Nearly everything done by humans requires energy. Making things and moving things take energy. Heating food and charging your cell phone also take energy. What would you do without electricity at home or school? Modern society relies on energy!

Nearly all work was done with muscle power until recent times. Both humans and animals have limited power and get tired easily. At the end of the Roman era, Europeans learned to use waterwheels. They were able to crush grain, saw wood, and do many more tasks. 1,200 years later, the Dutch used the power of wind to do many of the same tasks. Wind and water are hard to predict, though!

Image Source: Sakuramochi

James Watt patented the modern steam engine in 1769. Steam engines could be run all the time, but their belts ran all the time too. This made factories dangerous. Look at the textile factory below. You can see the shafts, belts, and pulleys which transferred power from a steam generator.

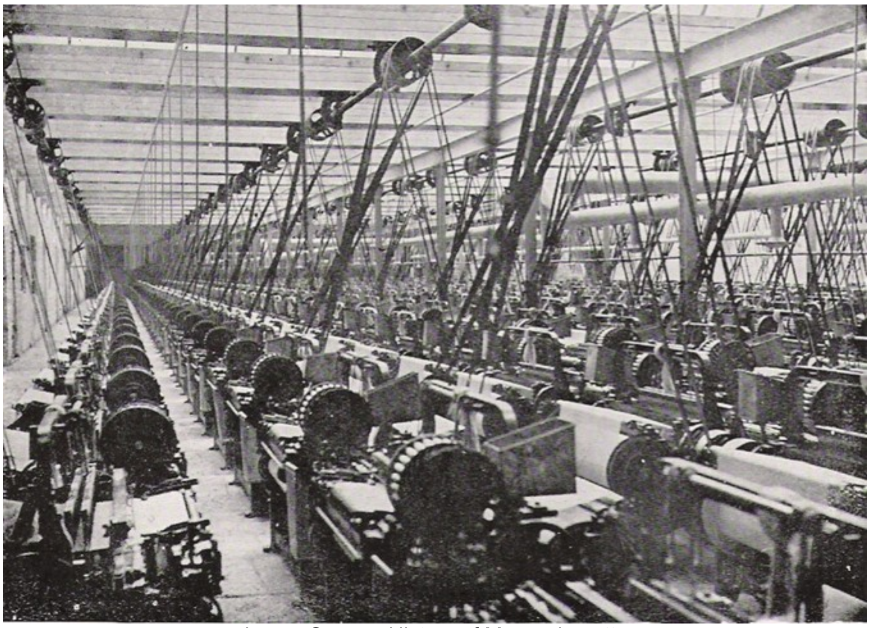

Image Source: History of Massachusetts

By 1831, Michael Faraday understood how magnetism and electricity worked together. A steam engine's motion could move a magnet. As the magnet moved, it could be changed into electrical energy.

One of the first uses of electricity was the electric motor, developed by Moritz Jacobi in 1834. An electric motor only needs two wires. This is much better than long shafts and belts, so many factories built their own power plants next door.

Access the grid construction game at https://cemastprojects.org/SGGC/ or https://gridconstruction.cemastprojects.org/.

Complete Challenge 1: Connecting Power Plants to Customers.
Why do you think your first power plant was a coal power plant?

Coal and wood were the first widely-used forms of power generation. Coal was readily-available, energy-dense, easily-transported, and it burned reliably to create steam and power the generators.

Image Source: The New York Times

The power plant above is Thomas Edison's Pearl Street Station, a coal plant. It does not look very different from coal plants today.

This game prevents a lot of problems which exist in the real world. Wires only connect between springs of matching colors. What might happen if you mismatched wires?

One consequence could be a "direct short." If electricity is allowed to flow through a circuit with nothing to slow it down, such as a light or motor, the wire will get hot and probably start a fire.

Complete Challenge 2: Adding Nearby Customers.

This game also eliminates ground/neutral wires. In the real world, ground/neutral connections are needed for safety. Electricity in your home is typically grounded in three ways. First, a grounding rod is pushed into the earth. Next, a ground wire is connected back to the substation or power plant. Last, a ground wire is connected to a cold water line. Each of these is a safer path for electricity than through a person!

Complete Challenge 3: Carrying Power Short Distances.

In the last challenge, you connected homes to a power plant or factory. How is using distribution poles better?

Distribution poles make longer distances possible. It is also never a good idea to connect buildings directly, as a problem in one building would make all neighbors lose electricity.

How difficult was it to find the downed wire at the end of the challenge?

Not very difficult, even by trial and error.

Think about the city you live in. How much more difficult would it be to track downed lines there?

Until fairly recently, the power company was only able to identify where lines went down when they mapped outages reported by customers' phone calls. This made tracking downed lines very difficult!

The game references a 1-mile limit for power lines. This was true of the DC (direct current) electricity used by Pearl Street Station. It provided power to one square-mile area of New York City in 1882. It mainly served rich customers like the New York Stock Exchange.

Complete Challenge 4: Using Transformers to Carry Power Long Distances.

You can think of voltage as the size of the pipe carrying electricity. The bigger the voltage, the more energy flow. What do you think would happen if you connected a high-voltage wire to a low-voltage device?

Voltage which is too high will generally result in overheating, and if the voltage is very different, overheating and fire can be near-instantaneous.

Today we use AC (alternating current), which can travel much further than DC. Of course, AC had a problem too. Low-voltage lines lose a lot of electricity. This problem was overcome by George Westinghouse and Nicola Tesla. They applied Michael Faraday's research on voltage to make transformers. Transformers at power plants and in your neighborhood increase or decrease the voltage of the electricity. High voltage travels well, but customers need low voltage.

All power lines are dangerous, but high voltage lines are more dangerous. The taller the distribution pole, the higher the voltage that the line carries. This is true even in the substation, pictured on the next page. In this station, you can see fins on vertical rods. In the game, fins are horizontal along the black boxes.

Image Source: Michael Gaida

Complete Challenge 5: Providing 3-phase Power to Large Customers.

All power plants produce 3-phase AC power. As a generator spins, electricity alternates from positive to negative 60 times each second. In 3-phase, there is always a phase which is nearly-positive and a phase which is nearly-negative. This provides more, smoother power for customers like factories. (When you ride your bike, you can think of yourself as using 2-phase power. When you lift one leg, the other leg is pushing down, so one leg is always providing energy.)

Look in the building supply menu. The third column has 3-phase customers, and the fourth column has single-phase customers. Do any of the buildings in each category surprise you? Why or why not?

Even large buildings like apartment buildings or banks typically use single-phase power. Most office buildings would use single-phase power, though large-area heating systems or large-scale printing presses might use 3-phase power.

Complete Challenge 6: Bringing Power to a Large Community. In this challenge you have access to all the buildings in the game, including multiple power plants.

Is it bad to have more than one power plant?

No, it is not! In fact, it generally helps to have more sources of energy close to their places of consumption, though larger power plants can be more efficient in other ways. In later challenges, it will become clear that a variety of *types* of power plants is advantageous.

In this challenge, you experienced two different storms. First, a single line was disrupted. Compare this experience to Challenges 3 and 5. Is it easier or harder to find downed wires as your city gets larger? Why?

It should get more difficult. With more customers to monitor and more lines to go down, repairs should take longer.

In the second storm, two lines were pulled down. How did losing two lines make solving the problem more difficult?

While difficulty depends on how lines are connected and which one comes down, the second line can often complicate finding the first downed line.

Complete Challenge 7: Adding Switches for Redundancy.

What does a switch do?

No matter the scale, switches control current flow by completing or breaking a circuit.

Why would the job of lineworkers be impossible without switches? (Lineworkers repair lines, repair equipment, or connecting customers.)

Switches allow this important work to be done when there is no power running through a line. Without switches, this work would be VERY unsafe!

Switches are often found alongside transformers. In this case, they were placed just after the transformers on the power plants rather than at the substation transformers. Redraw the map below – how would it change if the switches were moved but we still wanted to control which plant provided power?

Play for a while in Free-Play Mode. (This is accessible after you finish Challenge 7.)

What about this game is realistic?

How might this game be different from how power works in the real world?

As already discussed, the ground connection is not visible in this game. There are also some connections in this simulation which would not occur in the real world (eg. plant-to-customer-to-pole-to-customer connections are currently possible in the game).

You have now built a very large and complex grid system with lots of power plants, substations, and customers, but this is still a simple representation of the actual grid. Although the grid is complex, it is 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 future demands. For example, nearly all cars are powered by gasoline. As electric cars become more popular, the energy to move them will come from the grid, not the gas station.

Come back on November 1 to finish the last few challenges! You will be able to see how the smart grid can power more things, use less energy, and make blackouts a thing of the past.