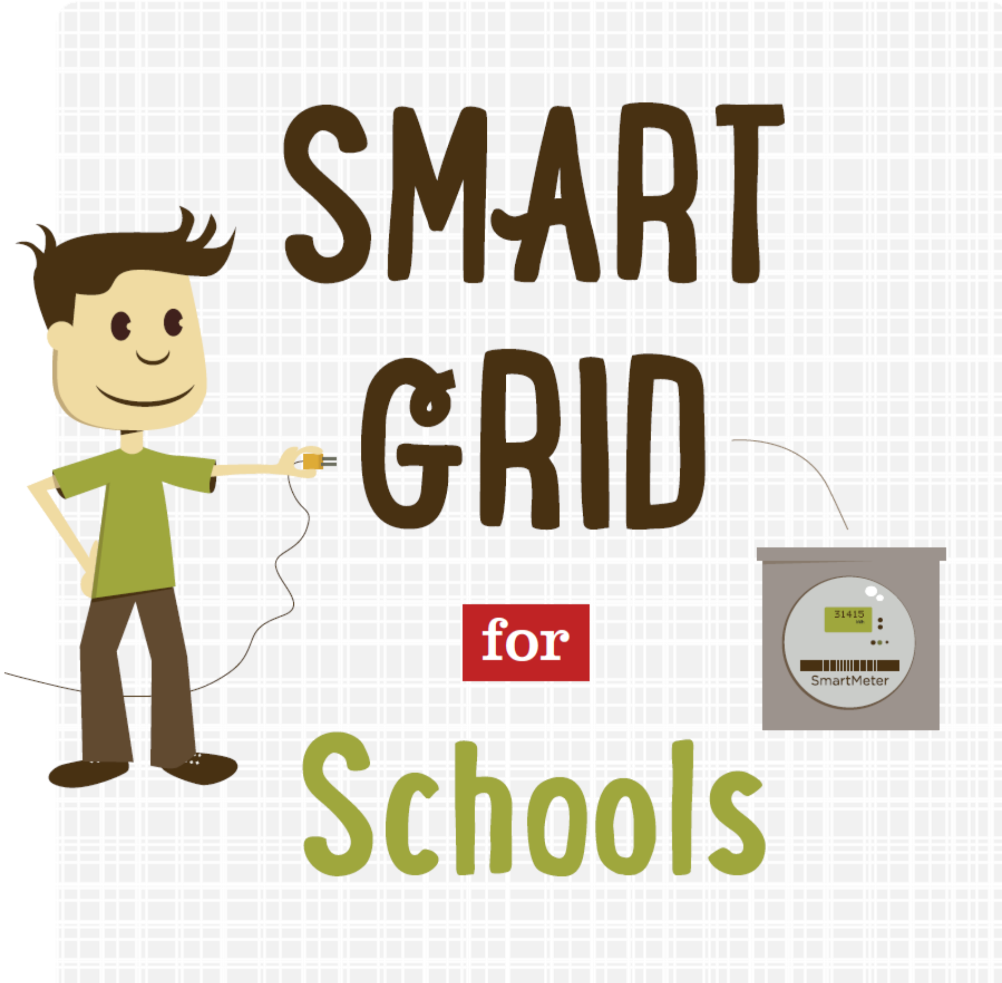

Construction Set Curriculum

Grades 4-8

Teacher Edition

Center for Mathematics Science and Technology

Center for Renewable Energy

Illinois State University

Normal, Illinois

Introduction:

The Smart Grid Construction Set allows your students to build a model of the electrical grid system in the same manner in which the actual grid was built. They start with early forms of energy and trace how electricity changed the landscape of energy production and use. Your students will study Michael Faraday and see his discoveries in action as they convert their muscle power into electricity. They will then see a demonstration of a steam engine and learn how it was connected to a generator to produce power. They will hook up a factory and then houses to their power plant and expand to it serve many customers. Your students will experience the need for monitoring as their grid grows and determine where sensors should be inserted. They will also learn about switching as they combine power grids to form a complex electrical grid system.

Use:

Each box (black plastic tote) of the Construction Set contains enough materials for up to sixteen students simultaneously. There are four different power plants that plug into one Headquarters Office. It is recommended that up to four students are assigned to each power plant. From these power plants, each group will create their electrical grid model. Later they will combine their grid lines into a larger grid. The curriculum is divided into time periods so that the students build their grid in the same manner as the actual grid was developed.

The amount of time required will vary by class, but figure that it will take approximately 1 hour for students to get their initial grid line hooked up. It will require another hour for students to install monitors and combine their grids with switching stations.

Safety:

The entire system operates on five volts of direct current (DC). This power comes from the Headquarters Office, not the individual power plants. This way voltages can be controlled easily regardless of the number of power plants. The low voltage poses very little risk of injury to students.

Do not allow students to connect the hand-crank generator to the grid system. It can produce far too much voltage and will destroy the LED lights. Be certain all generators are put away before work begins on the grid.

Since the electricity is DC and all of the lights are diodes (LED) polarity is important. The red, black, and blue wires must be used on the springs and the white wires on the alligator clips.

A direct short will result anytime a colored wire and white wire come into contact with each other. Since the voltage is so low, a spark probably will not be noticeable, nor will anything immediately become hot or start to burn. The green light on the power supply will begin to blink and power will automatically shut off. There is a two amp fuse on each power plant that will "blow" with a direct short. To restore power, simply remove the direct short and replace the fuse if necessary. Inspect student work to avoid direct shorts and fix the problem immediately if a short inadvertently occurs.

The Smart Grid for Schools program can be used to address several educational standards in Science (NGSS), Mathematics (CCSS.Math), Social Studies (SS), and English Language Arts (CCSS.ELA). Many of these standards are addressed within the curriculum while others can be addressed by implementing optional enhancements.

Grade Level	Discipline and Standard	Where and how the standard is addressed
Fourth	CCSS.ELA.W.4.2. Write informative/ explanatory texts to examine a topic and convey ideas and information clearly.	The discussion questions could be assigned as written responses in complete sentences. They could also be assigned reports on an energy-related topic requiring research. Another option is for them to write and illustrate instructions for how they made their grid. Pg 46
Fourth	CCSS.ELA.RI.4.5. Describe the overall structure (e.g., chronology, comparison, cause/effect, problem/solution) of events, ideas, concepts, or information in a text or part of a text.	These instructions are written in a Learning Cycle format. Students could be assigned to review and critique these instructions. Pg 47
Fourth	CCSS.ELA.W.4.7. Conduct short research projects that build knowledge through investigation of different aspects of a topic.	Many students will be very interested in this project and will want to learn more. Some may even consider a career in the electrical energy field because of this exposure. Facilitate independent research. Pg 16
Fourth	CCSS.ELA.W.4.8. Recall relevant information from experiences or gather relevant information from print and digital sources; take notes and categorize information, and provide a list of sources.	Require entries into a journal concerning the students experience with the Smart Grid for Schools system. Encourage them to organize this information into a digital slide show to be presented to parents and/or school board members. Pg 47
Fourth	NGSS.4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.	Ask students how the electrical energy is getting from the power plant to the customers. What do customers use electricity to do? Most of these models change electricity into light. The factory changes it to motion. What changes occur in their homes? Pg 28
Fourth	NGSS.4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.	Electrical energy is converted to light or motion in these models. Encourage students to experiment with other circuits and devices. Do not connect other devices to this set since it is not designed to handle additional loads. Pg 22
Fourth	NGSS.4-ESS3-1. Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment.	On page 24 (TE) students are asked to select the best power plant. This provides the opportunity to discuss energy sources and their impact on the environment and economy. Pg 29
Fourth	CCSS.ELA.RI.4.1. Refer to details and examples in a text when explaining what the text says explicitly and when drawing inferences from the text.	Note that Edison did not invent the light bulb. Edison made the bulb possible by inventing the system that made it available to lots of people. Pg 28

Grade Level	Discipline and Standard	Where and how the standard is addressed
Fourth	4. OA 2 Multiply or divide to solve word problems involving multiplicative comparison, e.g., by using drawings and equations with a symbol for the unknown number to represent the problem, distinguishing multiplicative comparison from additive comparison.1	Work fluidly with watts, volts, and amps. Watts is a measure of power. Volts is a measure of pressure, and Amps is a measure of volume. Watts= Volts x Amps Most outlets in a house are 120 volts. Watts or Amps are often printed on tags on electrical devices. Most fuses in a home are set to turn off at either 10 amps or 15 amps, depending on the size of the wire. Pg 34
Fourth but also appropriate for grades 5-8	CCSS.MATH.CONTENT.4.NBT.B.4 Fluently add and subtract multi-digit whole numbers using the standard algorithm. CCSS.MATH.CONTENT.4.NBT.B.5 Multiply a whole number of up to four digits by a one-digit whole number, and multiply two two-digit numbers, using strategies based on place value and the properties of operations. Illustrate and explain the calculation by using equations, rectangular arrays, and/or area models. CCSS.MATH.CONTENT.4.NBT.B.6 Find whole-number quotients and remainders with up to four-digit dividends and one-digit divisors, using strategies based on place value, the properties of operations, and/or the relationship between multiplication and division. Illustrate and explain the calculation by using equations, rectangular arrays, and/or area models. Similar standards can be found in grades 5-8.	Calculate the power output of students in the class. See ***Your Horsepower*** on page 10. Work = Force x Distance (going up, not horizontal) Power = Work / Time 1 horsepower = 550 pounds lifted 1 foot in 1 second 1 horsepower = 745 watts. Pg 10
Fifth	CCSS.ELA.RI.5.8. Explain how an author uses reasons and evidence to support particular points in a text, identifying which reasons and evidence support which point(s).	Review this document to identify key points and how those points are supported with evidence (references). Encourage additional research on energy-related topics to develop well-informed opinions and clear action steps. Pg 13
Fifth	CCSS.ELA.W.5.8. Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources.	Throughout the activity students are learning from experience and from the information presented in the curriculum. A written summary of the experience can be assigned. Pg 47
Fifth	CCSS.MATH.CONTENT.5.MD.A.1 Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems.	Measure distances between the customers and the power plant in various units and convert using a scale to real-life distances. For example, how far is your school from the nearest power plant? Are others further? Represent those distances on your model grid. Pg 31

Grade Level	Discipline and Standard	Where and how the standard is addressed
Fifth	SS.IS.5.3-5. Develop claims using evidence from multiple sources to answer essential questions.	A series of questions are presented in each of the "Discussion" sections of the curriculum. Student responses should be based on evidence. Also, several questions are included at the end of the activity prompting further research. Pg 44
Fifth	SS.IS.8.3-5. Use listening, consensus building, and voting procedures to decide on and take action in their classroom and school.	Now that students are somewhat familiar with the electrical energy and the distribution grid, ask them to identify (and possibly implement) actions that could be taken at their school to decrease energy use. To be successful, groups of students must listen to each other and reach consensus on what they are to do while designing and building their electrical grid. A culminating activity addresses energy conservation in their classroom and school which will require research, presentations, and voting. Pg 46
Fifth	CCSS.MATH.CONTENT.5.NF.A.1 Add and subtract fractions with unlike denominators (including mixed numbers) by replacing given fractions with equivalent fractions in such a way as to produce an equivalent sum or difference of fractions with like denominators.	Calculate total resistance in a circuit. See ***STEM of Energy*** on pages 44 and 45.
Fifth	CCSS.MATH.CONTENT.5.NBT.A.2 Explain patterns in the number of zeros of the product when multiplying a number by powers of 10, and explain patterns in the placement of the decimal point when a decimal is multiplied or divided by a power of 10. Use whole-number exponents to denote powers of 10.	Electricity is measured in Watts. Most often, however, it is seen as kilowatts (kW) or megawatts (MW). 1 MW = 1000 kW 1 kW = 1000 watts Research the power output of wind turbines, solar, coal, natural gas, and nuclear power plants converting data to a common unit. Pg 24
G3-5	NGSS. 3-5-ETS1-1 Define a simple design problem reflecting a need or a want that includes specific criterial for success and constraints on materials, time, or cost. NGSS.3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem. NGSS.3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.	When completed with this activity, propose that students design and build a model of the electrical grid of the future using all renewable energy sources. Provide them criteria and constraints such as power requirements and location restrictions. Test their designs to find failure points and aspects in need of improvement. Pg 47

Grade Level	Discipline and Standard	Where and how the standard is addressed
Sixth	CCSS.MATH.CONTENT.6.NS.A.1 Interpret and compute quotients of fractions, and solve word problems involving division of fractions by fractions, e.g., by using visual fraction models and equations to represent the problem.	Each switch will control a fraction of the entire grid. As grid lines are combined, each switch will control a fraction of a fraction, providing opportunity to work fluidly with fractions. Pg 35
Sixth	CCSS.MATH.CONTENT.6.SP.B.4 Display numerical data in plots on a number line, including dot plots, histograms, and box plots. CCSS.MATH.CONTENT.6.SP.B.5 Summarize numerical data sets in relation to their context,	Research types of power plants and determine changes necessary to reach Illinois energy goal of 25% renewable energy by 2025. Pg 29
Seventh	CCSS.MATH.CONTENT.7.RP.A.3 Use proportional relationships to solve multistep ratio and percent problems.	Compare output of various power plants as percents and ratios. For example, how many wind turbines or solar farms will be necessary to generate the power of one nuclear plant? Pg 29
Seventh	CCSS.MATH.CONTENT.7.SP.A.1 Understand that statistics can be used to gain information about a population by examining a sample of the population; generalizations about a population from a sample are valid only if the sample is representative of that population. Understand that random sampling tends to produce representative samples and support valid inferences. CCSS.MATH.CONTENT.7.SP.A.2 Use data from a random sample to draw inferences about a population with an unknown characteristic of interest. Generate multiple samples (or simulated samples) of the same size to gauge the variation in estimates or predictions. CCSS.MATH.CONTENT.7.SP.B.3 Informally assess the degree of visual overlap of two numerical data distributions with similar variabilities, measuring the difference between the centers by expressing it as a multiple of a measure of variability. CCSS.MATH.CONTENT.7.SP.B.4 Use measures of center and measures of variability for numerical data from random samples to draw informal comparative inferences about two populations.	Use a survey to gather data about energy use, conservation techniques, attitudes about various power plants, or other energy-related topics. Compare by grade level at the school or with adults. Pg 25

Grade Level	Discipline and Standard	Where and how the standard is addressed
Eighth	CCSS.MATH.CONTENT.8.EE.B.5 Graph proportional relationships, interpreting the unit rate as the slope of the graph. Compare two different proportional relationships represented in different ways.	Use Ohms Law to compare the relationship between resistance, voltage, and current. See ***STEM of Energy*** on pages 44 and 45.
Eighth	CCSS.MATH.CONTENT.8.F.A.1 Understand that a function is a rule that assigns to each input exactly one output. The graph of a function is the set of ordered pairs consisting of an input and the corresponding output.1	Complete various calculations of Ohms Law and graph the results. See ***STEM of Energy*** on pages 44 and 45.
Middle School	NGSS MS-PS2-3 Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. NGSS MS-PS4-3 Integrate qualitative scientific and technical information to support the claims that digitized signals are a more reliable way to encode and transmit information than analog signals.	Now that students have some experience with electricity, encourage them to make a telegraph system. They can set up "telegraph offices" at various places in the classroom. A telegraph is a digital system, consisting of either "on" or "off" signals. Pg 47
Middle School	NGSS MS-ESS3-5 Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.	Research the role of electrical power plants in producing pollution. Compare natural gas, coal, nuclear, and renewable sources including not only their operation, but also their construction, maintenance, and dismantling. Pg 47
Middle School	MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.	Assign that groups of students develop a system to generate and distribute electricity in a manner that minimizes harmful impacts. Pg 47

Career Connections:

The Smart Grid for Schools program provides an excellent introduction to energy-related careers.
All data is from the Occupational Outlook Handbook found at www.bls.gov . There is a page inserted for the student (pg 15 SE and pg 22 TE) but it does not contain as many listings as in the Teacher Edition.

Career Title	Description	Education Required	Median Salary In 2018	Job Outlook 2018-2028
Power plant operator	control the systems that generate and distribute electric power.	High school diploma. Long-term on-the-job training	\$83,020 per year \$39.92 per hour	-6% decline -3,100 jobs
Line installers and repairers	install or repair electrical power systems and telecommunications cables, including fiber optic	High school diploma. Long-term on-the-job training	\$65,880 per year \$31.67 per hour	+4% increase +10,700 jobs
Solar photovoltaic (PV) installers	assemble, install, and maintain solar panel systems on rooftops or other structures.	High school diploma. Moderate-term on-the-job training	\$42,680 per year \$20.52 per hour	+63% increase +6,100 jobs
Nuclear Engineers	research and develop the processes, instruments, and systems used to derive benefits from nuclear energy and radiation.	Bachelor's degree	\$107,600 per year \$51.73 per hour	-1% decline -100 jobs
Wind turbine service technicians	install, maintain, and repair wind turbines.	High school diploma. Long-term on-the-job training	\$54,370 per year \$26.14 per hour	+57% increase +3,800 jobs
Electrical engineers	design, develop, test, and supervise the manufacture of electrical equipment	Bachelor's degree	\$99,070 per year \$47.63 per hour	+2% increase +8,000 jobs
Geoscientists	study the physical aspects of the Earth	Bachelor's degree	\$91,130 per year \$43.81 per hour	+6% increase +1,800 jobs
Environmental engineers	use the principles of engineering, soil science, biology, and chemistry to develop solutions to environmental problems.	Bachelor's degree	\$87,620 per year \$42.13 per hour	+5% increase +2,900 jobs
Electricians	install, maintain, and repair electrical power, communications, lighting, and control systems.	High school diploma or equivalent	\$55,190 per year \$26.53 per hour	+10% increase +74,100 jobs
Electro-mechanical technicians	operate, test, and maintain unmanned, automated, robotic, or electromechanical equipment.	Associate's degree	\$57,790 per year \$27.78 per hour	+1% increase +100 jobs
Heating, air conditioning, and refrigeration technicians	work on heating, ventilation, cooling, and refrigeration systems.	High school diploma. Long-term on-the-job training	\$47,610 per year \$22.89 per hour	+13% increase +46,300 jobs

SMART GRID for Schools

Construction Set Curriculum

Grades 4-8

Nearly everything requires some type of energy. Of course moving a car or bus, manufacturing products, and constructing buildings require energy, but also the "little things" like heating your food and charging your cell phone. Energy allows things to be done. Imagine what would happen if electricity was shut off at your school. We are all very dependent on reliable energy.

Nearly all work was done entirely by muscle power until just the past 200 years or so. Using animals helped to make work easier and more efficient, but both humans and animals have very little power and get tired quickly.

Inventors have always been looking for ways to produce power that is reliable and inexpensive. Around 200 B.C. Europeans were using waterwheels to crush grain, saw wood, and do many more tasks. In 1000 A.D., the Dutch had harnessed the power of wind to do many of the same tasks as well as pump water out of manmade basins to expose land.

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Your Horsepower

When James Watt first invented the steam engine, he was naturally asked how much power it produced. Since everyone was familiar with horses, he came up the term "horsepower" and the formula to calculate it. He based his equation on measurements he took from an average draft horse.

How much horsepower can you produce? Lets find out.

Work

1. **Work** is **Force** X **Distance**. The force is how much weight you move and the distance is how far up it goes. Going horizontally does not count. You can run for miles on flat land and do no work. Not fair, is it?
2. Step on a scale and write down your weight it pounds. This is the ***Force.***
3. Go to a long straight set of stairs. Measure the riser (up) on one step in a staircase (in inches). Multiply by the number of steps to get the total ***Distance*** up. Divide total inches by 12 to get feet. Remember, the length does not matter, only the height.
4. Multiply the ***Force*** by the ***Distance*** to get the amount of ***Work*** done. It is measured in ***foot pounds***. You will see that lighter students do less work. Heavier students will do more work.

CCSS.MATH.CONTENT.4.NBT.B.4 CCSS.MATH.CONTENT.4.NBT.B.5
CCSS.MATH.CONTENT.4.NBT.B.6

Power

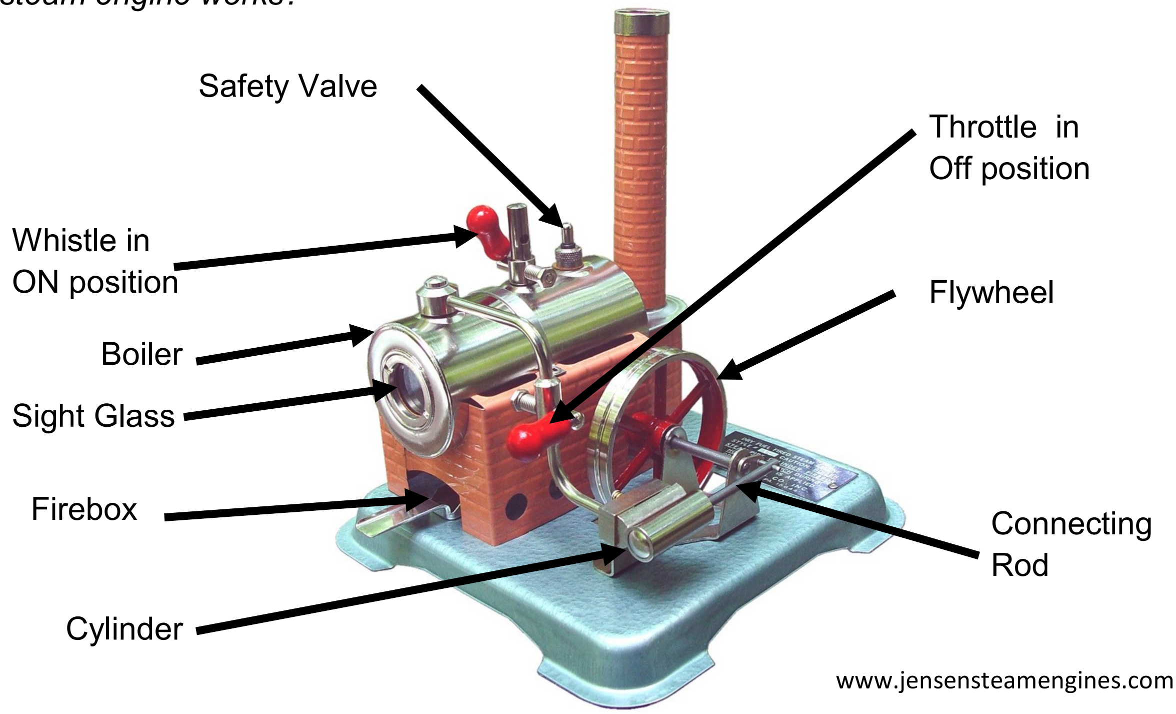
1. **Power** is **Work** divided by **Time.**
2. Have a friend time you as you run up the stairs as fast as possible. Write this down in seconds.
3. Divide ***Work*** by ***Time*** to get ***Power*** measured in ***foot pounds per second***
4. Divide ***Power*** by 550 to get ***horsepower***. 1 hp = 550 ft-lbs / second
5. Multiply ***horsepower*** by 746 to get ***watts***. 1 hp = 746 Watts

   It is very rare for a human to produce over 1 horsepower for more than a few seconds.
6. How do you compare? How long can you produce that much power?

Horse	Up to 15 horsepower for short periods of time. Average about 1 horsepower for a day of work.
Blow Dryer	1000 to 1500 watts, curling irons are usually 150 watts
Lawnmower	Small push mowers are usually 3.5 to 5 hp. Riding mowers usually are 10 to 22 hp.
Electric bicycle	Usually between 300 and 750 watts although some are larger.
Car	An average car is usually between 100 and 200 horsepower. Race cars are closer to 1000 hp.

Steam Power (1769-1820): Exploration

Wind and water are unpredictable, however, so other sources of energy were sought. In 1769, James Watt, a Scottish engineer, patented the modern-day steam engine. Steam engines quickly replaced less reliable sources of power. How do you think a steam engine works?



Your teacher will set up a steam engine and provide it with fuel.

Record what happens as the engine begins to run.

Teacher Note:

The steam engine is used only as a teacher demonstration. Unscrew the safety valve and use the small funnel to fill the boiler with water to about halfway up the sight glass on the end. Place 2 fuel tablets on the firebox tray. They light easily with a match. Within about 5 minutes steam pressure will build to the point that the engine will run. Usually this requires adjustment of the throttle and a quick flip of the flywheel. The whistles will be very effective in getting the students attention. Spend as little or as much time on the engine as your pacing allows. The main idea of including the steam engine is to provide a historical perspective on the transfer of energy. You may wish to use a rubber band as a drive belt to spin the shaft of a small motor. This will generate about 2 volts of electricity that can be measured with the multimeter (set on DC voltage) or possibly illuminate a small bulb. The fuel tablets can be extinguished by blowing them out. The engine will get hot so be careful when handling it and be sure it has cooled before packing it away.

Operation of the Steam Engine:

The chemical energy stored in the fuel tablet is converted to heat energy through burning (combining with oxygen). The heat is transferred to the water in the boiler. Since water expands 1600% when converted from a liquid to gaseous form (steam) pressure builds in the closed container. It would eventually burst the boiler if this pressure was not released through a valve or safety mechanism.

As the throttle valve is opened, steam pressure moves through the pipe to the valve mechanism. Notice how the cylinder rocks back and forth on a pivot point as the flywheel spins. When the top end of the cylinder rocks up, a hole in the side of the cylinder aligns with the steam pressure hole. Steam pressure is directed into one side of the cylinder where it pushes on the top of the piston. As a result, the piston slides to the other end of the cylinder. This motion is captured by the connecting rod and finally to an offset pin on the side of the flywheel. The reciprocating motion of the piston and connecting rod is converted to rotary motion at the flywheel.

As soon as the piston reaches the end of the cylinder, the energy stored in the spinning flywheel pushes the piston back into the cylinder. The cylinder rocks down, aligning the hole in the side of the cylinder with another hole that is just below the steam inlet hole. Steam can escape from this exhaust hole. Since the steam only pushes the piston one direction, this engine has a single-acting piston.

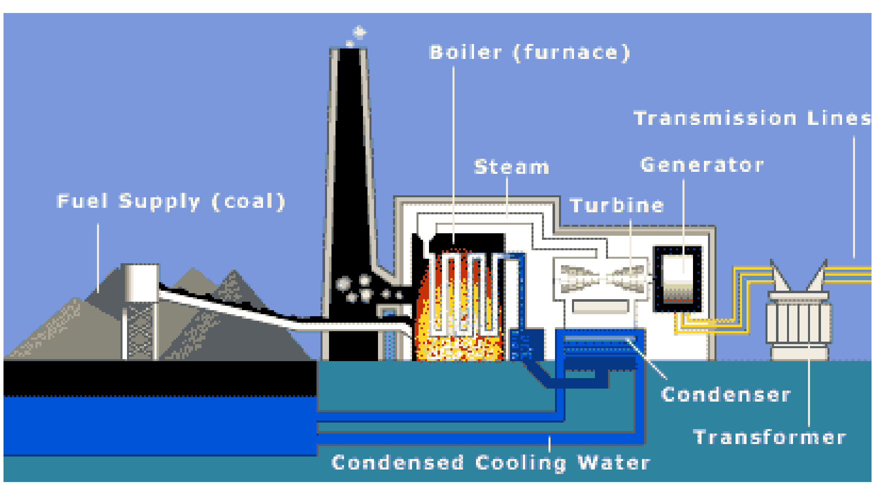
Steam locomotives use a side valve that first directs steam pressure to the top of the piston (pushing it down) and then sends steam pressure to the bottom of the piston (pushing it up). This is called a “double acting” engine since the piston is pushed both directions. A double acting engine runs much smoother and provides much more power than a single acting engine. As the slide valve is directing steam pressure to one side of the piston, it is also opening a hole on the other side of the piston so that the steam that had been on that side can escape. On a steam locomotive, this exhaust steam is directed up through the smoke stack resulting in “puffing” of the smoke and the characteristic “chug, chug, chug” sound.

An internal combustion engine in an automobile is not double acting. The piston is only pushed down, never up. Double acting is not practical with a gasoline or diesel engine.

The modern reciprocating steam engine was designed by James Watt in the mid-1700s and was still in operation in locomotives 200 years later. Modern power plants and many large ships use steam power, but with a turbine rather than a reciprocating engine. The steam turbine consists of a series of fan blades mounted on a single shaft. As steam pressure enters one end, it causes the fan blades to spin at a very high rate of speed. A series of gears slows the speed of the turbine shaft to spin a generator or the shaft of a propeller in a boat.

Nuclear energy, coal, and natural gas are all used to heat water into steam. So, other than the source of heat, all power plants are basically the same.

1. Water is heated into steam (chemical or nuclear energy converted to heat)
2. Steam turns a turbine (heat converted to mechanical motion)
3. The turbine turns a generator (mechanical motion converted to electrical energy)



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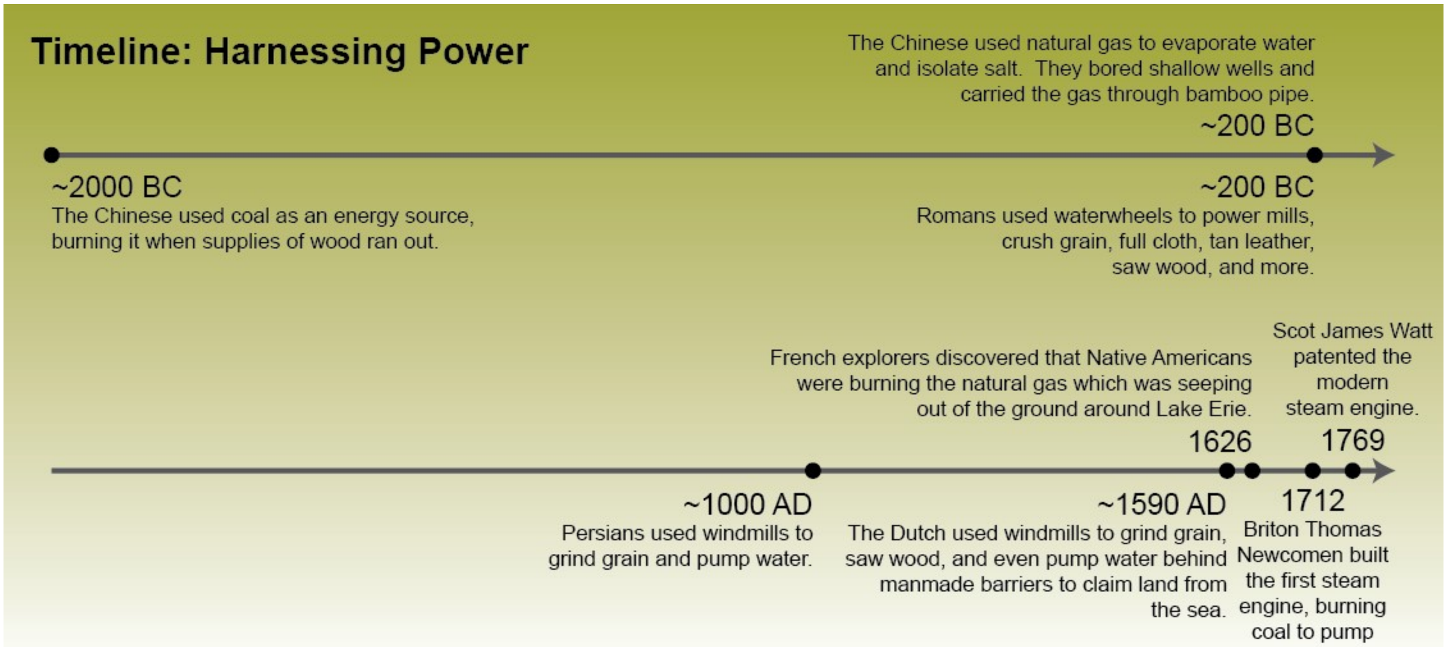

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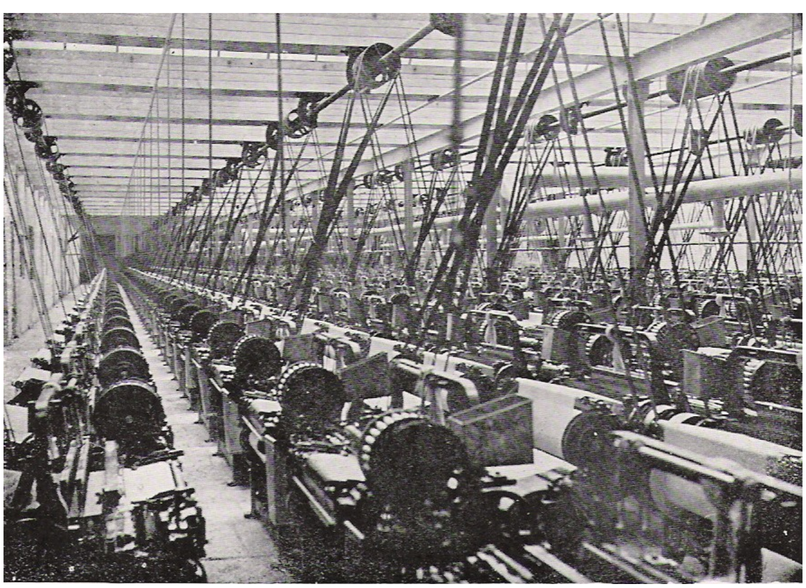
A steam engine provides great power to get work done, but only in a mechanical form – it must create motion. Factories using steam power in the 1800s transferred its mechanical motion throughout their work areas using long shafts with many pulleys and gears. Imagine how dangerous it would be to work in this factory!

CCSS.ELA.RI.5.8. Explain how an author uses reasons and evidence to support particular points in a text, identifying which reasons and evidence support which point(s).

Review this document to identify key points and how those points are supported with evidence (references). Encourage additional research on energy-related topics to develop well-informed opinions and clear action steps.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The shafts, belts, and pulleys which transferred power from a steam generator to factory machinery can all be seen in this textile factory.

Steam Power (1769-1820): Discussion

1. What is the source of energy for this steam engine?

   The energy that drives the steam engine is stored as chemical energy within the fuel.

2. What happens to the water as the fuel burns?

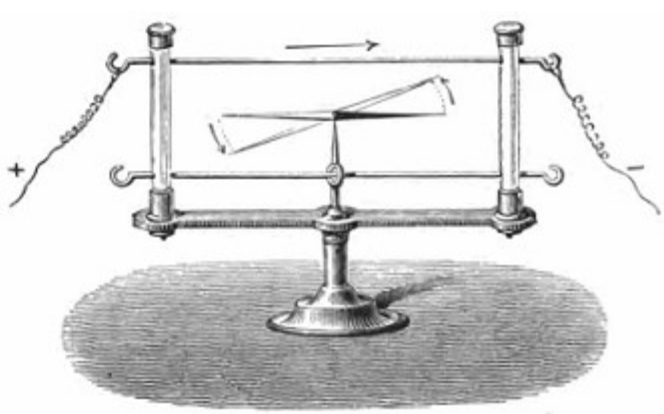
   The water gets hot and changes from a liquid to a gaseous (steam) form at 100^0 C. During this phase change, it expands by 1600%, producing pressure within the closed boiler.

3. Energy can be classified into many forms including thermal (heat) energy, chemical (stored) energy, mechanical energy (energy of motion), and/or electrical energy. What are the energy transformations you have seen in the steam engine?

____chemical_____ → __heat________ → __mechanical______________

Linking Magnetism & Electricity (1820-1831): Exploration

In 1820, Dane Hans Christian Oersted found that his compass needle moved when placed near a wire connected to a battery. A few years later, Frenchman Andre-Marie Ampere discovered that two wires with energy running in different directions could attract and repel one another, just like magnets. A decade later, Englishman Michael Faraday figured out that magnetism makes electricity and electricity makes magnetism.



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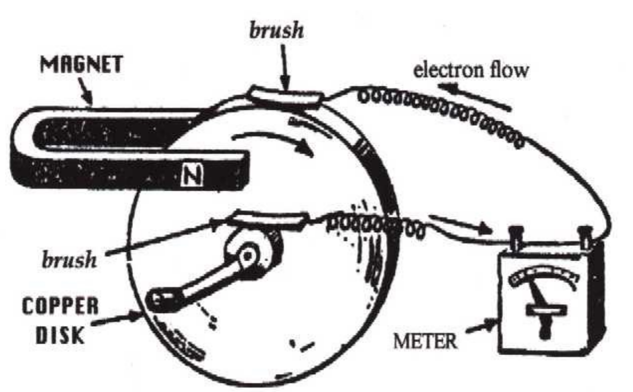

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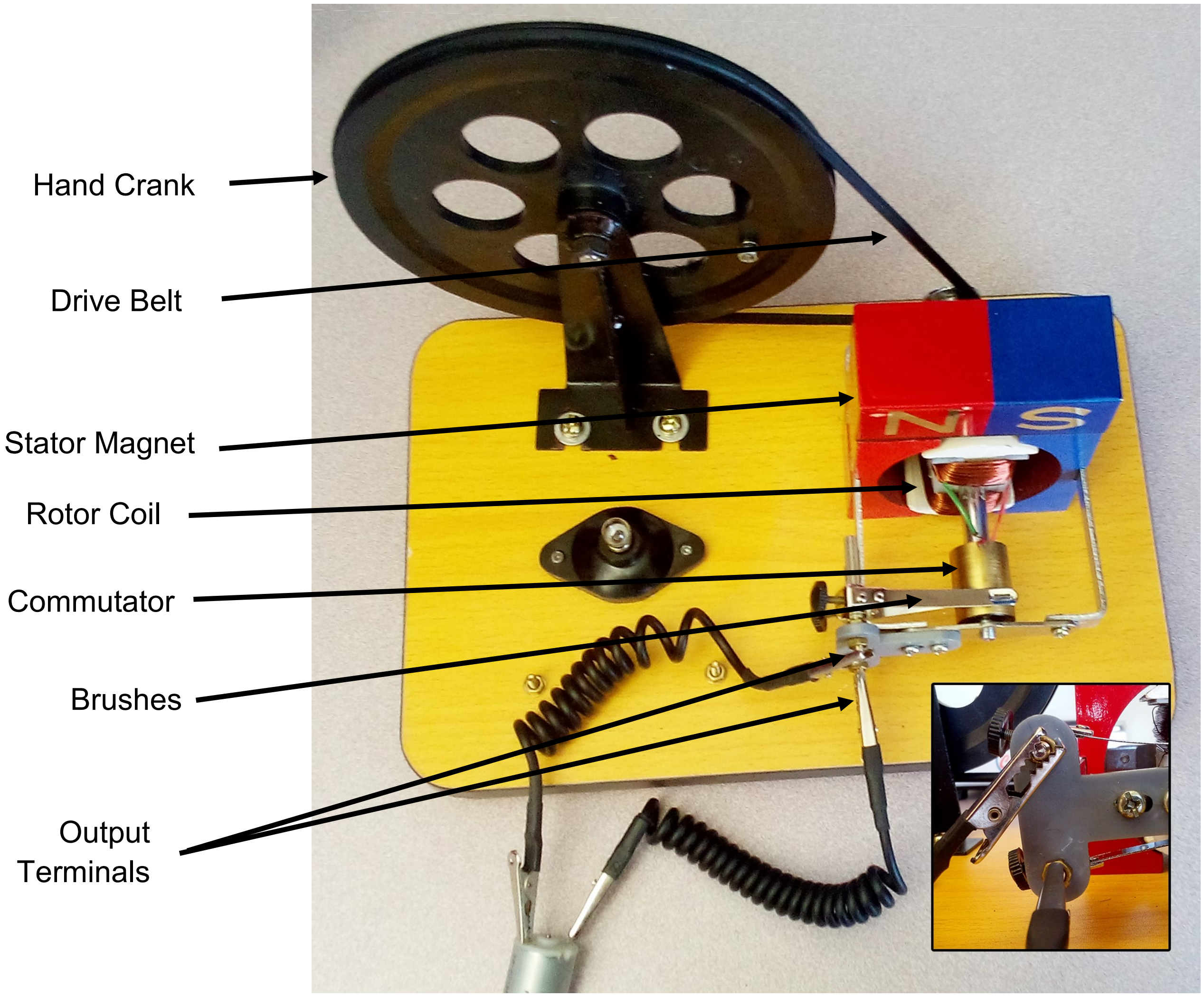


1. Without the motor or lamp connected, turn the hand-crank generator.

   What part(s) of the generator spin, and what part(s) stay in place?

Simply stated, the rotor rotates and the stator stays stationary. The commutator is mounted on the rotor shaft so it spins. The brushes slide on the commutator to provide an electrical connection.

2. Use the cables with alligator clips to connect the two little metal tabs on the back of the motor to the two output terminals on the generator. It does not matter which ones are connected.

The small tabs on the motor can make it difficult to connect the alligator clips correctly. They cannot touch the metal case of the motor and cannot touch each other.

3. Fold a small piece of tape around the motor shaft so you can easily see it spin.

A small piece of tape on the motor shaft will allow students to see that it spins surprisingly fast. You may wish to demonstrate that a motor and generator are the basically the same thing by hooking a multimeter to the motor terminals and spinning the shaft with your fingers. It will produce electricity.

4. Have each person on your team take a turn on the hand crank.

    What do you observe happening as you turn the crank?

5. Disconnect the wires and set the generator aside.

Linking Magnetism & Electricity (1820-1831): Discussion

1. Explain how you think the generator is producing electricity.

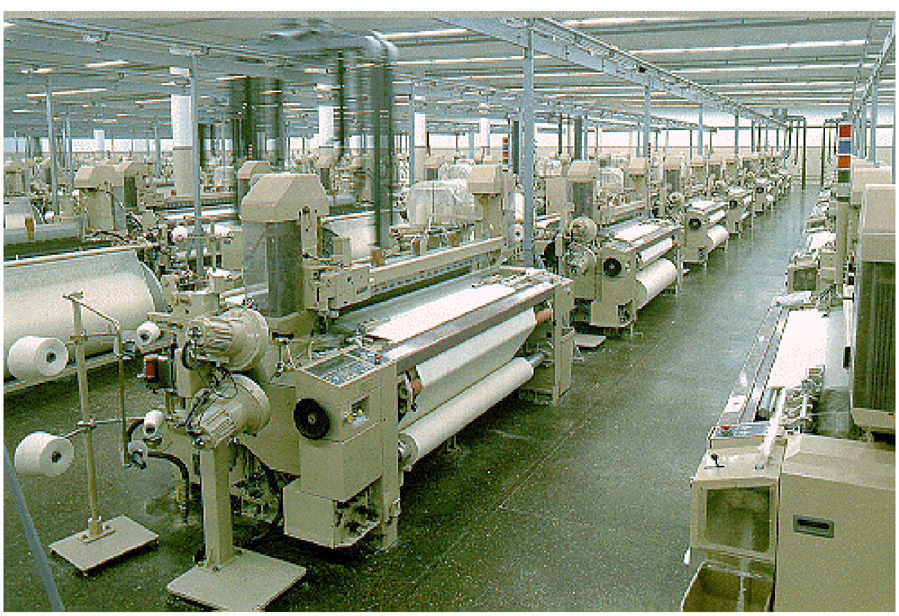
Students should notice that the spinning part (the rotor) consists of a long wire. The stator (the stationary part) is a large magnet. As the coil of wire spins inside the magnetic field, an electrical current is produced.

2. How does electricity get from the generator to the motor?

Electricity flows from the rotor through the commutator and into one of the brushes. It flows through the conductor (wire) to the motor. From the other tab on the motor it flows through the other wire, into the remaining brush and back to the rotor.

3. Trace the transfer of energy from the generator to the motor, using the terms thermal (heat) energy, chemical (stored) energy, mechanical energy (energy of motion), and/or electrical energy.

___muscle_______ → __mechanical________ → __electrical____________



CCSS.ELA.W.4.7. Conduct short research projects that build knowledge through investigation of different aspects of a topic.

Many students will be very interested in this project and will want to learn more. Some may even consider a career in the electrical energy field because of this exposure. Facilitate independent research.

http://www.ilocis.org/documents/images/tex09fe.gif

An electric loom uses a centralized motor, so any belts or shafts can be contained within the machine to keep workers safer.

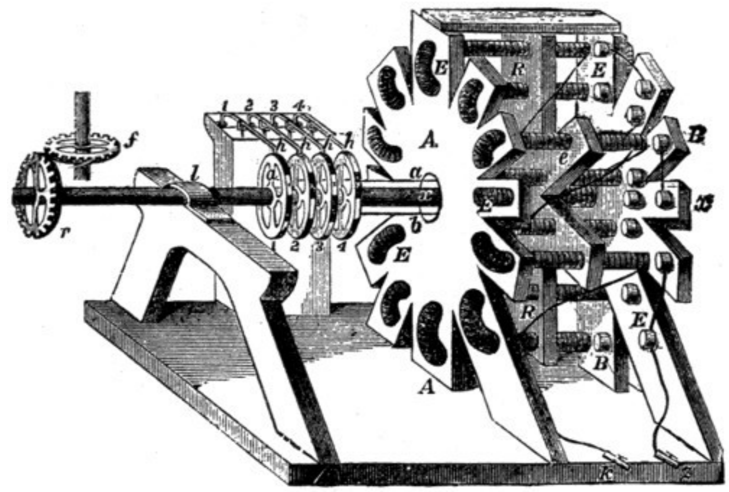
Michael Faraday made a machine that spun a copper disc inside a magnetic field. It called it a "dynamo" since it generated electricity. Electric generators convert mechanical energy (energy of motion) into electrical energy.

By the1850s inventors were attaching dynamos to steam engines. They burned coal to heat water into steam. The steam spun a shaft that was attached to the rotor of the generator. We still use coal-fired steam powered dynamos today to generate electricity.

One of the earliest uses of electricity was the electrical motor, developed by Prussian Moritz Jacobi in 1834.

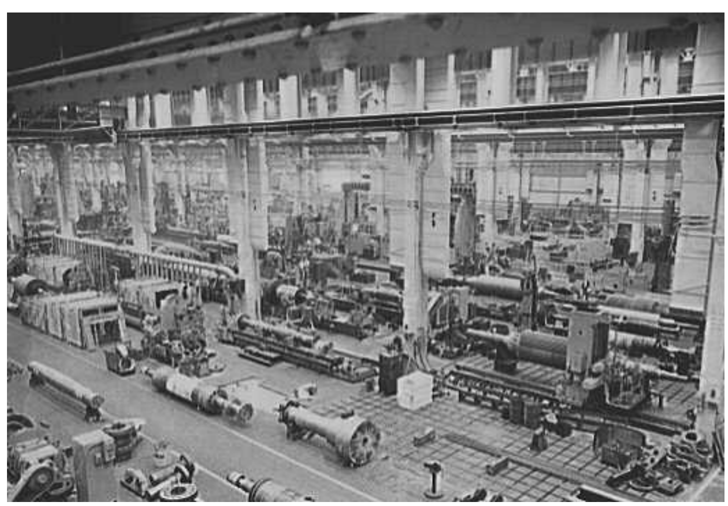
En.wikipedia.org

Moritz von Jacobi



https://www.gutenberg.org/files/41538/41538-h/41538-h.htm#SecVI_4

https://madeupinbritain.uk/Electric_Motor



It did not take long before factory owners realized that the electric motor was much better than the huge shafts, pulleys, and belts that were powering their machinery. Electric motor technology improved rapidly and many machines were converted to run on electricity. This posed a problem, however. There were no power plants producing electricity. Many factories set up their own power plants. Often these were built very close to the factory.

New Skills for Electricity (1830-today): Exploration

Inventors soon learned that working with electricity required a new set of skills. They had to learn how to cut and strip wires and hook up circuits. They also had a lot to learn about safety.

Wires are pipes for electricity, just like hoses carry water. Similar to hoses, the plastic around the wire basically keeps the electricity from leaking out. Without the coating, the electricity could follow the incorrect path.

A circuit is a complete path for the electricity to follow. It basically has to have a way out from the generator (or battery) to the electrical device and a way back to the generator. Think of it as water flowing through a pipe with one major difference: if a water hose is cut, water leaks out. If a wire is cut, electricity stops immediately because it no longer has a way to get back to the generator.

If electricity is allowed to flow through the circuit with nothing to slow it down, such as a light or motor, the wire will get hot and probably start a fire. This is called a "direct short." That is why it is so important that the wrong wires do not touch each other.

Electricians use different colors of wire so they don't connect the wrong ones together. There is some variation across the country in which colors are used for what applications, but there are general rules.

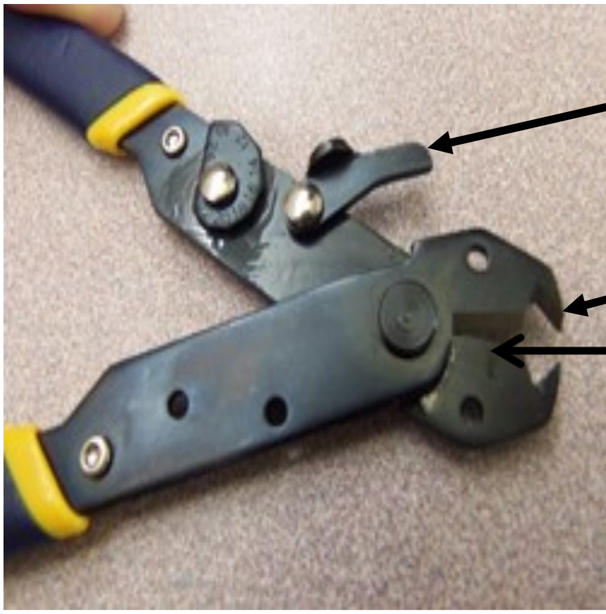
Red, black, blue, and sometimes yellow wires are used for power. They are considered the "hot" wires. In this Smart Grid Construction Set, connect the red, blue, or black wires to the springs and the spring-loaded clips.

White and green wires are used for "Common" or "Ground." These wires connect to the alligator clips. NEVER connect a white wire to a spring.

If you make a mistake and connect a spring to an alligator clip, there will be a direct short. To keep the wires from getting hot and possibly starting a fire, the power plants all have fuses. If there is too much electricity flowing in the wire, the fuse will "burn" and shut off the power. Fix the problem and then replace the fuse.

Your home has circuit breakers for protection. Perhaps you have plugged in or turned on too many devices in your home and "blew the fuse" or "tripped the circuit breaker.

1. You will be hooking up many wires. You will need to cut them to the right length and strip the insulation off both ends using a wire cutter/stripper.

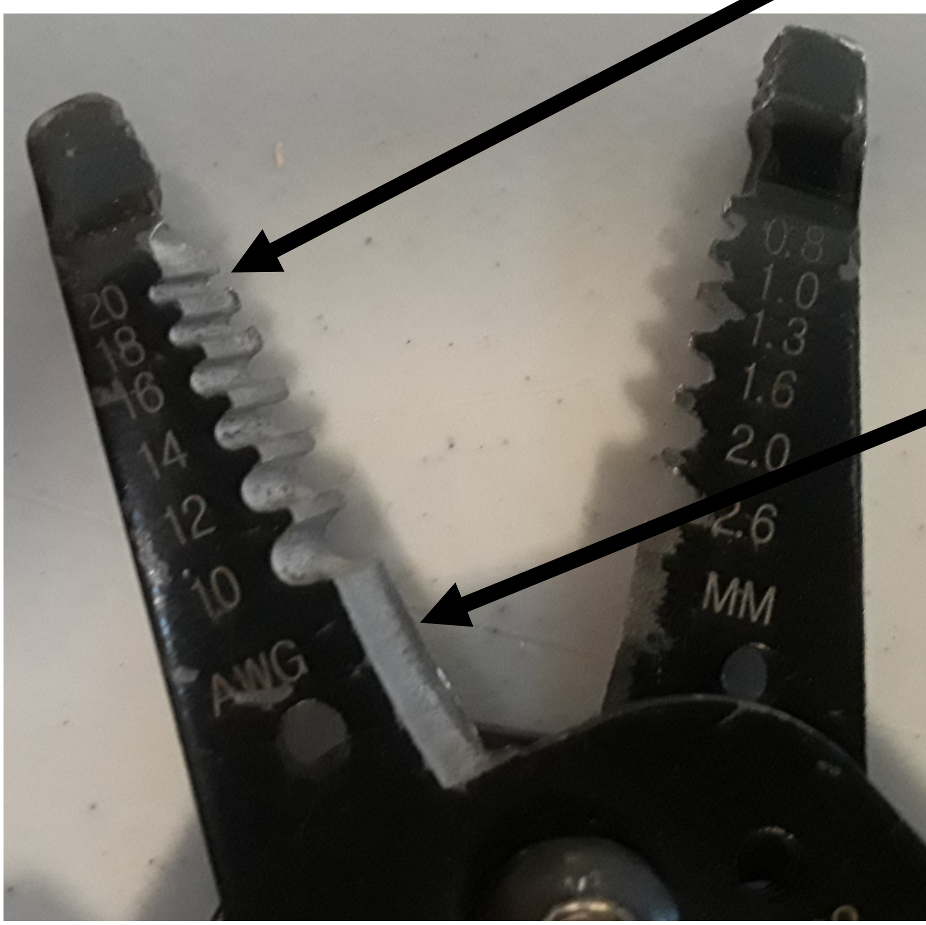


2. Adjust the cutter to strip the wire by turning the little dial on the side. It should be set on 20. This dial keeps the jaws open just enough so the Vee-shaped part will cut through the plastic coating but not through the wire itself. You might want to hold it with a small piece of tape.

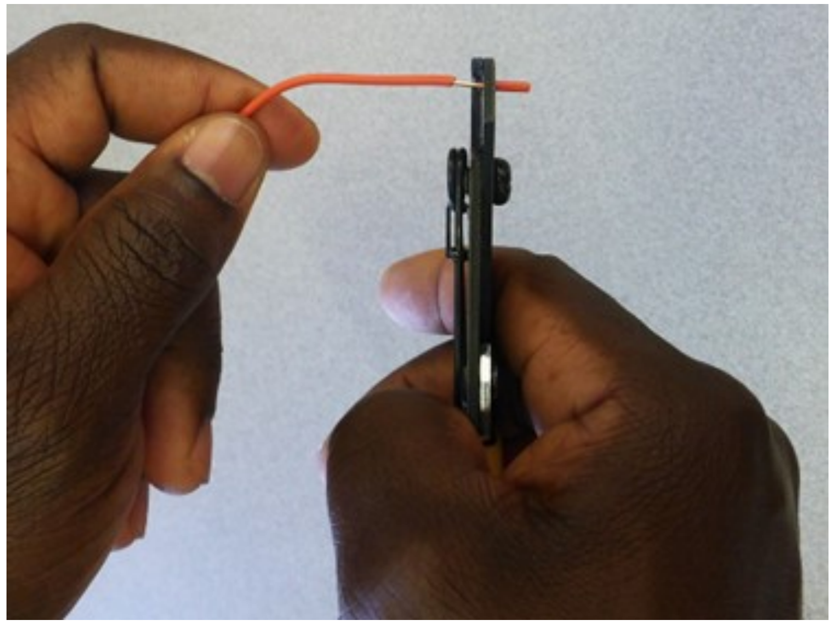
Your wire tool might look like this:

Use this notch to strip the wire.

Cut here



3. Measure the right length of wire by holding it between the two connections.



4. Cut it to the right length using the cutter blade on the wire tool.

5. Strip about 1/2 inch (about 1 cm) of plastic insulation off both ends of the wire.

6. To hook up a wire, simply bend the spring to the side and stick the bare end of the wire into the side of the spring between the coils. Be sure that the spring is touching the bare end of the wire and not the plastic insulator. To insert a second wire into the same spring, bend it the other direction so that pinches the first one in while the second is inserted.

Notice the fuse holder on each power plant. There are several replacement fuses packed with your kit. Also note the spring terminals and the alligator clips. The springs are for the colored “hot” wires and the alligator clips are for the white “ground” or “common” wires. Hot wires must never touch ground wires, and vice versa. Inspect the wiring before allowing students to connect to the Headquarters Office.

New Skills for Electricity (1830-today): Discussion

1. What is a circuit?

   A circuit is a complete path for the electricity to follow from the generator and back to the generator (or battery).

2. What is a "Direct Short?"

   A direct short (or sometimes called a short circuit) occurs when there is no load or re sistance in the pathway. The electricity is allowed to go straight from the generator back to the generator with nothing to slow it down, such as a lightbulb or motor.

3. How do electricians know what wires to hook together and which ones can never be connected?

   Hot wires can never be connected to ground wires. In a house, hot wires are black and ground wires are white. The black wire connects to the gold screw on the outlets and the white wire connects to the silver screw. All electricians do it this way.

4. Can a black or red wire ever be connected to a white or green wire? Why or why not?

   No, that would cause a direct short.

5. What happens if a wire carries too much electricity?

   The wire will get hot and perhaps start the plastic insulation on fire.

6. What device keeps the wires from getting hot and possibly starting a fire in your home?

   All homes have circuit breakers or fuses. If too much electricity is flowing through the wire (too many things plugged in and turned on), the circuit breaker "trips" shutting off the circuit.

<u>**NGSS.4-PS3-4**</u> Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

Electrical energy is converted to light or motion in these models. Encourage students to experiment with other circuits and devices. Do not connect other devices to this set since it is not designed to handle additional loads.

Careers in Energy

Not only did the electrical grid require new skills, but it also created a lot of very good jobs. As you work with this Smart Grid system you may want to explore a career in Energy.

Listed below are a few jobs. Your teacher has several more. This data came from the Occupational Outlook Handbook. Go to www.bls.gov for more information.

All of these careers require a high school education. It usually takes 2 years to earn an Associates Degree and 4 years to earn a Bachelors. Many offer on-the-job training.

Career Title	Description	Education Required	Median Salary In 2018	Job Outlook 2018-2028
Line installers and repairers	install or repair electrical power systems and telecommunications cables, including fiber optic	High school diploma. Long-term on-the-job training	$65,880 per year $31.67 per hour	+4% increase +10,700 jobs
Solar photovoltaic (PV) installers	assemble, install, and maintain solar panel systems on rooftops or other structures.	High school diploma. Moderate-term on-the-job training	$42,680 per year $20.52 per hour	+63% increase +6,100 jobs
Wind turbine service technicians	install, maintain, and repair wind turbines.	High school diploma. Long-term on-the-job training	$54,370 per year $26.14 per hour	+57% increase +3,800 jobs
Electrical engineers	design, develop, test, and supervise the manufacture of electrical equipment	Bachelor's degree	$99,070 per year $47.63 per hour	+2% increase +8,000 jobs
Environmental engineers	use the principles of engineering, soil science, biology, and chemistry to develop solutions to environmental problems.	Bachelor's degree	$87,620 per year $42.13 per hour	+5% increase +2,900 jobs
Electricians	install, maintain, and repair electrical power, communications, lighting, and control systems.	Associate’s degree and/or on-the-job training	$55,190 per year $26.53 per hour	+10% increase +74,100 jobs

Electrical Power (1830-1880): Exploration

New technology is always expensive so the people to use it first are usually those who can profit from it. Factory owners found that electric motors were more efficient, more adaptable, quieter, and safer than other forms of power. But, they needed electricity. They had to make their own.

1. Most power plants make electricity by burning a fuel to turn water into steam. The steam turns a turbine that spins a generator. This really has not changed much in the past 150 years. In the 1800s, however, they used wood or coal. Today we use coal and natural gas to produce a bit less than half of the electricity in Illinois. Nuclear power makes the other half. Wind power has been used to generate electricity for nearly 150 years, but it has never been a major source of power because it is not reliable.
2. Select one of the power plants. Notice it has 3 springs on the top and an alligator clip on the side. All power plants produce 3-Phase Alternating Current (AC). Each spring carries 1 phase. That is why most of the power lines you see have 3 (or sometimes 6) main wires.

http://www.tabula.ge/en/story/120489-gig-building-300-megawatt-coal-run-thermal-power-station

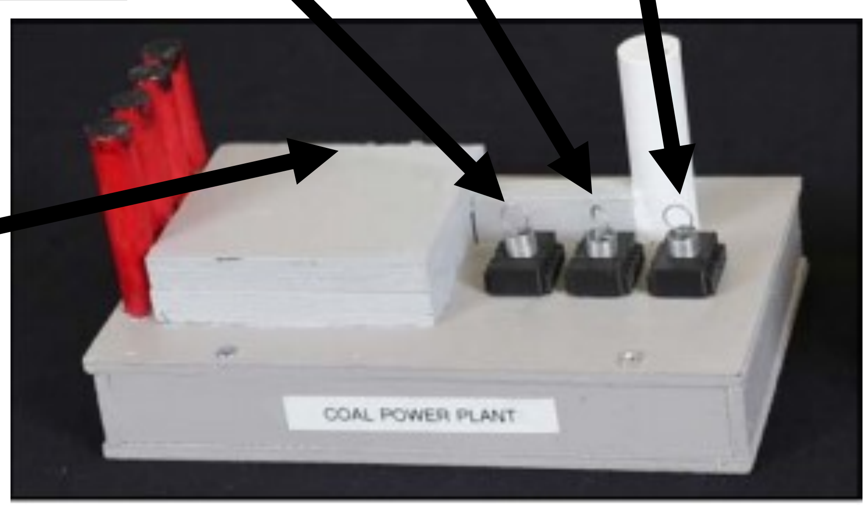
<u>CCSS.MATH.CONTENT.5.NBT.A.2</u>
Explain patterns in the number of zeros of the product when multiplying a number by powers of 10, and explain patterns in the placement of the decimal point when a decimal is multiplied or divided by a power of 10. Use whole-number exponents to denote powers of 10.

Research the power output of wind turbines, solar, coal, natural gas, and nuclear power plants converting data to a common unit.

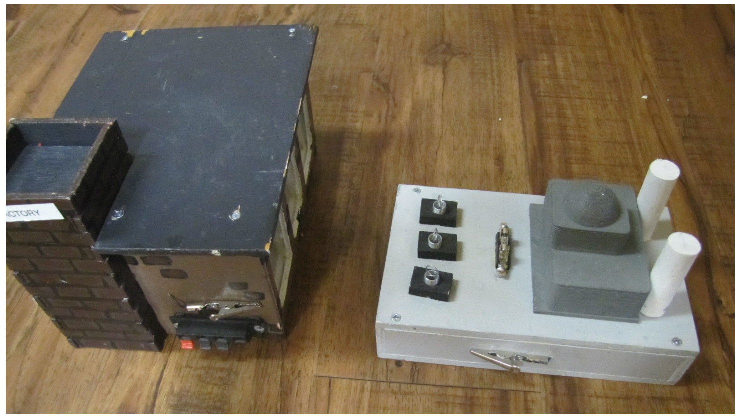
Attach all HOT wires to springs

RED **BLACK** **BLUE**

Attach all COMMON or GROUND wires to the alligator clip .



3. Just like 150 years ago, place the power plant beside the factory.
4. Measure, cut, and strip both ends of a white wire and connect it between the alligator clips.



5. Measure, cut, and strip both ends of a red, black, and blue wire and connect each between a spring and a clip on the factory. One of the clips on the factory is red, but that does not mean it has to be a red wire.

   No, this simulation is not using 3-phase electricity. The three terminals are attached to relays that must be powered before the connection is made to the motor.

6. Ask your teacher to inspect your work to make sure there are no direct shorts.
7. Connect the power plant to the Power Company headquarters office building using a cable with audio jack ends. The 5 volt electrical power for the grid comes from the adapter that plugs into a wall outlet and is inserted into the side of the Headquarters Office. The 1/4" jacks are power outputs.
8. Turn on the power. What happens? The factory will start to operate.

CCSS.MATH.CONTENT.7.SP.A.1
CCSS.MATH.CONTENT.7.SP.A.2
CCSS.MATH.CONTENT.7.SP.B.3
CCSS.MATH.CONTENT.7.SP.B.4

Use a survey to gather data about energy use, conservation techniques, attitudes about various power plants, or other energy-related topics. Compare by grade level at the school or with adults.

Electrical Power (1830-1880): Discussion

1. Before the use of electricity, what did factories use to power their machinery?

What was not done by muscle power was probably accomplished with mechanical power from a water wheel or steam engine.

2. What are some of the benefits of electric motors over other types of power? Electric motors are small, quiet, and safer that other forms of power because they could be turned off easily.

3. Why did factories have to install their own generators?

They had to generate their own electricity because there was no grid to deliver it to them.

Electrical Enlightenment (1880-1920): Exploration

https://greenwichmag.com/in-full-swing/

1. Set out the hand-crank generator.
2. Connect the output terminals to the light bulb.
   It does not matter which wire connects to with terminal.
3. Each person on your team should take a turn on the hand crank.
4. What do you observe happening as you turn the crank?
   The faster they crank the handle, the brighter the bulb glows.
5. Disconnect the wires and put the generator away. You will not need it again.
   Be absolutely certain that a hand-crank generator is NEVER attached to the grid system. It can generate far too much voltage and will burn out the lights.

Until the late 1800s, electricity was only for factories and big commercial buildings. Nobody ever thought they would need it in their home. That attitude changed quickly with the invention of the light bulb. Now with just a flip of a switch, people could have instant light. Inventors started coming up with more and more appliances that could run on electricity. Soon, everybody wanted their house hooked up to the power plant.

6. Turn off the power to the headquarters office.
7. Set a house near the factory.
8. Measure, cut, and strip both ends of a red, black, or blue wire.

Do not use white or grey, but either red, black, or blue will be fine.

9. Connect the spring on the house to one of the springs on the power plant.
10. Measure, cut, and strip both ends of a white wire.
11. Connect the alligator clip on the house to the alligator clip on the power plant.
12. Check your wiring for shorts.
13. When you are certain it is correct, turn on the power to the headquarters office.

    What happens?

Electrical Enlightenment (1880-1920): Discussion

1. Was there a difference when you turned the crank faster or slower? What was the change, and why do you think it occurred?

More mechanical energy was put into the system (turning faster) so more electrical energy is produced.

2. How are electric lamps an improvement over candles and other lights?

Electric bulbs do not need to be lit with a match and have no flame that can start a fire. Imagine that 150 years ago it was not uncommon to decorate a Christmas tree with candles.

3. Who do you suppose were the first people to get electricity in their homes? Why?

The wealthy were the first to electrify their homes due to the expense.

4. How did the electric light bulb change the way people lived?

With the electric bulb, it was much more likely for people to be out and doing things at night. This allowed employers to schedule a "night shift."

In 1841, Frederik de Moleyns, a British physicist, patented the first electrical light bulb. Thomas Edison is better known for his work with the light bulb because he provided both bulb and power source. Edison opened his Pearl Street Station in 1882, which provided power to electric lamps in a small neighborhood in New York City. His plant served 85 customers and powered 400 light bulbs. How many light bulbs do you suppose are in New York City today?

https://images.app.goo.gl/zheqgFTAvDuVmHxXA

NGSS.4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

Ask students how the electrical energy is getting from the power plant to the customers. What do customers use electricity to do? Most of these models change electricity into light. The factory changes it to motion. What changes occur in their homes?

CCSS.ELA.RI.4.1. Refer to details and examples in a text when explaining what the text says explicitly and when drawing inferences from the text.

Note that Edison did not invent the light bulb. Edison made the bulb possible by inventing the system that made it available to lots of people.

The Pearl Street Station showed the world what electricity could do. Companies immediately started building systems to get electricity to everyone. When prices came down, what had primarily been a tool for industry or a luxury for the wealthy quickly changed the lives of average Americans.

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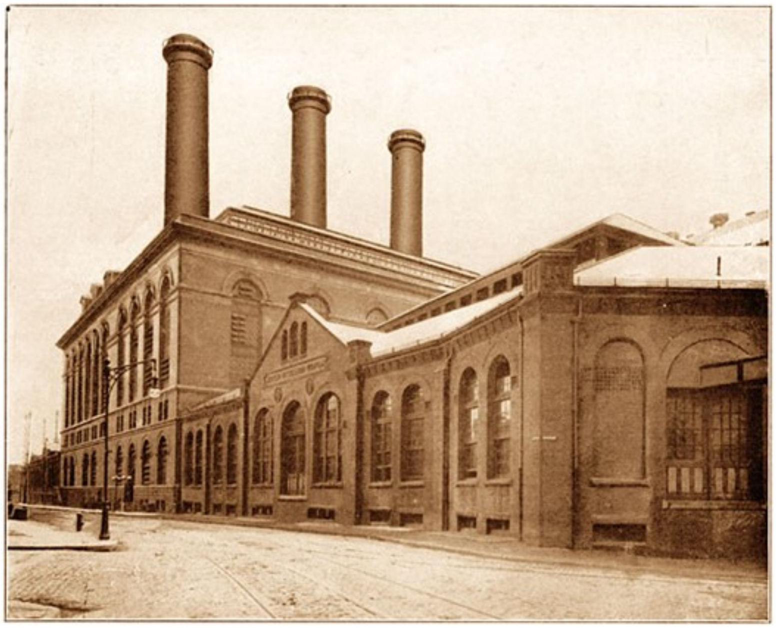


https://www.nytimes.com/2008/05/04/nyregion/

Edison's 1882 Pearl Street Station was a coal-powered plant. The first windmill used to generate electricity came soon after (in 1888) when Charles F. Brush built a turbine to power lights and motors at his home in Cleveland, OH.

While natural gas was used in different ways over time, the first natural gas power plant as we know it today was built for Oklahoma Gas & Electric in 1949.

The first nuclear and solar plants would come much later – the first nuclear power plant was built at Calder Hall in Cumbria, U.K. in 1956 and the first modern solar plant was built in the Mojave Desert in 1981.

https://www.nytimes.com/2008/05/04/nyregion/thecity/04cone.html

NGSS.4-ESS3-1. Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment.

Ask students to select the best power plant. This provides the opportunity to discuss energy sources and their impact on the environment and economy.

CCSS.MATH.CONTENT.7.RP.A.3
Use proportional relationships to solve multistep ratio and percent problems.

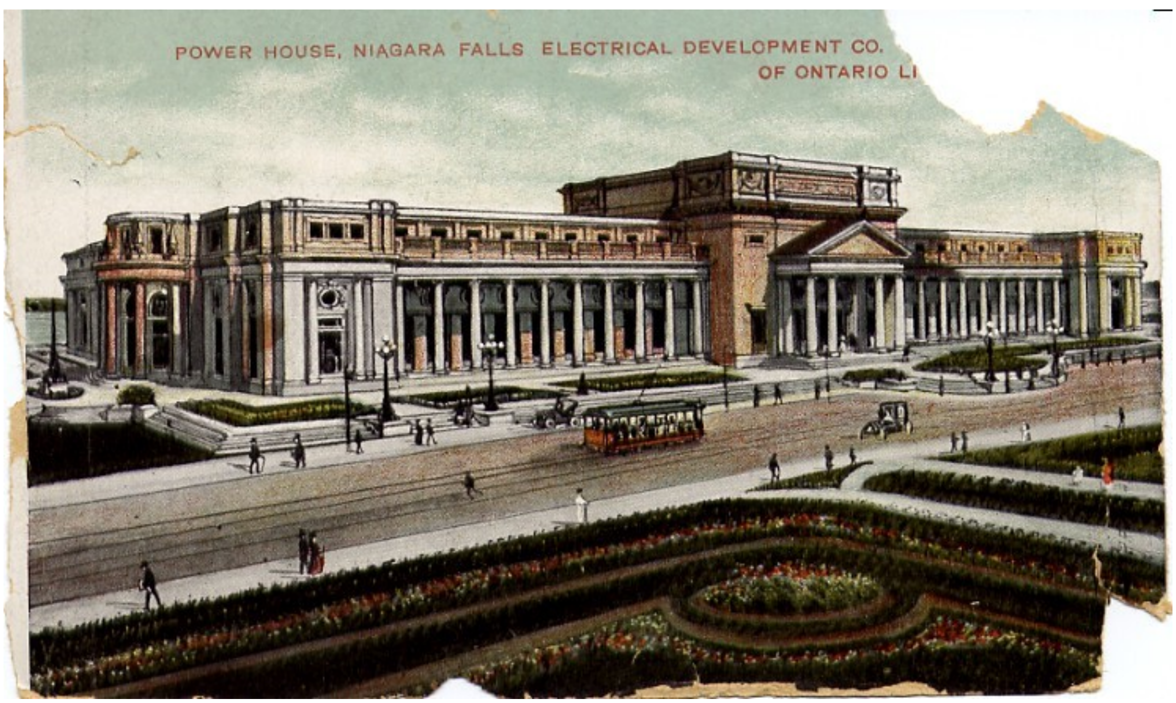
Compare output of various power plants as percents and ratios. For example, how many wind turbines or solar farms will be necessary to generate the power of one nuclear plant?

CCSS.MATH.CONTENT.6.SP.B.4 Display numerical data in plots on a number line, including dot plots, histograms, and box plots.

CCSS.MATH.CONTENT.6.SP.B.5 Summarize numerical data sets in relation to their context,

Research types of power plants and determine changes necessary to reach Illinois energy goal of 25% renewable energy by 2025.

Thomas Edison's Pearl Street Station had a major flaw. It used direct current which can only travel short distances. In 1886, Frank Sprague used an alternating current generator and transformer to make the first long-distance AC power transmission in Great Barrington, MA. Alternating current can travel much longer distances than direct current. In 1895, George Westinghouse partnered with Nicola Tesla to build a water turbine at Niagara Falls. It supplied power to the town of Buffalo, NY about 20 miles away. Unfortunately, alternating current transmission still had a flaw – the low-voltage lines lost a large amount of energy to electrical resistance. Michael Faraday had already solved this problem 50 years earlier. His early work on induction allowed Westinghouse and Tesla to increase and decrease the voltage using transformers. Higher voltages could be transmitted longer distances with less loss.



https://www.niagarafallsmarriott.com/niagara-seasons/toronto-power-generating-

Building the Grid (1886-1900): Exploration

1. Unplug the thick cable to the Headquarters Office before changing the wires.

2. Disconnect any existing power lines from your power plant.

3. Place the power plant and Headquarters office at one end of your table and set the homes, shops, factory, etc. around the edges of the table.

Each grid line should have a factory, one other building that requires 3-phase electricity, 3 houses, and a shop or other single phase customer.

CCSS.MATH.CONTENT.5.MD.A.1
Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems.

Measure distances between the customers and the power plant in various units and convert using a scale to real-life distances. For example, how far is your school from the nearest power plant? Are others further? Represent those distances on your model grid.

4. Basically, the taller the pole or the higher the wire is off the ground, the higher the voltage that the line carries. Transformers are used to change the voltage of a line. Notice that the springs on the power plant are on transformers. They “step up” the voltage so that it can go a long distance to the customers. A sub-station has several transformers.

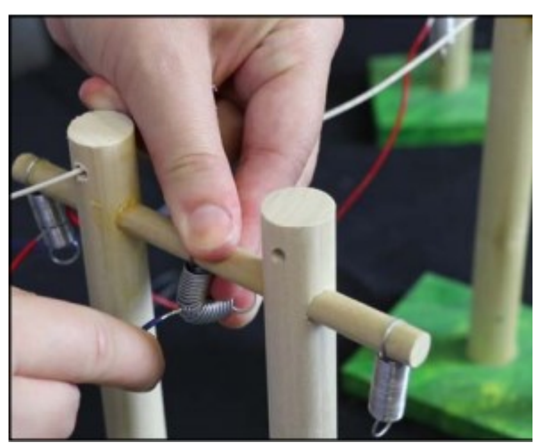
A typical power plant produces 13,000 VAC which is stepped up to 138,000 to 1 million volts for transmission. Power going from one substation to another substation is 69,000 volts. This is reduced to 7,200 volts for distribution.

5. Set up several high voltage H poles in a line from the power plant to the middle of your table.

6. Measure, cut, and strip both ends of red, black, and blue wires and connect them from the springs on the power plant to the first high voltage pole.

7. Continue connecting from one pole to the next until they connect to the factory.

Each wire starts at a spring and ends at the next spring. Do not use a single long wire for this step.



8. Thread a white wire through the holes in the top of the H-poles to extend all the way from the factory to the power plant.

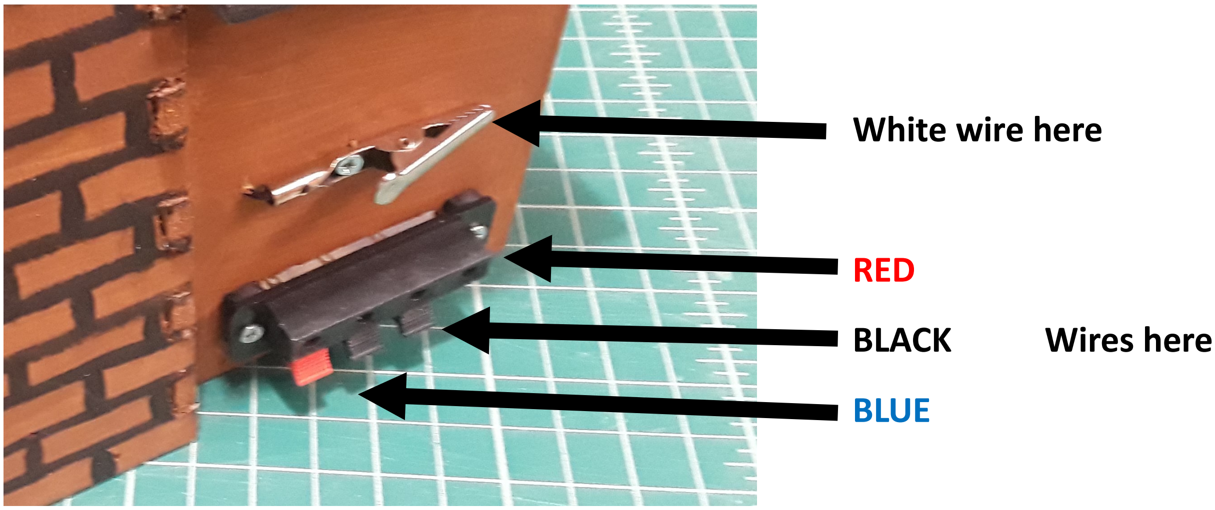
This could be one long continuous wire.

9. Cut the wire to the right length and strip the ends. Connect them to the alligator clips on the factory and the power plant.

10. Check your wires and turn on the power. Does the factory function?

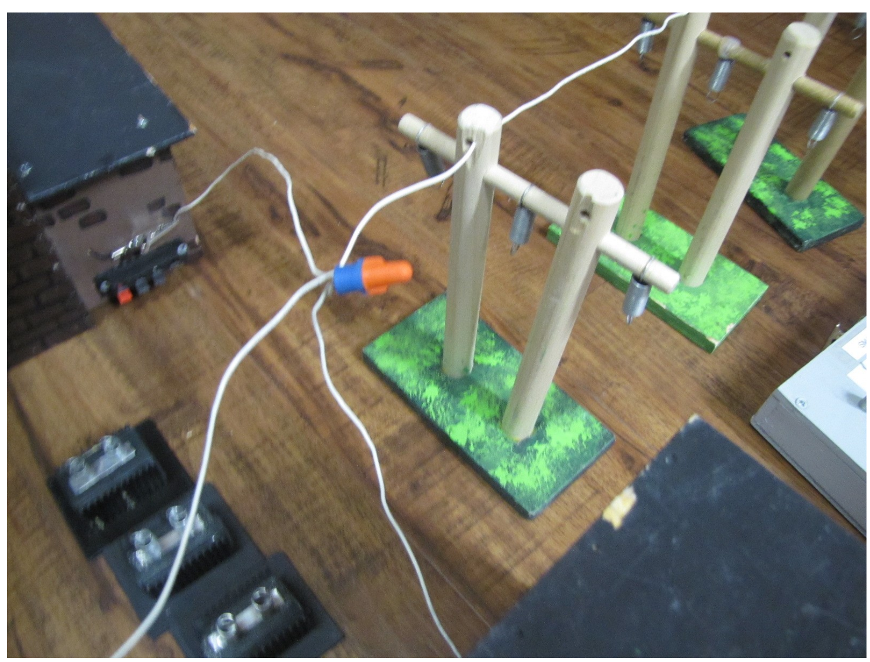
11. Turn off the power after testing.

12. Connect red, black, and blue wires to other customers that need 3-phase electricity. Simply branch off the springs on the towers.



13. Remember that you must have a complete circuit. The electricity has to have a way to get back to the power plant. One method is to tie your white wire to an existing white wire. Cut the existing wire and strip both ends. Insert both ends and the end of your new wire into a wire nut. Twist them together with the nut.

Connecting wires with a wire nut is a new skill introduced here. Wire nuts are used in nearly all electrical work. It is much more secure than simply twisting and taping wires together and much faster than soldering them.



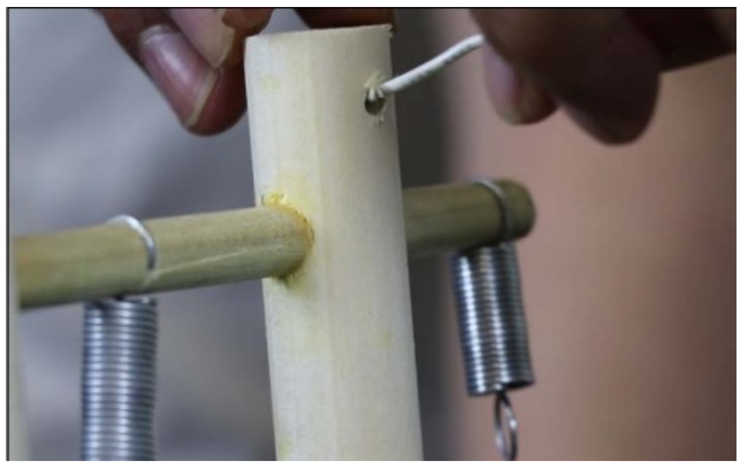
14. Check the wiring and turn on the power. Turn off the power when you are done testing.

Before distributing electricity to your neighborhood, the voltage has to be “stepped down”. The wires you see on your street are usually about 7200 volts. That is still very dangerous, but not nearly as dangerous as the 120,000 volts or more in the transmission lines. The 7200 volt line is stepped down again with a bucket transformer mounted on the pole just outside your house or by the transformer inside the green box in your backyard.

1. Connect a red, black, or blue wire from an H pole to one side of a transformer.

The two terminals of the transformer are connected to each other. One wire comes into one side and that same color wire goes out the other side. NEVER attach a white “ground” wire to a transformer.

2. Using that same color wire, connect from pole to pole to get to a house. The pole nearest the house should have a bucket transformer on it.



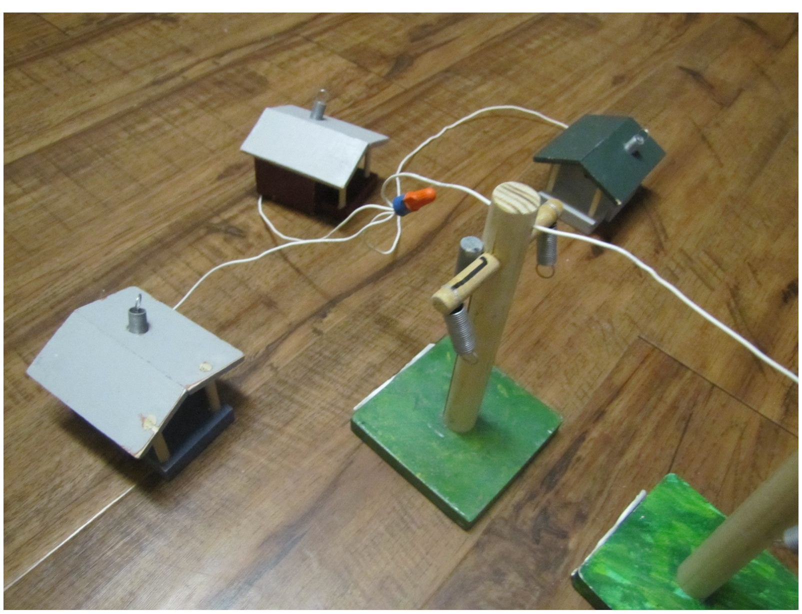
Some of the distribution poles have bucket transformers. If not, use another transformer to represent the green box found in many back-yards.

3. Hook up other wires and transformers to get power to every customer.

4. Run the white wire through the holes in the top of the poles all the way back to the power plant.

Most power poles have a ground wire running along the top. This provides a constant “ground” as well as protection from lightening strikes.

5. Connect the alligator clips of all of the houses and customers to the main white wire.



This may require a splice be made into the white wire with a wire nut.

6. When you are certain everything is hooked up correctly, turn on the power.

7. Do all customers have power? If not, what is wrong?

The usual culprit is a missing ground wire.

Building the Grid (1886-1900): Discussion

1. What is the advantage of high-voltage power transmission? Why couldn't all power lines be low voltage? High voltage lines do not "loose" as much power along the line. Basically, less power "leaks" out if the voltage is high.

2. What is the purpose of a substation? Substations contain several transformers to reduce voltage.

3. Why do substations always have high fences around them? High voltage is very dangerous.

4. Are there any substations, transformers mounted on poles or green boxes near your home? There is a transformer near every customer, but students may not have noticed it.

Safety: Never go near a downed power line. Get away and call 911 immediately. Never do anything that might connect you to a power line. A kite string, ladder, or even digging into a buried power line with a shovel can cause severe burns or death.

electrical-engineering-portal.com

__CCSS.MATH.CONTENT.4. OA 2__ Multiply or divide to solve word problems involving multiplicative comparison, e.g., by using drawings and equations with a symbol for the unknown number to represent the problem, distinguishing multiplicative comparison from additive comparison.

Work fluidly with watts, volts, and amps. Watts is a measure of power.

See ***Electrical Mathematics*** on page 9.

https://energyeducation.ca/encyclopedia/Electrical_substation

Most outlets in a house are 120 volts. Most houses can draw up to 100 amps at any given time. The maximum power an average house could ever use is 120 volts x 100 amps = 12,000 watts. Houses seldom use that much power but the grid must provide for it. Three houses in the same neighborhood could draw 36,000 watts. At 120 volts, that would be 300 amps.
watts=volts x amps amps=watts/volts

36,000 watts / 120 volts = 300 amps

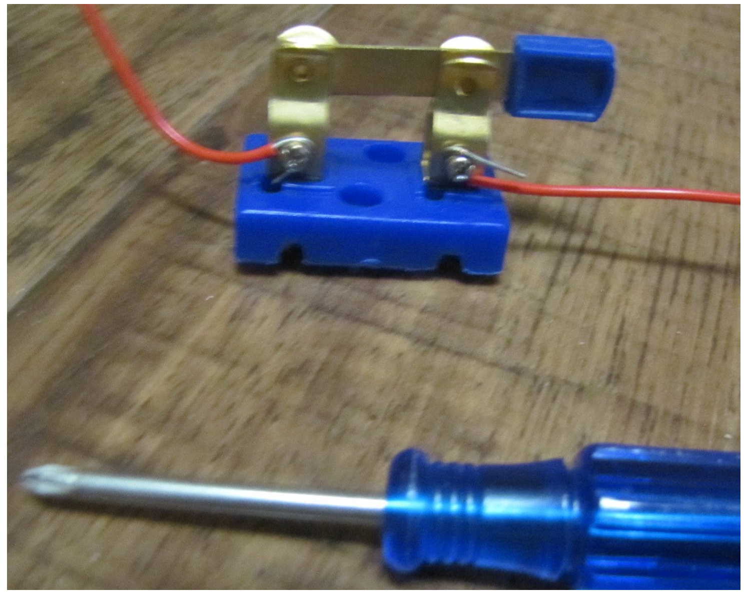
300 amps is a lot of current which requires large, expensive wire. To reduce the current, electric companies increase the voltage coming to the neighborhood to 7200 volts. Now 12,000 watts / 7200 volts = 1.6 amps. A smaller, cheaper wire can be used. A bucket transformer reduces the voltage to 120 volts right before it goes into the house.

Research electrical use of your school, local businesses, and industries and calculate watts, volts, and amps.

https://internationalelectricalsuppliers.weebly.com/

Switching the Grid (1900-1950): Exploration

As more and more customers were tied to the grid, a system had to be developed to shut off power to some locations and redirect it from others. Switches were installed at various places in the grid to control the flow of electricity.



1. Switches are always found at the substations with the transformers. They also can be found on many poles.
2. To hook up a switch, strip the ends of the wires and bend the bare wire around the screws. Tighten the screws to hold the wires in place.

It is best to wrap the wire around the screw in a clockwise direction so that it tightens rather than loosens when the screw is tightened.

3. Put several switches into your grid so that some circuits can be turned off while others stay on.
4. The switches ALWAYS go on the hot wire (red, black, or blue) and NEVER on the ground

Switching the Grid (1900-1950): Discussion

CCSS.MATH.CONTENT.6.NS.A.1
Interpret and compute quotients of fractions, and solve word problems involving division of fractions by fractions, e.g., by using visual fraction models and equations to represent the problem.

Each switch will control a fraction of the entire grid. As grid lines are combined, each switch will control a fraction of a fraction, providing opportunity to work fluidly with fractions.

1. What does a switch do?

A switch controls current flow by completing or breaking a circuit.

2. Why is it so important to have lots of switches in the grid?

The more switches, the closer any given location is to switch and the more options that are available for redirecting power.

3. How did the installation of switches promote safety and lead to fewer accidents?

Workers could be certain that the section of wire where they were working was turned on and not turned on again until they were ready.

The first long-distance high-voltage transmission line was established in 1917, carrying power from a steam plant at a coal mine to the city of Canton, OH 55 miles away. The ability to transmit energy efficiently over long distances transformed the way power companies began to operate – the Canton plant virtually eliminated the expensive transportation of coal since the power plant and coal mine were located in the same place!

Transporting electrical power over long distances, however, introduces another new problem: if a customer lost power, there was a much longer line to inspect for problems. You have probably already experienced how hard it can be to find a problem in your grid. As multiple power plants and multiple grids were interconnected, the grid gets larger and more complex, making it very, very difficult to pin-point a problem and fix it quickly. A smarter system was needed. Electricians added sensors to key locations to monitor electrical power.

https://woodpoles.org/

PHOTOGRAPH BY STATE ARCHIVES OF NORTH CAROLINA

Monitoring the Grid (1950- today): Exploration

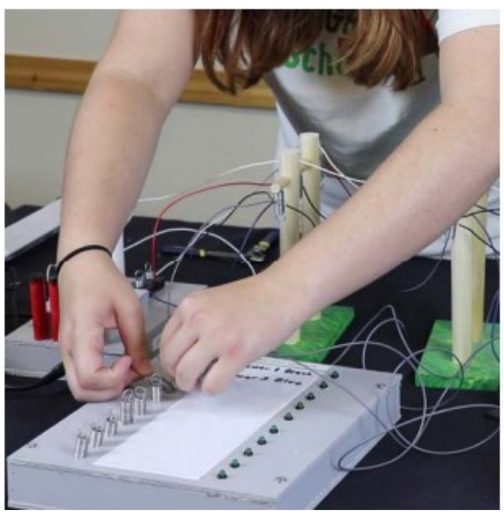
There have been devices used for decades that monitor the flow of electricity in the grid. Since they were rather expensive, only a few were installed. Over the years as technology advances, these sensors and monitors have become more and more "smart," leading to the development of the "Smart Grid."

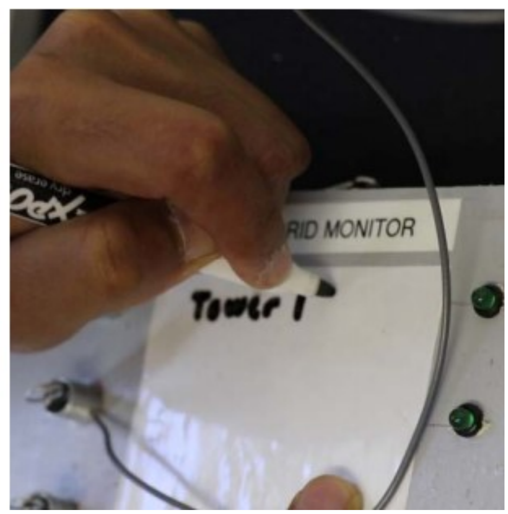
1. Connect a long white wire from your Smart Grid Monitor to the alligator clip on the power plant.
   The monitor box must be grounded.

2. Use a grey wire to connect from the top spring on the monitor to any spring on your grid.
   The spring should already have a colored wire attached to it.

3. Record the number for this location on the panel using a dry erase marker.
   Some of the devices and poles are numbered. Everything owned by a power company has a number for identification.

4. What happens when you connect this wire? What does the Smart Grid Monitor tell you?
   The light on the monitor indicates that there is power at the point where it is connected.





5. Repeat the instructions above to connect grey wires to 4 main locations throughout your grid.
   Eventually they will hook up all of the springs on the monitor, but for now limit them to four. This is similar to how the grid was monitored for decades.

6. Since you only have a few sensors, where should you put them? Record the number of the location on the monitor tablet.
   Some locations will be more effective than others in providing information about the grid.

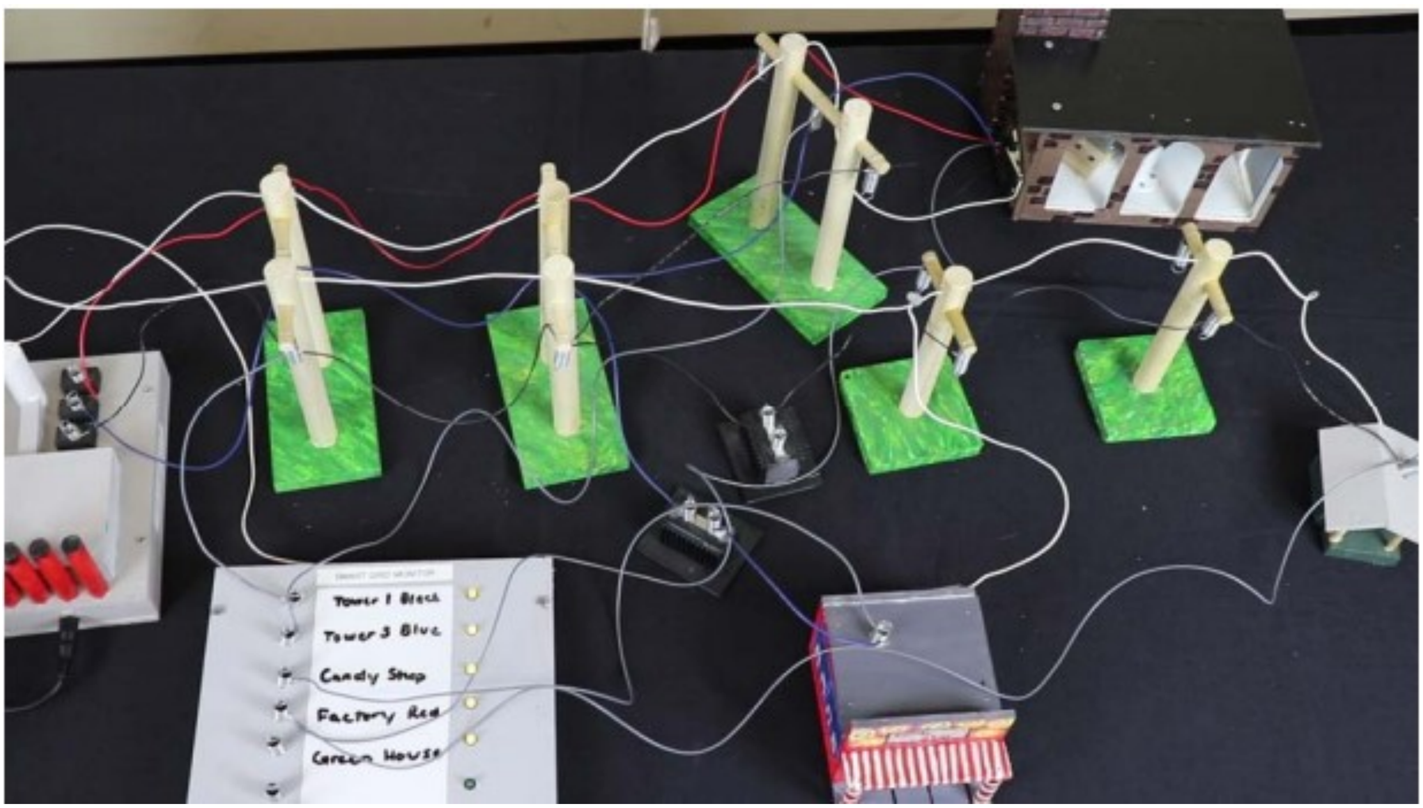
7. Have a team member disconnect a wire from somewhere in the middle of your grid while everyone else watches the Smart Grid Monitor.

Did any of the sensor lights turn off? Why or why not?

If the sensors are located strategically, disconnecting any main wire will result in change on the monitor. With only 4 sensors, however, power going off at a house will probably not be indicated by the monitor.

8. Have a team member disconnect a second wire from somewhere else in your grid while everyone else watches the Smart Grid Monitor. Instead of fixing the problem, use your monitor and switches to reroute the electrical power around the problem to the affected customers. You may need to move some sensors and switches.

It takes time to repair damaged wires. If power can be delivered to the customer through an alternative route, however, getting the power back on can be almost instantaneous. It is unlikely that the switches and sensors will be located in the right places to allow this to happen.



Monitoring the Grid (1950-today): Discussion

1. How did you decide where to put your sensors?

Sensors were probably placed only on the main lines, not for each individual customer.

2. How did these sensors help you find problems?

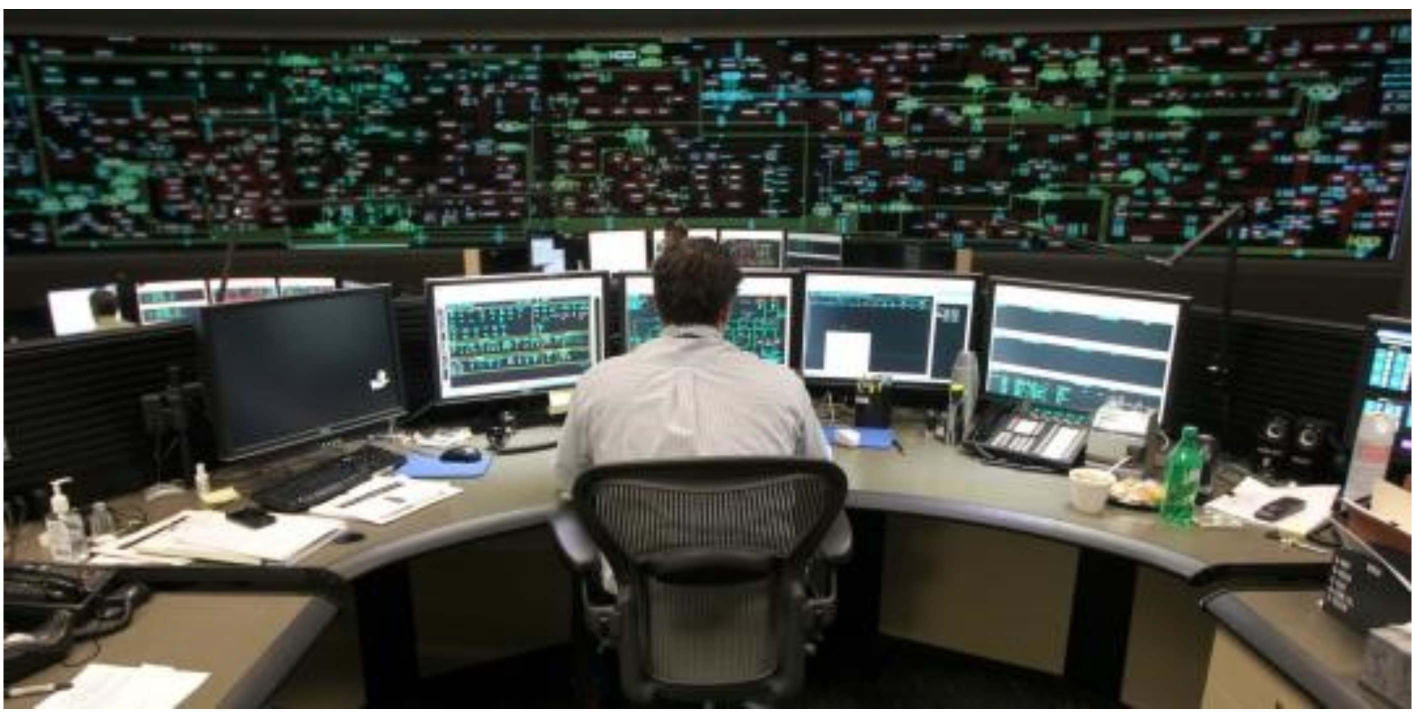
Knowing exactly where power is present and where it is not helps to pinpoint the problem.

3. How could the monitor system be improved to find problems more accurately?

More sensors will make the system more accurate.

4. Because sensors were expensive, they were reserved for important locations and the "big" customers (like factories and commercial buildings). They were not installed on homes. How did the power company know if the electricity went off at a house?

If one of their sensors was not activated, the only way a power company knew of a power outage was by the telephone called they received. By mapping the calls from customers, they could get an idea of where to start looking for problems.



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In 1953, American Electric Power built a seven-state interconnected grid to share power. With the grid, if a power plant stopped working, others could generate more to keep the power on. This required a lot of switches.

The Grid Grows (1950-today): Exploration

1. Unplug the thick cable to the Headquarters Office before changing the wires.

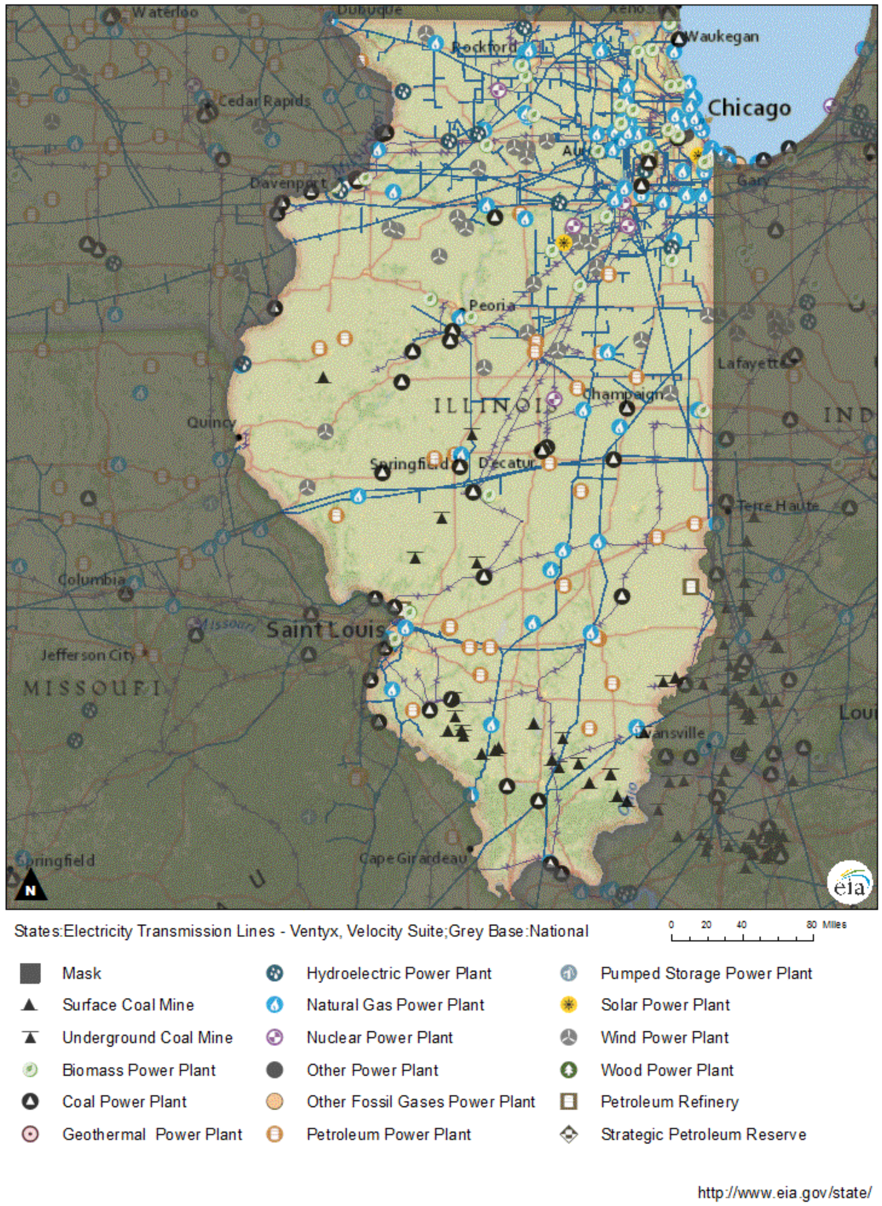
Power can be turned off at a power strip.

2. Move your entire table (your entire grid) so it is alongside at least one other group.

3. Working with the other group, figure out a way to use switches to control how power from either one of the power plants can reach your customers.

This will require the careful placement of several switches.

4. How do you need to change your grid to have a switch control which power plants provide power?



It is likely that the substations will have several switches.

5. How do you need to change your grid to have a switch control which neighborhoods and customers receive power?

Students may wish to attach switches to poles. This can easily be done with tape or rubberbands.

The Grid Grows (1950-today): Discussion

1. Why is it a good idea to have the grids of cities, states, and entire regions interconnected?

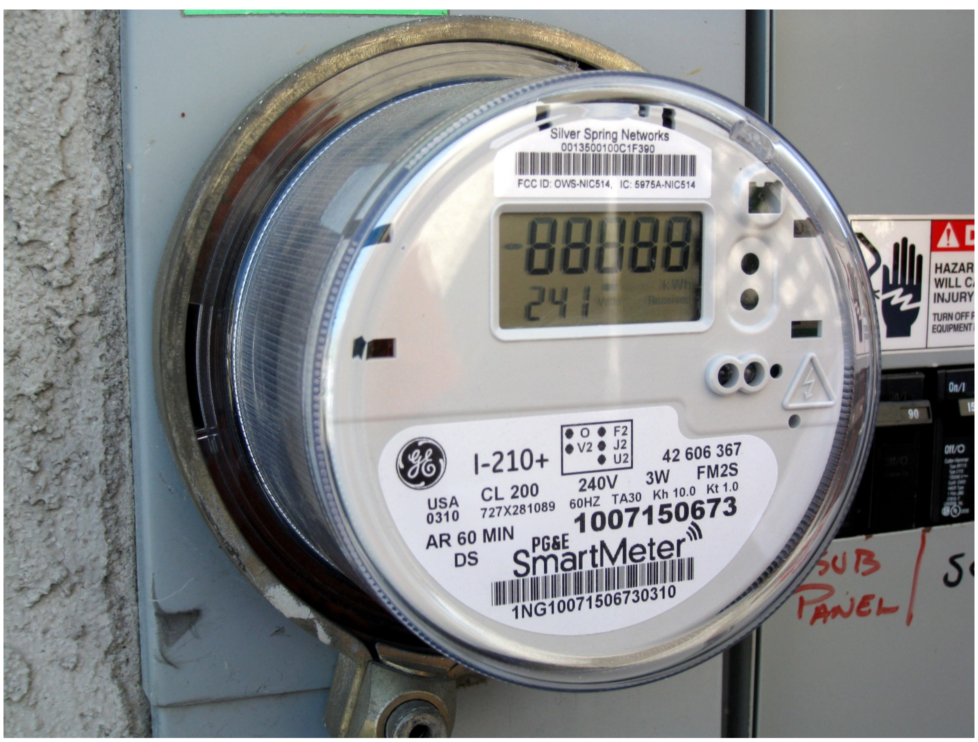
   With an interconnected power grid, any single power plant could go off-line without affecting power to any region. Other power plants simply produce more power to make up for the loss.

2. How did switches help your customers?

   Switches make it possible to turn off power to problem areas or to re-route power around a problem.

3. How do your sensors help control the grid and locate problems?

   Sensors tell the power company employees where problems are most likely to be found and which switches should be turned on or off to direct power around the problem.



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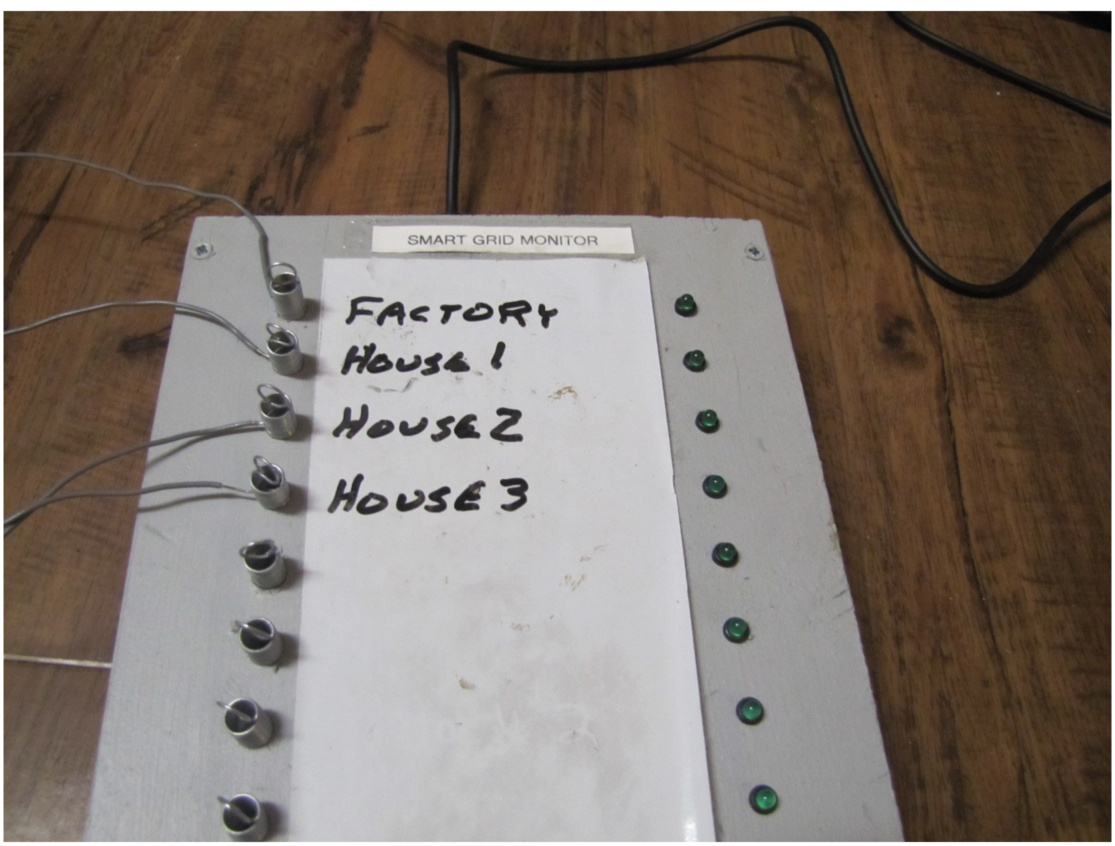
Making the Grid Smart (2000-2020): Exploration

1. Place smart sensors wherever you need them throughout your entire grid. Be sure to label them on your monitor tablet.
   The more sensors installed, the better.

2. Disconnect power lines to see if you can use your Smart Grid Monitor to quickly find problems.
   With sensors on every pole and every customer, problems can be located immediately.

One of the main advantages of a Smart Grid system is that the sensors control the switches. When a problem is detected by Smart Grid sensors, switches are automatically opened or closed at various locations throughout the grid to reroute power around the problem.

A Smart Meter on a house is a sensor that is in two-way communication with the power company. All Smart Meters transmit data about power use and receive commands that adjust the circuits to assure that all homes have enough power. If a Smart Meter has not yet been installed on your home, it will be soon.



Making the Grid Smart (2000-2020): Discussion

1. How did you decide where to put the sensors?

    With lots of sensors available, the location of each one is less critical.

2. What can you do with the sensors that you cannot do without them?

    With a sensor at each customer, telephone calls to the power company are no longer necessary. They already know exactly where problems can be found and can fix them quickly.

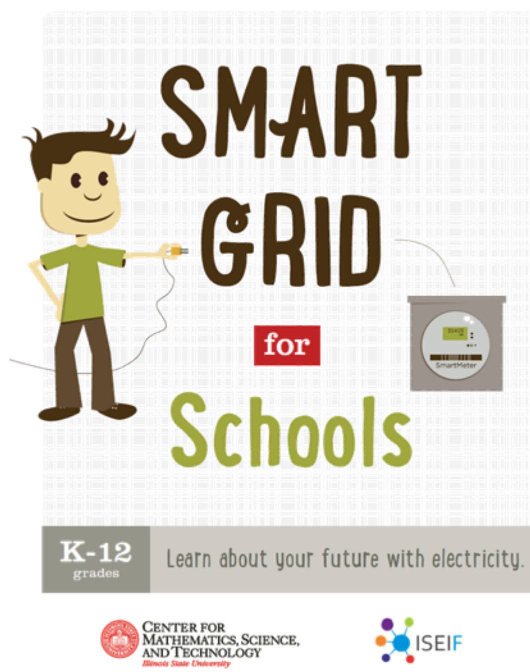
3. List some of the advantages of allowing the sensors to automatically control the switches.

    There are lots of possible alternatives. The computer can sort through these options and quickly de termine the optimal path.

4. Explain why is it is a good idea for power companies to put Smart Meters on all homes in Illinois.

    More sensors create a more accurate and detailed view of the function of the grid.

You now have now built a very large and complex grid system with lots of power plants, sub-stations, and customers, but this is still a simple representation of the actual grid. Although the grid is large and complex, it is still based on 100-year-old technology. If Edison, Westinghouse, and Tesla were alive today, they would recognize our current system. It works well now, but it may struggle to meet projected future demands. For example, nearly all cars are currently powered by gasoline. As electric cars become more prevalent, the energy to move them will be purchased from the electrical grid, not the gas station. This alone could greatly increase electricity demand. The Smart Grid is one big step towards managing electrical production and consumption, making our system much more efficient.



The STEM of Energy

Here is some information about electricity that you teacher may want to use to help you better understand circuits and how they work.

Science is the study of the natural world. In this case, electricity. During this study, patterns are discovered. Scientist learn that certain things work in predicable ways. These patterns are written as mathematics equations. Engineers use these patterns to design products and systems that we call *technology*. You have already worked with some of the Engineering and Technology. Here is some of the Science and Mathematics.

Electricity in a wire is a lot like water flowing in a hose.

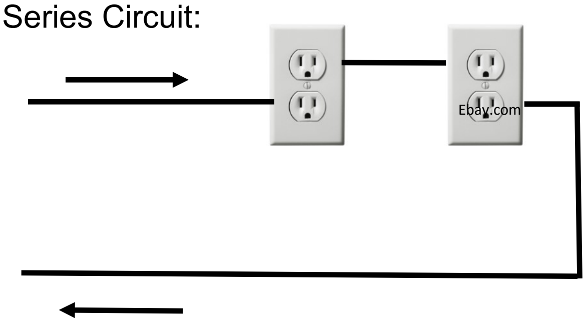
- The volume of electricity is called the "current" and is measured in **Amps**.
- The pressure that pushes the electricity is measured in **Volts.**
- The force that tries to slow it down is call "resistance" and is measured in **Ohms.** Think of it as how much you squeeze the hose and reduce the flow.

A scientist named Georg Simon Ohm discovered the pattern that is now known as Ohm's Law. It states that:

Volts = Ohms x Amps so **Amps** = Volts / Ohms and **Ohms** = Volts / Amps

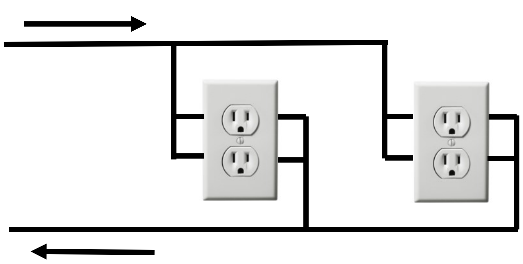
Upsbatterycenter.com

Series Circuit:



Ebay.com

Parallel Circuit:



Unlike water in a hose, however, electricity only flows from its source back to its source. This pathway is called a "circuit." If you cut a wire, the flow stops. You do not get a puddle of electricity spilled on the floor.

There are two types of circuits, series and parallel.

In a series circuit, the electricity has only one path and goes through every device. If a device is not plugged in and turned on, the electricity stops because it has no other option. Obviously that would not work in your house.

Houses are wired in Parallel. There are many pathways for the electricity to flow. This provides the same volts to every outlet and current is available regardless of what else is plugged in or turned on.

Calculate Total Resistance in a Parallel Circuit.

Each load (device connected to the circuit) is considered a resistor. To calculate the total resistance (R_t) of a parallel circuit, use 1 as the numerator and the ohms as the denominator and add the fractions together. R_t is the sum.

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

Notice that as more resistors are added, the total resistance goes down. Yes, it is counter-intuitive. That is why the more devices you turn on, the more electricity you use.

1. To determine the resistance of any electrical device, first find its wattage. This is usually listed on a tag or printed on the device somewhere. Amps is the measure of how much electricity if flowing, basically its volume, and Volts is the pressure pushing it.
2. Watts Law states that Watts = Volts x Amps so divide the Watts by Volts to get Amps. All household items (in the United States) are 120 Volts.
3. Now use Ohms Law: Volts = Amps x Ohms Amps = Volts / Ohms Ohms = Volts / Amps

   A 1200 watt blow dryer / 120 volts = 10 amps

   Volts / Amps = Ohms so 120 volts / 10 amps = 12 ohms

   A 60 watt light bulb / 120 volts = .5 amps 120 volts / .5 amps = 240 ohms

   A 150 watt curling iron / 120 volts = 1.25 amps 120 volts / 1.25 amps = 96 ohms

4. When the blow dryer, light bulb, and curling iron are turned on, the total resistance in the parallel circuit is:

$$\frac{1}{Rt} = \frac{1}{12} + \frac{1}{240} + \frac{1}{96}$$

$1/R_t$ = 20/480 + 2/480 + 5/480 = 47/480 Since it is $1/R_t$, invert to 480/47 and divide to get 10.213 ohms. 120 volts / 10.213 ohms = 11.75 amps

Total Amperage is much easier to calculate. They are simply added together. The 10 amp blow dryer with the .5 amp light bulb and the 1.25 amp curling iron will require 11.75 amps.

Have you ever "blown a fuse" or "tripped a breaker." The fuse and circuit breaker are safety devices in your home's electrical system. They shut off the circuit if too much electricity starts to flow. They keep the wires from getting hot and possibly starting a fire. Most fuses and circuit breakers are set at either 10 amps (for small wires) or 15 amps (larger wires). These 3 devices would not "trip" a 15 amp circuit breaker but would "trip" a 10 amp breaker.

5. Calculate the Watts, Amps, and Resistance of electrical devices in your home. Remember, household voltage is always 120 volts.
6. Although it is a different form of electricity, you can use the same equations for electrical circuits in your car. The car, however, uses 12 volts.

Follow Up Discussion Questions

- There were four different power plants available: coal, natural gas, nuclear, and renewable energy (both solar and wind power). What is the difference between these plants?

- How do the different power plants impact the environment?
  Coal:
  Natural Gas:
  Nuclear:
  Renewable:

- Government initiatives are spurring investment in solar and wind energy. How is this beneficial?

  Why would some people suggest that natural gas is a better investment?

- If your school were to install a way to generate its own power, which method should they purchase? Why?

- Suggest some ways that you could reduce energy consumption.

- There are some people opposed to the installation of Smart Meters on their homes. What reasons are given? Are their reasons valid?

- Describe your vision for the future of electricity.

SS.IS.8.3-5. Use listening, consensus building, and voting procedures to decide on and take action in their classroom and school.

Now that students are somewhat familiar with the electrical energy and the distribution grid, ask them to identify (and possibly implement) actions that could be taken at their school to decrease energy use. To be successful, groups of students must listen to each other and reach consensus on what they are to do while designing and building their electrical grid. A culminating activity addresses energy conservation in their classroom and school which will require research, presentations, and voting.

CCSS.ELA.W.4.2. Write informative/explanatory texts to examine a topic and convey ideas and information clearly.

The discussion questions could be assigned as written responses in complete sentences. They could also be assigned reports on an energy-related topic requiring research. Another option is for them to write (and illustrate) instructions for how they made their grid.

CCSS.ELA.RI.4.5. Describe the overall structure (e.g., chronology, comparison, cause/effect, problem/solution) of events, ideas, concepts, or information in a text or part of a text.

These instructions are written in a Learning Cycle format. Students could be assigned to review and critique these instructions.

CCSS.ELA.W.4.8. Recall relevant information from experiences or gather relevant information from print and digital sources; take notes and categorize information, and provide a list of sources. Require entries into a journal concerning the students experience with the Smart Grid for Schools system. Encourage them to organize this information into a digital slide show to be presented to parents and/or school board members.

NGSS. 3-5-ETS1-1 NGSS.3-5-ETS1-2. NGSS.3-5-ETS1-3.

When completed with this activity, propose that students design and build a model of the electrical grid of the future using all renewable energy sources. Provide them criteria and constraints such as power requirements and location restrictions. Test their designs to find failure points and aspects in need of improvement.

CCSS.ELA.W.5.8. Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources.

Throughout the activity students are learning from experience and from the information presented in the curriculum. A written summary of the experience can be assigned.

SS.IS.5.3-5. Develop claims using evidence from multiple sources to answer essential questions.

A series of questions are presented in each of the "Discussion" sections of the curriculum. Student responses should be based on evidence. Also, several questions are included at the end of the activity prompting further research.

NGSS MS-PS2-3 Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

NGSS MS-PS4-3 Integrate qualitative scientific and technical information to support the claims that digitized signals are a more reliable way to encode and transmit information than analog signals.

Now that students have some experience with electricity, encourage them to make a telegraph system. They can set up "telegraph offices" at various places in the classroom.

A telegraph is a digital system, consisting of either "on" or "off" signals.

NGSS MS-ESS3-5 Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

Research the role of electrical power plants in producing pollution. Compare natural gas, coal, nuclear, and renewable sources including not only their operation, but also their construction, maintenance, and dismantling.