Electricity

Introduction

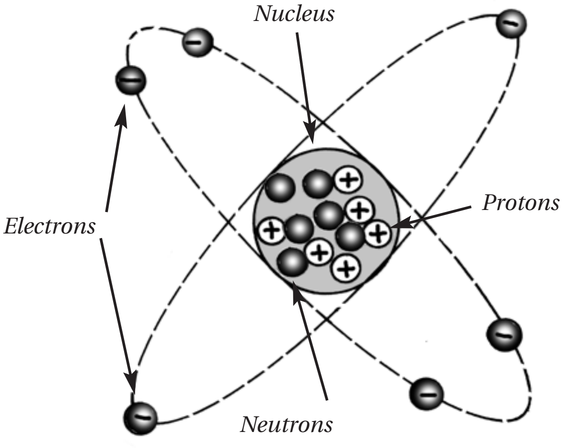
Electricity is a **secondary energy source**, that is, it is generated from the conversion of a **primary energy source**—nonrenewable resources such as oil, coal, natural gas, and nuclear; or renewable resources such as solar, water, wind, and geothermal. Electricity is unique, as it is **energy in transit**, kinetic energy, obtained when electric charges are set in motion by an **electromotive force**.

To most people, electricity is the form of energy that powers their electronic equipment and lights their home. They have a limited understanding of the scientific principles and technologies required to generate, transmit, use, and manage electricity.

What is the atomic structure of matter?

The early Greeks thought that matter was made up of **atoms** ("atom" is the Greek word for "indivisible"), though their ideas about the nature of these "indivisible" particles were vague. Through the work of Niels Bohr, Lord Rutherford and others it was revealed that atoms actually have a complex structure. According to Bohr's theory, an atom consists of a positively charged **nucleus**, surrounded by negatively charged particles, called **electrons**. The nucleus of an atom consists of two fundamental particles: **protons** and **neutrons**. The proton carries a positive charge while the neutron has no charge.

The positive charge of a proton is equal to the negative charge of an electron. Since atoms ordinarily are electrically neutral, the number of positive charges equals the number of negative charges—that is, the number of protons in the nucleus is equal to the number of electrons surrounding the nucleus.

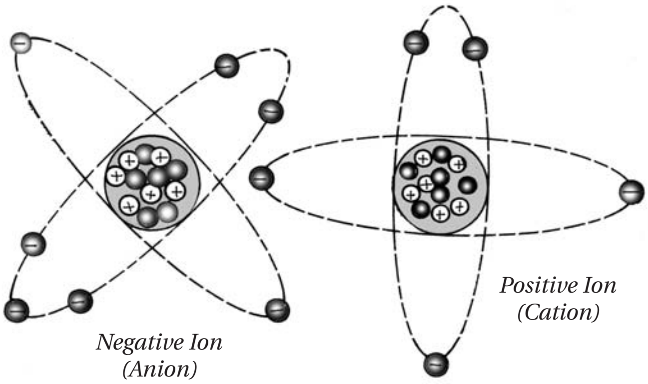


A Carbon Atom

What are ions and ionization?

An **ion** is an atom that has become electrically unbalanced by the loss or gain of one or more electrons. When an atom loses an electron, its remaining electrons no longer balance the positive charge of the nucleus, and the atom acquires a positive charge. This atom is called a **cation**. Similarly, when an atom gains an electron, it acquires a negative charge and is called an **anion**. The process of producing ions is called **ionization**.

Ionization does not alter the chemical properties of an atom, but it does produce an electrical charge. Ionization can be brought about by the collision of electrons or by exposure to radiation. This is because the electrons in the outermost shell of an atom are held rather loosely and, hence, can be dislodged easily.



Carbon Ions

What are free electrons, conductors and insulators?

Electrons that have been "knocked" out of the outer shell of an atom are known as "**free**" **electrons**. These free electrons can exist by themselves outside of the atom, and it is these electrons which are responsible for most electrical phenomena. The movement of free electrons constitutes an electric current.

All substances normally contain free electrons that are capable of moving from atom to atom. Metallic materials, such as silver, copper or aluminum, contain numerous free electrons capable of carrying an electric current and are called **conductors**. Non-metallic materials, which contain few free electrons, are called **insulators**. Materials that have an intermediate number of free electrons available are classed as **semiconductors**. The more free electrons a material contains, the better is will conduct electricity.

What is electric current?

The free electrons in a **conductor** are ordinarily in a state of chaotic motion. However, when an electromotive force (or **voltage**) is applied, such as that provided by a battery or electric power plant generator, the free electrons in the conductor are guided in an orderly fashion, atom to atom. This orderly motion of free electrons, under the influence of an electromotive force, is called an **electric current**. Although electrons drift through the wire at a relatively slow speed, the disturbance or impulse is transmitted almost at the speed of light. The electron current continues to flow through the conductor as long as the electromotive force is applied. The conductor itself remains electrically neutral, since electrons are neither gained nor lost by the atoms within the conductor. What happens is electrons enter the conductor from one end and an equal number of electrons are given up by the other end. Thus, the free electrons present within the conductor act simply as current carriers.

Electric current then is the transport of electric charge (electrons). Electric current is measured in **amperes** and is the amount of electrons passing a given point in one second. An ampere is equal to about 6.25×10^{18} electrons per second.

Voltage, on the other hand, is a measure of potential difference, the electromotive force necessary to move electrons through conductors. The amount of electric current moved through a conductor by the voltage is influenced by the conductors resistance.

Electric power, the work performed by moving electrons (electric current) is measured in **watts**, and is determined by multiplying the current by the voltage:

$$1 \text{ watt} = 1 \text{ amp} \times 1 \text{ volt}$$

Because of the relationship between electric current and voltage to perform work, the same amount of work can be performed with either a high current and low voltage or a low current and high voltage.

What is resistance?

The opposition to the flow of free electrons in a material is called **resistance**. The resistance of a material dissipates energy in the form of heat, because of **friction** between the free electrons and atoms of the material. As the material is heated, more collisions occur and the resistance to the flow of electric current increases.

The resistance of electrical conductors depends on their dimension and on their composition. As the cross-sectional area increases, the resistance decreases; but as the length increases, the resistance increases. A long, thin conductor, therefore, has more resistance than a short, thick one with the same volume of material. Silver has less resistance than copper, whereas aluminum and iron have more resistance.

Although the same voltage may be applied to a light bulb and an electric iron, the actual current flow is different in each, because each has a different resistance. So not only does the voltage determine how much current flows through an electrical appliance, but so does the resistance of the appliance. The relationship between resistance (R), voltage (V), and current (i) then, can be expressed by the mathematical formula: $i = V/R$. The unit of measure for resistance is the **Ohm**, named after George Ohm who was the first person to specify the relationship between resistance, voltage, and current. It is this resistance property of conductors which is used to produce light or heat from electricity.

What is static electricity?

When certain materials are rubbed together, free electrons are transferred by friction from one to the other, and both materials become electrically charged. These charges are not in motion, but reside statically on each material, and hence this type of electricity is know as **static electricity**. We've all had experience with static electricity: lightning during a storm; sparks flying after we shuffle over a rug; hair standing up on end after brushing – typical examples of the effects of static electricity. This type of electricity is produced by friction, mechanical energy.

What is thermoelectricity?

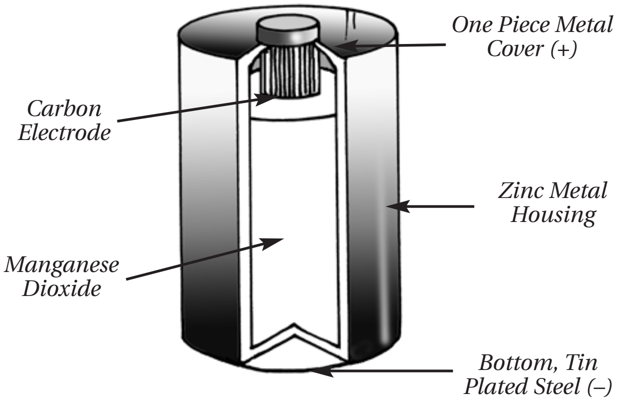
When two dissimilar metals, such as a copper and iron wire, are joined together at both ends, free electrons will pass haphazardly in both directions across the junction. Because of the different atomic structure of the metals, electrons pass more readily in one direction than in the other. This results in a displacement of charges, making one metal positive and leaving the other negative. By keeping one junction at a higher temperature than the other, a **thermal electromotive force** is obtained, and an electric current is produced.

A single junction of two different metals that are twisted, brazed or riveted together at one end, is called a **thermocouple**. Thermocouples are not used to produce electric current, since the effect is small. Their chief use is for measuring temperatures and currents in electrical appliances and furnaces.

What is electrochemistry?

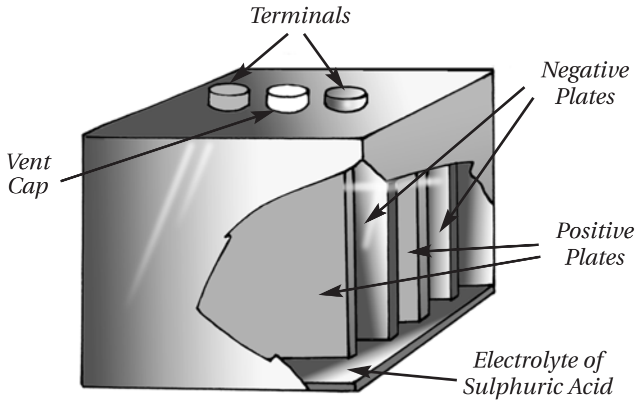
In 1795, the Italian physicist Alessandro Volta made the first **electrical cell** by placing two dissimilar metal **electrodes** in a conducting chemical solution, called an **electrolyte**. An **electromotive force** is produced in such a cell by the separation of charge, brought about by the chemical reaction between the electrodes and the electrolyte. This arrangement is know as a **voltaic cell** after its inventor. The electromotive force generated by a voltaic cell depends on the tendency of the electrodes' atoms to lose electrons and thus form positive ions.

The voltaic cell most widely used as a convenient source of “portable” electricity is the “**dry cell**,” or common flashlight **battery**. A typical dry cell consists of a zinc metal housing, which acts as the negative electrode, and a carbon rod in the center, acting as the positive electrode. The electrolyte is a chemical paste consisting of ammonium chloride mixed with manganese dioxide. The manganese dioxide absorbs hydrogen produced from the chemical reaction. In operation, the metallic zinc delivers positive zinc ions to the electrolyte, causing a difference in charge between the zinc and carbon electrodes. If the zinc and carbon electrodes are connected in a circuit, electrons will flow from the zinc electrode to the carbon electrode, producing an electric current of about 1.5 volts. Since the electric current produced by a battery flows only in one direction, it is called **direct current** (DC).



Dry Cell Battery

Secondary cells, also called **lead storage batteries**, deliver current by chemical reaction like voltaic cells. However, the chemical reaction in a secondary cell is reversible, permitting it to be restored to its original condition. To restore or recharge a secondary cell, all you have to do is pass an electric current through it in a direction opposite to that of its normal use or discharge. The lead storage batteries in automobiles are secondary cells.



Lead Storage Battery

What are magnetism and electricity?

Magnetism and **electricity** are not two separate phenomena. In fact, whenever an electric current flows, a magnetic field is created, and whenever a magnet moves, an electric current is produced. The properties of magnetism and electricity are both bound up in the nature of the physical structure and arrangement of atoms and their electrons. Materials that appear to be magnetic, without any outside source of electricity, depend on electron movement within their atomic structure to provide the electric current.

Electromagnetism is the effect by which electrical currents produce **magnetic fields**. The magnetic field around a straight wire is weak. Stronger magnetic fields are obtained by coiling wire into a spiraling loop, known as a **solenoid**. The effect of producing a solenoid is to increase the intensity of the magnetic field without having to increase the current. An iron-cored solenoid has a stronger magnetic field than that of an air-cored solenoid. This is because the electrons in the iron align themselves with the magnetic field produced by the current. Iron-cored solenoids are called **electromagnets**. Electromagnets energize the fields of motors and generators, and are part of telephones, loudspeakers, buzzers, electric bells, telegraphs, relays, electric meters and many other devices.

To produce an electric current from a magnet, the magnet must rotate inside a loop of wire or the wire loop must rotate between two magnets. The magnet creates an electromotive force, which causes the electrons in the wire to move, inducing an electric current. The rotation of the magnet or wire loop alternates between “pushing” and “pulling” the electrons due to the magnets polarity. The electric current produced thus alternates its direction of flow, and is, therefore, called **alternating current** (AC). Alternating current changes direction 60 times a second in North America.

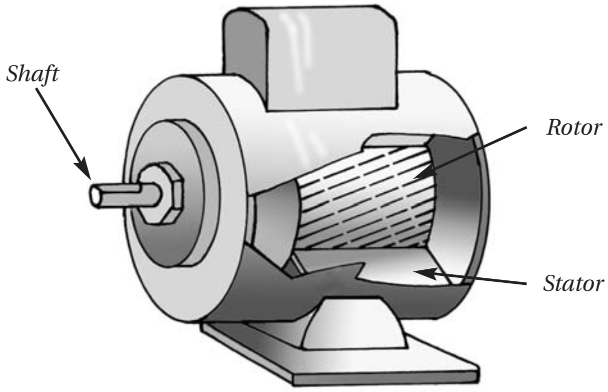
How do motors and generators work?

Motors and generators are basically the same in construction, although their functions are opposite. **Motors** are supplied with electrical energy to provide mechanical energy; **generators** are supplied with mechanical energy to produce electrical energy.

The two most essential elements of each of these machines are the **field** and the **armature**. The field is a magnetic field which may be derived from permanent magnets or electromagnets.

The armature is a conductor arranged to pass through the field’s magnetic lines of **flux** at right angles. The armature conductors may be wound onto a cylinder that rotates in the field, or they may be fixed to the inner walls of a cylinder, within which the field windings rotate. The armature is generally wound on a soft iron core to produce maximum flux for a given current. The soft iron is laminated (made up of thin slices) to prevent the electric current from circulating in the iron itself, and thus generating heat. The static part of the machine is called the **stator** and the revolving part the **rotor**. Both the field and the armature may be on either the stator or the rotor.

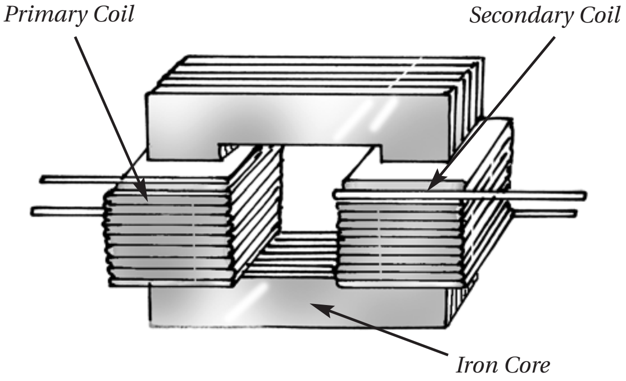
The armature must be supplied with electrical current if it is the rotor of a motor, and there must be a way of taking the electric current from it if it is a generator.



An Electric Motor

What is a transformer?

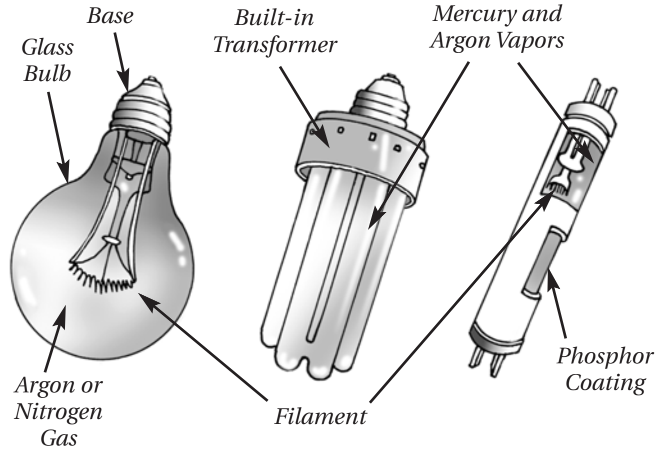
One of the most essential electrical devices is the **transformer**. It is used in power stations and at substations—in the former to boost voltages for transmission over power lines and in the latter to reduce voltages to levels suitable for industrial or domestic use. Transformers contain two separate wire coils wrapped around an **iron core**. Electricity flows into the transformer through the first coil. As the electricity flows through the first coil, it produces a magnetic field in the iron core. The magnetic field then induces an electric current in the second coil which flows out of the transformer. Oil is circulated around the coils and iron core to insulate and cool the transformer. If the voltage is to be increased, the second coil contains more turns of the wire than the first coil. If the voltage is to be decreased, the second coil contains fewer turns of the wire than the first coil. Transformers are also used in many electrical appliances—such as radios, televisions and battery chargers—wherever voltage different from the supply is required.



A Transformer

How does the light bulb work?

The **incandescent** light bulb consists of a thin resistive tungsten filament, attached to a metal screw-type base. The filament is mounted inside a glass bulb, which is filled with an inert gas—either argon or nitrogen. The inert gas prevents the rapid burning of the filament. The resistance causes the filament to be heated to incandescence, producing light, a form of energy.



Incandescent Bulb *Compact Fluorescent Lamp* *Fluorescent Lamp*

Fluorescent light bulbs contain filament-like electrodes at each end of the tube. The tube wall is coated with phosphor (a material that fluoresces under ultra-violet radiation) and is filled with mercury and argon vapors. Electricity flows through the filament, causing the filament to emit electrons. The electrons cause the mercury vapor to break down and discharge ultra-violet radiation, which causes the phosphor to fluoresce, producing light.

Fluorescent lights are more efficient than incandescent lights. A 40-watt fluorescent light bulb will produce the same amount of lumens (light) as a 150–watt incandescent light bulb.

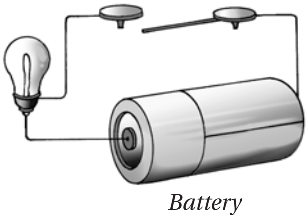
How does a circuit work?

An **electric circuit** is the system by which an electric current is directed or controlled—switched on or off. Circuits can contain from two or three to many hundred different components, according to the way in which the current is to be controlled.

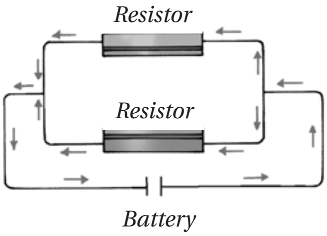
The primary requirement of a circuit is that it form a complete path; electrons must be able to flow through the whole system so that as many electrons pass back into the source of the current as leave it.

If the electricity is able to flow completely through the circuit, the circuit is said to be a "**closed-circuit**." (The light switch is on.) If the electricity is unable to flow completely through the circuit, the circuit is said to be an "**open-circuit**." (The light switch is off.)

There are two basic circuits which electricity flows through; **series** or **parallel**. In a series circuit all of the electrical components are connected to each other in a "series," thus the electric current has only one path to follow, and flows through each component. In parallel circuits, the electrical components are connected individually to the main electrical circuits, thus the electric current has more than one path to follow. Parallel circuits allow for individual control of each electrical component. Buildings, most appliances, motors, etc., are wired in parallel circuits.



Series Circuit



Parallel Circuit

How is electricity distributed in the home?

Electricity is brought to a house through a three-wire cable and connected via an **electric meter**, which indicates power consumption to the household **circuit breaker** or **fuse box**. The two "live wires" are then brought from the fuse box to power outlets (plug-ins), utility boxes (lighting), and wall switches. Each of the two live wires is at a voltage of 120 volts relative to ground and 240 volts relative to each other. The third wire, or neutral, is brought to a grounding bar in the circuit breaker box, or attached to a metal cold water pipe, as well as to all power outlets, utility boxes, and wall switches. Every appliance that is plugged into an outlet also has a ground connection. The appliance ground is connected to the metal or plastic case of the appliance.

If the two live wires should inadvertently come in contact with each other or the ground, a "**short circuit**" occurs which can result in a fire. In a properly wired house, such a short circuit causes a fuse to melt or a breaker to open, thus breaking or opening the circuit preventing electricity from flowing to that portion of the house or appliance and causing damage.

Fuses contain a metal alloy strip that melts when overloaded. **Circuit breakers** are essentially heat or current activated switches that open when overloaded.

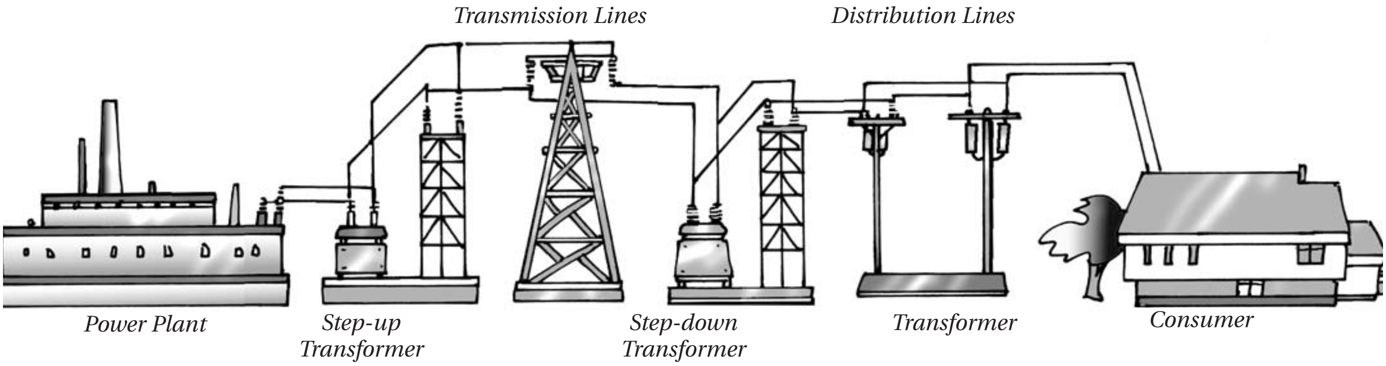
At each power and lighting outlet no current flows until a lamp or appliance is plugged in and switched on. However, there is always a voltage at that point whether current flows or not. It is like a water tap; the pressure is always there although there is no flow until it is turned on.

How is electricity generated, transmitted and distributed?

Heat, produced by the combustion of fossil fuels (coal, oil or natural gas) or the fission of uranium, is used to convert water to steam. The **steam** is piped to a **turbine** where it pushes against the turbine blades, causing the turbine shaft to rotate. The rotating turbine shaft is connected to the **generator's** magnet. As the turbine shaft rotates, it spins the generator's magnet. The spinning magnet, surrounded by massive wire coils, induces an **electric current** in the wire coils. The generator produces an electric current of about 22,000 volts. The electric current flows from the generator to a **transformer** where the voltage is increased or stepped up.

The voltage is increased to reduce **transmission loss**. Transmission loss is due to the **resistance** in the transmission line to the flow of the electric current. The resistance produces heat. As the electric current increases, so does resistance and thus transmission loss. Since the same power can be obtained by either transmitting electricity at high current and low voltage or high voltage and low current, it is more efficient to transmit electricity at high voltage and low current, as less electricity is converted to heat through transmission line resistance. However, at high voltages the air surrounding the transmission line becomes partially ionized and some electricity is lost through atmospheric discharge. The distance the electricity needs to be transmitted determines how much the voltage is increased; the voltage can be stepped up to as high as 765,000 volts. A 765,000-volt transmission line can transport as much electricity as five 345,000-volt transmission lines, due to transmission loss of the lower voltage system.

From the power plant transformer, the electricity is transmitted throughout the electric utility's service area through high power **transmission lines**. The utility's transmission lines are also connected with other electric utility's transmission lines forming a **power pool**. The transmission lines transport the electricity to the electric utility's local substations. **Substation** transformers decrease or step down the voltage to between 5,000 and 35,000 volts (12,000 volts is the most common). In some older areas of a city or town you may see wooden utility poles with power lines running to each house or business



Generation, Transmission, and Distribution

and a small transformer hanging on one of the power poles. In some areas of newer construction, the distribution lines are underground. Underground, the power lines are protected from the weather, which can cause lines to break, and people are protected from the dangers of the over-head lines. It is important though, to remember to ask utility companies—electric, natural gas or telephone—to mark their underground lines before you begin digging on your property.

What is energy conservation?

For the past 100 years, electricity has made our homes more comfortable and enjoyable, and our industries more productive. And today, electricity is powering a new world of electronics—computers, TVs, CDs, DVDs, VCRs. To generate this electricity, the nation's power plants rely on finite natural resources such as coal and natural gas, as well as renewable energy sources such as water and wind. Using these energy sources does have an impact on the environment. It is important, therefore, to use electricity as efficiently as possible. This will help to protect our environment and preserve our natural resources. Using electricity wisely will also help you save money in your home and business, and will keep our nation's electricity supply more reliable.

Residential appliances consume roughly one-third of the electricity produced in the United States. Refrigerators alone utilize the electrical output of about 25 large power plants, nearly seven percent of the nation's total consumption. Improving the energy efficiency of appliances is, therefore, an important step toward conserving fuel resources.

When buying home appliances it is important to:

- Check the energy efficiency rating. Find out about the Energy Star program.
- Purchase the right size appliance. Oversized appliances consume more electricity and undersized appliances will have to work harder and thus, consume more electricity.
- Compare the wattage of appliances. Wattage will inform you how much electricity the appliance will consume.

Also be sure to turn off electrical appliances and electronic equipment when you are not using them. Use compact fluorescent bulbs when possible and always turn off lights when not in use.

Is electricity safe?

When used properly, electricity is a safe and convenient form of energy, but when used improperly, electricity can cause fire, shocks, injuries, and even death. The following safety tips will help you avoid electrical accidents.

- Be careful with electric cords. Don't place cords where people will trip over them or where they will receive excessive wear. Keep cords away from heat and water. Don't pull on cords to disconnect them, pull on the plug. Don't twist, kink or crush cords.
- Never use an electrical appliance while you are standing in water or when you are wet.
- Keep combustible materials away from lamps or heating devices.
- Disconnect appliances before cleaning.
- Keep ladders away from electric power lines.
- Turn off switches when changing light bulbs or when you are wiping the dust off bulbs.
- In case of an electrical fire, call the fire department. Unplug the appliance, if you can do safely. Use a fire extinguisher or baking soda to extinguish the fire, never use water.
- Never touch broken electric lines. Call police and the electric company immediately.

- In case of electric shock, do not touch the victim until the electricity is turned off. If the victim is in contact with the electric power lines, call the power company. If the victim is in contact with a low voltage cord, use a dry rope or stick to remove victim. Call the hospital and, if necessary, give artificial respiration. For shock, cover the victim and raise his/her feet.
- Never attempt to remove a kite from electric power lines. Be aware of the location of electric power lines when flying kites.
- When climbing trees, be sure that electric power lines don't touch the tree; if they do DO NOT climb the tree.

What is green power?

Across North America green power partnerships have been developed to promote the use of renewable energy to generate electricity.

Green power is electricity that is generated from resources such as solar, wind, geothermal, biomass, and hydropower facilities. Presently a high percentage of electricity is generated by burning fossil fuels. However, the increasing availability of green power allows customers the opportunity to purchase power that is environmentally friendly. As more green power sources are developed the overall environmental impact associated with electricity generation will be reduced.

Purchasing green power does not mean the electricity entering your home is the exact electricity produced by the renewable energy source. It means a utility purchases a portion of its power from a renewable source and offers its customers the opportunity to support their purchase of green power.

Customers can install their own renewable energy generating equipment at their facility. On-site renewable generation can increase power reliability, provide stable electricity costs and help manage waste streams. In many areas, excess green power generated on-site can be returned to the electric grid, allowing customers to obtain credit from their utility.

For more information log onto: www.epa.gov/greenpower or www.mb.ec.gc.ca

What is distributed generation?

Distributed generation is not a new concept. In the early 1970s it was called "on-site generation" and usually existed in two forms:

- **Backup/emergency generation**—such as that at a hospital, hotel, and/or manufacturing facility.
- **Cogeneration**, the production of heat and power to support the energy needs of a user.

Today distributed generation (DG) is defined as electric generation connected to the distribution level of the power grid usually located at or near the intended place of use.

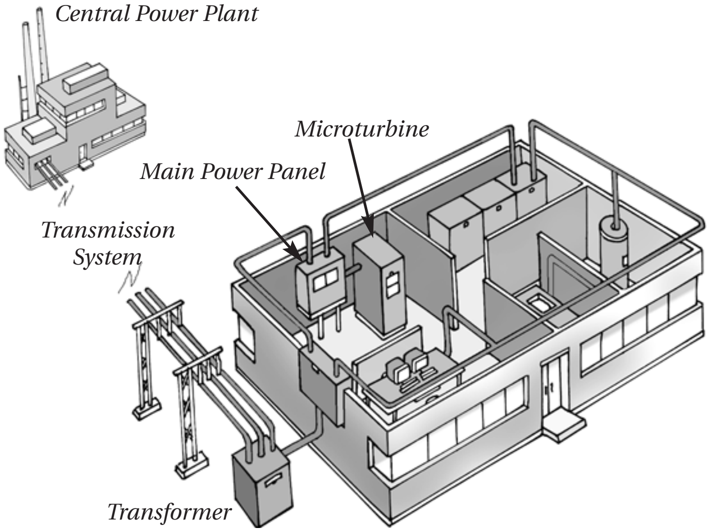
Distributed generation allows customers to reduce their reliance on the transmission system by "distributing" or placing smaller generators (many of which use renewable energy) closer to the locations at which electricity is used—at customers' homes or businesses.

The **generator** or **microturbine** connects directly to a facility's electrical distribution system—either operating in parallel with the utility grid or when grid power is not available. Microturbines can operate on a variety of fuels—natural gas; methane gas, a by-product of organic waste and industrial processes; wind; water; or solar. Installing reliable, on-site electric capacity does not require additional transmission lines or new central power plants.

For many commercial and industrial businesses, interruptions and losses from a power outage can be very costly. By taking advantage of on-site power generation, businesses can avoid such interruptions and maintain a steady workflow. For businesses, or even homes in remote areas, microturbines are designed to continuously generate electricity without a connection to the power grid.

One of the problems of distributed generation seen by local utilities is based on safety concerns. Utility crews working in the field may not know that current is flowing from a distributed source and can be seriously or even fatally injured.

Distributed generation is not now and probably never will be a replacement for central station power, but it can be a distribution system support to help balance supply and demand.



A birds-eye view of how distributed generation can work. Electricity can be supplied to the facilities main power panel by either the central power plant or the microturbine.