perform useful tasks is determined by the power required to move the electrons through a specific device. This power is measured in units called watts. A typical incandescent light bulb requires 100 watts to operate. A

[2]By far, the best explanation of how electrical devices work in plain language is a book found on many a child's bookshelf titled *The New Way Things Work*, by David Macaulay.

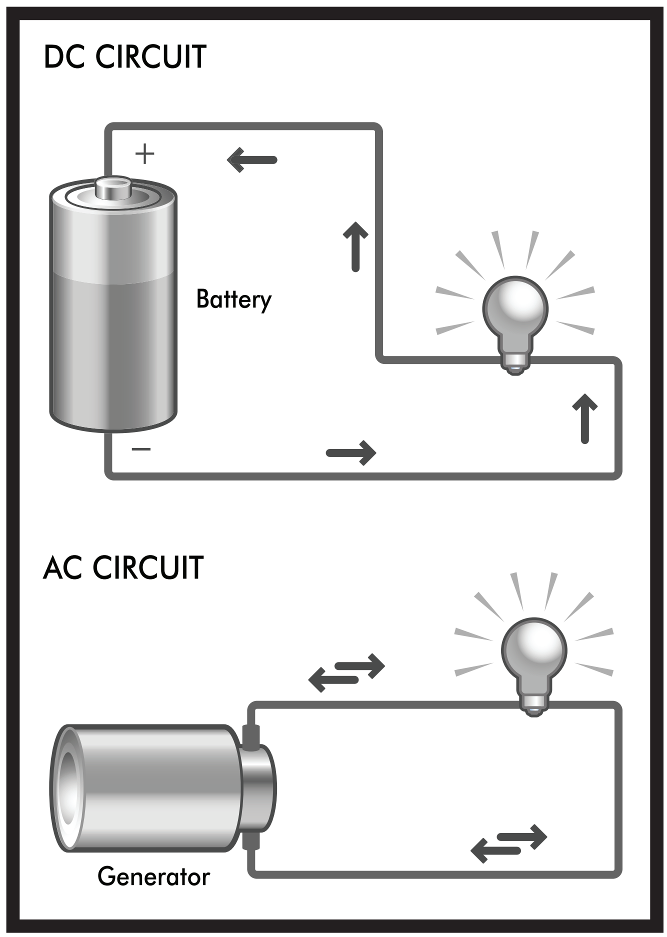
fluorescent bulb, on the other hand, requires only 40 watts to deliver comparable light. (Thus the push to replace incandescent bulbs with fluorescent ones!) Power used over time is commonly called energy. So anyone using that 100 watt bulb for one hour will consume 100 watt-hours of energy.

The current, voltage and power available in a circuit are related:

1 watt = 1 volt x 1 amp

So the power available in a home service of 200 A delivered at 120 V is:

Power (watts) = 120 V x 200 A = 24,000 W (which is the same as 24 kW)



As you have learned, electricity is delivered to the devices that use it via an electrical circuit. If a circuit is not complete, the flow of electrons will stop. Thus, in all circuits – including the electrical distribution system – electrons flow from one end of the source, through the conductor and devices, and then back to the source.

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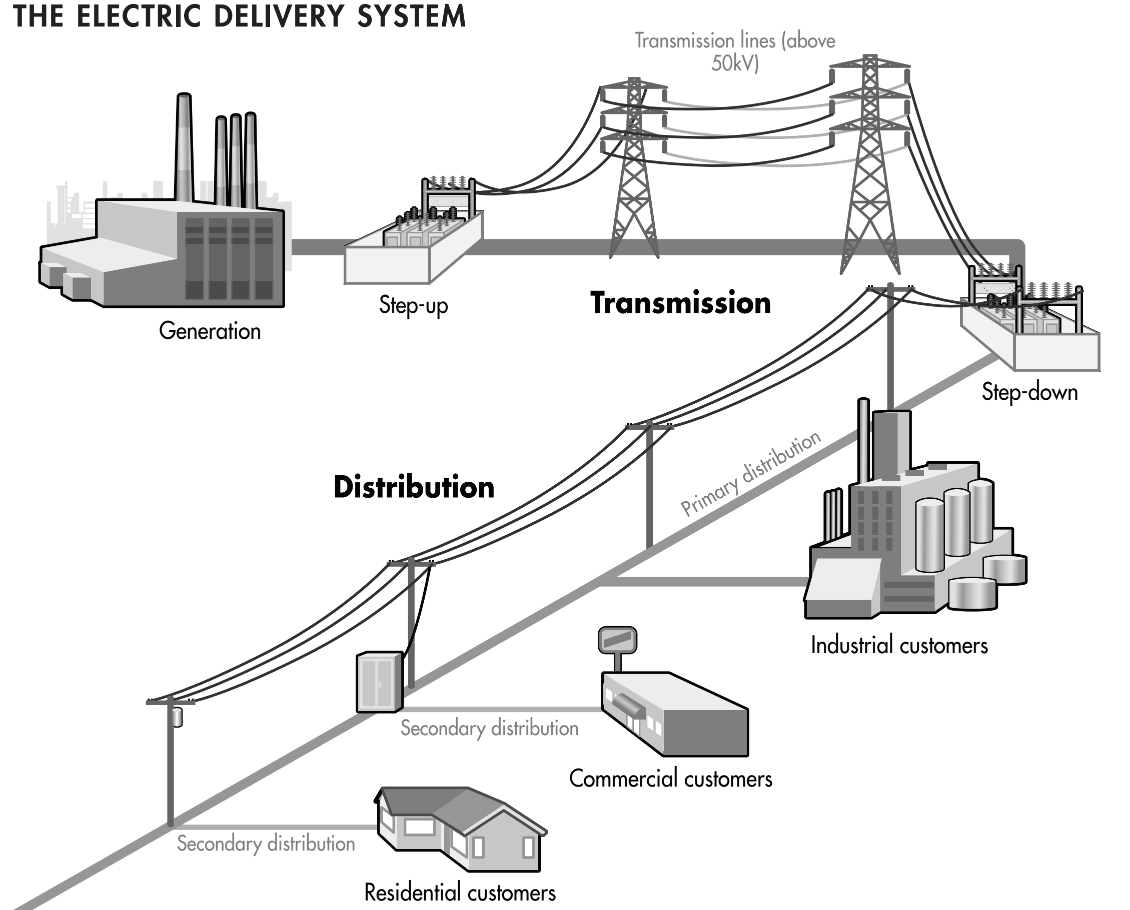
Now that you understand how current flows through a circuit, we need to confuse matters just a bit. Electric currents come in two types – direct current (DC) and alternating current (AC). In DC circuits the power flows continually in one direction, from the negative terminal to the positive terminal. In an AC circuit, the direction in which the electrons flow changes periodically and repeatedly. Electrons first flow from the generator towards the load. The flow then reverses direction and again flows to the load but from the opposite direction. Each time the direction of flow changes we say that the electricity has completed one-half cycle. A full cycle, then, is when the electricity flows first in one direction, and then the opposite. The unit of hertz (hz) is used to measure frequency, or how often electrons change direction. Utilities in the U.S. operate on a standard of 60 hz (meaning that electrons complete 60 cycles per second). Unfortunately, this is not the standard elsewhere in the world. Europe operates on 50 hz, which explains why your hair dryer requires a converter in your London hotel.

The Key Components of the Electric Delivery System

Now let's take what you've learned about a simple circuit and expand it to explain how electricity is created and delivered to consumers. An electric delivery system is, in its basic sense, simply a very large circuit. The flow of electrons, or current, is created by the generator. The electrons are transmitted to and back from consumers via conductors – transmission and distribution lines. And completing the circuit are the millions of energy-consuming devices.

The voltage created by generators is generally several thousand volts. This voltage is then stepped-up to transmission voltage by a step-up transformer. Banks of step-up transformers are typically located in a substation immediately adjacent to the genera-

THE ELECTRIC DELIVERY SYSTEM



tor. These transformers facilitate electric transmission because it is much more efficient to move electricity long distances at high voltages. Unfortunately, current at high voltages is capable of sparking or jumping large distances and is extremely dangerous to humans. This is why high voltage transmission lines are located on large towers.

As the electricity approaches an area where it will be consumed, the voltage is dropped to a safer voltage. This is performed by a distribution transformer located in a distribution substation. The electricity then continues its journey via the lower voltage distribution lines until it reaches the service line (the line entering a consumer's building). At the interconnection with the service line, the voltage is often transformed again to the necessary service voltage. The current then passes through the meter, flows through the consumer's internal wiring, through the consuming devices, and back through the system to the generator, completing the circuit.

In any electrical circuit, electrons always make their way back to the source generator. Thus, the electrons themselves are not used up. The reason that electrical systems require a continual input of energy (natural gas, coal, water flow, etc.) is simply to keep the electrons moving.

The Key Physical Properties of an Electric Delivery System

There are a number of physical properties unique to electricity that are extremely important to understand. As you will learn later in this book, electricity is a commodity like no other. Understanding these properties will help you to understand why the electricity business operates as it does.

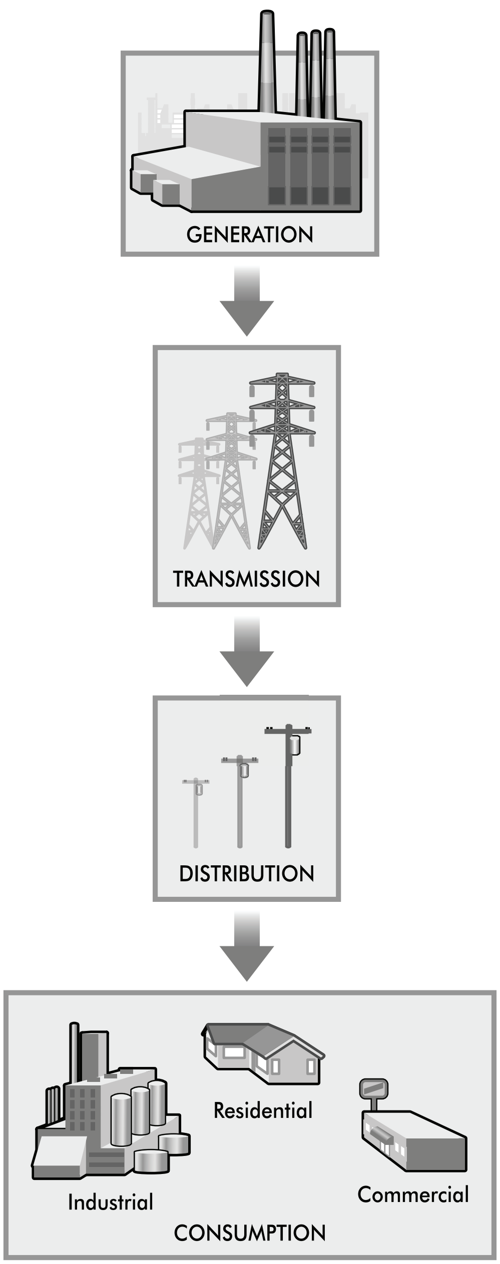
Electricity Cannot be Stored

Flowing electrons cannot be easily stored. This means the electrical system must be operated to ensure that supply and demand are continually in balance throughout the system at all times. If electrical supply is not available to match instantaneous electrical demand, the whole system will crash, resulting in blackouts. Thus an electrical system requires continual surveillance and adjustment to ensure supply always matches demand.

The Path of Electrical Flow is Difficult to Control

Electrons flow on the path of least resistance. And if the least resistant path is from the transmission line through a wet tree branch to the ground, that's precisely where the electricity will flow. Similarly, if this is from one utility's transmission system into another interconnected utility's transmission system, that is where electrons will travel. Thus all utilities on an interconnected system must cooperate in operating their systems as the action of one may cause electrons to flow into or out of the others' systems.

FOUR KEY PHYSICAL SECTORS



Disturbances Travel Very Quickly and are Hard to Contain

Changes in voltage or frequency on electrical lines move at the speed of light, which is 984 million feet (300 million meters) per second. So any disturbance – say a sudden burst of high voltage or a frequency that is out of whack – also travels very quickly. This is why a tree hitting a power line in Oregon can quickly result (and has) in lights going out in Los Angeles. This means that not only must system operators cooperate, but they must also be prepared to react to one another's actions (and problems) almost instantly.

Outages and Significant Voltage or Frequency Fluctuations are Not Acceptable

With the advent of modern electric controls and microchip-based devices, our consumption of electricity no longer tolerates momentary outages or fluctuations in voltage or frequency. Thus the entity that is responsible for matching supply and demand not only has to do so every minute of every day, but must also do it with little margin for error.

There you have it – the four physical properties of electricity that make it different from any other form of energy. These properties not only necessitate a centralized coordinating function called system operations, they also create business complexities unlike any other business in the world today.

The Four Key Physical Sectors of the Electricity Business

Now that we have studied how electricity is created and delivered, and discussed its key physical properties, we are ready to focus on the four key physical sectors of the electricity business. These are generation, transmission, distribution, and consumption. These are also the four components that comprise the circuit which we call the electric delivery system. Because generation, transmission and distribution are designed to serve specific customer needs, we will discuss electric consumers first. This will be followed by a look at the generation, transmission and distribution sectors. We will explore the business entities and market structures that provide these functions throughout much of the rest of this book.