What happens when you flip a switch?

A series of hands-on activities to help students understand what energy is and how we generate it

Gerald Darling

Energy is one of the most fundamental and unifying concepts in science. It's also identified in the *Next Generation Science Standards* as both a crosscutting concept and a disciplinary core idea in the physical sciences (Achieve Inc. 2013). But when students ask you what energy is, what do you tell them? We teach our students about energy resources and global climate change, but what about the bigger picture of how we generate energy for civilization? Or, what happens when you flip a switch?

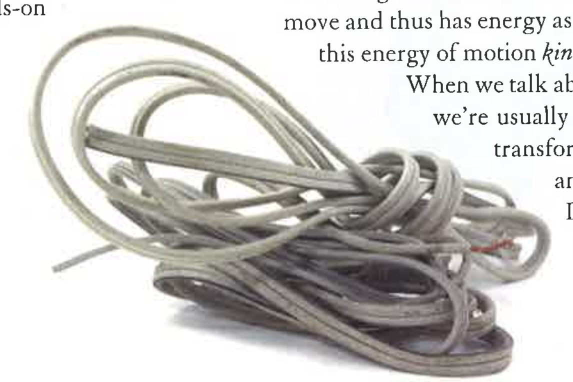
Understanding the answers to these questions is critical as we search for a more sustainable energy future. This article presents a series of inexpensive, hands-on activities appropriate for any high school science unit on energy. These activities allow students to explore what energy is, synthesize the big picture of energy production, and find answers to the pressing questions above.

Activity 1

What is energy, and how is it converted from one form to another?

In science textbooks, *energy* is defined as "the ability to do work," and *work* is defined as "the transfer of energy, which occurs when a force acts on an object, causing it to move" (Giancoli 2004). Familiar examples and hands-on activities can help illuminate these somewhat confusing textbook definitions for students. For example, motion is one obvious indication of energy. Think about a hammer hitting a nail. A moving hammer can make something else (i.e., the nail) move and thus has energy associated with its motion. We call this energy of motion *kinetic energy*.

When we talk about energy in our science classes, we're usually talking about the conversion or transformation of one type of energy into another. To illustrate this concept, I hold a metal sphere (available at science supply stores) in each



hand, as a student demonstrates in Figure 1A, and smash the two together. There's a loud crack as the spheres come to rest, and I ask students what happened. "Each sphere was moving, but now each is at rest," I say. "Where did that kinetic energy go—did it just disappear?" At this point, a student usually recalls the law of conservation of energy (i.e., energy cannot be created nor destroyed but is transformed from one form to another). Here, the kinetic energy has been transformed into another form of energy. "But into what?" I ask.

To help students answer this question, I hold a sheet of paper by one corner and ask a student, wearing safety goggles, to smash the two metal spheres together with the paper between them (Figure 1B). The balls collide with a loud crack, and students are amazed to smell smoke and see a hole burned into the paper (Figure 1C, p. 36). They realize the spheres' kinetic energy has been converted into thermal energy, though no open flame is produced. Next, I ask for volunteers to replicate the process, and students spend several minutes converting kinetic energy into thermal energy.

Many examples of this conversion are available in nature. On a cool fall morning, for example, we rub our hands together—converting energy of motion into thermal energy—and our hands get warmer. Have students try this. It helps them synthesize the concepts of energy and its transformation. But what about the opposite conversion? If we have thermal energy, can we convert it to make something move?

Activity 2

How do we convert thermal energy into kinetic energy?

Science, engineering, technology, and indeed civilization itself are built on moving things: We have tractors to plant and harvest crops, washing machines to move our clothes though soap and water, dryers to move them through warm air, cars and buses to move children to and from school, elevators to move people up and down in buildings, beaters and mixers to move and prepare our food, airplanes to move us across

Connections to the *Next Generation Science Standards* (Achieve Inc. 2013)

Standard: HS-PS3-3 Energy

Performance expectation: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS3-3)	*PS3.A: Definitions of Energy* At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-3) *PS3.D: Energy in Chemical Processes* Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3)	*Energy and Matter* Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS3-3) *Connections to Engineering, Technology, and Applications of Science* *Influence of Science, Engineering, and Technology on Society and the Natural World* Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS3-3)

FIGURE 1A

Metal spheres for Activity 1.

the country, trucks to move goods across the continent. You get the idea.

But how do we do all this? What is the source of energy that has been transformed into this tremendous amount of kinetic energy?

In the 1700s, scientists discovered how to extract vast quantities of kinetic energy from the thermal energy of a hot gas. They accomplished this with a device called a *heat engine,* which at its heart is a cylinder with a movable piston. If a gas inside this cylinder is heated, the gas expands and pushes the movable piston out—converting some of the thermal energy of the hot gas into the kinetic energy of the moving piston.

I help students explore this concept with the heat engine (available from major science supply stores) shown in Figure 2 (p. 36). I begin by passing the heat engine around so students can examine it. The cylinder with its movable piston is quite wide (about 10 cm) but only 1 cm in height. But the first thing students notice is the large propeller connected to the movable piston. Students turn the propeller with their fingers and see that they are causing the piston to move up and down in the cylinder. I explain that they are running the device backward. We want kinetic energy as an *output* of the heat engine, not an *input.* In other words, the engine should move the propeller, and not vice versa.

Once each student has examined the heat engine, I place it on a 600 ml beaker holding 300 ml of water, which is boiled with a Bunsen burner. Steam builds up on the base of the engine and heats the gas inside the cylinder. After about five seconds, the piston begins to move up and down, and the propeller starts to spin. As students watch the engine convert the thermal energy of a hot gas into the kinetic energy of the piston (and the connected propeller), I ask them for examples of heat engines they use every day. Soon they mentally connect this heat engine and its cylinder, piston, and propeller with the internal combustion engines used in cars, buses, and airplanes.

The heat engine fueled the industrial revolution—freeing humanity from many forms of physical labor. But what about the electrical energy we use when we flip a switch or plug in our smart phones?

Activity 3

How do we convert kinetic energy into electrical energy?

In the 1800s, scientists made another great discovery: If a copper wire is moved in the presence of a magnet, the electrons in the copper wire also move, and an electric current flows! Thus, kinetic energy can be converted into electrical energy. The device that converts kinetic into electrical energy is an *electric generator.* To provide students experience with this remarkable device, I give them a small electric generator that lights a bulb (Figure 3, p. 37). Each student turns the crank, which then turns a copper wire in the presence of a magnet and produces an electric current that lights the bulb.

So, what happens when you flip a switch?

Now I put it all together so students understand the big picture of how electrical energy is generated. First, I remind stu-

FIGURE 1B

Smashing the spheres together.

FIGURE 1C

The result: burned paper.

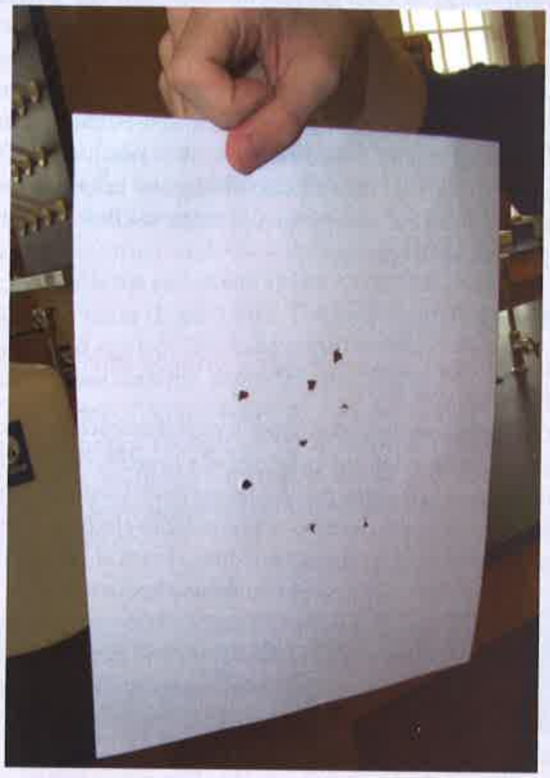
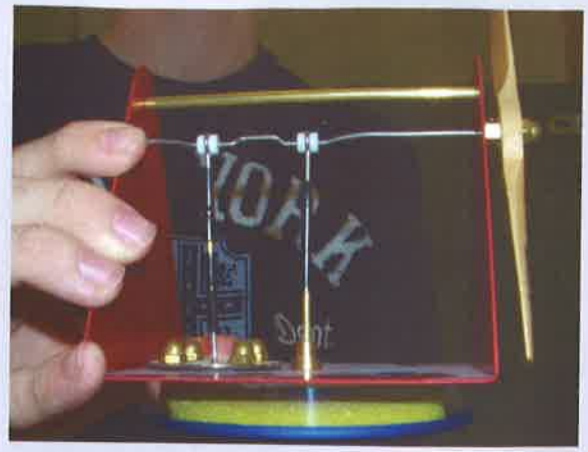


FIGURE 2

Heat engine for Activity 2.



dents that we burned natural gas (via the Bunsen burner) to boil water in the beaker and produce steam, which provided the energy input for the heat engine placed on the beaker. When the propeller turned, the heat engine's kinetic energy output provided the energy input to the generator. Then I turned the generator's crank and the bulb lit.

This is how we generate most of the electrical energy used in the United States. We burn fossil fuels to boil water and produce steam; we use a heat engine to transform some of the steam's thermal energy into kinetic energy; finally, we use a generator to transform the kinetic energy into electrical energy. We then use this energy in our homes, schools, factories, hospitals, and so on.

Many students are stunned to find that about 70% of our electrical energy is generated by burning coal or other fossil fuels (Giancoli 2004). This is a true eureka moment, the first time students comprehend exactly how electrical energy is produced.

In the 1940s, we discovered a more sophisticated way to boil the water needed for electrical energy: nuclear fission. When a uranium nucleus is split, nuclear energy is released and can be transferred to the thermal energy of water. From there on, the story remains the same: We use nuclear energy to boil water, and the thermal energy of the steam is transformed into electric energy through a heat engine and electric generator. The big difference between a fossil fuel–burning power plant and a nuclear power plant is simply in how the water is boiled! About 20% of the electrical energy in the United States is generated from nuclear energy (Giancoli 2004).

Thus about 90% of electrical energy in the United States is generated by boiling water to make steam and using a heat engine and electric generator to convert its thermal energy into electrical energy. Of the remaining 10% of electrical energy generated in the United States, most comes from simply letting falling water or wind turn the crank of the generator, through what's known as hydroelectric or wind power, respectively (Giancoli 2004).

Assessment

Assessment of this lesson will vary by individual teacher and discipline. I teach it in one 47-minute class period. At the beginning of class, I tell students I will give a short quiz at the end of the period, emphasizing the main ideas presented in class. This has proven to be an excellent way to focus their attention. Alternatively, teachers may assign an essay in which students answer the following question: "What happens when you flip a switch, and how does this affect your daily energy use?"

Whatever the individual teacher's choice, assessment should follow from the activity's learning outcomes (see box, p. 37).

Conclusion

Although energy is fundamental to our civilization, few high school students have a clear picture of what happens

FIGURE 3

Electric generator used to light a bulb in Activity 3.

when they use it. To become informed citizens and decision makers, every high school student must understand how we generate electrical energy. Working through the series of inexpensive, hands-on activities presented in this article, students learn what energy is and get the big picture of how it's generated.

After the activities, the study can go in multiple directions. For example, Earth science or biology teachers may continue with a lesson on global climate change and how we can increase the use of wind and solar energy for a more sustainable future. Chemistry or physics teachers may continue with the laws of thermodynamics, which are superbly demonstrated by the heat engine.

No matter where you go from here, the activity will help students truly understand the concepts of energy. ■

Learning Outcomes

After completing the activities described in this article, students should be able to

- explain what energy is, using everyday examples;
- describe the law of conservation of energy;
- identify everyday examples of converting kinetic energy into thermal energy;
- explain how a heat engine converts a hot gas's thermal energy into kinetic energy;
- identify everyday examples of heat engines;
- describe how an electric generator converts kinetic energy into electrical energy; and
- explain how energy is generated, or what happens when you flip a switch.

Gerald Darling (jdarling@usj.edu) is a professor of physics at the University of Saint Joseph in West Hartford, Connecticut.

Resources

Metz, S. 2012. *Fuel for thought: Building energy awareness in grades 9–12.* Arlington, VA: NSTA Press.

Robertson, W.C. 2002. *Energy: Stop faking it! Finally understanding science so you can teach it.* Arlington, VA: NSTA Press.

References

Achieve Inc. 2013. *Next generation science standards.* Washington, DC: National Academies Press.

Giancoli, D. 2004. *Physics: Principles with applications.* 6th ed. New York: Prentice Hall.