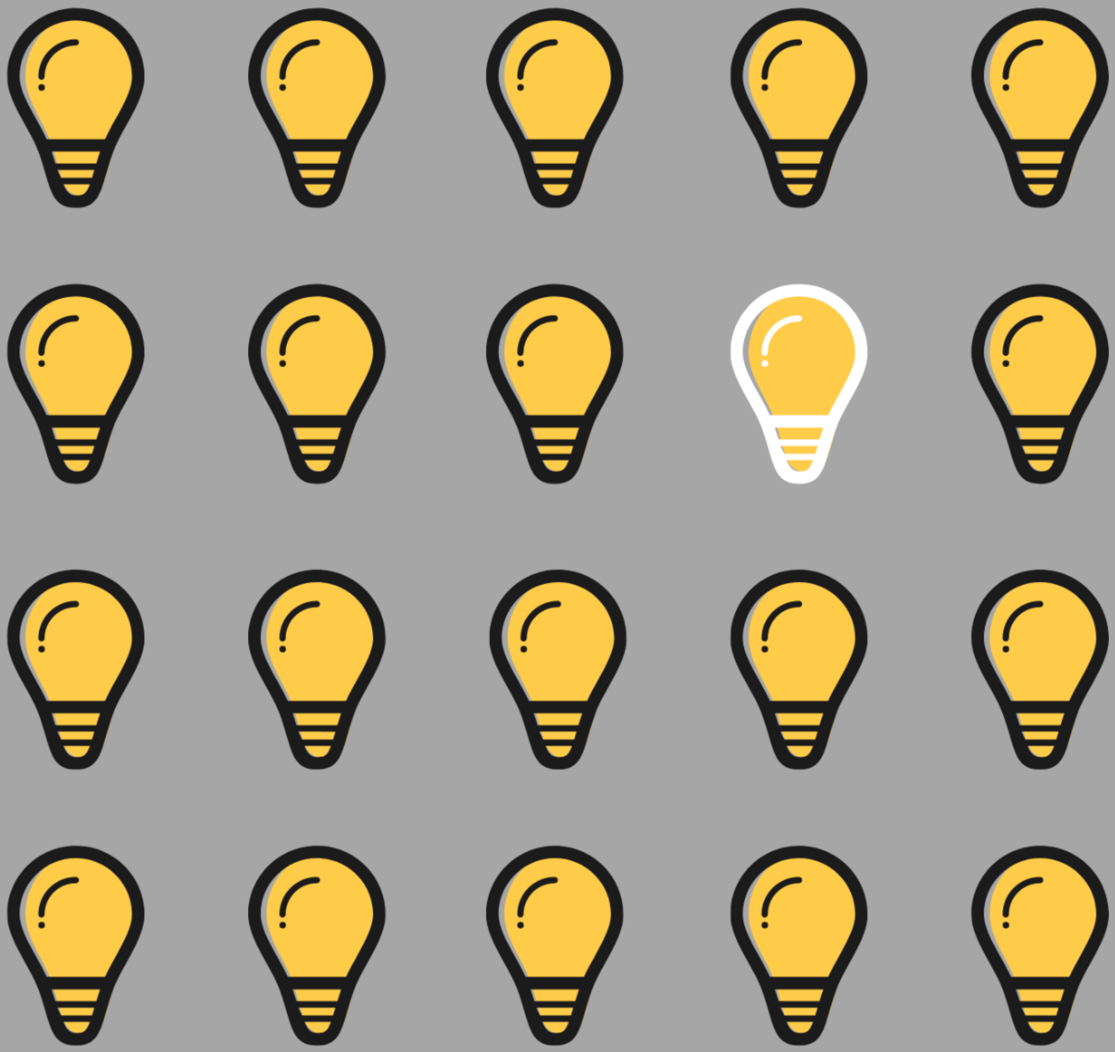


HAWAI`I STATE ENERGY OFFICE

RENEWABLE ENERGY LABS

GRADES: 9-12 #1

State of Hawai‘i

Department of Business, Economic Development, and Tourism

Hawai‘i State Energy Office

CLEAN ENERGY EDUCATION CURRICULA and TOOLKITS

The purpose of the Hawai‘i State Energy Office (HSEO) is to promote energy efficiency, renewable energy, and clean transportation to help achieve a resilient clean energy economy by 2045. HSEO is developing a statewide clean energy public education and outreach program to empower teachers’, students’, and their families’ participation in Hawai‘i ’s transition to a decarbonized economy; and to encourage Hawai‘i ’s K-12 students to become the next generation of clean energy leaders.

This project and material is based upon work supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE) under the State Energy Program Award Number DE-EE0008286.

Developed by Maui Economic Development Board, STEMworks^{TM} on contract for the Hawaiʻi State Energy Office

Curriculum at a Glance	
Grade Levels	9 - 12
Time Required	Approximately 5 Class Periods + Extension Activities
Activity Group Sizes	3 - 4 (supplies provided for 15 groups)
NGSS Performance Expectations	HS-PS3-2, HS-PS3-3, HS-ETS1-1, HS-ETS1-2 HS Energy Summary, HS Engineering Design Summary
Activity Title	**Guiding Questions**
Lab 1: Tools of the Trade - Multimeter	How do electronics and electrical components work? What is a multimeter and what does it measure? How are voltage, amperage, and power related?
Lab 2: Electricity Generation from Wind	How is energy transformed? How does a wind turbine's blade length, shape, and pitch affect the power output?
Lab 3: Design a Better Rotor	What is the engineering design process? How do engineers use science, data, and observations to inform their solutions? How can we improve our rotor's power output using the lessons learned from making observations and collecting data in Lab 1 & 2?
Online Extension Activity: GIS Suitability Analysis Wind Farms	What factors need to be considered when deciding where to install a wind farm? How can GIS be used to help locate the optimal wind farm location? Where are the most suitable places in Hawaii to site a wind farm?
At Home Extension Activity: Energy Consumption Monitoring	How do I read an electric bill? What can I do to reduce my electricity consumption?

Summary

What is energy? Energy is all around us. It is the power that brings nature, humans and machines to life. The purpose of this **renewable energy** curriculum is to provide learners in grades 9-12 with the opportunity to begin building **energy literacy** through exploration, experimentation, engineering, and hands-on fun. In the pages that follow, *your students* will explore how energy is transformed from one form to another. Through experimentation and observation, students will build wind turbines to study the transfer of the kinetic energy from the wind to mechanical energy that spins a shaft in a motor, which is then transformed into electrical energy that can be measured as power output using a simple equation. Students will experiment and test how changing a variable in their rotor's design results in varying power output, and they will put the engineering design process into practice to solve a real-world, complex problem of wind turbine optimization. Throughout the activities they will be exposed to fun facts, key renewable energy concepts, careers, and more.

The classroom toolkit for this curriculum includes a copy of *"The Boy Who Harnessed the Wind"* which can be used for inspiration, building literacy and critical thinking skills, and making cross-cultural connections. The toolkit also includes a Flinn Scientific Wind Energy Kit with enough supplies for 15 groups and a digital multimeter for making measurements and collecting data. Throughout the activities students will practice developing models, collecting data, analyzing their results, revising their designs, and presenting their reflections and solutions to their peers - just like real scientists and engineers. We also included an online extension activity on how to determine the best locations for wind farms using geospatial data that can be done in the classroom or at home, as well as an at home extension activity about home electricity usage to engage other members of the household. *This renewable energy curriculum and the inquiry-based labs are aligned to both Physical Science and Engineering Next Generation Science Standards (NGSS).*

Growth Objectives: Science and Engineering Practices

Asking Questions and Defining Problems: A practice of **science** is to **ask** and **refine questions** that lead to empirically tested descriptions and explanations of how the natural and designed world(s) works. **Engineers** generate questions to **clarify problems** to **determine criteria for successful solutions** and **identify constraints** to **solve problems** about the designed world. After completing this curriculum, we hope your students learn better how to think and ask questions like scientists and engineers. These lessons herein will help your students to:

- Ask questions that arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information. *In Lab 2, students will build a rotor to test on the windmill testing station to see how much power they can generate. At this stage, they will make observations about how their rotor performed relative to their peers, note any unexpected results, and in Lab 3, will seek additional information in terms of how to optimize rotor designs. This exploration activity should help reveal gaps in their knowledge about how wind turbines work and aerodynamics.*

- Ask questions to clarify and/or refine a model, an explanation, or an engineering problem. *In Lab 3, students are presented with a challenge to improve the power output of their original rotor design, and test how modifications to their rotor affects its power output by changing one variable at a time. Students should seek information about windmill work, compare their model with their peers, and make changes based on their observations and scientific principles.*
- Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. *In Lab 2 and Lab 3, students will define testable hypotheses such as "If I change the angle of the blades by 10 degrees, the windmill will produce more power". This is a testable hypothesis within the confines of the classroom.*

Developing and Using Models: A practice of both science and engineering is to use and construct **models as helpful tools for representing ideas and explanations**. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling tools are used to develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used to revise models and designs.

- Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. *Students will create their first rotor model in Lab 2, and based on its performance relative to their peers, they will create and test a second model to compare its performance relative to their original design. They should then ask themselves why one model performed better than the other, and use that information to inform future modifications for continued design improvement. The goal is to produce as much power as possible with their rotor and a constant wind source.*

Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working **collaboratively** as well as individually. Their investigations are **systematic** and require clarifying what counts as data and identifying variables or parameters. Engineering investigations identify the **effectiveness, efficiency,** and **durability of designs under different conditions.**

- Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible variables or effects and evaluate the confounding investigation's design to ensure variables are controlled. *Students will work collaboratively in teams to plan their rotor designs. In Lab 3, they will test the effects of changing one variable at a time. Data will be collected using the multimeter included in the toolkit.*
- Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables. *In Lab 3, students will collect data to test how variable blade length, shape, angle, and other variables affect their power output. They should identify failure points and avoid*

including those in their design. For example - how do blades perpendicular to the wind work? Would this be a design failure point or not?

Analyzing and Interpreting Data: Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis. Engineering investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria—that is, which design best solves the problem within given constraints. Like scientists, engineers require a range of tools to identify patterns within data and interpret the results. Advances in science make analysis of proposed solutions more efficient and effective.

- Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. *Each rotor design trial provides students with new data to develop an explanation of how their rotor interacts with the wind source to produce electrical energy.*
- Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. *Using all the data they collect from their trials, each student team should come to an optimal solution. Success will be defined as the team that was able to generate the most power and the team that was able to show the highest % of increase in power relative to their original design.*

Constructing Explanations and Designing Solutions: The end-products of science are explanations and the end-products of engineering are solutions. The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories. The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. The optimal choice depends on how well the proposed solutions meet criteria and constraints.

- 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 trade off considerations. *In the online extension lab 2, students will explore how we can use geospatial data to determine the optimal location to site a wind farm. This is a complex real-world problem that requires consideration of wind availability, land use, communities and potential human impact.*

Engaging in Argument from Evidence: Argumentation is the process by which evidence-based conclusions and solutions are reached. In science and engineering, reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem. Scientists and engineers use argumentation to listen to, compare, and evaluate competing ideas and methods based on merits. Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to evaluate claims.

- Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. *In the online extension lab 2, students will create and present an argument for where the optimal locations for wind farms are in Hawaii based on geospatial data.*

Career Connections

Engineer

Engineers are problem solvers who design and create products, buildings, machines, instruments, and more, for human use and benefits. During the creation of these things, all engineers go through the process of design, modeling, prototyping, and multiple iterations of modifying their designs until there is an optimal product or solution. Oftentimes, engineers need to work in teams made up of people with different subject matter expertise. For example, *Electrical Engineers* are experts on electricity generation while *mechanical engineers* are experts on mechanical applications (how to get the parts of the machine to work). During the laboratory activities herein, students will have the opportunity to practice teamwork and their communication skills. The average salary for engineers in Hawaiʻi is $84,631/year.

Electricians

Electricians are trades people who specialize in electrical wiring of buildings, machines, transmission lines, and related electrical equipment. Electricians may also specialize in wiring ships, airplanes and other mobile platforms. Typically electricians are employed in the installation of new electrical components or the maintenance and repair of existing infrastructure. The average salary of an electrician in Hawaiʻi, as of February 2022, is $33.89/hour.

Geospatial Analysts/GIS Scientists

Geospatial Analysts and Geographic Information System (GIS) Scientists use mapping technologies and, geospatial data, and geographic information systems (GIS) to do complex geospatial analysis. GIS specialists are in more demand than ever before with nearly every industry in need of locational data for better decision making. The yearly global value of GIS and the related geospatial industry is $350 billion. Geospatial analysts on average make $74,000/year with higher wages in the intelligence community. In the renewable energy sector, GIS technology is used to create location intelligence around where to find energy sources and how to deliver it to people who need it by using geospatial data such as demographics,geology, terrain, weather, the built environment, and more.

Green Jobs

Green jobs are jobs that people do to benefit the environment, or to conserve natural resources. Solar installers, solar technicians, marketers for solar companies, manufacturers that produce renewable energy equipment, project managers that oversee renewable energy operations, artists that promote going green, some chemical engineers, some data analysts, and environmental scientists are all examples of green jobs. Check out the outlook for green jobs here: Where the Green Jobs Grow | U.S. Department of Labor Blog (dol.gov). Wind turbine technicians are an example of a green job with foreseeable growth.

Introduction

Aloha e Energy Explorers!

Welcome to this adventure into the world of **renewable energy** with a focus on **Wind**. Throughout these lessons and hands-on laboratory activities, you will discover the answer to questions like these*:

- **What is energy?**
- **What is electricity?**
- **Where does electricity come from and how does it power the electronics we use daily?**
- **How do we transform various forms of energy into electrical energy to power our homes and communities?**
- **How can the wind be harnessed and transformed into electricity efficiently?**
- **What role do scientists and engineers play in the renewable energy revolution?**
- **How can I reduce my energy consumption?**

**Take a minute to pose these questions to your students and let them share some of their ideas. There are no right or wrong answers at this point.*

And **more importantly**, you'll **learn how to ask and investigate the answers to your own questions to develop solutions** and **to engineer models**.

So *what is energy*? Well, energy is all around us! It is the power that brings things to life. Energy describes the work that can be done from energy sources like fossil fuels such as oil and gas (non-renewable), biofuels, nuclear fuels, wind, and solar radiation (renewable). Electricity is **a carrier** of energy. We use electricity to carry energy through wires and circuits to power our homes and everyday electronics.

Did you know that in Hawaiʻi, our state established **the Hawaiʻi Clean Energy Initiative in 2008** (HCEI) with an ambitious goal to produce **100%** of our energy needs from **renewable energy sources** like solar, wind, geothermal, hydroelectricity, biomass, and biofuels by the year 2045. As of 2020, 30% of electricity generated in our state has come from renewable sources! There is still a lot of work to be done, but we're on our way and will need everyone to get on board to be successful.

In the labs that follow, you will test how energy is transformed from kinetic to mechanical to electrical energy using a wind turbine, and how to calculate the power output of your turbine using a tool called a multimeter. But first, let's think a little bit about where electricity comes from.

Electricity is everywhere! Whether you live in a skyscraper in urban Honolulu or a home in the countryside of Molokai, our homes, schools, and communities are powered by **electricity**. To understand electricity, you have to understand the smallest bit of any material called an **atom**. Atoms are made up of tiny particles called **protons** and **neutrons** bundled together at the center, and **electrons** whizzing around in a “cloud”. Each electron (-) and proton (+) has an itty-bitty **electric charge**. If two particles have opposite charges they will attract, and if they have the same charge, they will repel each other away. Electrons are special in that they can break free from their original atom, and hop from one atom to another. These adventurous electrons are what make all electronics come to life.

Kilo Exploration and Observations

Take a minute to walk around your classroom and if you have time, your school campus. Identify items that need electricity, and where *you think* (your best guess) that electricity comes from:

Table 1: Electricity Exploration and Hypotheses

	Item	**Where do you think the electricity comes from** *(Hypothesis)*	**Voltage (V)** **Amperage (mA)**	**Where does the electricity actually come from** *(Research)*
1	Lights			
2	Air Conditioner			
3				
4				
5				
6				
7				
8				
9				
10				

How does electricity get from one place to another like from the wall to your computer? How did it get to the wall? **Do some research and see if your hypotheses in Table 1 were correct.**

You may want to start your research here (look for your school): [Mana - HDOE Dashboard - Ahuimanu Elementary (manamonitoring.com)]

Question: Did you discover anything that surprised you? ________________________________
____
____

Answers will vary. If your school is partially powered by solar power, your students might be surprised to learn this.

Sometimes electronics and electrical components have a problem that needs to be **troubleshooted**. In Lab 1, you'll have a chance to learn how to measure features of electricity like voltage and amperage (amps) using a tool called a **multimeter**. Multimeters are great for troubleshooting electrical problems or testing electrical performance.

In Labs 2 and 3, you will explore how to transform energy into electricity using windmills and design your own **rotors** (rotating assembly in a wind turbine) which will spin under windy conditions - in this case using a fan. **Wind energy** will spin a rotor which will turn a motor that will convert this **mechanical energy** into **electrical energy.** The electrical energy will then travel through conductive wires as an **electrical current** to **power** electronic objects.

Check out this video: Wind Energy 101 Video

How much power you are able to produce with your rotor will largely depend on the amount of wind energy you have to begin with as well as the configuration, shape, and weight of the blades you use for your rotor. You will **experiment** with different rotor designs to create as much power as you can. Your **observations** from your **experimental trials** should be used to inform your design changes in Lab 3. But how will you measure the power that your rotor generates? Well, **qualitatively** you could make observations such as a LED did not light up, it lit up dimly, or it lit up brightly. However, there is a better way to measure this power output **quantitatively**. We can use a tool called a **multimeter** and some **simple mathematical equations based on physical laws.** Let's try!

Lab 1: Tools of the Trade - Multimeter *(1 class period*)

NGSS Performance Expectations
The NGSS focuses on a conceptual understanding of core ideas. The standards include the core ideas of energy transfer into and out of systems, providing a basis for understanding the concept of **power**. The equation for power can be introduced and applied, as needed, for instructional purposes. **Related PEs and Bundles:** HS-PS3-1 Energy, HS-PS3-3 Energy, HS-PS3-5 Energy, HS-PS3 Energy, HS.Energy **Disciplinary Core Idea:** PS3A: Definitions of Energy, PS3B: Conservation of Energy and Energy Transfer, PS3C:

Relationship Between Energy and Forces, PS3D: Energy in Chemical Processes and Everyday Life		
This exercise focuses on the following three dimensional learning aspects of NGSS		
Science & Engineering Practices	Disciplinary Core Idea	Crosscutting Concepts
Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS3-4)	**PS3.A: Definitions of Energy** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. **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.	**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. ***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. **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS3-1)
HĀ outcomes practiced: 1. Belonging - students will work in teams, actively participate, and practice communicating with clarity and confidence. 2. Responsibility - students will be active learners, encouraged to ask for help, will need to set goals and complete tasks with their team. 4. Aloha - students should learn to appreciate the gifts and talents of their team members, make everyone feel welcomed and heard, be respectful of all ideas, and share responsibilities.		

Before Activity:

- Open the multimeter box and look for a yellow and red e-book download instructions and claim code
- Download the e-book from www.books.plusivo.com

Materials List - For this activity, you will need:

- Multimeter (*included*)
- 9V or other Battery (*not included*)
- Pencil (not included - may want to have colors)

Multimeters are an essential tool for testing and troubleshooting electrical problems. The multimeter provided in your toolkit is able to measure direct current **(DC) voltage**, alternating current **(AC) voltage**, **DC current**, **resistance**, **diode**, and **continuity test**.

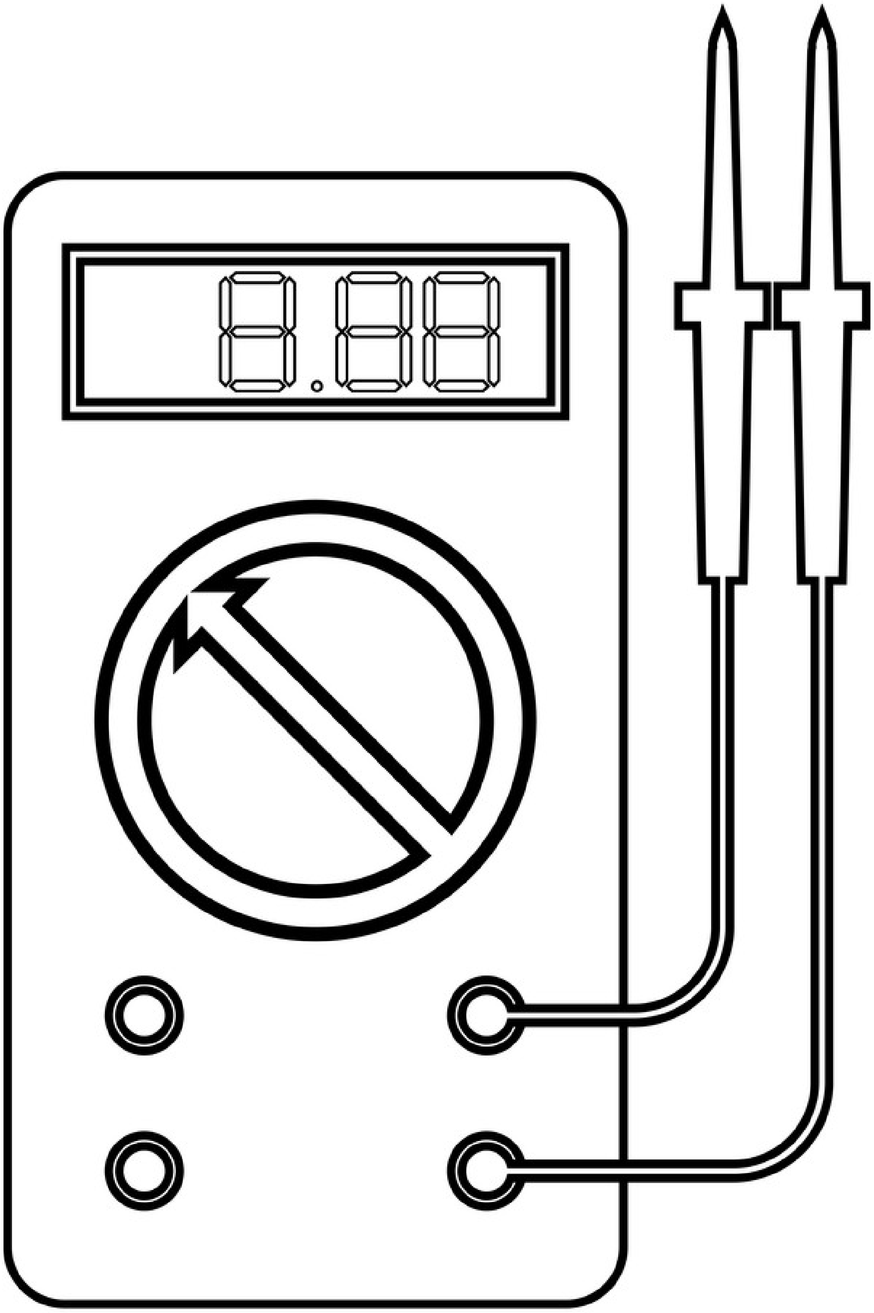
Potential Safety Issues

- When changing the function or range, the test leads (red/black wired) should be taken off of the object that is being tested.
- If anything unusual happens, or if the multimeter malfunctions, stop using the product.

Procedure

Part 1: Familiarize yourself with the multimeter

1. Look at your Multimeter. Write down all the symbols and numbers that you see:

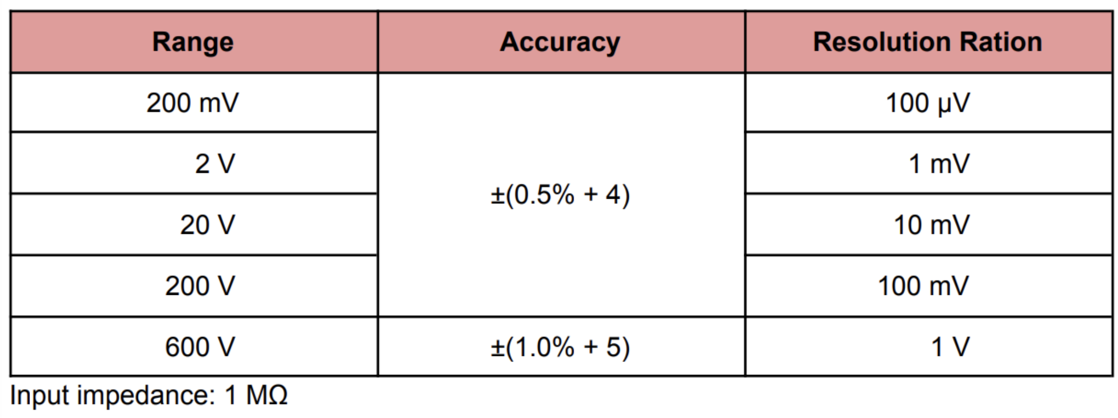


Question 1: Which symbol(s) do you recognize? List them below with their meaning.

Question 2: Which symbols do you not recognize? List them below.

2. Review **Tables 1-7** below to check your understanding

Table 1: DC Voltages

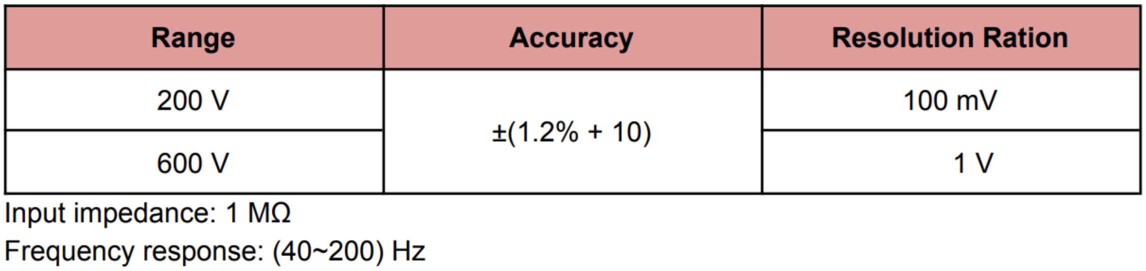


Range	Accuracy	Resolution Ration
200 mV	±(0.5% + 4)	100 µV
2 V		1 mV
20 V		10 mV
200 V		100 mV
600 V	±(1.0% + 5)	1 V

Input impedance: 1 MΩ

The current **electricity flows in a single direction in a steady voltage**. The major use of DC is to supply power to electrical devices and also to charge batteries. Example: mobile phone batteries, flashlights, flat-screen television and electric vehicles.

Table 2: AC Voltages

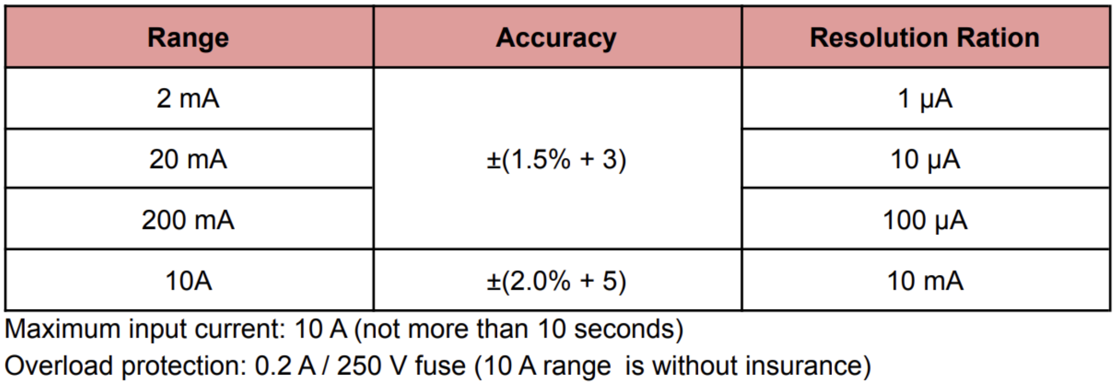


Range	Accuracy	Resolution Ration
200 V	±(1.2% + 10)	100 mV
600 V		1 V

Input impedance: 1 MΩ
Frequency response: (40~200) Hz

In alternating current, the electric charge flow changes its direction periodically. AC is the most commonly used and most preferred electric power for household equipment, office, and buildings, etc.As a result, the **voltage** level also reverses along with the current. The measurement is read as Hertz or Hz.

Table 3: DC Current



Range	Accuracy	Resolution Ration
2 mA	±(1.5% + 3)	1 µA
20 mA		10 µA
200 mA		100 µA
10A	±(2.0% + 5)	10 mA

Maximum input current: 10 A (not more than 10 seconds)
Overload protection: 0.2 A / 250 V fuse (10 A range is without insurance)

Direct current is one-directional flow of electric charge. An electrochemical cell, such as a battery, is a prime example of DC power. Direct current may flow through a conductor such as a wire, but can also flow through semiconductors, insulators, or even through a vacuum as in electron or ion beams.

Difference between AC and DC Video

Table 4: Resistance

Range	Accuracy	Resolution Ration
200 Ω	±(1.0% + 5)	0.1 Ω
2 kΩ	±(0.8% + 3)	1 Ω
20 kΩ		10 Ω
200 kΩ		100 Ω
2 MΩ	±(1.0% + 15)	1 kΩ

Overload protection: 250 V DC and AC peak

Electrical resistance–is **a force that counteracts the flow of current**. In this way, it serves as an indicator of how difficult it is for current to flow. Resistance values are expressed in ohms (Ω).

Table 5: Diode and Continuity Test

Range	Display	Test Conditions
	The diode forward voltage	DC current is about 1 mA Reverse voltage: 3 V
	Buzzer sound Test Resistance smaller than (20 ±1) Ω	Circuit starting voltage: about 3 V

Overload Protection: 250 V DC or AC peak

Table 6: Table of SI Units

Quantity	SI Unit	Abbreviation
Voltage	Volts	V
Current	Ampere	A
Power	Watt	W
Energy	Joule	J
Electric charge	Coulomb	C
Resistance	Ohm	Ω
Capacitance	Farad	F
Inductance	Henry	H
Frequency	Hertz	Hz

Table 7: Table of SI Units

Prefix	Power	Numeric Representation
Tera (T)	10^{12}	1 trillion
Giga (G)	10^{9}	1 billion
Mega (M)	10^{6}	1 million
Kilo (k)	10^{3}	1 thousand
No prefix	10^{0}	1 unit
Milli (m)	10^{-3}	1 thousandth
Micro (μ)	10^{-6}	1 millionth
Nano (n)	10^{-9}	1 billionth
Pico (p)	10^{-12}	1 trillionth

Part 2: Battery Test and Common Laws

1. In this test, you’ll use a multimeter to measure the **DC Voltage** of a battery. Insert the black wire to "COM" and the red wire to the "V/Ω" port;

2. Put the range switch to the corresponding DC voltage range and then put the test probes to the source to be measured. The polarity will be shown on the display.

- If the range of the voltage you are measuring is unknown, set the range switch to the highest rank to start, then adjust as needed.
- If "1"appears on the display screen, this means that the range is exceeded and the range switch must be set to a higher gear.
- Do not measure a voltage over 600 V, because there is a risk of damage to the instrument circuit.
- When measuring a high voltage circuit, **do not touch** any high voltage part of the circuit. You could get electrocuted.

Question 1: What is the measured voltage for your battery? ______________________________

3. For a 1.5 V battery test, there is a 40 ohm-resistor test load that is included internally in the multimeter. For the 9 V battery test, there is a 400 ohm-resistor test load that is included internally in the multimeter. Put the range switch to the appropriate notch. The screen shows the **current flow in mA**. The higher current you get, the stronger battery you have.

Question 2: What is the measured current for your battery? ______________________________

(You could test a nearly dead battery and a new battery for comparison.)

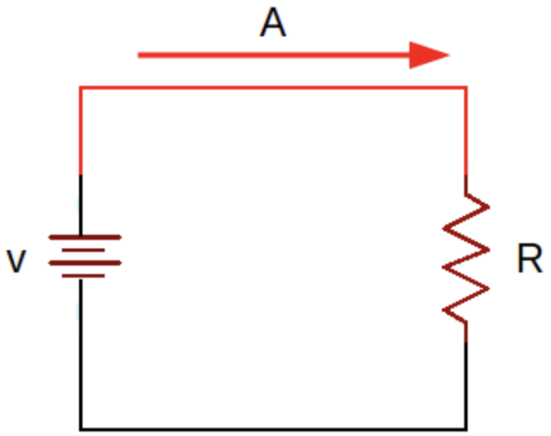
Ohm's Law It is a law that illustrates the relationship between the **voltage**, the **current**, and the **resistance**.

$$V = I \cdot R$$

$$R = \frac{V}{I}$$

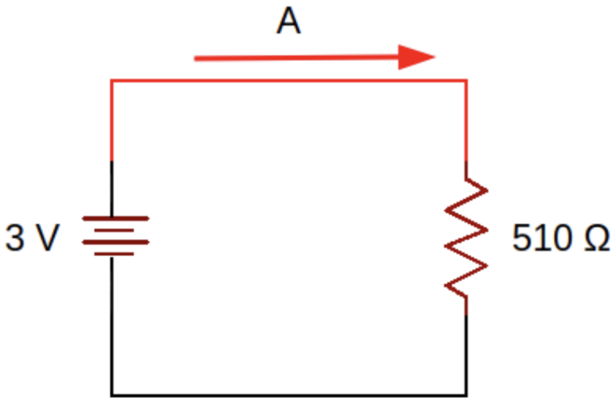
$$I = \frac{V}{R}$$

I is the current through the resistor.
V is the voltage around the resistor.
R is the resistance.



Question 3: What is the current in the circuit below? ________________________________

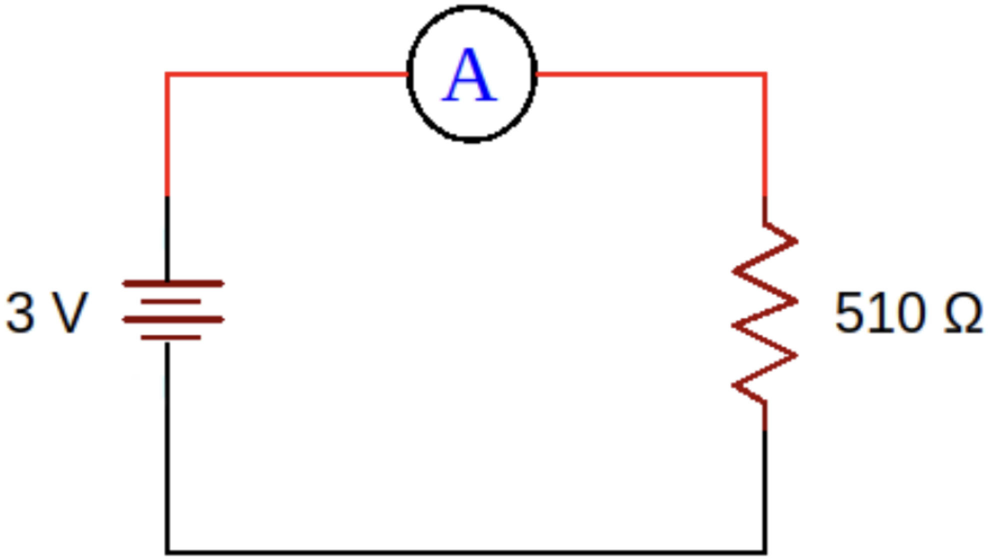
(Hint: you can use Ohm's law: $I = V/R$)



(Answer: $\frac{3\,V}{510\,\Omega} = 0.00588\,A = 5.88\,mA$)

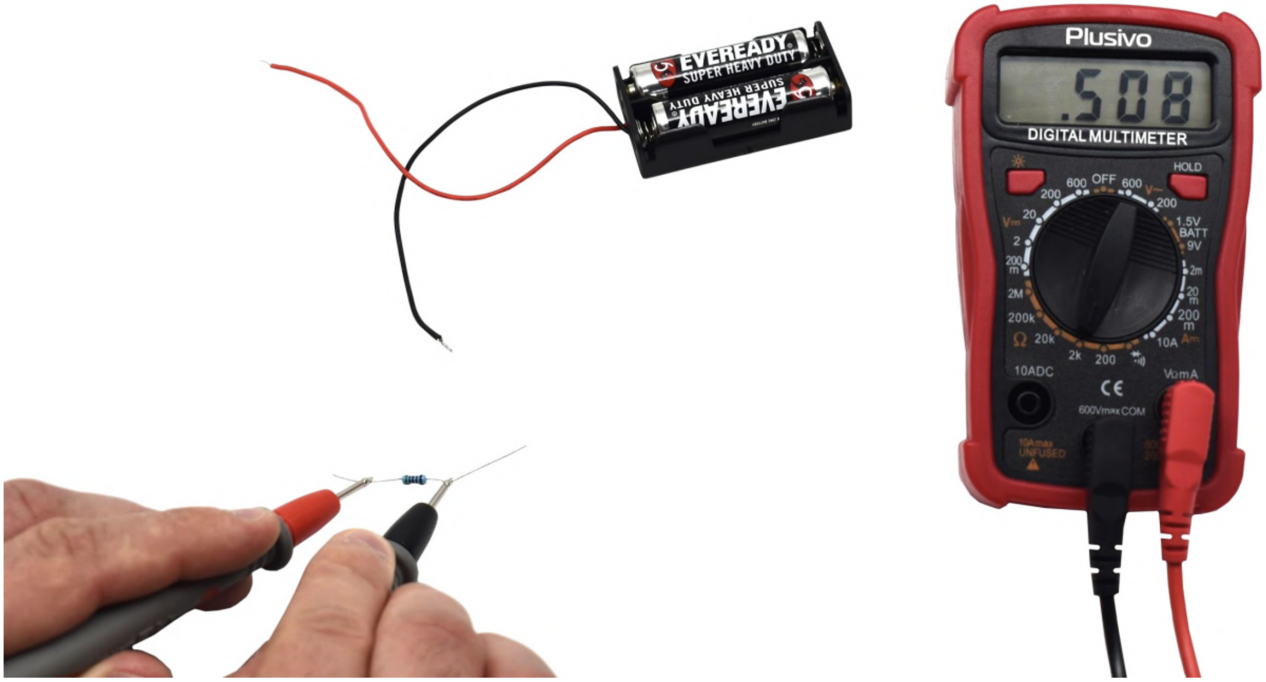
NOTE:

If we built this circuit in reality and measure the current using the multimeter as in the following schematic:



We should read on the screen of the multimeter: **5.88 mA**

But this is if we have an ideal circuit, in reality, we will not get this specific value because each component in this circuit has tolerance, for example, if we measure the resistance:



Joule's Law for Electrical Power It is a law that illustrates the relationship between the **voltage**, the **current**, and the **resistance**. Electric power is the rate of the emitting power from a resistor per unit time, the unit of power is watt. *(Note: There are many types of emitting power, it may be a rotary power, light, heat, etc.)*

$$P = I \cdot V$$

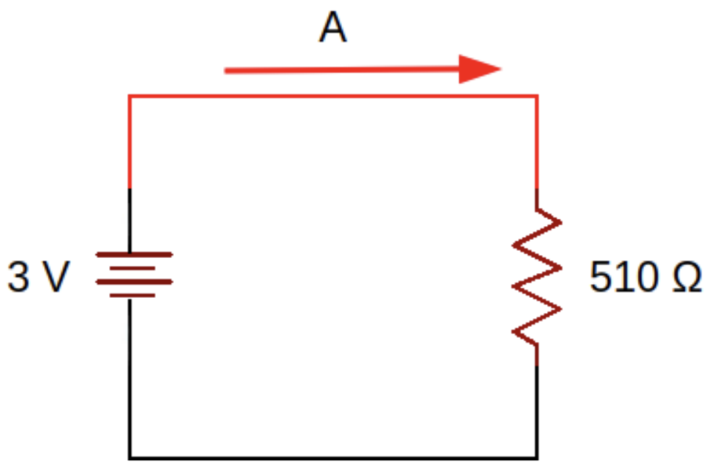
$$P = I^2 \cdot R$$

$$P = \frac{V^2}{R}$$

P is the power on the resistor.
I is the current through the resistor.
V is the voltage around the resistor.
R is the resistance.

Question 4: Calculate the power of the resistor as modeled below: ____________________________

(Hint: To calculate the power on the resistor, you will need two of these values: Voltage, Current or Resistance. In this example, we have the voltage and the resistance, so you can use this formula: P = V *^2/*R *)*



(Answer: $\frac{(3\,V)^2}{510\,\Omega} = 0.0176\,W = 17.6\,mW$ *)*

Key Concepts: Multimeters are a tool that we can use to measure electricity, test batteries (DC), outlets (AC), and electrical equipment. Multimeters are able to measure direct current voltage, alternating current voltage, resistance (resistors in electronics need to carry the correct amount of power to work) and current measured as amperage (amps). This tool is also sometimes referred to as a voltmeter, ammeter, or ohmmeter because it functions as all three. Measuring AC voltage is the most common usage of a multimeter. You can check the plug on an appliance or outlet to help isolate an electrical problem. **Want to do a deeper dive?** Check out the experiments in this Plusivo Handbook.

Remember: Electricity is the flow of electrical energy from one place to another, and a closed circuit is necessary for an electrical current made up of moving electrons to flow and power our electronic devices. Atoms are made up of protons and neutrons at the center, and the electron cloud buzzes around the nucleus. These electrons can escape and transition from one atom to another. In this exercise, the battery pushes electrons through the circuit of which the multimeter is a part of. The multimeter then reports back via the digital screen the qualities of the electrical current that it can measure.

Common Misconception: **Energy**, **Electrical Energy, Electricity,** and **Power** are not the same thing. Nevertheless it is common to hear people using these words interchangeably. Each of these terms have distinct meanings. *Energy is the ability to do work (a force that moves objects)*. There are numerous measurements of energy, but the most common is watt-hour. Energy also appears in many forms. *Electrical energy is energy that is stored as charged particles* within an electric field. Batteries store electrical energy. *Electricity is the flow of this energy*. Current electricity (not to be confused with static electricity) is the flow of electrons through conductive wires and cables to power electronic devices. *Power* is how fast you are able to produce or consume electricity. If you want to go to the grocery store from your home, you could take a car or walk. A car will be able to complete this task faster, which means the car has more power than your legs.

Renewable Energy Connection: The electrical components in the digital multimeter were powered by batteries holding potential chemical energy waiting to be activated. Batteries are likely to play a big role in our renewable energy future as well. The Hawaiʻi State Energy Office has taken a leadership role in advancing clean transportation including facilitating the deployment of zero emission, electric vehicles and charging infrastructure. Using electric vehicles, which are typically powered by 12-volt rechargeable batteries, will help us to reduce fossil fuel consumption and greenhouse gas emissions in the transportation sector. Multimeters can be used on large batteries like those found in electric vehicles as well to test if a battery is working properly.

While batteries are commonly used to power personal electronic devices, electric vehicles, and are even used to store energy from solar panels, most of the electricity we use in our world is generated by large **generators** driven by high pressure steam or water pressure created by **burning fossil fuels**, or increasingly by **wind**. Wind is moving air. You cannot see air, but it is all around you. You can also not see wind, but you know it is there. Wind is energy in motion is kinetic energy, and it is a renewable resource. Wind turbines are being used today to harness the wind to power generators in place of fossil fuels. Let’s do some experiments to test how a wind turbine can be used to transform kinetic energy from the wind into mechanical energy that will spin a motor that will generate an electric current.

Lab 2: Generating Electricity with Wind *(2 class periods)*

NGSS Performance Expectations

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative position of particles (objects).

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

In this lab, students are provided with materials that they can use (constraints) to develop a rotor that will convert wind energy into electrical energy. Success is measured by whether or not their rotor spins sufficiently to produce a measurable voltage, milliamps and power reading. Students will need to use a systematic process to assemble their rotor. Teams may select Design 1 or Design 2 and will test an original and modified design. After comparison of their two trials as well as their peers, students will be challenged in Lab three to independently improve their design constrained only by the materials provided.

This exercise focuses on the following three dimensional learning aspects of NGSS

Science & Engineering Practices	Disciplinary Core Idea	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. **Constructing Explanations and Designing Solutions** Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. 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.	**PS3.A: Definitions of Energy** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. **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. **ETS1.A: Defining and Delimiting an Engineering Problem** Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary)*	**Energy and Matter** Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. 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. ***Connections to Nature of Science*** **Science is a Human Endeavor** Most scientists and engineers work in teams. Science affects everyday life. **Influence of Science, Engineering, and Technology on Society and the Natural World** Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands. ***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.

HĀ outcomes practiced: 1. Belonging - students will work in teams, actively participate, and practice communicating with clarity and confidence. 2. Responsibility - students will be active learners, encouraged to ask for help, will need to set goals and complete tasks with their team. 4. Aloha - students should learn to appreciate the gifts and talents of their team members, make everyone feel welcomed and heard, be respectful of all ideas, and share responsibilities.

Prerequisite Knowledge

- *Students should be comfortable with unit conversions. In this activity, the motors produce power in the milliwatts (mW) range and the measurements are in milliamps (1mA = 0.001A).* ***Power(mW) = Volts x Milliamps (mA) or P(mW) = V x mA***
- *Ideally, students should know about the difference between renewable and nonrenewable energy. If not, you may want to review this with them.*

Before the Activity

- Have students select their teams of 2-3 students. Make sure that each team member has a chance to participate in the hands-on portion of the lab.
- Set up a team tracker on the board or a screen to show the power produced by each team's rotor configurations. This will allow teams to compare how successful their turbine was relative to their peers which should inform their design changes in Lab 3.

Materials List - For this activity, you will need:

Included Items (*Enough for 15 groups of 2 students*):

- Bamboo Skewers
- Corks
- Cap
- DC Motor 1.5V
- Sand Paper
- Cardboard Sheets 8.5" x 8.5"
- Foam Sheets 8.5" x 5.5"
- Manila folders
- Polystyrene Sheets, 12" x 12"
- 2 Alligator Cords
- Multimeter

Additional Materials for *Each Group* (*not included)*:

- Something to generate wind such as fan or hair dryer
- Clamp, Buret
- Bunsen Burner, Lighter, or Candle
- Metric Ruler
- Meter Stick (optional)
- Large Paperclip
- Scissors
- Support Stand
- Tape or glue
- Timer
- Tongs
- Wire Stripper (*might be needed*)

Potential Safety Issues

- Be cautious around any open flames. Make sure you use tongs to hold the paperclip or wear heat resistant gloves.
- Do not run with the skewers. The end is sharp- cut or sand down the end to smooth it out.

Potential Obstacles

- If using skewers, students will need to cut them. The best way to do this is to score with scissors then snap. Use sandpaper to smooth the rough edges if needed.
- Each team should decide on the blade size and shape before they begin cutting the materials or order to avoid mistakes and waste.

Pre-Activity Assessment

Question 1: Why is wind considered a renewable energy source?______________________________

____

____

(Answer: *Wind is considered a renewable energy source because using it today will not result in there being less wind available in the future.*

Question 2: A spinning rotor is attached to a multimeter. The meter displays 18 V and 6 A. How much power is produced by the rotor?____

____

____

(Answer: *P = 18 V x 6 A =108 W)*

Question 3: The current of the model rotors in this activity will actually be measured in **milliamps** (1 mA = 0.001 A) and the power output will be calculated in **milliwatts** (mW) using this equation:

P(mW) = V x mA

Calculate the power output of a spinning rotor in mW with meter readings of 0.15 V and 7.8 mA.

____

____

(Answer: *P = 0.15 V x 7.8 mA = 1.17 mW)*

What is the power output of the rotor in watts? ____

____

____

(Answer: $1.17\ mW \times \frac{1\ W}{1000\ mW} = 0.00117\ W$)

Power Station/Lab Setup

1. Cut each manila folder in half.
2. Cut the sandpaper into 15 pieces, one for each group.
3. Set up the testing stations.
   - *a.* Obtain a paperclip, Bunsen burner or candle and a bottle cap.
   - *b.* Unbend the paperclip so that a free end is exposed.
   - *c.* Light the burner or candle.
   - *d.* Using tongs, heat the free end of the paper clip in the flame.
   - *e.* Place the hot paperclip in the center of the cap and lightly press to make a hole.
   - *f.* Position the hole of the cap, flat side down, onto the motor shaft (see Figure 1). Press the cap all the way down so it is flush with the motor and the shaft protrudes through the hole.

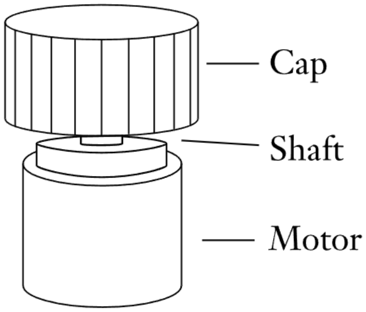


Figure 1

   - *g.* Secure the motor in the clamp and attach the clamp to the support stand.
   - *h.* Set the fan 20 cm from the motor, facing the cap attached to the motor.
   - *i.* Using alligator cords, connect each wire from the motor to a lead of the multimeter. *You may need to strip some of the insulation from the motor wires for a good connection.*
   - *j.* Repeat steps a–i to construct the second testing station.
   - *k.* The large end of the corks that students use for the central hubs of their rotors will fit snugly in the cap. Hold the cap securely and twist the cork into the cap to avoid bending the motor shaft. The shaft should press into the cork to help secure the cork in the center of the cap (see Figure 2).

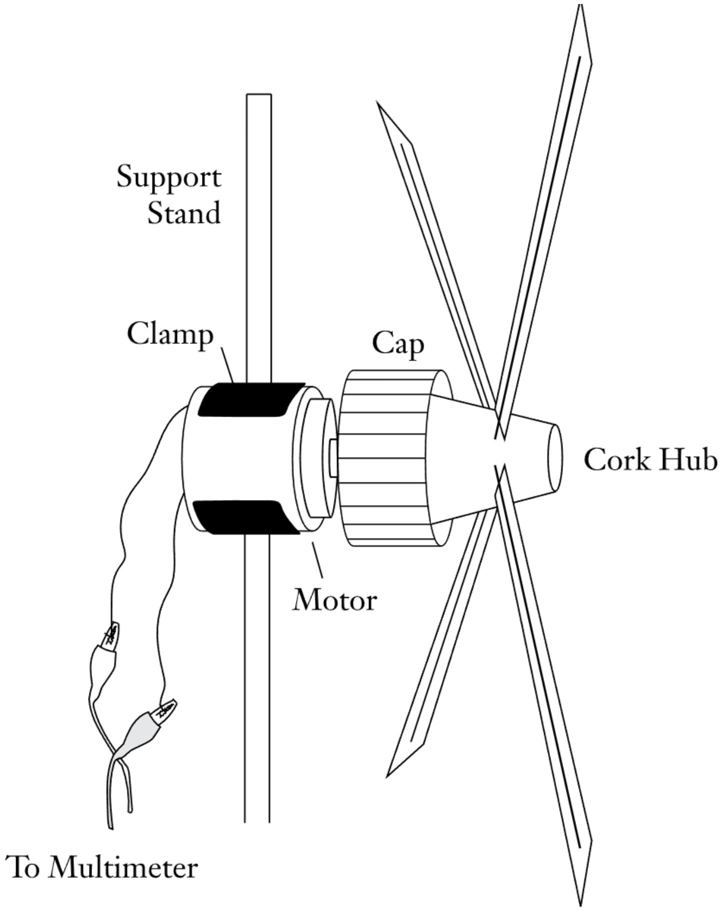


Figure 2

Procedure

Part 1: Initial Rotor Design

1. Each team should choose Design 1 or Design 2.

Design 1	Design 2
Materials: Polystyrene Foam Sheet	Materials: Paper
Shape and size: trapezoid; 23cm length; narrow end is 5cm; wide end is 10 cm	Shape and size: 4-blade pinwheel; 18-cm diameter
Pitch: Blades mounted parallel to each other; no angle. The skewers acting as support for the blades should be inserted evenly around the center of the cork	Pitch: Blades should be inserted at an angle that results in a counterclockwise spin.

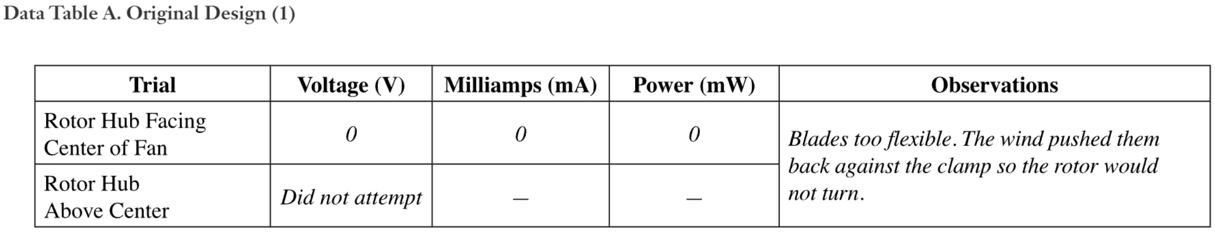
2. Take 5-10 minutes to plan your rotor design

3. Create the rotor design that you selected
4. Test your rotor’s performance at the power testing station. Your teacher will attach a rotor to the motor at a set distance from the fan.
5. Set the multimeter to measure volts and record the highest value within a 20 second window.
6. With the fan still running, switch the multimeter to register milliamps
7. Record the highest amperage displayed within a 20 second window and fill out the data table below:

Trial: Original	**Voltage (V)**	**Milliamps (mA)**	**Power (mW)**	**Observations**
Rotor facing center of the fan				
Rotor above center of the fan				

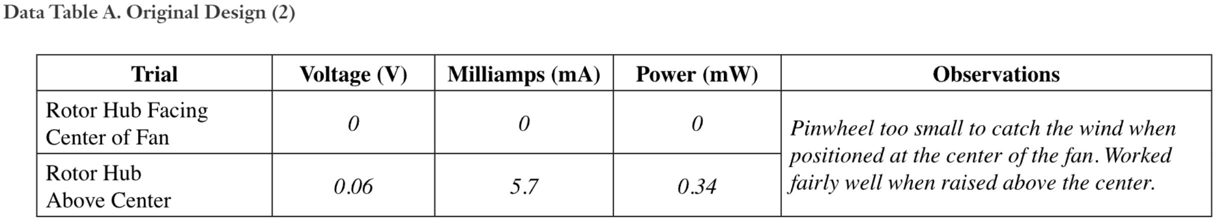
8. Once each group has tested its rotor facing the center of the hub, adjust the height of the motor on the testing station support stand to the rotor hub is halfway between the center and the top of the fan. Repeat steps 4-7. If the rotor does not spin, move on to the next step.
9. Calculate the power output in milliwatts for each test using the equation provided in the pre-activity section.

Answers may look something like this:



Data Table A. Original Design (1)

Trial	Voltage (V)	Milliamps (mA)	Power (mW)	Observations
Rotor Hub Facing Center of Fan	*0*	*0*	*0*	*Blades too flexible. The wind pushed them back against the clamp so the rotor would not turn.*
Rotor Hub Above Center	*Did not attempt*	–	–	



Data Table A. Original Design (2)

Trial	Voltage (V)	Milliamps (mA)	Power (mW)	Observations
Rotor Hub Facing Center of Fan	*0*	*0*	*0*	*Pinwheel too small to catch the wind when positioned at the center of the fan. Worked fairly well when raised above the center.*
Rotor Hub Above Center	*0.06*	*5.7*	*0.34*	

10. Make a list of problems, if any, your rotor experienced during testing. ____________________

____

____

Things to consider:

- If your rotor did not spin, this means that all of the forces acting on the blades were balanced, resulting in zero net force (no movement). How do you think you could modify the blades to correct this? ____

  ____

  ____

- The pitch of the blade is the angle of the blades in relation to the plane in which they are rotating. Was the pitch of your blades consistent throughout the testing? ________________

- How might changing the size of the blades affect your power output ____________________

  ____

- Was the rotor well balanced? If not, how could you improve it? ________________________

  ____

- How did your peers' rotors compare to yours? Is there anything they did better that could inform your improved design?____

  ____

Part 2: Modified Rotor Design

The goal here is to see if you can increase the power output from your original rotor design following the constraints provided.

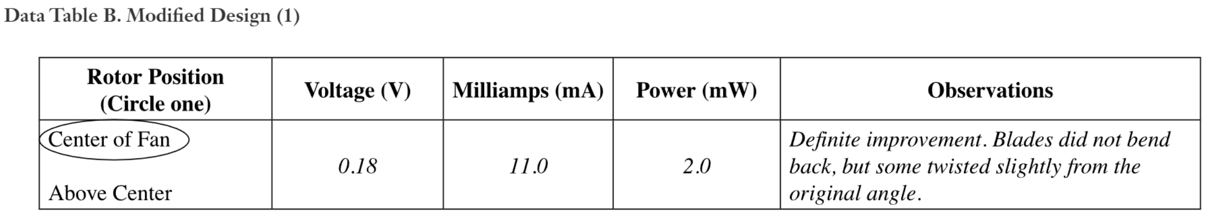
1. Modify your design according to the constraints listed below. Take a few minutes to plan out your modifications before making them.

Design 1	Design 2
Shorten blades to 20cm; trim wide end to 9 cm	Open the pinwheel blades slightly to 20 cm diameter to catch more wind
Move skewers closer to the front of the hub, away from the clamp	Change the angle configuration to produce a clockwise rotation
Angle the blades slightly all in the same direction	

2. As in Part 1, test your modified rotor design to see how it compares to your original design. Record your data below:

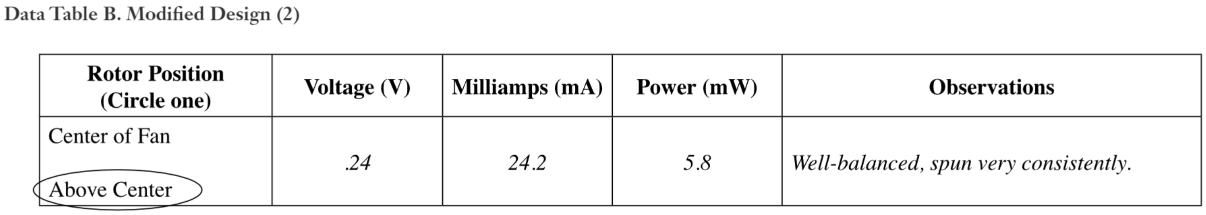
Trial: Modified	Voltage (V)	Milliamps (mA)	Power (mW)	Observations
Rotor facing center of the fan				
Rotor above center of the fan				

(Answer:In both cases, each team should see some improvements. Answers may look something like this:



Data Table B. Modified Design (1)

Rotor Position (Circle one)	Voltage (V)	Milliamps (mA)	Power (mW)	Observations
[✓ Center of Fan] Above Center	*0.18*	*11.0*	*2.0*	*Definite improvement. Blades did not bend back, but some twisted slightly from the original angle.*



Data Table B. Modified Design (2)

Rotor Position (Circle one)	Voltage (V)	Milliamps (mA)	Power (mW)	Observations
Center of Fan [✓ Above Center]	*.24*	*24.2*	*5.8*	*Well-balanced, spun very consistently.*

Post Activity Assessment:

1. Calculate the amount of power the improved rotor design generated in Part 2. Remember: *P(mW) = V x mA*

   ____

   ____

2. Compare the power output of the modified rotor to the original. Did your modifications result in greater power production? Be specific.

   (Example Answer: Yes, the original design 1 did not work and the modified design generated 2 mW of power. The modified design 2 increased the power output from 0.34 mW to 5.8 mW.)

3. Which design modification is responsible for the difference in power? Explain your reasoning.

   ____

   ____

   ____

(Example Answers: Design 1: Shortening the blades prevented them from bending back and hitting the clamp. Setting the blades at an angle may have helped, since the more successful designs in the class had angled blades. ***Both designs: Without testing each modification separately, it cannot be determined what effect each change had on the power output.)***

4. Traditionally, motors use electricity to spin objects. In this Lab, your rotor is connected to the motor, but the motor is not attached to any source of electricity. What makes the shaft of the motor spin? ____

   ____

   (Answer:The wind from the fan makes the rotor turn. The spinning rotor hub turns the shaft of the motor.)

5. Hawaii has significant offshore and onshore wind resources. Wind energy made up 22% of our state's total renewable electricity in 2020. Our use of wind energy will continue to increase in the future. What are some of the advantages and disadvantages of using wind power for electricity generation? ______________________________________

   ____

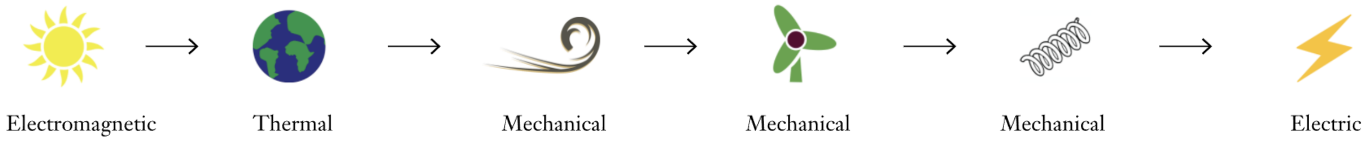
   ____

   ____

   ____

   (Answer: Wind is a naturally occurring, clean, renewable source of energy. However wind is variable, not all areas are suitable for utilizing wind energy, cost of research, transporting materials, and construction, possible effect on birds and other wildlife.)

Key Concepts: Sunlight, an unlimited resource, provides electromagnetic energy which is absorbed by the Earth's atmosphere and converted into thermal (heat) energy. The Earth's surface does not heat uniformly because water, rock, ice, vegetation, and all the variable landforms that make up the surface of the earth heats up at different rates and to different degrees. This uneven heating causes differences in temperature and air pressure. These pressure differences result in air moving from areas of high pressure to low pressure. We call this **moving air wind**. Mechanical *wind energy* pushes the blades of a wind turbine's rotor, which turns a coil of wire inside a generator within the turbine. The wire coil turns within a magnetic field, causing electric current to flow in the conductive wire. This electrical current can be transported over long distances to power homes and communities.



Graphic from Flinn Scientific

In this lab, you designed your own rotor out of the materials and constraints provided with a goal of producing the greatest amount of power. As the shaft of the motor provided in this kit turned, electric current ran through the wires. A coil of wire turning through a magnetic field is inside of the motor and responsible for creating the electric current. You used the multimeter to measure the voltage and amperage to calculate the amount of power you generated through the transfer of energy. While your windmill created an ittybit of power, a single wind turbine in the real world can power hundreds of homes. **Bonus Video:** Renewable Energy 101: How Does Wind Energy Work? - YouTube

Common Misconception: Power plants do not "produce energy". They convert energy from one form to another. For example, they can convert the energy from burning fossil fuels (chemical energy) into electricity (electrical energy). Or, as you learned in this lab, we can also convert wind (mechanical energy) into electricity (electrical energy). Energy can neither be created or destroyed, only transformed.

Renewable Energy Connection: Wind is a desirable energy source as it is both non-polluting and renewable. It does not emit air pollutants or greenhouse gasses and using it does not diminish future supply. Solar power and wind power are both free, clean, and renewable. In just one hour, the sun sends more energy to our planet than we, all humans, consume in an entire year. The sun is also responsible for generating the winds. Scientists and engineers around the world are researching ways we can improve our technologies to harness enough solar and wind energy to supply our electricity needs. These renewable energy resources have enormous potential as a clean source of renewable energy to replace fossil fuels. According to the Hawaiian Electric Company, in 2021 renewable energy increased across the islands they serve as follows:

Fuel	Oahu	Maui County	Hawaii Island
Solar	5.1%	1.1%	0.3%
Wind	2.65%	20.4%	12.4%

Career Connection: In Lab 2, you observed for yourself how energy can be transformed from one form to another and you also collected data to calculate the power output of your wind turbine design which were created following given constraints. **Making observations, collecting data, analyzing data, and sharing results are all important skills that scientists need to use everyday.** In Lab 3, you will practice thinking like an **engineer,** by working through an engineering design challenge using the seven steps in **STEMworks' engineering design process**.

Lab 3: Engineering Design Challenge - Build a Better Rotor *(2 class periods)*

NGSS Performance Expectations
HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

<table>
<tr><td colspan="3">HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for society needs and wants.</td></tr>
<tr><td colspan="3">This exercise focuses on the following three dimensional learning aspects of NGSS</td></tr>
<tr><th>Science & Engineering Practices</th><th>Disciplinary Core Idea</th><th>Crosscutting Concepts</th></tr>
<tr><td>Asking Questions and Defining Problems
Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.

Analyze complex real-world problems by specifying criteria and constraints for successful solutions.</td><td>ETS1.A: Defining and Delimiting Engineering Problems
Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.

Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.</td><td>Energy and Matter
Energy can be transferred in various ways and between objects.
- -
<i>Connections to Engineering, Technology, and Applications of Science</i>

Influence of Science, Engineering, and Technology on Society and the Natural World New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.</td></tr>
<tr><td colspan="3">HĀ outcomes practiced: 1. Belonging - students will work in teams, actively participate, and practice communicating with clarity and confidence. 2. Responsibility - students will be active learners, encouraged to ask for help, will need to set goals and complete tasks with their team. 4. Aloha - students should learn to appreciate the gifts and talents of their team members, make everyone feel welcomed and heard, be respectful of all ideas, and share responsibilities.</td></tr>
</table>

Prerequisite Knowledge

- *Students should understand how a generator works. When wind turns the shaft in a motor, a coil of wire on the shaft spins past a magnet and an electric current is created in the wire.*
- *Take a minute to discuss* ***variables*** *and the importance of changing one variable at a time.*

Before the Activity

- Break up into your teams. *You may want to come up with a name for your Engineering or Design Firm*

Materials List

Determine what materials students are limited to. For example, may they use paper clips to attach the blades to the hub? How about a 3D printed component? Materials in the kit are sufficient if you want to keep the experiments simple.

- Blade materials + Spine
- Cork
- Scissors
- Scrap paper
- Pencil
- Windmill Testing Stations

- Box Fan or Hair Dryer

Potential Safety Issues

- Be careful with sharp objects including scissors and the tips of skewers.

Potential Obstacles

- *It is important to change and test one variable at a time. Students will likely want to make many design changes, but if they make more than one modification, they will not know which change improved or hurt the performance of their rotor.*

Engineering Design Challenge: Living on an island, we have limited land space available for **onshore wind farms**, so it is essential to maximize the power output from each turbine to power our communities. Your challenge is to create a wind turbine that results in greater power output than your original design created in Lab 2. Awards will go to teams with modified designs that meet the following **criteria**:

- The greatest power output
- The greatest % increase in power output relative to original design

You may want to offer extra credit, a certificate, a free homework pass or something for an award.

All engineers are limited by supplies, resources, budgets, and time. We call these limitations **constraints**. Note that constraints are not always a negative thing. Constraints, if viewed positively, can lead to creative and innovative solutions. For example, in the book, "The Boy who Harnessed the Wind ", which documents the true story of William Kamkwamba's family, who lived in a tiny village in Malawi. They lost all of their season's crops, leaving them with nothing to eat and nothing to sell. It was during this devastating famine that William had to drop out of school because his father could not afford to pay the fees that William began to explore science books in his village library, looking for a solution. From his research, he came up with the idea that would change his and his family's life forever: he could build a windmill to generate electricity that would help his family pump water to irrigate their fields and power lights. The only materials William had were scrap metal and old bicycle parts from the junkyard. It took a lot of creativity, perseverance, and courage for William to succeed!

Optional Reading Assignment - You may select certain pages for students to read or the entire book. A film of this memoir is also available on Netflix if you would like to show the movie during a class period or two. Trigger warnings: Famine, Starvation, Death of People and Death of a Beloved Dog.

Engineering is all about creativity and problem solving. Let's take a look at the Engineering Design Process before we begin developing models and prototypes.

Engineering Design Process Directions:

Define the Problem

Choose a goal to tackle with your team!

Gather Pertinent Information

Plan your story using: Tips: Storyboard and Plot Events Cards.
Where does the story take place (setting)?
Who are your characters and what are their strengths and weaknesses?
What obstacles do characters encounter or create? How do they persevere through these obstacles? Do they succeed in the end?

Generate Multiple Solutions

From your story, consider each scene with your team.
How would your team bring each scene to life through a series of images?
What props and backdrop would need to be created?

Choose a Solution

Based on your team's ideas, choose one scene to animate.
Bring team ideas together into one solution. How many seconds will the scene last? How many frames per second (fps) will you use? How many frames (pictures) do you need to create to bring this scene to life?

Design a Culturally Responsive Solution

Work together and use Tips: Scene Animation.
How can your team share the work to reach goals and deadlines? Are your scene actions and images sequenced so they tell a story that makes sense? Do you need to adjust your fps?

Test and Optimize

As you film your story, play and replay your animation.
Does your animation makes sense to someone viewing it the first time?
Does it flow smoothly? Do you need more or less frames?
Use what you learned to improve your creative solution.

Share & Reflect

How did your team find solutions and practice perseverance?
What was one problem your team encountered and had to overcome?
Talk to your team: What went well? What could have gone better?

Procedure

In this activity you will construct a rotor using the constraints and materials provided by your teacher. **Follow STEMworks' Engineering Design Process from start to finish**.

1. **Define the problem:** ____

   ____

2. **Gather pertinent information**: This may include lessons learned from Lab 2 as well as online or textbook research. ____

   ____

   ____

   ____

3. **Generate multiple solutions:** Sketch a plan of your design first before you begin building your rotor. Engineers and designers will often need to develop a number of **models** before beginning to build an **assembly**. Be sure to collaborate with your teammates. **You may require a scaled model.*

4. **Choose a solution**: Decide on **one variable change** that you would like to test. ________
____
____

5. **Design a culturally responsive solution**: work with your teammates, take turns, and be patient with each other. Make sure everyone plays a role in designing and creating your solution. Who will be responsible for what? ______________________________________
____
____
____

6. **Test and Optimize**: Just like you did in Lab 2, **test three design modifications**, measure the voltage, amperage, and calculate the power. After each trial, ask how your design can be improved. Be patient as this step will take time.

Variable 1 Description: ______________ ______________	**Voltage (V)**	**Milliamps (mA)**	**Power (mW)**	**Observations**
Rotor facing center of the fan				
Rotor above center of the fan				
Variable 2 Description: ______________ ______________	**Voltage (V)**	**Milliamps (mA)**	**Power (mW)**	**Observations**
Rotor facing center of the fan				
Rotor above center of the fan				
Variable 3 Description: ______________ ______________	**Voltage (V)**	**Milliamps (mA)**	**Power (mW)**	**Observations**
Rotor facing center of the fan				
Rotor above center of the fan				

Post-Activity Assessment:

7. **Share and Reflect:** Based on your data and observations, which design modification resulted in the greatest difference in power and why? Explain your reasoning.

   ____

   ____

   ____

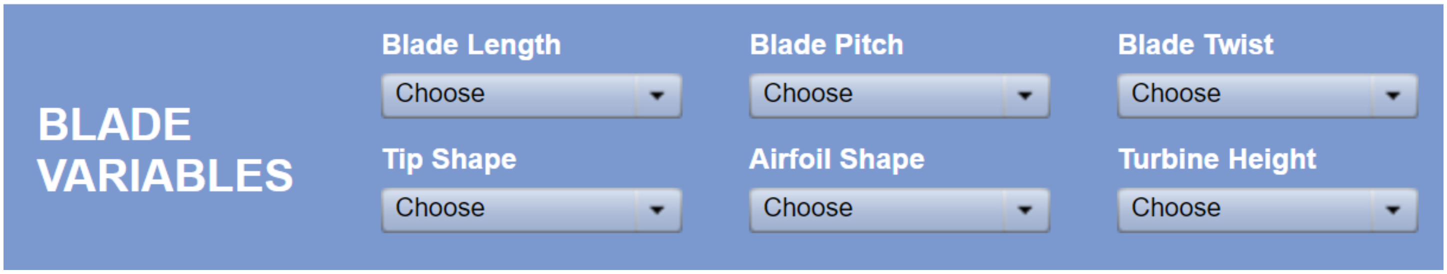
   ____

   ____

   If you had unlimited resources, what would your rotor look like? Think about materials, size and shape of the blade, the blade pitch, number of blades, etc. Sketch your model below:

What other renewable energy resource could you use to spin blades/rotors? _______________
____(*water*)

Optional Deeper Dive *(highly recommended)*: Explore how kinetic wind energy can be transformed into mechanical energy by a wind turbine and then transformed into electrical energy via the internal motor in this online Interactive Wind Energy activity. This online application allows you to explore the difference between offshore, and onshore (plains and hilly terrain) wind energy. You will also be able to test the effects of changing the following variables:



Key Concepts: In engineering and design, form and function are both important. From these experiments, you should have observed that the structure, configuration and form of your turbine determines how well it will function. The blades must be sturdy, balanced, and need to be at a pitch that is able to catch the wind. The motor's shaft also needs to easily rotate in order to transfer mechanical energy into electrical energy. Longer blades produce more electricity, but the longer the blades are the taller the tower must be.

Engineers use science, math, technology and creativity to solve problems. When it comes to developing renewable energy solutions and infrastructure, it may take many iterations and inventions to successfully transition to 100% renewable energy sources. In this activity, you independently practiced the Engineering Design Process - which is a series of steps used by engineers to guide the creative problem solving process and optimize a design solution. Engineers in all sectors must deal with constraints which may include time, budget, and/or materials. Usually a combination of all three. Your ideal solution may be very different from the solution you created with constraints, however, constraints are a fact of life. Way to make the best of the materials you had to work with!

Common Misconceptions: Many students are afraid to become engineers because they do not like math. In these lab exercises, you were able to practice engineering with very little mathematics. Math is an important part of engineering, but you do not have to be a mathematician to pass the required math classes. You just have to get through them, and then you can still be a successful engineer. **The key is grit and perseverance.**

Renewable Energy Connection: Humans have been harnessing this movement of air for thousands of years to power ships using sails and to pump water or grind wheat using windmills. Today, we use windmills to generate electricity, just like you did here in your two windmill models. The wind pushes on blades (rotors) which spin a generator which induces an electric current. In your model, the motor has a coil of wire with many loops inside and as the shaft spins, the coil of wire moves past a permanent magnet and an electric current is created in the wire. Wind turbines come in many sizes, with small turbines to power a single school campus and large turbines to power that can power hundreds of homes.

Solar power and wind power are both free, clean, and renewable. In just one hour, the sun sends more energy to our planet than we, all humans, consume in an entire year. The sun is also responsible for generating the winds. Scientists and engineers around the world are researching ways we can improve our technologies to harness enough solar and wind energy to supply our electricity needs. These renewable energy resources have enormous potential as a clean source of renewable energy to replace fossil fuels.

Conclusion

Climate change, largely driven by the emission of greenhouse gasses from burning fossil fuels, is at our doorstep. Our state is expected to experience loss of infrastructure, habitats, and cultural resources, from rising seas and will see more frequent and more severe storms and flooding. In order to reduce the severity of climate change, we must reduce our greenhouse gas emissions from burning fossil fuels. Renewable energy resources including solar, wind, biofuel, hydropower, and geothermal, are ultimately our best options to continue to power our homes, schools, and communities. Using renewable energy will help us to reduce our environmental impact so that we can enjoy the natural gifts and beauty of our planet for generations to come.

The Hawaiʻi State Energy Office is working within its means to set clean energy goals for our state. **However, each of us, as individuals, still need to consider our energy consumption habits and create an action plan for conserving energy.** Note that while renewable energy sources such wind power is often referred to as clean energy, the hardware and materials needed to create wind turbines often come from nonrenewable resources to manufacture things like the blades, motors, and wires to transport the electrical energy. No single person or technology is going to solve all of our energy needs or environmental problems. We must all work together to reduce our energy consumption, and to work toward powering our energy needs with a balanced portfolio of efficient renewable energy resources. In the future, we will continue to need scientific and engineering breakthroughs in the energy sector, and maybe someone, **possibly you**, will help.

Mahalo nui loa for joining us on this energy exploration into the world of wind power. With your help, our future will be bright!

Learn more about Hawai'i's Clean Energy Initiative by visiting: | Securing the Renewable Future (Hawaiʻi .gov) **energy.Hawaiʻi .gov**

Hawaiʻi Quick Facts

- Hawaiʻi was the first state to set a deadline for generating 100% of its electricity from renewable energy sources, which is required to be achieved by 2045.
- Despite being among the five states with the lowest total energy consumption, Hawaiʻi uses about 11 times more energy than it produces. More than four-fifths of Hawaiʻi 's energy consumption is petroleum, making it the most petroleum-dependent state.
- In 2019, solar power provided more than half of Hawaiʻi 's total renewable electricity generation, primarily from small-scale, customer-sited solar panel systems, which have roughly tripled in capacity since 2015.
- The amount of Hawaiʻi 's coal-fired generation in 2019 was the lowest since 1992, and coal fueled 12% of the state's electricity generation. The state's one coal-fired power plant is scheduled to be retired in 2022.
- Hawaiʻi has the highest average electricity retail price of any state, in part because it relies on petroleum for more than 60% of its electricity generation.
- Current Renewable portfolio standards (RPS)
    - Hawaiʻi Island - 43%
    - Kauai - 56%
    - Maui County (including Molokai and Lanai) - 41%
    - Oahu - 25%

Last Updated: January 21, 2021 SOURCE: EIA.GOV

Words to know

Note many vocabulary words do not explicitly appear in the NGSS standards, because the NGSS focus on a deep understanding of the concept behind a vocabulary word. Vocabulary can be introduced and applied, as needed, for instructional purposes.

- Amp: a unit of electrical current. Short for "ampere"
- Climate Change: changes in the average weather patterns in an area over a long period.
- Conserve: to use less of something like electricity or water.
- Consumption: the use of resources like energy, water, food, minerals, and more.
- Data: facts about something that have been measured, observed and can be analyzed.
- Design Constraints: The limitations placed on a possible engineering solution.
- Efficient: wasting as little as possible; working as best as possible with fewer resources.
- Emissions: something that is sent or given out, such as smoke, gas, heat, or light.
- Engineering: the use of science and math in the design and construction of things.
- Electrical Engineer: Engineers who use their knowledge of electrical currents and electricity to develop solutions and designs for electrical systems like buildings, computers, robots, and even electric cars.
- Electricity: flow of electrical power or charge.
- Fossil Fuels: coal, oil, natural gas. These energy resources come from the fossils of plants and tiny animals that lived millions of years ago.
- Generator: a device that converts mechanical energy to electrical energy.

- Greenhouse gasses: gasses that trap heat and contribute to warming temperatures including water vapor, carbon dioxide, carbon monoxide, and methane.
- Hypothesis: What do we think or predict the answer will be.
- Innovation: a new invention or way of doing something
- Modular: products that have components that can be fixed, removed, and replaced without having to throw away the entire product and starting from scratch. Modular designs are better for the environment.
- Renewable energy: a form of energy that doesn't get used up, including the energy from the sun, wind, and tides.
- Research: The process of gathering reliable, relevant information and ideas related to a scientific or technological issue.
- Solar Power: energy from the sun that is converted into electricity.
- Technology: tools, methods, and systems used to solve a problem or do work.
- Trade-off: a compromise.
- Troubleshoot: as you design a blueprint or build a model, something may not work. In this case you will need to think about what went wrong and how you can fix it. Sometimes this will be a process of trial, error, and discovery.
- Turbine: a device that uses pressure on blades by water, air, or steam to spin generators that create electricity.
- Volts: a unit of electrical potential also known as electromotive force.
- Windmill: a machine with blades or rotors that are rotated by the wind to do work.

Online Extension Activity: Wind Farm Suitability Analysis *(2-3 class periods)*

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural and environmental impact.

Any use of energy, *even renewable energy*, will have some environmental, social, and cultural impact. Even an activity as seemingly simple as where to place a wind farm (a group of wind turbines) is, in reality, an extremely complicated, real-world problem. A large wind farm could cover hundreds of square miles of land. This land could also be used for agriculture, homes, or could be along a bird migratory route. The endangered Hawaiian hoary bat could also be affected. **Where** to build a wind farm is a complex optimization problem, and one tool that we can use to make better location-based decisions is **GIS**.

Before the Activity

- *Students should set up an ArcGIS Online Account (email Katie Taladay at STEMworks for account login information, katie@medb.org)*
- *Students should be comfortable with ArcGIS Online navigation and following directions*
- Discuss with your class whether or not your area of the state is ideal for harnessing wind energy.

Procedure

1. Log on to ArcGIS Online
2. Follow this step-by-step Wind Farm Suitability Analysis Lesson for a Colorado-based wind energy company to identify several potential sites in the state.

Post-Activity Assessment:

1. How did GIS help you solve the complex problem of where to locate a wind farm?

   ____

   ____

   ____

2. This activity was for Colorado? What other data layers might you need to consider for Hawaii?

   ____

   ____

   ____

ArcGIS StoryMap Challenge: Using the workflow you learned in this activity, create your own map for Hawaii and tell a story about where you'd put a wind farm in the form of an ArcGIS online StoryMap.

At Home Extension Lesson: Electricity Reduction Experiment (*Homework*)

This week, your child learned all about **energy transfer** and **renewable energy generation,** specifically **Wind Power.** They had the opportunity to build their own wind turbine, test its power output performance, and improve their design by following the engineering design process.

They also learned that Hawaiʻi was the first state to set a deadline for generating 100% of its electricity from renewable energy sources. Our state has a goal to achieve this milestone by 2045. To achieve this, everyone must get onboard. Take a minute to discuss the following questions with the members of your household:

1. How do you and your household use electricity in your daily life? ______________________

   ____

   ____

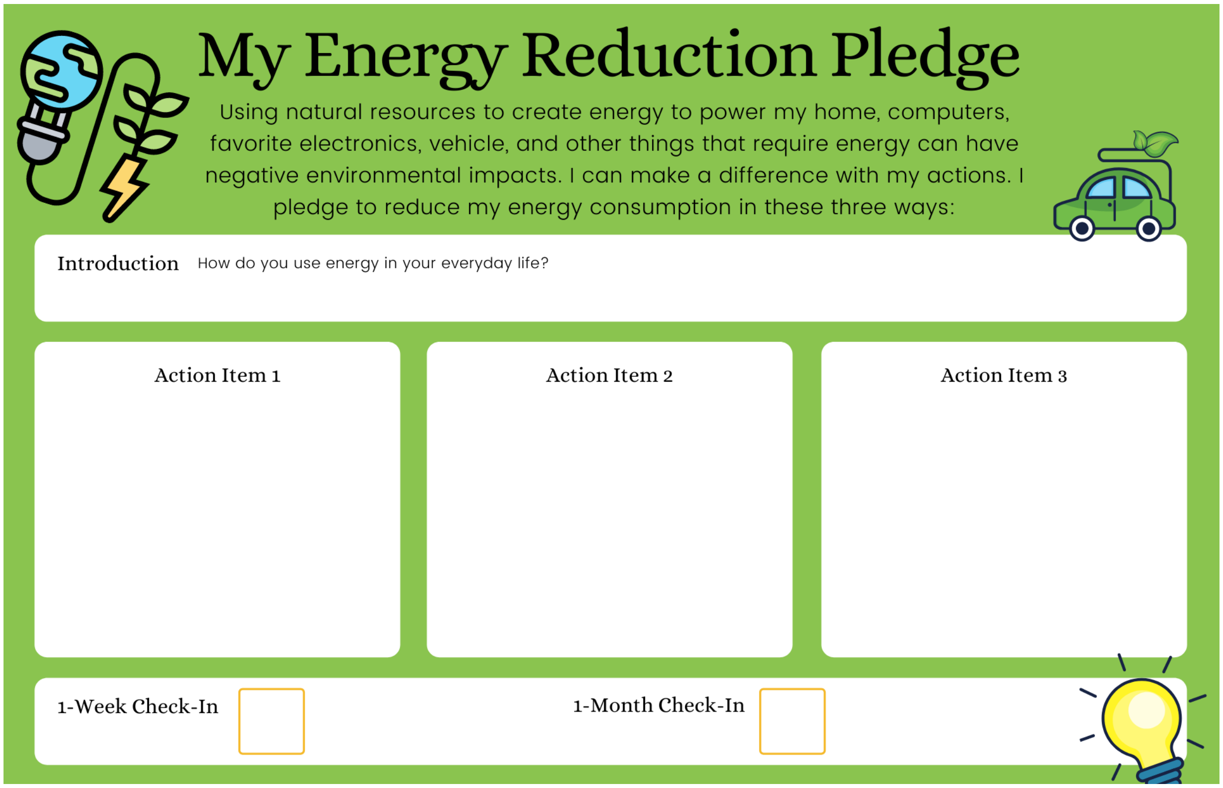
   ____

   ____

   ____

   (You may want to make a list of items in your home that use electricity. Some big consumers are hot water heaters, refrigerators, washing and drying machines, and other large appliances.)

2. What are some ways that you can reduce your energy consumption? Come up with at least three action items.



My Energy Reduction Pledge

Using natural resources to create energy to power my home, computers, favorite electronics, vehicle, and other things that require energy can have negative environmental impacts. I can make a difference with my actions. I pledge to reduce my energy consumption in these three ways:

Introduction How do you use energy in your everyday life?

Action Item 1	Action Item 2	Action Item 3

1-Week Check-In ☐ 1-Month Check-In ☐

3. How will reducing your energy consumption benefit your community? ____________________

____

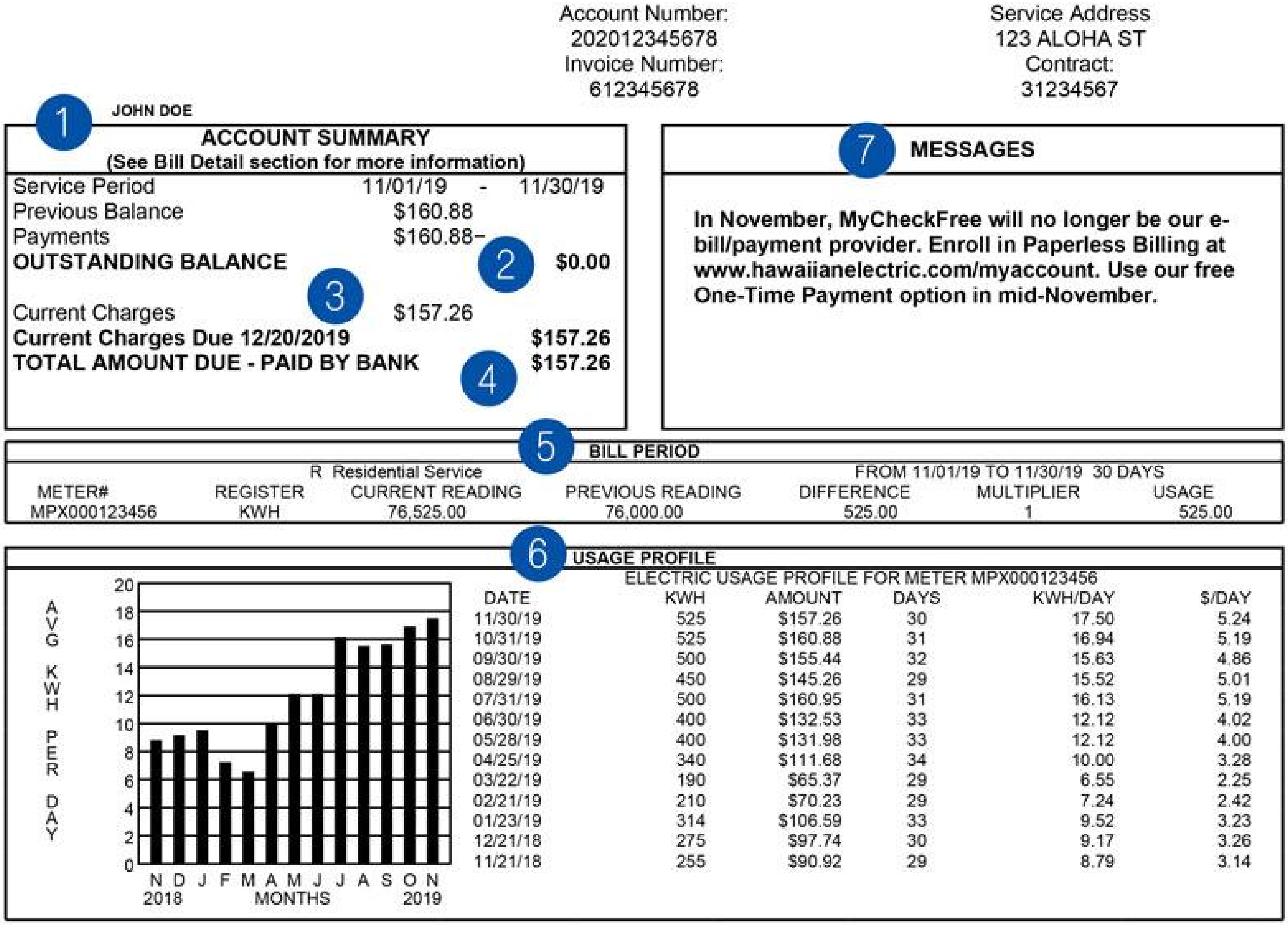
____

4. How will reducing your energy consumption affect your family's finances? To test this, take a look at your electric bill for this month and then compare 1-month later after practicing your energy pledge actions

Original Bill KWH/Day_______________ Conservation Month Bill KWH/Day _______________

Amount Saved? $_______________

To get a better understanding of your energy consumption, you can check your electrical bill. Sit down as an ʻohana, and look over your electric bill together. It should look something like this:



Account Number:
202012345678
Invoice Number:
612345678

Service Address
123 ALOHA ST
Contract:
31234567

① **JOHN DOE**

ACCOUNT SUMMARY
(See Bill Detail section for more information)

Service Period	11/01/19 - 11/30/19	
Previous Balance	$160.88	
Payments	$160.88-	
OUTSTANDING BALANCE ②		**$0.00**
③ Current Charges	$157.26	
Current Charges Due 12/20/2019		**$157.26**
TOTAL AMOUNT DUE - PAID BY BANK ④		**$157.26**

⑦ **MESSAGES**

In November, MyCheckFree will no longer be our e-bill/payment provider. Enroll in Paperless Billing at www.hawaiianelectric.com/myaccount. Use our free One-Time Payment option in mid-November.

⑤ **BILL PERIOD**

R Residential Service FROM 11/01/19 TO 11/30/19 30 DAYS

METER#	REGISTER	CURRENT READING	PREVIOUS READING	DIFFERENCE	MULTIPLIER	USAGE
MPX000123456	KWH	76,525.00	76,000.00	525.00	1	525.00

⑥ **USAGE PROFILE**

ELECTRIC USAGE PROFILE FOR METER MPX000123456

DATE	KWH	AMOUNT	DAYS	KWH/DAY	$/DAY
11/30/19	525	$157.26	30	17.50	5.24
10/31/19	525	$160.88	31	16.94	5.19
09/30/19	500	$155.44	32	15.63	4.86
08/29/19	450	$145.26	29	15.52	5.01
07/31/19	500	$160.95	31	16.13	5.19
06/30/19	400	$132.53	33	12.12	4.02
05/28/19	400	$131.98	33	12.12	4.00
04/25/19	340	$111.68	34	10.00	3.28
03/22/19	190	$65.37	29	6.55	2.25
02/21/19	210	$70.23	29	7.24	2.42
01/23/19	314	$106.59	33	9.52	3.23
12/21/18	275	$97.74	30	9.17	3.26
11/21/18	255	$90.92	29	8.79	3.14

1. **Account Summary:** This section provides the electric service billing period for the current bill and summarizes what is owed on the current bill.
2. **Outstanding Balance**: The previous balance line item shows the total charges on your last electric bill. The payments you made toward the last bill are subtracted from the previous balance to determine how much, if anything, remains to be paid toward the previous bill, that amount is the outstanding balance.
3. **Due Date**: This is when your payment should be received to avoid a late payment charge.
4. **Total Amount Due**: This is how much you currently owe. The total amount due includes the current charges, any adjustments made to your bill, plus the outstanding balance. Adjustments may include items such as: fees for service establishment, reconnection, late payment, returned check, or Sun Power for Schools donation.
5. **Bill Period**: This box contains data that describes your electricity use during the billing period and the rate schedule (such as R Residential Service) used to compute your electricity charges. The beginning and ending dates of the electric service billing period and the number of days in the billing period are provided.

   Meter # is the identification number on the electric meter. Register provides the meter's unit of measure. KWH means kilowatt-hours. For accounts that have two electric meters, the second meter number and corresponding data will be shown below the data provided for the first meter.

   Current Reading is the cumulative number of kilowatt-hours shown on the meter when it was read for the current electric bill. Previous reading is the cumulative number of kilowatt-hours shown on the meter when it was read for the previous bill. The difference is computed by subtracting the previous reading from the current reading. For accounts that use large amounts of electricity, the meters may not register electricity use by single kilowatt-hours. They may register electricity use by tens or hundreds of kilowatt-hours. That is explained by the multiplier. **For most residences the multiplier is 1.** For large power users, like a university or hospital, the multiplier may be as high as 240. When the difference is multiplied by the multiplier, the electricity usage for the billing period is determined in kilowatt-hours. At times, your electric bill may have to be estimated. In those cases, (EST) will be printed on the bill next to the current reading.

   Residential and Schedule G commercial customers with **advanced meters** may see a KW line item underneath their KWH usage. Please disregard this at this time as it does not factor into your bill calculation. It may be used in the future when additional rate options and programs become available.
6. **Usage Profile:** This section provides you with a historical view of your electricity use. The handy bar graph on the left side tells you at a glance how much your average daily electricity use has fluctuated over the past year. The electric usage profile for your meter can help you monitor your electricity use. It provides a record of the electricity use for your account for the past year. The date is the ending date of a billing period. KWH is the number of kilowatt-hours used during that period. The amount and days are the total current charges on your electric bill and the number of days in that billing period, respectively. **KWH/day lists the average number of kilowatt-hours of electricity used per day during the period. $/day tells you, on average, how much your electricity costs per day.**
7. **Messages:** This area contains useful information and tips for managing your electricity use. It also may contain specific messages for individual customers about their electric account.

EXTERNAL RESOURCES ON PERFORMANCE EXPECTATIONS

How to Read the Next Generation Science Standards

NGSS Webpage that allows you to search for Performance Expectations based on grade, discipline, SEP, DCI, and/or CCC

Evidence Statements (describe a detailed look at the NGSS performance expectations)

NSTA Performance Expectation Finder

www.stemworksHawai‘i .org

energy.Hawai‘i .gov