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2019 Volume IV: Energy Sciences

Harnessing the Wind Like William Kamkwamba: Building Model Windmills in a 4th Grade STEM Lab

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by Jason Ward

We live in a world that is made possible by the energy around us. While we cannot always see or touch energy, energy is everywhere and its usage has become as vital to human life as food, water, and shelter. We depend on energy for essential services, such as to warm or cool our homes, to grow and cook our food, to purify and deliver freshwater, to provide transportation, and to enable us to communicate. All of them are essential to life as we know it. Energy is an important topic and scientists and researchers are still working on finding better solutions to meet the global demand for energy that is affordable, dependable, and won't cause more harm than good.

This unit is designed to strengthen the teaching of the 4th grade Next Generation Science Standards (NGSS) related to the topic of energy by providing a close look at the science behind how a wind turbine can be used to generate electricity. It is inspired by the story of William Kamkwamba, a 15-year-old farmer from Malawi who built a windmill in his village to bring electricity and water during a time of famine.

Kamkwamba's story rose to fame in 2006, when a local newspaper wrote about the boy who created a windmill to power his home and irrigate his family farm. He was featured in a 2007 TED talk, where he nervously told his story. This inspired several benefactors to sponsor his education at the African Bible College Christian Academy in Lilongwe, the capital of Malawi. He went on to receive a scholarship to the African Leadership Academy and in 2014 graduated from Dartmouth College in New Hampshire with a degree in Environmental Studies. He followed up with an additional TED talk in 2009, as well as wrote a memoir about his experiences entitled "The Boy Who Harnessed the Wind: Creating Currents of Electricity and Hope" that has been adapted into several easy-reader versions and biographies. It is also the basis of a 2019 Netflix film and several poignant documentaries, all of which I will reference in the teacher resources section. He was named one of Time Magazine's 30 People Under 30 in 2013. He now works with the WiderNet Project in Chapel Hill, NC to develop technologies and curricula that help young people bridge the gap between 'knowing and doing' in Malawi, and across Africa. [1]

Kamkwamba's story is just one of the millions in the global quest for energy. On one side, it is a simple tale of a boy who built a windmill out of junkyard parts so he could listen to some music and light his home. I believe most students can connect to that idea no matter their age. Upon looking deeper, it also inspires some profound questions about humanity's relationship with energy. Kakwamba's ingenuity as he worked with local resources to meet a demand for energy during a time of famine will give learning about wind-turbine generated electricity a personal face and a global connection. I was inspired by his story, and I believe my students will be as well.

This curriculum unit is the result of my work in the 2019 Yale National Initiative seminar titled Energy Sciences. This two-week intensive, teacher-led summer institute was led by Dr. Gary Brudvig, Yale Professor of Chemistry and Molecular Biophysics & Biochemistry and director of the Yale Energy Sciences Institute. I have 18 years of experience as an elementary teacher at the time of this writing, and for the past five years, I have been developing STEM lab curricula and teaching STEM to K-4 grade students in New Haven, CT.

New Haven demographics reflect those of many urban areas, with more than 80% of the local student population receiving free or reduced-price lunch. In addition to meeting the full educational requirements of the Connecticut State Standards, our "Communications" themed magnet school includes specialized programs in public speaking and debate, Chinese and American Sign Language, and communication technologies such as photography, video production, and a robust K-4 robotics program. The STEM lab is a hub of discovery and learning and is where many of the technological elements of our magnet program come to life. It is also where much of the "hands-on" Next Generation Science Standards (NGSS) teaching takes place and where this unit will be taught to several classes of 4th-grade students.

As it turns out, energy is an incredibly huge and diverse topic. This unit will not help you teach everything there is to know about energy in the 4th grade NGSS standards. It will, however, serve as a supplement that will help students develop a deep understanding of the process of generating electricity

The timing of this unit should take 8 1 hour lessons, but these lessons lend themselves to be readily customizable in complexity and scope. The first three lessons are background information (learning what Kamkwamba learned) as well as introducing Kamkwamba's story.

The end-product of this project is to design and construct a scale replica of Kamkwamba's windmill from the ground up. They will create "electric wind" like Kamkwamba. His original windmill was about 14 feet high, and I built a 1:2 scale model as a demo piece (7 feet tall, photos and instructions included). Students will work together to create a scale model (1 to 3 feet tall) of a windmill. They will need to design the tower, the blades with a shaft and rotor, an electrical generator to power an LED or a buzzer, and a circuit to transmit power.

In a K-12 education based on the current Next Generation Science Standards (NGSS), students learn about energy from the sun starting in kindergarten. First graders learn about light and sound waves, while in third-grade students are learning more about forces and their interactions. It is not until fourth grade that students learn about how energy can be transferred from place to place by sound, light, heat, and electrical currents, as well as that energy and fuels are derived from natural resources that impact the environment. A typical ten-year-old fourth-grade student should also have some background knowledge based on their experiences. They usually know electricity travels from an outlet to a device, and that a switch can control the flow of electricity. They know fuels such as gasoline are a source of energy to make vehicles move. They know batteries store energy, come in different sizes, and that some batteries can be "recharged" (technically batteries are not recharged, they are re-energized). They may also have misconceptions about energy such as "batteries have electricity inside them", or that "energy can be created". It will be important to build on what students already know, as well as to challenge their thinking on misconceptions as they arise.

Tackling an engineering task of building a working windmill is going to take an understanding of several scientific ideas first, beginning with some background on the essential questions "What is energy?" and "How do we get the energy we need?" The following background information takes the topic of energy that is very large in scope and although it is general, it will be sufficient understanding to prepare an educator for teaching 4th graders about energy.

What Is Energy?

Perhaps the simplest answer is that energy is the ability to do work, and work is what makes things happen. Without energy, nothing would ever change. We can observe energy as it interacts in various ways, such as producing movement, heat, or light for example.[2]

We classify energy in two ways. First is potential energy, which is the amount of energy something has stored inside it. Anything can have potential energy. A battery has potential energy stored by a difference in ionic concentration. A book on a table has potential energy as well, how much depends on the mass of the book and its height. A great deal of energy is also stored in chemical bonds.

The second is classification is kinetic energy, which is the energy of an object in motion. Anything that is moving has kinetic energy. Mechanical objects, such as a clock, have kinetic energy, but so do light, sound, wind, and water.

Energy cannot be made or destroyed; it can only be changed into different forms. Those forms include:

Chemical energy: energy stored in the bonds of chemical compounds (atoms and molecules). Chemical energy is released in a chemical reaction, often in the form of heat. We use the chemical energy in fuels like wood and coal by burning them.

Electrical energy: the energy carried by moving electrons in an electric conductor. It is one of the most common and useful forms of energy. Other forms of energy are also converted to electrical energy. For example, power plants convert chemical energy stored in fuels like coal into electricity.

Mechanical energy: the energy a substance or system has because of its motion. Machines use mechanical energy to do work.

Thermal energy: the energy a substance or system has related to its temperature, i.e., the energy of moving or vibrating molecules. We use radiation to cook food.

Nuclear energy: the energy that is trapped inside each atom. Nuclear energy can be produced either by the fusion (combining atoms) or fission (splitting of atoms) process. The fission process is the widely-used method. Even mass is a form of energy, as Albert Einstein's famous $E = mc^2$ showed.

We know energy is not lost because the law of conservation of energy, also known as the first law of thermodynamics, states that the energy of a closed system must remain constant—it can neither increase nor decrease without interference from outside. The universe itself is a closed system, so the total amount of energy in existence has always been the same. The forms that energy takes, however, are constantly changing. For instance, chemical energy is converted to thermal and light energy when a candle is lit. If one adds up all the forms of energy that are released in the combustion, in this case, both thermal and light, one will get the exact decrease of chemical energy in the fuel source.

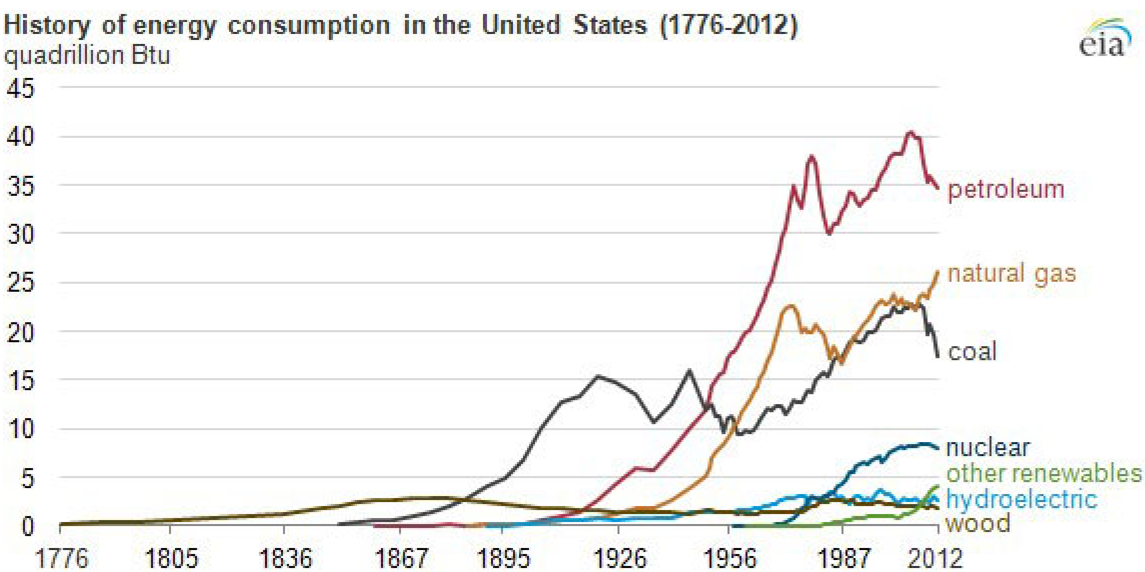
How Do We Get the Energy We Need?

We owe the sun for most of our energy here on Earth. Without it, well, there wouldn't be much here for us. The energy radiating from the sun has enriched our planet by providing conditions possible to support life. That energy is abundant, and a great deal has been stored and can be harvested as fuel.

Human technology for harvesting energy likely evolved when early mankind burned wood (or another fuel source) for heat and light. In a modern region with electric power, a power plant produces electricity by changing the chemical energy in fuel into electrical energy. First, fuel is burned within the plant, converting its chemical energy into heat. Next, the heat turns water into steam, which moves a turbine motor or generator. Finally, the generator produces electricity which then either needs to be stored or transmitted and used.

This steam-based technology was first discovered in the early 1700s when engineers began to figure out ways to use the energy in steam released by boiling water. They developed engines that converted steam energy into mechanical energy for use in farm and factory machinery, and later for trains and cars. The development of the steam engine sparked the period in modern history called the industrial revolution "A typical American family from the time our country was founded used wood (a renewable energy source) as its primary energy source until the mid- to late-1800s. Early industrial growth was powered by water mills. Coal became dominant in the late 19th century before being overtaken by petroleum products in the middle of the last century, a time when natural gas usage also rose quickly.

Since the mid 20th century, the use of coal has again increased (mainly as a primary energy source for electric power generation), and a new form of energy—nuclear electric power—emerged. After a pause in the 1970s, the use of petroleum and natural gas resumed growth, and the overall pattern of energy use since the late 20th century has remained fairly stable."[3]

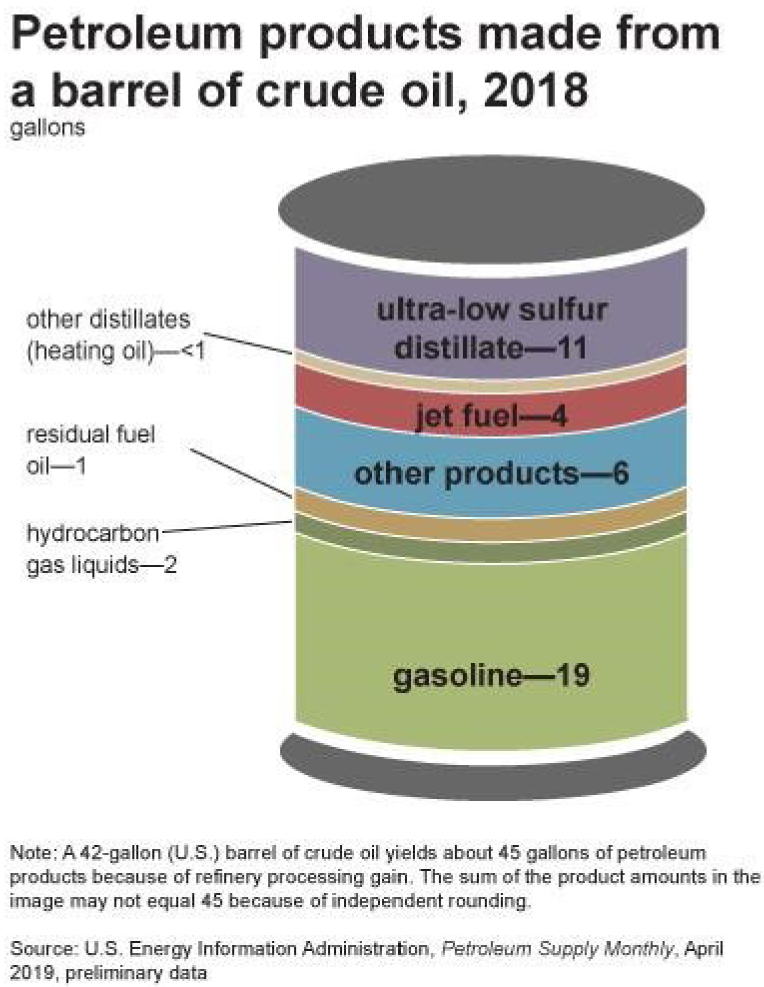


Source: U.S. Energy Information Administration[4]

Energy consumption patterns have changed significantly over the history of the United States as new energy sources have been developed and as uses of energy changed.

Nonrenewable Energy Sources

Nonrenewable energy sources are classified as nonrenewable because they can not be replenished in a short time. Most nonrenewable energy sources are based on crude oil (petroleum), natural gas, and coal. These are known as fossil fuels. Uranium is also considered a nonrenewable resource because it has to be mined or harvested from seawater.



Crude Oil: “Crude oil is a mixture of hydrocarbons that formed from plants and animals that lived millions of years ago. Crude oil is a fossil fuel, and it exists in liquid form in underground pools or reservoirs, in tiny spaces within sedimentary rocks, and near the surface in tar or oil sands. Petroleum products are fuels made from crude oil and other hydrocarbons contained in natural gas. Petroleum products can also be made from coal, natural gas, and biomass. After crude oil is removed from the ground, it is sent to a refinery where different parts of the crude oil are separated into useable petroleum products. These petroleum products include gasoline, distillates such as diesel fuel and heating oil, jet fuel, petrochemical feedstocks, waxes, lubricating oils, and asphalt.” [5]

About 100 countries produce crude oil. However, in 2018, five countries accounted for about half of the world's total crude oil production. The top five crude oil producers and their shares of world crude oil production in 2018 were:

- United States—13.2%

- Russia—13.0%
- Saudi Arabia—12.6%
- Iraq—5.6%
- Canada—5.2% [6]

Natural Gas: Odorless, invisible, and tasteless natural gas is made of many different compounds, with the largest component methane, a compound with one carbon atom and four hydrogen atoms (CH_4). The chemical methyl mercaptan is added to give it a sulfur odor to help detect leaks. Like crude oil, natural gas is a fossil fuel and a product of millions of years worth of plants and animals, including diatoms, that decomposed and were buried in the crust of the earth. Some of this carbon and hydrogen-rich material, over time and pressure and heat, formed into either coal, natural gas, or crude oil. When burned, it is an energy source. There are several sources of natural gas, including on-shore and off-shore oil wells and coal beds. However, "during the 1980s and 1990s, Mitchell Energy experimented with alternative methods of hydraulically fracturing the Barnett Shale (a geological formation in northern Texas). By 2000, the company had developed a hydraulic fracturing technique that produced commercial volumes of shale gas. As the commercial success of the Barnett Shale became apparent, other companies started drilling wells in this formation, and by 2005, the Barnett Shale was producing almost half a trillion cubic feet (Tcf) of natural gas per year."[7] This technology continues to evolve, with horizontal drilling allowing even greater access to previously hard to reach reserves. Fracking technology, while greatly increasing our national supply of energy resources, also has environmental concerns. Fracking requires high-pressure water and chemicals injected into the ground, which introduces a concern over triggering earthquakes and storage of wastewater, in addition to how much freshwater is contaminated in the process. "One of the main chemicals released in the fracking process is methane, and it is estimated that 4% of it escapes into the atmosphere during extraction. Because methane is 25 times stronger than carbon dioxide in terms of trapping heat, the release of this gas is detrimental to the air quality of surrounding fracking sites."[8] Most of the methane is burned off, and large sites like North Dakota's Bakken Shale look as bright as a large city at night due to the flaring of methane gas. Similar sites in New Mexico and Texas are also flaring large amounts of methane as a waste byproduct of fracking.

Coal: Coal is a dark-colored sedimentary rock heavy in carbon and hydrocarbons that accumulated over millions of years as energy stored in swampy plants became buried and exposed to long term heat and pressure. There are several different types of coal, categorized by carbon content. About half of the coal produced in the coal mining regions around West Virginia, Kentucky, Indiana, and Pennsylvania contain bituminous coal, which is abundant and has a high enough carbon content to generate electricity or to be used as a raw material for making metals such as iron and steel. Coal mining has environmental impacts, such as above-ground environmental destruction, water pollution, and the venting of methane gas. Burning coal releases several compounds that have harmful effects. Nitrogen oxides, sulfur dioxides, and particulate matter contribute to a hazy smog and can trigger respiratory illnesses and acid rain. The release of carbon dioxide is another huge detriment to the burning of coal. Carbon dioxide is a greenhouse gas, and the world has seen historic concentrations of it in our atmosphere on a growing trend over the past 100 years. The effects of a warmer climate are predicted to have rippling effects throughout the world, including climate and ocean shifts that can have a devastating impact on world economies and populations. While coal may be an abundant and currently inexpensive resource, we must live through whatever happens as a result of its use and it is time for an energy dependence shift.

Nuclear: Nuclear fission of uranium atoms produces a large amount of heat and radiation. The nuclear reaction is controlled within a nuclear power plant and the resulting energy is used for the generation of electricity. Uranium is more abundant than silver, but nuclear power plants require a rarer form known as U-235 because its atoms are easier to split. While nuclear power plants do not produce direct carbon dioxide emissions, radioactive waste needs to be contained and either disposed of or stored away. The cost of constructing and maintaining a nuclear power plant, obtaining and processing U-235, and taking care of waste by-products are all concerns related to the continued use of nuclear energy.

Renewable Energy Resources

Renewable energy sources are sustainable alternatives to fossil fuels because are constantly renewed by natural means. Several of the top sources are biomass, geothermal, hydrogen, hydropower, solar, ocean thermal, and wind. Although these alternatives do pose some environmental concerns, they are a much cleaner source of energy if the means of production and storage or transmission are practical and the challenges of any environmental impact can be mediated. The reduction of carbon dioxide should be a priority, as this will have the most global impact. Regional availability of resources, energy production and storage technology, governmental policy, financial interests, and worldwide collaboration are all factors in making an energy resource shift.

Biomass: Biomass fuels are produced from organic materials such as wood, waste, ethanol, biodiesel, and landfill gas. These fuels can either be burned directly or converted to liquid biofuels such as ethanol. These organic materials are formed via solar energy through the process of photosynthesis.

Geothermal: Geothermal energy is the result of the slow decay of radioactive particles in the earth's core. The earth has four major parts or layers: an inner core of iron, an outer core of molten rock, a mantle of magma and rock surrounding the outer core, and a crust of solid rock that is between 15 to 35 miles thick under the continents and 3 to 5 miles thick under the oceans. “Scientists have discovered that the temperature of the earth's inner core is about 10,800 degrees Fahrenheit (°F), which is as hot as the surface of the sun.”[9] Water heated by a geothermal process is at the surface in the form of hot springs. Regions with easy access to this natural resource can use it as a source of heating and cooling, or electricity production. In Iceland, they use geothermal heating in most of their public buildings. Geothermal reserves can also be found by drilling into the crust. “The United States leads the world in the amount of electricity generated with geothermal energy. In 2018, there were geothermal power plants in seven states, which produced about 16.7 billion kilowatt-hours (kWh), equal to 0.4% of total U.S. utility-scale electricity generation.” [10]

Hydrogen: The combination of hydrogen and oxygen molecules in a fuel cell produces an electric current and zero carbon dioxide emissions. Liquid hydrogen is currently used as rocket fuel, and gaseous hydrogen is used for treating metals and processing petroleum. It can be used as a more efficient fuel source than fossil fuels for powering an internal combustion engine. A major obstacle to the adoption of hydrogen-based transportation is the availability of fueling stations within our current infrastructure, although many large cities are using hydrogen to power public transportation.

Hydropower: Hydropower relies on the process of the water cycle. Flowing water is used to spin a turbine or turn a wheel, resulting in kinetic energy. This kinetic energy is converted to electrical energy which can then be stored or transmitted. In most cases, hydropower is a practical resource if located near the source of water due to the expense of transportation or limitations of storage technology.

Ocean Thermal and Tidal: Ocean thermal conversion uses the temperature differences between deep, cool water and warm, shallow water to run a heat engine and produce electricity. A tidal barrage system, which uses sluice gates to control water levels, is a potential energy resource in regions that have the necessary topography. Tidal turbines, which need to be resistant to corrosion and ocean elements, can be placed on the seafloor in strong tidal zones. "The United States does not have any tidal power plants, and it only has a few sites where tidal energy could be economical to produce. France, England, Canada, and Russia have much more potential to use tidal power." [11]

Solar: The sun has been producing energy for billions of years and it is the root source of most of the energy on Earth. We can also directly collect solar energy for electricity using photovoltaic cells. "Sunlight is composed of photons, which are particles of solar energy. These photons contain varying amounts of energy that correspond to the different wavelengths of the solar spectrum. A PV cell is made of semiconductor material. When photons strike a PV cell, they may reflect off the cell, pass through the cell, or be absorbed by the semiconductor material. Only the absorbed photons provide energy to generate electricity. When the semiconductor material absorbs enough sunlight (solar energy), electrons are dislodged from the material's atoms. Special treatment of the material surface during manufacturing makes the front surface of the cell more receptive to the dislodged, or free, electrons, so the electrons naturally migrate to the surface of the cell."[12] Solar cells are easy to add to the tops of buildings and in open areas that receive a lot of direct sunlight. Solar energy does not release additional carbon into the air as a result of the energy conversion, so it is a suitable alternative source of fuel only limited by the amount of available sunlight. Photovoltaic cells can be small and generate enough electricity to power a watch or calculator. Larger cells can be used to heat or cool homes and water. Even larger installations can be used to power big areas. Current photovoltaic cells are about 18% efficient at absorbing and converting solar energy. The main obstacles to solar energy usage are the cost to generate and store electricity and the availability of enough sunlight to meet the energy demand. Dr. Brudvig, the Yale seminar leader for the seminar sessions from which this unit was created, is currently researching artificial photosynthesis and methods of storing and releasing energy held in chemical bonds, similar to the process used by all of the green plants on Earth. Current solar energy technologies also use solar energy to heat molten salt (which can store that heat for several hours after sunset). In other areas, solar energy is distributed to other regions or stored in advanced, large capacity batteries.

Wind: As the sun shines down on the land and water, various areas absorb and reflect solar energy at different rates. This uneven heating and cooling process drives the movement of large air masses. This energy can be collected through spinning turbines and transferred to an electrical generator to convert mechanical energy to electrical energy using the principle of electromagnetic induction. "In 2018, wind turbines in the United States were the source of about 6.6% of total U.S. utility-scale electricity generation.

The amount of electricity generated from wind has grown significantly since 2000. Electricity generation from wind in the United States increased from about 6 billion kilowatt-hours (kWh) in 2000 to about 275 billion kWh in 2018. New technologies have decreased the cost of producing electricity from wind, and growth in wind power has been encouraged by government and industry incentives." [13]

Teaching Strategies: Constructing a Windmill

There are many ways we can obtain, store, or transfer energy and to discuss them further would exceed the scope of this unit. The above background information summarizes a general understanding of energy and energy resources. From here on, we will follow Kamkwambe's journey in the construction of a windmill using spare parts and knowledge of electricity. The four elements of the next section will be dedicated to information related to the construction of a device that will harness the wind and convert it into electrical energy. A windmill. The four phases of this project have been divided into four sections: tower construction, turbine construction, electrical generator construction, and circuit construction.

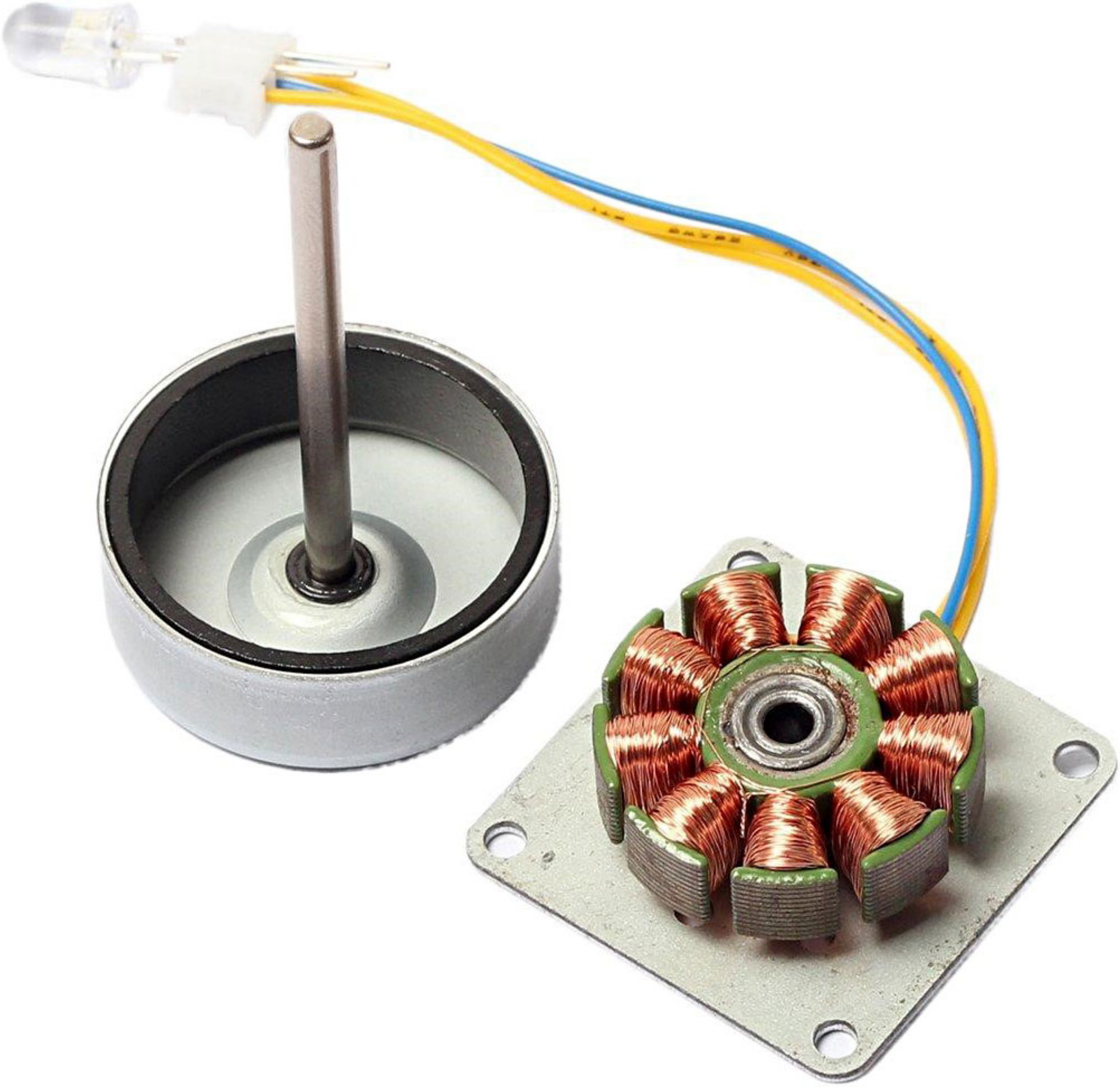
Electrical Generator Construction: In the nineteenth-century, British physicist and chemist Michael Faraday made the first electric generator, called the dynamo, as well as the first electric motor. "In Michael Faraday's generator, coils of copper wire rotating between the poles of a magnet produce a steady current of electricity. One way to rotate the disk is to crank it by hand, but this isn't a practical way to make electricity. Another option is to attach the shaft of the generator to a turbine and then let some other energy sources power the turbine. Falling water is one such energy source, and, in fact, the first major plant ever built took advantage of the enormous kinetic energy delivered by Niagara Falls."[1] Many electrical generators take advantage of steam, which will transfer energy to a turbine and on to a generator. The most popular way to make steam is to heat water by burning coal or natural gas, but it is possible to use other methods such as controlled nuclear reactions or solar energy.

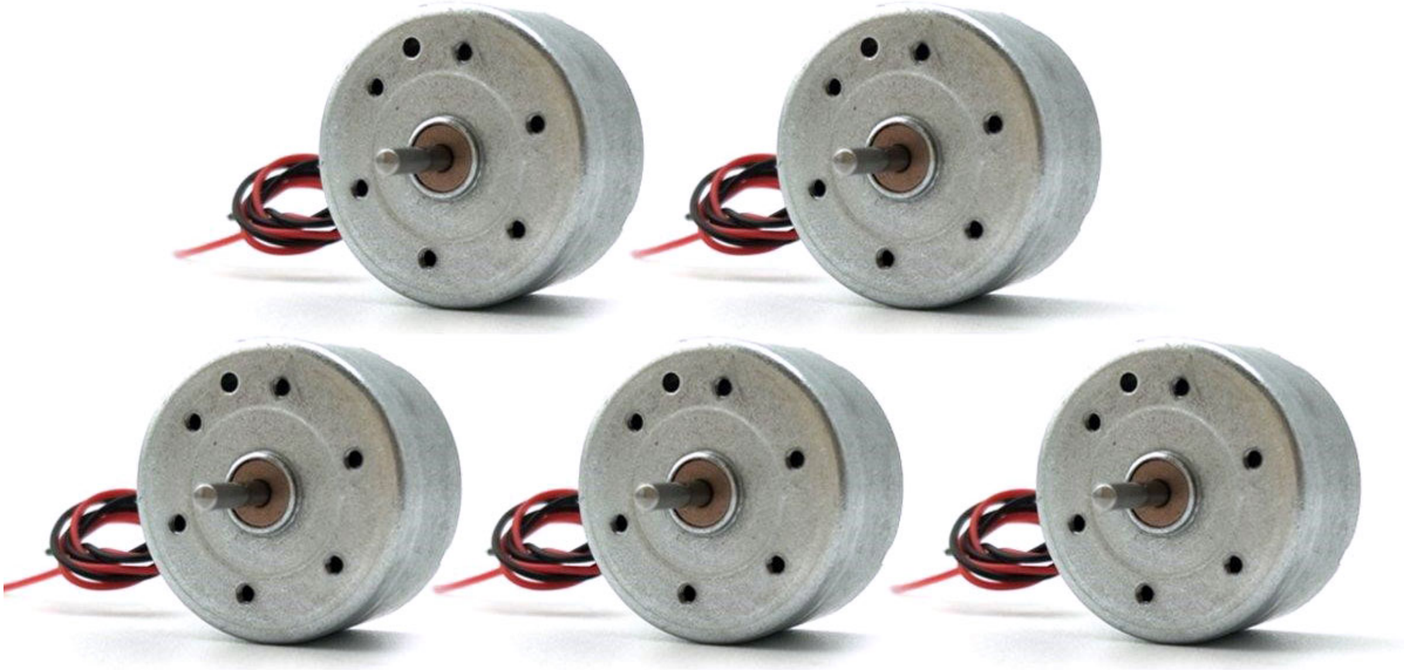
Kamkwambe needed an electrical generator to turn the mechanical energy of the spinning turbine into electrical energy. He used a device invented by Faraday known as a Dynamo. Kamkwambe acquired his from a bicycle headlight, the type that would light up as the rider pedaled. Making a do-it-yourself generator is possible, although this may present one of the greater challenges for 4th graders to make on their own as it involves wrapping very tight copper wire coils. In my class, I will have several low voltage DC electric generators on hand that students can use pre-assembled, just like Kamkwambe. They are 3V to 12V dc motors, so the combination of lights and buzzers added to the load should be more than 3V and under 12V. These motors can be found in bulk rather inexpensively and are worth the investment. If you elect to have students make a generator from scratch, at least have a few of these on hand for teaching purposes.

I may elect to have some students make their own generator if they are ready for the challenge. The web site Instructables.com has an excellent, step-by-step guide titled "Electric Generator Powering LEDs" and at the time of this writing, can be accessed at www.instructables.com/id/Electric-Generator-Powering-LEDs. It an excellent guide, but I highly recommend adult help with this task.

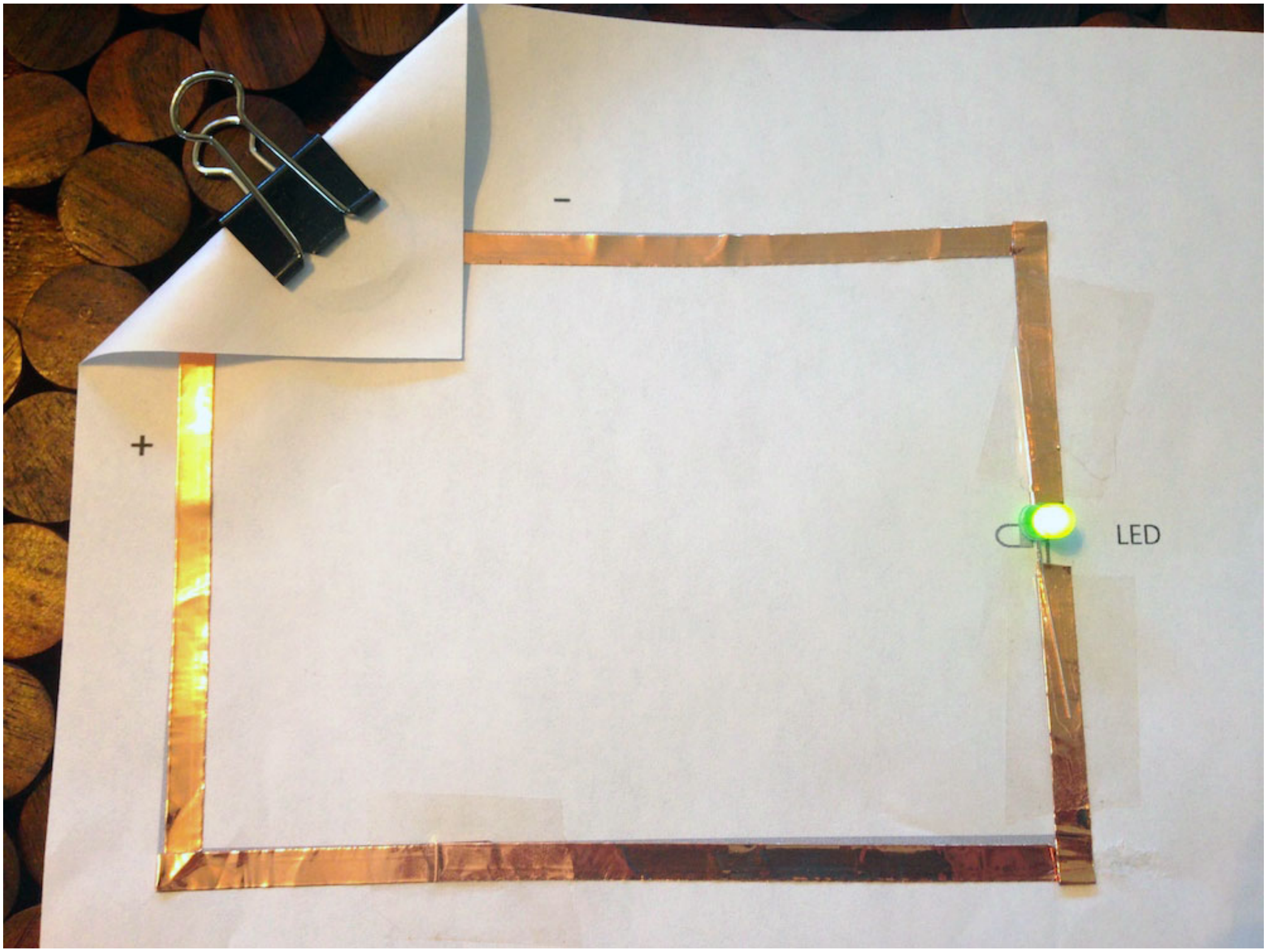
Buy the generators. They can be a useful item to stock in a STEM class. Make the generator on your own before introducing it to students.

Circuit Construction: The leads or wires coming off the generator are sufficient to attach to a small device or light that operates on DC, or direct current electricity. The generator produces a continuous flow of electrons from negative to positive through a conductive material such as a copper wire. The direction of the current is opposite the flow of electrons and will be necessary to match polarity correctly to power an LED or buzzer. Positive connects to positive and negative connects to negative. You can have students use a wire (I recommend using a type with insulated alligator clip connectors) to connect to the leads on a light or a small buzzer. I use small 3V to 24V electronic buzzers that have red and black wires attached to them. They can be obtained in bulk rather easily and inexpensively. The same with any LEDS, 3 volts is sufficient.





I teach students about electric circuits by first attaching the leads of an LED to a CR2032 coin battery. Students observe that one way it lights up, but switch the leads and it does not. This is an excellent talking point to hold an initial discussion about electric circuitry. I demonstrate that I can also connect those leads to an index card that has copper lines taped from the top of one side, all the way down the middle of the long side, and overlapping the edge by about an inch. On one side is the battery, and when I fold the card, the overlapping copper line connected to the battery completes the circuit, and there is light or sound.

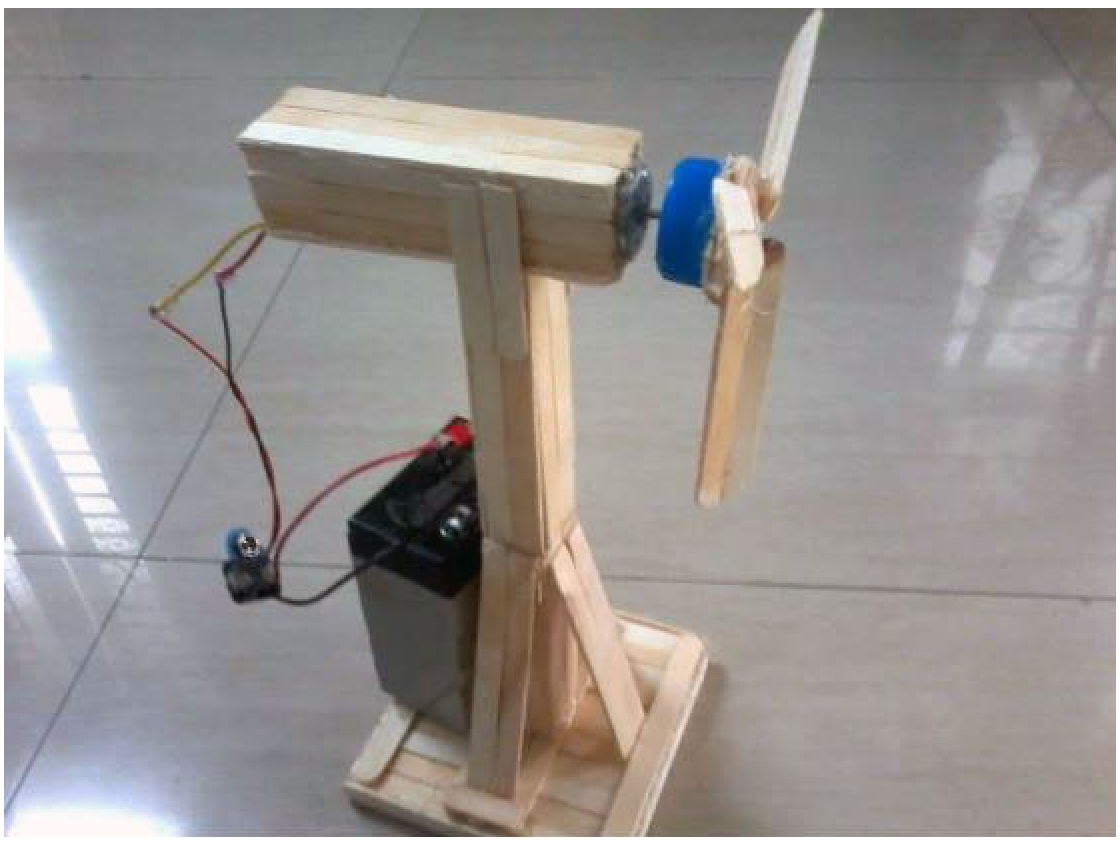


On a sheet of paper at least 3” x 5”, but can be larger, I have students create a circuit using copper tape (sometimes found in a gardening store as a natural slug repellent, or in craft stores for stained-glass supplies), a battery, and an LED or buzzer. Having a model like the one pictured is useful and students can either copy it or create their own. In my experience, even insecure students don't mind starting with a copy of the model but are often excited to go off and try their version after that initial success.

After they have completed their circuits, they can extend their learning by creating lighted models, animated greeting cards, and artwork or writing pieces that light up.

Turbine Construction: Students can design and cut out the turbine blades using construction paper, card stock, or thin cardboard like the kind cereal boxes are made from. They can experiment with different designs, shapes, and sizes to find what works best. Another alternative is to purchase pinwheels and use the blades as your turbine. I was able to locate a variety of different styles at a local dollar store.

Tower Construction: The tower needs to be tall enough to hold the spinning turbine off the ground, as well as be balanced enough to hold a spinning turbine without falling over. A simple truss tower with a wide base should work, but at this scale even a well-supported straight tower should be sufficient. I recommend using straws with interlocking connectors or craft sticks. Attention will need to be made to designing a section that holds the turbine in place.



Lesson Sequencing

Since this is a project, lesson sequencing will vary depending on the abilities of the class. I recommend the following sequence:

Day 1: Introduce Kamkwambe's story through literature and TED talks. Discuss the concepts of energy as described in the background information of this unit. Allow students do some research on windmills.

Day 2: Design Phase. Students research and plan each stage of their windmill. The four sections are tower, turbine, generator, and circuit. Students review material availability and plan for the materials they will use.

Day 3: Tower Construction. I recommend this stage first in case glue needs to dry, although students can build any section in any order.

Day 4: Turbine Construction.

Day 5: Electrical Generator Construction.

Day 6: Testing & Redesign. Use lights, buzzers, or multimeter to detect voltage.

Bibliography

EIA. "U.S. Energy Information Administration." Accessed August 1, 2019. https://www.eia.gov/.

The United States government EIA site was the basis for most of my information in this unit. It is factual, easy to understand, and provides links to additional resources.

HORTON, MELISSA. "What Are the Effects of Fracking on the Environment?," 2019. https://www.investopedia.com/ask/answers/011915/what-are-effects-fracking-environment.asp.

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End Notes

1. Moving Windmills, "About William Kamkwamba."
2. O'Connel, "What Is Energy?"
3. EIA, "U.S. Energy Information Administration."

4. EIA.
5. EIA.
6. EIA.
7. EIA.
8. HORTON, “What Are the Effects of Fracking on the Environment?”
9. EIA, “U.S. Energy Information Administration.”
10. EIA.
11. EIA.
12. EIA.
13. EIA.
14. Marshall Brian, William Harris, “How Electricity Works.

Appendix: Implementing District Standards

The unit was designed specifically to enhance the teaching of the following standards:

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

4-PS3-4 Energy: Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

And the following NGSS Science and Engineering Practices:

Asking Questions and Defining Problems

Developing and Using Models

Planning and Carrying Out Investigations

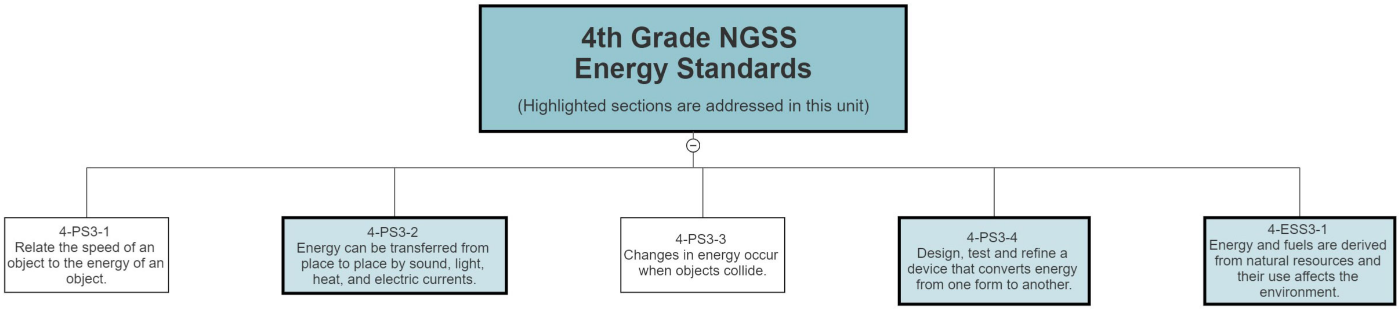
Analyzing and Interpreting Data

Using Mathematics and Computational Thinking

Constructing Explanations and Designing Solutions

Engaging in Argument from Evidence.

The following graphic illustrates what this unit covers, and does not cover under NGSS:


4th Grade NGSS
Energy Standards
(Highlighted sections are addressed in this unit)
4-PS3-1
Relate the speed of an object to the energy of an object.
4-PS3-2
Energy can be transferred from place to place by sound, light, heat, and electric currents.
4-PS3-3
Changes in energy occur when objects collide.
4-PS3-4
Design, test and refine a device that converts energy from one form to another.
4-ESS3-1
Energy and fuels are derived from natural resources and their use affects the environment.